



BSI Standards Publication

Semiconductor devices – Discrete devices

Part 7: Bipolar transistors

National foreword

This British Standard is the UK implementation of IEC 60747-7:2010+A1:2019. It supersedes BS IEC 60747-7:2010, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by **A1** **A1**.

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INTERNATIONAL STANDARD

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**Semiconductor devices – Discrete devices –
Part 7: Bipolar transistors**

**Dispositifs à semiconducteurs – Dispositifs discrets –
Partie 7: Transistors bipolaires**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES – DISCRETE DEVICES –

Part 7: Bipolar transistors

FOREWORD

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

This third edition cancels and replaces the second edition published in 2000 and IEC 60747-7-5 published in 2005.

The main changes with respect to previous edition are listed below.

- a) Clause 1 was amended by adding an item that should be included.
- b) Clauses 3, 4, 5, 6 and 7 were amended by adding terms, definitions, suitable additions and deletions those should be included.
- c) The text of the second edition was combined with that of IEC 60747-7-5.

This standard is to be read in conjunction with IEC 60747-1:2006.

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

FDIS	Report on voting
47E/404/FDIS	47E/408/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 2.

A list of all the parts in the IEC 60747 series, under the general title *Semiconductor devices – Discrete devices*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

SEMICONDUCTOR DEVICES – DISCRETE DEVICES –

Part 7: Bipolar transistors

1 Scope

This part of IEC 60747-7 gives the requirements applicable to the following sub-categories of bipolar transistors excluding microwave transistors.

- Small signal transistors (excluding switching and microwave applications);
- Linear power transistors (excluding switching, high-frequency, and microwave applications);
- High-frequency power transistors for amplifier and oscillator applications;
- Switching transistors for high speed switching and power switching applications;
- Resistor biased transistors.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-521:2002, *International Electrotechnical Vocabulary – Part 521: Semiconductor devices and integrated circuits*

IEC 60747-1:2006, *Semiconductor devices – Part 1: General*

IEC 60747-4:2007, *Semiconductor devices – Discrete devices – Part 4: Microwave diodes and transistors*

3 Terms and definitions

For the purposes of this document the following terms and definitions apply.

3.1 Specific functional regions

3.1.1

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 1 to entry 3.1.1 In the normal operating mode, this functional region is located in the collector region and, in the inverse operating mode, in the emitter region.

3.1.2

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 1 to entry 3.1.2 In the normal operating mode, this functional region is located in the emitter region and, in the inverse operating mode, in the collector region.

3.1.3

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

3.1.4

collector(-base) space-charge region; collector(-base) depletion layer

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

3.1.5

emitter(-base) space-charge region; emitter(-base) depletion layer

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

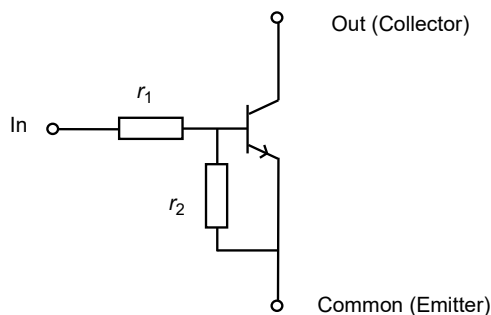
3.2 Resistor biased transistor

3.2.1

general description

bipolar junction transistors that incorporate with two bias resistors. One bias resistor is connected between the In terminal and the base region and the another between the base region and the common terminal. The resistor biased transistor is specified as a logic circuit element.

The graphical symbol as shown in Figure 1 is used in this standard for resistor biased transistors npn or pnp.



IEC 2910/10

Figure 1 – Resistor biased transistor graphical symbol

3.2.2

input terminal

terminal connected to the bias resistor 1

3.2.3

output terminal

terminal connected to a collector

3.2.4

common terminal

terminal connected to an emitter

3.2.5

bias resistor 1

resistor connected between the input terminal and the internal base of the transistor

3.2.6

bias resistor 2

resistor connected between the internal base of the transistor and the common terminal

3.3 Terms related to ratings and characteristics

3.3.1

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

 Note 2 to entry  "Reach-through voltage" is a term also in the USA.

3.3.2

saturation voltages

3.3.2.1

collector-emitter saturation voltage

voltage between the collector and emitter electrodes under conditions of base current beyond which the collector current remains essentially constant as the base current increased.

 Note 1 to entry  This is the voltage between the collector and emitter electrodes when both the base-emitter and base-collector junctions are forward biased.

3.3.2.2

base-emitter saturation voltage

voltage between the base and emitter electrodes under conditions of emitter current or collector current and base current beyond which the collector current remains essentially constant as the base current increased.

 Note 1 to entry  This is the voltage between the base and emitter electrodes when both the base-emitter and base-collector junctions are forward biased.

3.3.3

cut-off current

reverse current

reverse current of the base-collector junction or base-emitter junction.

3.3.4

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 1 to entry  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 should be specified.

3.3.5

emitter depletion layer capacitance

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

 Note 1 to entry  The emitter depletion layer capacitance is a function of the total potential difference across the depletion layer.

3.3.6

collector depletion layer capacitance

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

 Note 1 to entry  The depletion layer capacitance is a function of the total potential difference across the depletion layer.

3.3.7 switching times

for bipolar transistors, the input waveform is the base current and the output waveform is the collector current. The lower and upper limits are usually 10% and 90% of the amplitude.

3.3.7.1 turn on delay time rise time carrier storage time fall time

$t_{d(on)}$, t_r , t_s and t_f

see IEC 60050-521:2002, 521-05-21, IEC 60050-521:2002, 521-05-22, IEC 60050-521:2002, 521-05-23, IEC 60050-521:2002, 521-05-24.

3.3.7.2 turn-on time

time interval between a step function change of the input signal level and the instant at which the magnitude of the signal at the output terminals reaches a specified upper limit when the semiconductor device is being switched from its non-conducting to its conducting state. The lower and upper limits are usually 10 % and 90 % of the amplitude.

3.3.7.3 turn-off time

time interval between a step function change of the input signal level and the instant at which the magnitude of the signal at the output terminals reaches a specified lower limit when the semiconductor device is being switched from its conducting to its non-conducting state. The lower and upper limits are usually 10 % and 90 % of the amplitude.

3.3.8 collector-emitter sustaining voltage

$V_{CE(SUS)}$

collector-emitter breakdown voltage at higher values of collector current where the breakdown voltage is relatively constant over decreasing collector current for a specified termination between base and emitter terminals

3.3.9 turn-on energy (per pulse)

E_{on}

energy dissipated in transistor during turn-on

3.3.10 turn-off energy (per pulse)

E_{off}

energy dissipated in transistor during turn-off

3.3.11 maximum frequency of oscillation

f_{max}

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

Note 1 to entry This frequency approximates the frequency at which the maximum available power gain has decreased to unity.

3.3.12
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/octave

3.3.13
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 $\overline{A_1}$

3.3.14
transfer ratio

3.3.14.1
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.

3.3.14.2
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

3.3.14.3
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

3.3.14.4
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

3.3.14.5
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

3.3.15
resistor ratio (of resistor biased transistor)

ratio of the values of bias resistor 2 and bias resistor 1

3.3.16
input voltage (of resistor biased transistor)

voltage between the input terminal and the common terminal of the device

3.3.17
off-state input voltage (of resistor biased transistor)

input voltage at which the output current has reached its defined off-state value

3.3.18
on-state input voltage (of resistor biased transistor)

input voltage at which the output current has reached its defined on-state value

3.3.19

output voltage (of resistor biased transistor)

voltage between the output terminal and the common terminal of the device

3.3.20

off-state output current (of resistor biased transistor)

current flowing into the output terminal in the off-state

3.3.21

on-state output voltage (of resistor biased transistor)

current flowing into the output terminal in the off-state output voltage with specified I_i and I_o in such a way that the transistor is in its specified on state

4 Letter symbols

4.1 General

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

Subclause 4.2 of IEC 60747-1:2006 applies.

4.2 Additional subscripts

In addition to the list of recommended general subscripts given in Clause 4 of IEC 60747-1:2006, the following subscripts are recommended for bipolar transistors:

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

4.3 Lists of letter symbols

4.3.1 General

The symbols contained in the following lists are recommended for use in the field of bipolar transistors. They have been compiled in accordance with the general rules in Clause 4 of IEC 60747-1:2006.

4.3.2 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}	
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}	

4.3.3 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}	
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_{BE} specified	I_{BEX}	

4.3.4 Powers

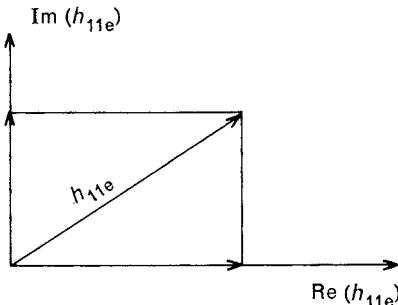
Name and designation	Letter symbol	Remarks
Collector power dissipation with T_a or T_c specified	P_C	
Total input power (d.c. or average) to all electrodes with T_a or T_c specified	P_{tot}	

4.3.5 Electrical parameters

4.3.5.1 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 $V_{CE} = \text{constant}$

4.3.5.2 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}	

4.3.5.2 (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 $V_{eb} = \text{constant}$

4.3.5.2 (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}	

4.3.5.3 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.

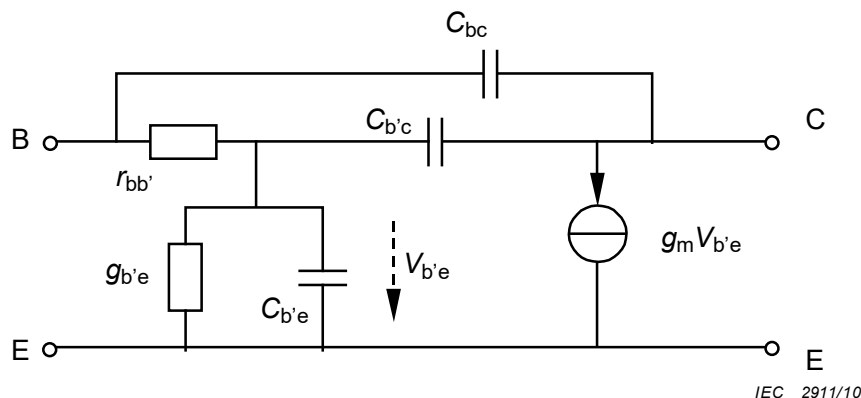


Figure 2 – Modified hybrid π equivalent circuit

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}	

4.3.6 Frequency parameters

Name and designation	Letter symbol	Remarks
Cut-off frequency:		
– in common-emitter configuration	$f_{h_{21e}}$ or $f_{h_{fe}}$	
– in common-base configuration	$f_{h_{21b}}$ or $f_{h_{fb}}$	
– in common-collector configuration	$f_{h_{21c}}$ or $f_{h_{fc}}$	
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$

4.3.7 Switching parameters

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

4.3.7 (continued)

Name and designation	Letter symbol	Remarks
Turn-on time	t_{on}	$t_d + t_r$
Turn-off time	t_{off}	$t_s + t_f$
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}	

4.3.8 Energies

Name and designation	Letter symbol	Remarks
Turn-on energy	E_{on}	Energy is always per pulse
Turn-off energy	E_{off}	

4.3.9 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	
Power added efficiency	η_{add}	see IEC 60747-4:2007, Clause 7. The abbreviation "PAE" is still in common use for power added efficiency.

4.3.10 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}$	

4.3.11 Resistor biased transistor

Name and designation	Letter symbol	Remarks
Bias resistor 1	r_1	
Bias resistor 2	r_2	
Off-state output current	$I_{O(off)}$	Correspond to I_{CEX} of bipolar transistor.
Off-state input voltage	$V_{I(off)}$	
On-state input voltage	$V_{I(on)}$	
On-state output voltage	$V_{O(on)}$	Correspond to V_{CEsat} of bipolar transistor.

5 Essential ratings and characteristics

5.1 General

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

5.2 Small signal transistors

5.2.1 Ratings (limiting values)

5.2.1.1 Temperatures

Minimum and maximum value of operating temperatures, ambient or case or virtual junction temperature (T_a or T_c or T_{vj}).

Minimum and maximum value of storage temperatures (T_{stg})

5.2.1.2 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, and the following values shall be stated.

- 5.2.1.2.1 Maximum collector-base voltage with zero emitter current (V_{CBO})**
- 5.2.1.2.2 Maximum collector-emitter voltage with zero base current (V_{CEO})**
- 5.2.1.2.3 Maximum emitter-base reverse voltage with zero collector current (V_{EBO})**
- 5.2.1.2.4 Maximum collector current (I_C)**
- 5.2.1.2.5 Maximum emitter current (where appropriate) (I_E)**
- 5.2.1.2.6 Maximum base current (where appropriate) (I_B)**
- 5.2.1.3 Power dissipation (P_{tot} or P_C)**

Maximum total power dissipation (P_{tot} or P_C), and where thermal resistance is not given in the characteristics, Maximum total power dissipation as a function of temperature over the range of operating temperatures.

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

5.2.2 Characteristics

5.2.2.1 General

The values shall be stated at one of the voltages and/or currents taken from the list in 5.9 of IEC 60747-1:2006.

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

Maximum value at rated maximum collector-base voltage. Maximum value at the specified maximum collector base voltage, at a high temperature and at approximately zero power dissipation.

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

Maximum value and at a specified emitter-base voltage

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

Maximum value, where appropriate, and at specified collector and base currents

5.2.2.5 Base-emitter voltage (V_{BE})

Where appropriate, maximum value at specified collector current and specified collector-emitter voltage.

5.2.2.6 Static value of the common-emitter forward current transfer ratio (h_{21E})

Minimum value and, where appropriate, maximum value at specified collector-emitter voltage and specified collector current

5.2.2.7 Small-signal parameters (common-emitter)

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

5.2.2.8 Transition frequency (f_T)

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

5.2.2.9 Output capacitance (C_{ob}) or Collector-base capacitance (C_{cb})

Maximum value at specified frequency and collector base voltage

NOTE The 3 terminal measurement method is valid for C_{cb} and the two terminal method is valid for C_{ob}

5.2.2.10 Noise factor (where appropriate)

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

5.2.2.11 Thermal resistance

Maximum value, where virtual junction temperature is specified in 5.2.1.1.

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

5.2.2.12.1 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.

5.2.2.12.2 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).

5.2.2.12.3 Change in difference of base-emitter voltages between two temperatures

$$|\Delta(V_{BE1} - V_{BE2})|_{\Delta T}$$

Maximum absolute value of the change in the difference of the base-emitter voltages (as in 5.2.2.12.2) between two specified temperatures, at specified voltage (V_{CE}) and current (I_C).

5.2.2.12.4 Matching collector currents

Maximum ratio of the values of the collector currents (I_{C2}/I_{C1}) with specified common collector - emitter voltage, total shared base current, and case or ambient temperature.

5.3 Linear power transistors

5.3.1 Ratings (limiting values)

5.3.1.1 Temperatures

Minimum and maximum value of operating temperatures, ambient or case or virtual junction temperature (T_a or T_c or T_{vj}).

Minimum and maximum value of storage temperatures (T_{stg})

5.3.1.2 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 voltage and current ratings apply for both continuous and peak conditions.

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

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

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

5.3.1.2.4 Maximum collector current (I_C)

5.3.1.2.5 Maximum emitter current (where appropriate) (I_E)

5.3.1.2.6 Maximum base current (I_B)

5.3.1.3 Power dissipation (P_{tot} or P_C)

Maximum total power dissipation (P_{tot} or P_C), and where thermal resistance is not given in the characteristics, Maximum total power dissipation as a function of temperature over the range of operating temperatures.

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

5.3.2 Characteristics

5.3.2.1 General

The values shall be stated at one of the voltages and/or currents taken from the list in clause 5.9 of IEC 60747-1:2006.

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

Maximum value at the rated maximum collector-base voltage

Maximum value at a specified collector-base voltage, at a high operating temperature and at approximately zero power dissipation with the emitter open circuit.

5.3.2.3 Base-emitter forward voltage (V_{BE})

Typical and, where appropriate, maximum values at specified collector current and collector-emitter voltage

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

Maximum value at a specified high value of collector current and a specified base current

5.3.2.5 Static value of the common-emitter forward current transfer ratio (h_{21E})

Minimum and maximum values at a specified low value of collector-emitter voltage and a specified high value of either emitter or collector current.

When the I_{CBO} component is significant, the inherent (large-signal) forward current transfer ratio $|h_{21EL}|$ shall be stated.

5.3.2.6 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 or 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.

5.3.2.7 Output capacitance (C_{ob}) or Collector-base capacitance (C_{cb})

Maximum value at 25 °C, at zero d.c. emitter current, for specified values of voltage V_{CB} and frequency

NOTE The 3 terminal measurement method is valid for C_{cb} and the two terminal method is valid for C_{ob}

5.3.2.8 Maximum thermal resistance

Maximum value, where virtual junction temperature is specified in 5.3.1.1.

5.4 High-frequency power transistors for amplifier and oscillator applications

5.4.1 Ratings (limiting values)

5.4.1.1 Temperatures

Minimum and maximum value of operating temperatures, ambient or case or virtual junction temperature (T_a or T_c or T_{vj}).

Minimum and maximum value of storage temperatures (T_{stg})

5.4.1.2 Voltages and currents

5.4.1.2.1 Maximum collector-base voltage with emitter open circuit (V_{CBO})

5.4.1.2.2 Maximum collector-emitter voltage under specified base-emitter condition (V_{CEX})

5.4.1.2.3 Maximum emitter-base reverse voltage with open collector circuit (V_{EBO})

5.4.1.2.4 Either: maximum collector current (d.c. or mean value) (I_C or $I_{C(AV)}$) or: maximum emitter current (d.c. or mean value) (I_E or $I_{E(AV)}$)

5.4.1.2.5 Either: maximum peak collector current (I_{CM}) or: maximum peak emitter current (I_{EM})

5.4.1.2.6 Maximum base current (d.c. or mean value) (I_B or $I_{B(AV)}$)

5.4.1.3 Power dissipation (P_{tot} or P_C)

Maximum total power dissipation (P_{tot} or P_C), and where thermal resistance is not given in the characteristics, Maximum total power dissipation as a function of temperature over the range of operating temperatures.

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

5.4.1.4 Safe operation area

Where appropriate, a safe operation area (e.g. curves I_C versus V_{CE}) d.c. and pulse should be chosen.

5.4.2 Characteristics

The values shall be stated at one of the voltages and/or currents taken from the list in clause 5.9 of IEC 60747-1:2006".

5.4.2.1 Static value of the common-emitter forward current transfer ratio (h_{21E})

Minimum and maximum values at a specified value of collector-emitter voltage and a specified value of collector current (typical value), d.c. or pulse as specified.

5.4.2.2 Where appropriate, static value of the common-emitter forward current transfer ratio (h_{21E})

Minimum value at a specified low value of collector-emitter voltage and a specified high value of collector current, d.c. or pulse as specified.

5.4.2.3 Transition frequency (f_T) or modulus of the forward transmission coefficient ($|S_{21e}|$)

Either:

minimum values and where appropriate maximum value at specified values of collector current, collector-emitter voltage, and frequency

or:

minimum value at specified values of collector current, collector-emitter voltage, and frequency, source and load impedances (preferably 50 Ω)

5.4.2.4 Cut-off currents

5.4.2.4.1 Collector-base cut-off current (I_{CBO}) or collector-emitter cut-off current (I_{CEX})

Either:

maximum value, at specified value of the collector-base voltage (preferably the maximum rated value), and with the emitter open-circuited

or:

maximum value at specified value of the collector-emitter voltage (preferably the maximum rated value), and with the base-emitter voltage specified

5.4.2.4.2 Where appropriate, collector-emitter cut-off current (I_{CER})

Maximum value at specified value of the collector-emitter voltage (preferably the maximum rated value), and under specified base-emitter resistance

5.4.2.4.3 Where appropriate, collector-emitter cut-off current (I_{CES})

Maximum value, at specified value of the collector-emitter voltage (preferably the maximum rated value), and with the base short-circuited to the emitter

5.4.2.4.4 Where appropriate, collector-emitter cut-off current (I_{CEO})

Maximum value, at specified value of the collector-emitter voltage (preferably the maximum rated value), and with the base open-circuited

5.4.2.5 Cut-off currents at a specified high temperature

5.4.2.5.1 Collector-base cut-off current (I_{CBO}) or collector-emitter cut-off current (I_{CEX})

Either:

maximum value, at a specified voltage preferably between 65 % and 85 % of the maximum rated collector-base voltage, and with the emitter open-circuited

or:

maximum value, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage, with the base-emitter voltage specified.

5.4.2.5.2 Where appropriate, collector-emitter cut-off current (I_{CER})

Maximum value, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage, under specified base-emitter bias resistance.

5.4.2.5.3 Where appropriate, collector-emitter cut-off current (I_{CES})

Maximum value, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage, with the base short-circuited to the emitter.

5.4.2.5.4 Where appropriate, collector-emitter cut-off current (I_{CEO})

Maximum value, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage, with the base open-circuited.

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

Maximum value, at a specified high value of collector current and specified base current

5.4.2.7 Output power (P_{out}) or power gain (G_p)

Either:

minimum value, circuit and bias conditions to be specified, f = specified high value where appropriate, at a lower frequency f_1 , for the same specified conditions of circuit and bias

or:

minimum value, same conditions as for output power.

5.4.2.8 Where appropriate, either:

Overall efficiency (η_{tot})

Minimum value, same conditions as for output power

$$\eta_{\text{tot}} = \frac{P_{\text{out}}}{P_{\text{in}} + P_{\text{(d.c.)}}}$$

or:

Collector efficiency (η_c)

Minimum value, same conditions as for output power

$$\eta_c = \frac{P_{\text{out}}}{P_{\text{C(d.c.)}}}$$

or:

Power added efficiency (η_{add})

Minimum value, same conditions as for output power

$$\eta_{\text{add}} = \frac{P_{\text{out}} - P_{\text{in}}}{P_{\text{C(d.c.)}}}$$

5.4.2.9 Capacitances

Maximum value at specified conditions.

5.4.2.9.1 Collector-base capacitance(C_{cb})

Maximum value at specified collector base and emitter base voltages.

5.4.2.9.2 Where appropriate , collector-emitter capacitance(C_{ce})

Maximum value at specified collector base and emitter base voltages.

5.4.2.9.3 Where appropriate , emitter-base capacitances(C_{eb})

Maximum value at specified collector base and emitter base voltages.

5.4.2.10 Where appropriate, inter modulation factor or other linearity criterion

Minimum and maximum values under specified conditions.

5.4.2.11 Maximum thermal resistance

Maximum value. Where virtual junction temperature is specified in 5.4.1.1.

5.5 Switching transistors

5.5.1 Ratings (limiting values)

5.5.1.1 Temperatures

Minimum and maximum value of operating temperatures, ambient or case or virtual junction temperature(T_a or T_c or T_{vj}).

Minimum and maximum value of storage temperatures (T_{stg})

5.5.1.2 Voltages and currents

The ratings must cover the operation of the device over the range of operating temperatures. Where such ratings are temperature dependent, this dependence should be indicated as follows.

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

5.5.1.2.2 Maximum collector-emitter voltage, either with zero base current or with a specified emitter-base reverse voltage (V_{CEO} or V_{CEX})

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

5.5.1.2.4 Collector-emitter sustaining voltage (V_{CEXsus})

Maximum rated value at specified collector current and specified base-emitter (reverse) voltage should be state.

5.5.1.2.5 Maximum continuous collector current (I_{C})

5.5.1.2.6 Where appropriate, maximum peak repetitive collector current, under specified conditions (I_{CRM})

5.5.1.2.7 Maximum continuous base current (I_{B})

5.5.1.2.8 Where appropriate, maximum peak repetitive base current, under specified conditions (I_{BRM})

5.5.1.2.9 Where appropriate, maximum emitter current, continuous and/or peak repetitive, under specified conditions (I_{E} , I_{ERM})

5.5.1.3 Power dissipation (P_{tot} or P_{C})

Maximum total power dissipation (P_{tot} or P_{C}), and where thermal resistance is not given in the characteristics, Maximum total power dissipation as a function of temperature over the range of operating temperatures.

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

5.5.1.4 Safe operating areas

5.5.1.4.1 Forward biased safe operating area (FBSOA)

Diagram showing the area of collector currents (I_{C}) and collector-emitter voltages (V_{CE}) which the transistor will sustain simultaneously without being damaged by thermal overload or by the first or second breakdown, for d.c. and pulse operation.

5.5.1.4.2 Reverse biased safe operating area (RBSOA)

Diagram showing the area of collector currents (I_{C}) and collector-emitter voltages (V_{CE}) which the transistor will sustain simultaneously for a short period of time during turn-off without being damaged.

5.5.1.4.3 Short circuit safe operating area SCSOA

SCSOA is given by a pair of values of short circuit duration ($t_{\text{p(sc)}}$) and collector-emitter voltage (V_{CE}) that may not be exceeded under the load short circuit conditions. The device may be turned on and turned off again for shorting a voltage source without failure.