

Semiconductor devices —

Part 1: Discrete devices —

Section 1.7 Recommendations for bipolar transistors

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Electronic Components Standards Policy Committee (ECL/-) to Technical Committee ECL/12, upon which the following bodies were represented:

- British Broadcasting Corporation
- British Telecommunications plc
- Electronic Components Industry Federation
- Electronic Engineering Association
- GAMBICA (BEAMA Ltd.)
- Ministry of Defence
- National Supervising Inspectorate

This British Standard, having been prepared under the direction of the Electronic Components Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 29 September 1989

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The following BSI references relate to the work on this standard:
Committee reference ECL/12
Draft for comment 81/21411 DC

ISBN 0 580 17512 X

Amendments issued since publication

Amd. No.	Date of issue	Comments
7206	September 1992	
8705	September 1995	Indicated by a sideline in the margin

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National foreword

This British Standard has been prepared by Technical Committee EPL/47. It is identical with IEC Publication 748-7:1988 *Semiconductor discrete devices and integrated circuits — Part 7: Bipolar transistors*, as amended by Amendment 1:1991 and Amendment 2:1994, published by the International Electrotechnical Commission (IEC).

This British Standard constitutes Section 1.7 of the British Standard for semiconductor devices (BS 6493). (See national foreword of BS 6493-1.1:1984.)

Cross-references

International Standard	Corresponding British Standard
IEC 747-1:1983	BS 6493 <i>Semiconductor devices: discrete devices and integrated circuits</i> Section 1.1:1984 <i>General</i> (Identical)

Additional information. For the purposes of this British Standard, any references to IEC page numbers in the text should be ignored.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, pages 1 to 96, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Chapter I. General

1 Introductory note

As a rule, it will be necessary to use Publication 747-1 together with the present publication. In 747-1 the user will find all basic information on:

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

The sequence of the different chapters in the present publication is in accordance with Publication 747-1, Chapter III, Sub-clause 2.1.

2 Purpose

The present publication gives standards for the following subcategories 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.

3 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.

Chapter II. Terminology and letter symbols

1 Types of transistor

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.

1.2 Bi-directional transistor

A 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.

1.3 Tetrode transistor

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

1.4 Unipolar transistor

A transistor which utilizes charge carriers of only one polarity.

2 General terms

2.1 Specific physical regions (of a junction transistor)

2.1.1 *Collector region*

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

2.1.2 *Emitter region*

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

2.1.3 *Base region*

The physical region located between the collector junction and the emitter junction and that contains the control region and, in a simple, discrete transistor, is externally accessible by the designated base terminal.

2.1.4 *Collector(-base) junction*

The transition region between the collector region and the base region.

2.1.5 *Emitter(-base) junction*

The transition region between the emitter region and the base region.

2.1.6 *Collector terminal*

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

2.1.7 *Emitter terminal*

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

2.1.8 *Base terminal*

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

2.2 Specific functional regions

2.2.1 *Functional collector region*

A 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.

2.2.2 *Functional emitter region*

A 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.

2.2.3 Functional base region

The 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.

2.2.4 Collector(-base) space-charge region;

collector(-base) depletion layer

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

2.2.5 Emitter(-base) space-charge region;

emitter(-base) depletion layer

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

3 Circuit configurations

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.

3.2 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 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.

3.4 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.

3.5 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.

3.6 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.

4 Terms related to ratings and characteristics

4.1 Punch-through voltage

The 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 used in the U.S.A.

4.2 Saturation voltages

4.2.1 Collector-emitter saturation voltage

The 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.

4.2.2 Base-emitter saturation voltage

The 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.

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.

4.4 Collector series resistance

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

4.5 Emitter series resistance

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

4.6 Saturation resistance

The 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.

4.7 Extrinsic base resistance

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

4.8 Emitter depletion layer capacitance

The 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.

4.9 Collector depletion layer capacitance

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

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

4.10 Delay time (of a switching transistor)

The 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, page 5).

4.11 Rise time (of a switching transistor)

The 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).

4.12 Carrier storage time (of a switching transistor)

The 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).

4.13 Fall time (of a switching transistor)

The 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).

4.14 Maximum frequency of oscillation

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

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

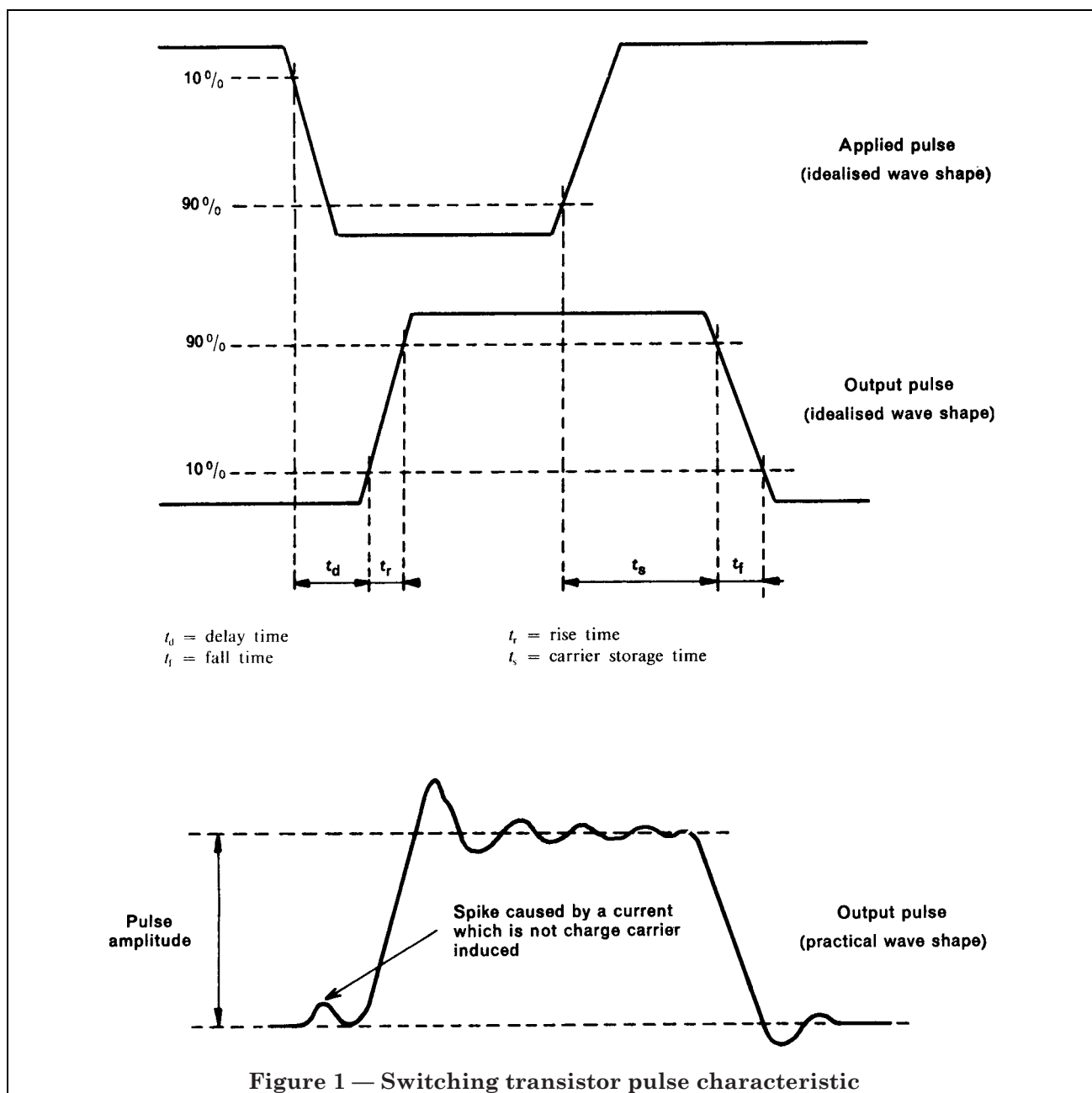


Figure 1 — Switching transistor pulse characteristic

4.15 Transition frequency (f_T)

The 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.

4.16 Frequency of unity current transfer ratio (f_1)

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

4.17 Current transfer ratio; current amplification factor**4.17.1 Small-signal short-circuit forward current transfer ratio**

The 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.

4.17.2 Static value of the forward current transfer ratio

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

4.17.3 Inherent (large-signal) forward current transfer ratio

The 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.

4.18 Small-signal open-circuit reverse voltage transfer ratio

The 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.

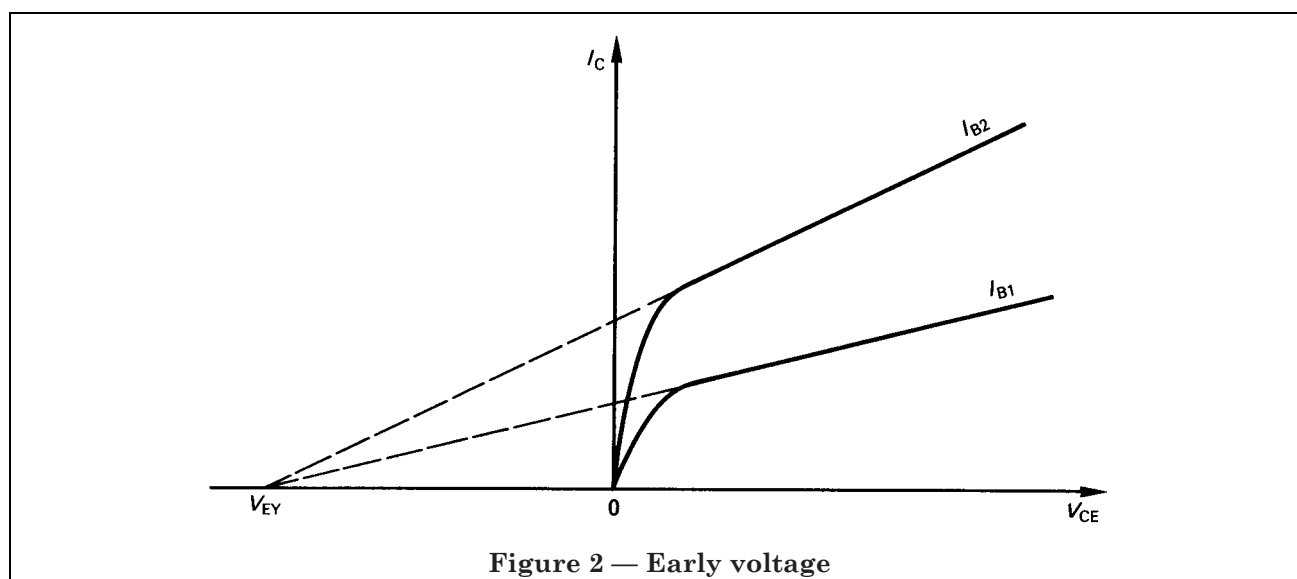
4.19 Transient current ratio in saturation (of a switching transistor)

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

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

The 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).



5 S-parameters

5.1 General introduction

The s -parameters are defined by the following two equations:

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

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

They 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:

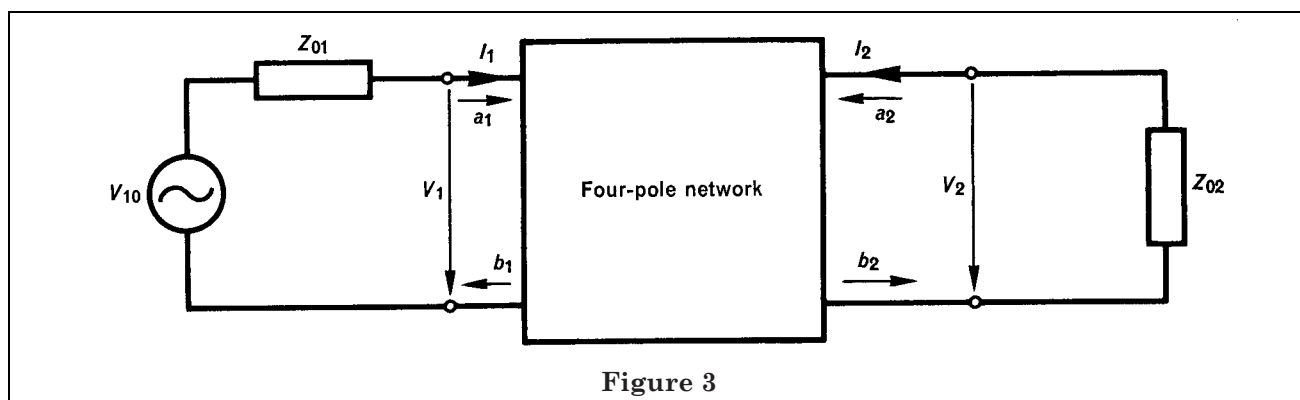
$$\left. \begin{aligned} a_i &= \frac{V_i + Z_{0i} I_i}{2\sqrt{|R_{0i}|}} \\ b_i &= \frac{V_i - Z_{0i}^* I_i}{2\sqrt{|R_{0i}|}} \end{aligned} \right\} \quad (2)$$

where: $i = 1 \text{ or } 2 \text{ and } R_{0i} \neq 0$

and: $Z_{0i} = R_{0i} + jX_{0i}$

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

(see Figure 3 below)



Z_{01} and Z_{02} are 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:

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

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

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

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

= 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 $a_2 = 0$ $\left\{ \begin{array}{l} \text{ratio of the complex value of the transmitted wave at the output to that of} \\ \text{the incident wave at the input, both the output terminating resistance and} \\ \text{the source resistance having the value } R_0 \end{array} \right.$

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

= 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 .

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.

5.2.1 Input reflection coefficient (s_{11})

The 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 .

5.2.2 Output reflection coefficient (s_{22})

The 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 .

5.2.3 Forward transmission coefficient (s_{21})

The 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 .

5.2.4 Reverse transmission coefficient (s_{12})

The 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 50 ohms.

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).

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

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

5.3 Application of the s -parameters

The s -parameters as defined in Sub-clause 5.2 can be used, e.g. as follows:

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

The following matrix equivalences hold:

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

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

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

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

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

The following equivalences hold:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Conditions for unconditional stability:

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

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

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

6 Letter symbols

6.1 Letter symbols for currents, voltages and powers

6.1.1 General

Clause 2 of Publication 747-1, Chapter V applies.

6.1.2 Additional subscripts

In addition to the list of recommended general subscripts given in Publication 747-1, Chapter V, Sub-clause 2.2.1, 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.

6.2 Letter symbols for electrical parameters

6.2.1 General

Clause 3 of Publication 747-1, Chapter V applies.

6.2.2 Additional subscripts

In addition to the list of recommended general subscripts given in Publication 747-1, Chapter V, Sub-clause 3.3.1, 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.

6.3 Letter symbols for other quantities

6.3.1 General

Publication 747-1, Chapter V, Clause 4 applies.

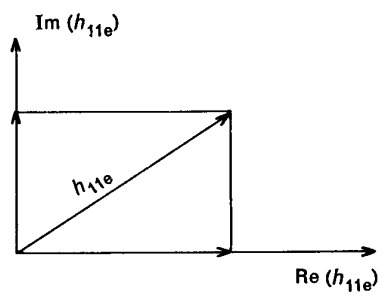
6.4 List of letter symbols

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.

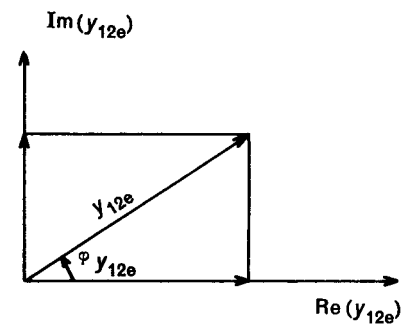
Name and designation	Letter symbol	Remarks
6.4.1 Voltages		
Collector-base (d.c.) voltage	V_{CB}	
Collector-emitter (d.c.) voltage	V_{CE}	
Emitter-base (d.c.) voltage	V_{EB}	
Base-emitter (d.c.) voltage	V_{BE}	
Collector-base (d.c.) voltage with $I_E = 0$ I_C specified	V_{CBO}	
Emitter-base (d.c.) voltage 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}	

Name and designation	Letter symbol	Remarks
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 voltages (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 this quantity
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_{EBf}	
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}	
6.4.2 Currents		
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}	
Emitter 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}	
6.4.3 Powers		
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}	— —

Name and designation	Letter symbol	Remarks
6.4.4 Electrical parameters		
6.4.4.1 Static parameters (specified for bias conditions)		
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 $V_{CE} = \text{constant}$
6.4.4.2 Small-signal parameters (specified for bias and frequency conditions)		
Small-signal value of the short-circuit input impedance:		
— in common-emitter configuration	h_{11e} or h_{ie}	$h_{11e} = \frac{V_{be}}{I_b}$ with $V_{ce} = \text{constant}$
— in common-base configuration	h_{11b} or h_{ib}	$h_{11b} = \frac{V_{eb}}{I_e}$ with $V_{cb} = \text{constant}$
Small-signal value of the open-circuit reverse voltage transfer ratio:		
— in common-emitter configuration	h_{12e} or h_{re}	$h_{12e} = \frac{V_{be}}{V_{ce}}$ with $I_b = \text{constant}$
— in common-base configuration	h_{12b} or h_{rb}	$h_{12b} = \frac{V_{eb}}{V_{cb}}$ with $I_e = \text{constant}$
Small-signal value of the short-circuit forward current transfer ratio:		
— in common-emitter configuration	h_{21e} or h_{fe}	$h_{21e} = \frac{I_c}{I_b}$ with $V_{ce} = \text{constant}$
— in common-base configuration	h_{21b} or h_{fb}	$h_{21b} = \frac{I_c}{I_e}$ with $V_{cb} = \text{constant}$
Small-signal value of the open-circuit output admittance:		
— in common-emitter configuration	h_{22e} or h_{oe}	$h_{22e} = \frac{I_c}{V_{ce}}$ with $I_b = \text{constant}$
— in common-base configuration	h_{22b} or h_{ob}	$h_{22b} = \frac{I_c}{V_{cb}}$ with $I_e = \text{constant}$

Name and designation	Letter symbol	Remarks
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}	$h_{11e} \simeq \text{Re}(h_{11e}) + \frac{1}{j\omega C_{11es}}$ $h_{11b} \simeq \text{Re}(h_{11b}) + \frac{1}{j\omega C_{11bs}}$
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}	
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	y_{11e} or y_{ie}	$y_{11e} = \frac{I_b}{V_{be}}$ with $V_{ce} = \text{constant}$ and $y_{11e} = \frac{1}{h_{11e}}$

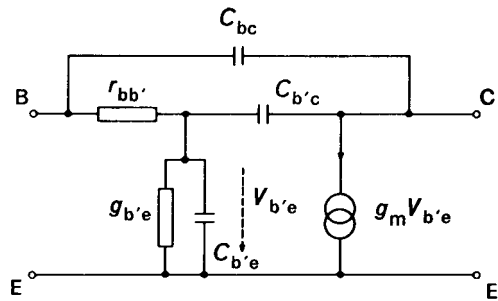
Name and designation	Letter symbol	Remarks
— in common-base configuration	y_{11b} or y_{ib}	$y_{11b} = \frac{I_e}{V_{eb}}$ with $V_{eb} = \text{constant}$ and $y_{11b} = \frac{1}{h_{11b}}$
Small-signal value of the short-circuit reverse transfer admittance:		
— in common-emitter configuration	y_{12e} or y_{re}	$y_{12e} = \frac{I_b}{V_{be}}$ with $V_{be} = \text{constant}$
— in common-base configuration	y_{12b} or y_{rb}	$y_{12b} = \frac{I_e}{V_{cb}}$ with $V_{eb} = \text{constant}$
Small-signal value of the short-circuit forward transfer admittance:		
— in common-emitter configuration	y_{21e} or y_{fe}	$y_{21e} = \frac{I_c}{V_{be}}$ with $V_{ce} = \text{constant}$
— in common-base configuration	y_{21b} or y_{fb}	$y_{21b} = \frac{I_c}{V_{eb}}$ with $V_{cb} = \text{constant}$
Small-signal value of the short-circuit output admittance:		
— in common-emitter configuration	y_{22e} or y_{oe}	$y_{22e} = \frac{I_c}{V_{ce}}$ with $V_{be} = \text{constant}$
— in common-base configuration	y_{22b} or y_{ob}	$y_{22b} = \frac{I_c}{V_{cb}}$ with $V_{eb} = \text{constant}$
Modulus of the short-circuit reverse transfer admittance:		
— in common-emitter configuration	$ y_{12e} $ or $ y_{re} $	
— in common-base configuration	$ y_{12b} $ or $ y_{rb} $	
Phase of the short-circuit reverse transfer admittance:		
— in common-emitter configuration	φ_{y12e} or φ_{yre}	
— in common-base configuration	φ_{y12b} or φ_{yrb}	



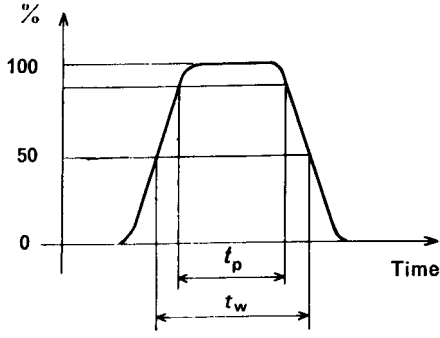
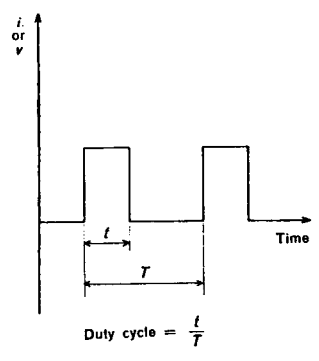
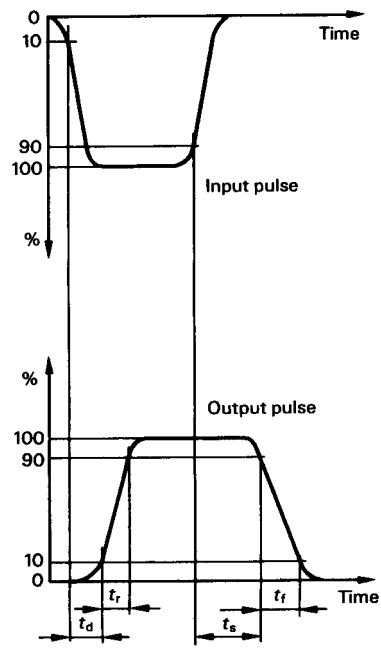
Name and designation	Letter symbol	Remarks
Modulus of the short-circuit forward transfer admittance: — in common-emitter configuration — in common-base configuration	$ y_{21e} $ or $ y_{fe} $ $ y_{21b} $ or $ y_{fb} $	
Phase of the short-circuit forward transfer admittance: — in common-emitter configuration — in common-base configuration	φ_{y21e} or φ_{yfe} φ_{y21b} or φ_{yfb}	
Input reflection coefficient: — in common-emitter configuration — in common-source configuration — in common-base configuration — in common-gate configuration — in common-collector configuration — in common-drain configuration	s_{11e} or s_{ie} s_{11s} or s_{is} s_{11b} or s_{ib} s_{11g} or s_{ig} s_{11c} or s_{ic} s_{11d} or s_{id}	
Output reflection coefficient: — in common-emitter configuration — in common-source configuration — in common-base configuration — in common-gate configuration — in common-collector configuration — in common-drain configuration	s_{22e} or s_{oe} s_{22s} or s_{os} s_{22b} or s_{ob} s_{22g} or s_{og} s_{22c} or s_{oc} s_{22d} or s_{od}	
Forward transmission coefficient: — in common-emitter configuration — in common-source configuration — in common-base configuration — in common-gate configuration — in common-collector configuration — in common-drain configuration	s_{21e} or s_{fe} s_{21s} or s_{fs} s_{21b} or s_{fb} s_{21g} or s_{fg} s_{21c} or s_{fc} s_{21d} or s_{fd}	
Reverse transmission coefficient: — in common-emitter configuration — in common-source configuration — in common-base configuration — in common-gate configuration — in common-collector configuration — in common-drain configuration	s_{12e} or s_{re} s_{12s} or s_{rs} s_{12b} or s_{rb} s_{12g} or s_{rg} s_{12c} or s_{rc} s_{12d} or s_{rd}	

6.4.4.3 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}	
6.4.5 Frequency parameters		
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_{lse}	$f_{se} = f$ for $ s_{21e} = 1$
— in common-source configuration	f_{ss}, f_{lss}	$f_{ss} = f$ for $ s_{21s} = 1$
— in common-base configuration	f_{sb}, f_{lsb}	$f_{sb} = f$ for $ s_{21b} = 1$
— in common-gate configuration	f_{sg}, f_{lsg}	$f_{sg} = f$ for $ s_{21g} = 1$
— in common-collector configuration	f_{sc}, f_{lsc}	$f_{sc} = f$ for $ s_{21c} = 1$
— in common-drain configuration	f_{sd}, f_{lsd}	$f_{sd} = f$ for $ s_{21d} = 1$

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

Name and designation	Letter symbol	Remarks
Turn-on time	t_{on}	$t_{\text{d}} + t_{\text{r}}$
Turn-off time	t_{off}	$t_{\text{s}} + t_{\text{f}}$
Emitter depletion layer capacitance	C_{Te}	
Collector depletion layer capacitance	C_{Tc}	
Stored charge	Q_{s}	
Transient current ratio in saturation	$h_{21 \text{ Esat}}$ or h_{FEsat}	
Collector-emitter saturation resistance: – small-signal value – large-signal value	r_{cesat} r_{CEsat}	
6.4.7 Sundry quantities		
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	$A_{\text{I}} A_{\text{i}}$	
Voltage amplification	$A_{\text{V}} A_{\text{v}}$	
Gain	G	
Power gain	$G_{\text{P}} G_{\text{p}}$	
Insertion power gain	$G_{\text{I}} G_{\text{i}}$	
Transducer power gain	$G_{\text{T}} G_{\text{t}}$	
Available power gain	$G_{\text{A}} G_{\text{a}}$	
Efficiency	η	
Collector efficiency	η_{C}	
6.4.8 External circuit parameters		
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}	
6.4.9 Matched-pair bipolar transistors		
Ratio of static values of common-emitter forward current transfer ratio	$h_{\text{FE1}}/h_{\text{FE2}}$ $h_{2\text{IE1}}/h_{2\text{IE2}}$	The smaller of the two values is taken as the numerator
Difference between base-emitter voltages	$V_{\text{BE1}} - V_{\text{BE2}}$	The smaller value is subtracted from the larger value
Change in difference of base-emitter voltages between two temperatures	$ \Delta(V_{\text{BE1}} - V_{\text{BE2}}) _{\Delta T}$	

Chapter III. Essential ratings and characteristics

Section 1. Low-power signal transistors (excluding switching applications)

1 General

1.1 Range of application

This section gives standards for low-power signal transistors applicable for operation at either high or low frequencies.

1.2 Rating methods

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

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 Publication 747-1, Chapter VI, Clause 5.

2 Ratings (limiting values)

The following ratings shall be stated:

2.1 Temperatures

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

2.1.2 Range of storage temperatures (T_{stg}).

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.

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

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

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

2.2.4 Maximum collector current (I_{C}).

2.2.5 Maximum emitter current (where appropriate) (I_{E}).

2.2.6 Maximum base current (where appropriate) (I_{B}).

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.

3 Characteristics

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 Publication 747-1, Chapter VI, Clause 6.

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

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

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 IEC Publication 747-1, Chapter VI, Clause 5.

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

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

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.

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.

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

Minimum and, where appropriate, maximum values (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.

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_{oc} = output conductance with input open-circuited to a.c. (where appropriate).

Maximum value.

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 of 2 to 10.

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 at 25 °C only.

3.9.1 3-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.

3.9.2 4-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.

3.10 Noise factor (where appropriate)

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

3.11 High frequency parameters (for high frequency transistors)

In this section, 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. 3–30 MHz.

These parameters shall be stated at 25 °C only.

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.

They should be specified as follows:

- Minimum value of 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 Sub-clause 3.8).
- Maximum value of the output capacitance C_{22b} .

This parameter shall be specified in the same way as in Sub-clause 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:

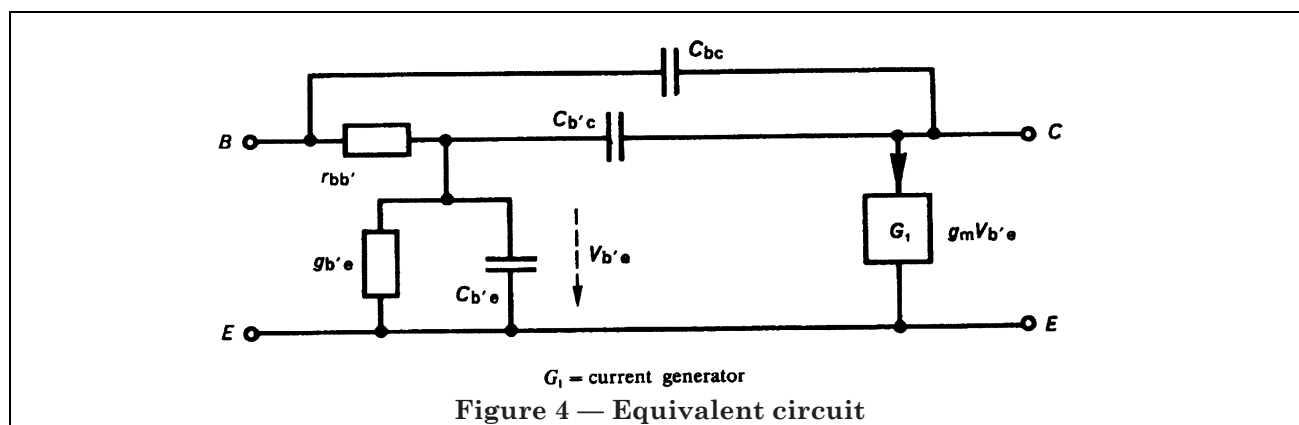
$\text{Re}(h_{11e})$ at a high frequency f_{h1}

$|h_{21b}|$ 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:



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

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

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

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

3) $C_{b'e} = \frac{qI_E}{kT} \cdot \frac{1}{2\pi f_T}$

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

$f_T = |h_{21e}| \cdot f_{h2}$

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

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

6) $g_m = \frac{qI_E}{kT}$

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 by the above formulae. (The values used in the above formulae are defined in Sub-clause 11.3.2.)

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}^a
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}^a
Common-base short-circuit forward transfer admittance	Y_{21b}
Common-base short-circuit output admittance	Y_{22b}

^a 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.

b) *s*-parameters

As an alternative to the *y*-parameters, the following *s*-parameters may be given in the complex form. They shall be stated with reference to a resistive load of 50 ohms and for the recommended configuration under specified conditions of bias, temperature (25 °C) and mounting:

- s_{11} — Typical value
- s_{22} — Typical value
- s_{12} — Typical value
- s_{21} — Minimum and typical values.

If the manufacturer recommends the transistor for use at a specified frequency, the values of the *s*-parameters shall then be stated at this frequency.

If the manufacturer proposes operation over a range of frequencies, the *s*-parameters shall then be stated at two frequencies within the recommended range of operating frequencies. In addition, curves may be included in the section on “Application data”.

3.12 *Specific characteristics of matched-pair bipolar transistors, used in low-frequency differential applications*

3.12.1 *Ratio of static values of common-emitter forward current transfer ratios*

Minimum value of the ratio h_{FE1}/h_{FE2} , where h_{FE1} and h_{FE2} are the static values of the common-emitter forward current transfer ratio of each transistor, under specified voltage (V_{CE}) and current (I_C).

NOTE This ratio should be the smaller value divided by the larger value.

3.12.2 *Difference between base-emitter voltages*

Maximum absolute value of the difference between the base-emitter voltages of the two transistors, under specified voltage (V_{CE}) and current (I_C).