มาตรฐานผลิตภัณฑ์อุตสาหกรรม

THAI INDUSTRIAL STANDARD

มอก. 1864 – 2552

IEC 60747 – 7(2000 – 02)

อุปกรณ์สารกึ่งตัวนำ - อุปกรณ์ไม่รวมหน่วย

เล่ม 7 ทรานซิสเตอร์สองขั้ว

SEMICONDUCTOR DEVICES -

PART 7: BIPOLAR TRANSISTORS

สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

กระทรวงอุตสาหกรรม ICS 31.080.30 ISBN 978-606-231-073-7

มาตรฐานผลิตภัณฑ์อุตสาหกรรม

อุปกรณ์สารกึ่งตัวนำ - อุปกรณ์ไม่รวมหน่วย

เล่ม 7 ทรานซิสเตอร์สองขั้ว

มอก. 1864 – 2552

สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม
กระทรวงอุตสาหกรรม ถนนพระรามที่ 6 กรุงเทพฯ 10400
โทรศัพท์ 02 202 3300

ประกาศในราชกิจจานุเบกษา ฉบับประกาศและงานทั่วไป เล่ม 127 ตอนพิเศษ 91ง
วันที่ 29 กรกฎาคม พุทธศักราช 2553

มาตรฐานผลิตภัณฑ์อุตสาหกรรมอุปกรณ์สารกึ่งตัวนำ–อุปกรณ์ไม่รวมหน่วย เล่ม 7 ทรานซิสเตอร์สองขั้ว ได้ประกาศใช้ครั้งแรกโดยรับ IEC 747-7(1988-11) Semiconductor Devices- Discrete devices- Part 7: Bipolar transistors มาใช้ในระดับเหมือนกันทุกประการ (Identical) โดยใช้ IEC ฉบับภาษาอังกฤษเป็นหลัก โดยประกาศในราชกิจจานุเบกษา ฉบับประกาศทั่วไป เล่มที่117 ตอนพิเศษที่ 134ง วันที่ 29 ธันวาคม พุทธศักราช 2543

เนื่องจากIECได้แก้ไขปรับปรุงมาตรฐาน IEC 747-7(1988-11) เป็น IEC 60747-7(2000) จึงได้ยกเลิกมาตรฐานเดิมและกำหนดมาตรฐานใหม่โดยรับ IEC 60747-7(2000) Semiconductor devices- discrete devices Part 7: Bipolar transistors มาใช้ในระดับเหมือนกันทุกประการโดยใช้มาตรฐาน IEC ฉบับภาษาอังกฤษเป็นหลัก

คณะกรรมการมาตรฐานผลิตภัณฑ์อุตสาหกรรมได้พิจารณามาตรฐานนี้แล้ว เห็นสมควรเสนอรัฐมนตรีประกาศตามมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511

ประกาศกระทรวงอุตสาหกรรม

ฉบับที่ 4204 (พ.ศ. 2553)

ออกตามความในพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม

พ.ศ. 2511

เรื่อง ยกเลิกและกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม

อุปกรณ์สารกึ่งตัวนำ – อุปกรณ์ไม่รวมหน่วย

เล่ม 7 ทรานซิสเตอร์สองขั้ว

โดยที่เป็นการสมควรปรับปรุงมาตรฐานผลิตภัณฑ์อุตสาหกรรม อุปกรณ์สารกึ่งตัวนำ – อุปกรณ์ไม่รวมหน่วย เล่ม 7 ทรานซิสเตอร์สองขั้ว มาตรฐานเลขที่ มอก.1864-2542

อาศัยอำนาจตามความในมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511 รัฐมนตรีว่าการกระทรวงอุตสาหกรรมออกประกาศยกเลิกประกาศกระทรวงอุตสาหกรรม ฉบับที่ 2745 (พ.ศ.2543) ออกตามความในพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ.2511 เรื่อง กำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม อุปกรณ์สารกึ่งตัวนำ – อุปกรณ์ไม่รวมหน่วย เล่ม 7 ทรานซิสเตอร์สองขั้ว ลงวันที่ 9 ตุลาคม พ.ศ.2543 และออกประกาศกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม อุปกรณ์สารกึ่งตัวนำ – อุปกรณ์ไม่รวมหน่วย เล่ม 7 ทรานซิสเตอร์สองขั้ว มาตรฐานเลขที่ มอก.1864-2552 ขึ้นใหม่ ดังมีรายละเอียดต่อท้ายประกาศนี้

ทั้งนี้ให้มีผลตั้งแต่วันถัดจากวันที่ประกาศในราชกิจจานุเบกษา เป็นต้นไป

ประกาศ ณ วันที่ 7 เมษายน พ.ศ. 2553

ชาญชัย ชัยรุ่งเรือง

รัฐมนตรีว่าการกระทรวงอุตสาหกรรม

มาตรฐานผลิตภัณฑ์อุตสาหกรรม
อุปกรณ์สารกึ่งตัวนำ - อุปกรณ์ไม่รวมหน่วย
เล่ม 7 ทรานซิสเตอร์สองขั้ว

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นโดยรับ IEC 60747-7(2000) Semiconductor devices- discrete devices Part 7: Bipolar transistors มาใช้ในระดับเหมือนกันทุกประการ (identical) โดยใช้ IEC ฉบับภาษาอังกฤษเป็นหลัก

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้มีวัตถุประสงค์เพื่อใช้กับทรานซิสเตอร์สองขั้วประเภทย่อย ดังต่อไปนี้

- ทรานซิสเตอร์สัญญาณกำลังต่ำ (ไม่รวมถึงการใช้งานการสวิตช์)
- ทรานซิสเตอร์กำลัง (ไม่รวมถึงการใช้ในงานการสวิตช์และการใช้งานที่ความถี่สูง)
- ทรานซิสเตอร์กำลังความถี่สูง สำหรับ เครื่องขยายเสียงและอุปกรณ์สัญญาณแกว่ง
- ทรานซิสเตอร์การสวิตช์

รายละเอียดให้เป็นไปตาม IEC 60747-7(2000)

IEC Central office
3, rue de Varembé,
CH-1211 Geneva 20
Switzerland
E-mail : inmail@iec.ch
Web : www.iec.ch

CONTENTS

Clause Page

Page

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES –

Part 7: Bipolar transistors

FOREWORD

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

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

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

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

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

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

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

SEMICONDUCTOR DEVICES –

Part 7: Bipolar transistors

Introductory note

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

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

1 Scope

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

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

2 Normative references

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

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

3 Terms and definitions

3.1 Types of bipolar transistors

3.1.1
junction transistor
transistor having a base region and two or more junctions

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

3.1.2
bi-directional transistor
transistor which has substantially the same electrical characteristics when the terminals normally designated as emitter and collector are interchanged

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

3.1.3
tetrode transistor
four-electrode transistor, usually a conventional junction transistor having two separate base electrodes and two base terminals

3.2 General terms

3.2.1 Specific physical regions (of a junction transistor)

3.2.1.1
collector region
physical region that is designed by the manufacturer to contain in the normal operating mode the collection region and which, in a simple discrete transistor, is externally accessible by the designated collector terminal

3.2.1.2
emitter region
physical region that is designed by the manufacturer to contain in the normal operating mode the supply region and which, in a simple discrete transistor, is externally accessible by the designated emitter terminal

3.2.1.3
base region
physical region located between the collector junction and the emitter junction and containing the control region and which, in a simple discrete transistor, is externally accessible by the designated base terminal

3.2.1.4
collector(-base) junction
transition region between the collector region and the base region

3.2.1.5
emitter(-base) junction
transition region between the emitter region and the base region

3.2.1.6
collector terminal
specified externally available point of connection to the collector electrode and collectc region

3.2.1.7
emitter terminal
specified externally available point of connection to the emitter electrode and emitter region

3.2.1.8
base terminal
specified externally available point of connection to the base electrode and base region

3.2.2 Specific functional regions

3.2.2.1
functional collector region
collection region that acquires principal-current charge carriers from the functional bas 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 invers operating mode, in the emitter region.

3.2.2.2
functional emitter region
supply region that delivers principal-current charge carriers into the functional base regio 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 invers operating mode, in the collector region.

3.2.2.3
functional base region
control region through which the principal current passes and in which the concentration c principal-current charge carriers is the result of an applied base current

3.2.2.4
collector(-base) space-charge region;
collector(-base) depletion layer
space-charge region between the functional collector region and the functional base region

3.2.2.5
emitter(-base) space-charge region;
emitter(-base)depletion layer
space-charge region between the functional emitter region and the functional base region

3.3 Circuit configurations

3.3.1
common base
circuit configuration in which the base terminal is common to the input circuit and to the output circuit and in which the input terminal is the emitter terminal and the output terminal is the collector terminal

3.3.2
inverse common base
circuit configuration in which the base terminal is common to the input circuit and to the output circuit and in which the input terminal is the collector terminal and the output terminal is the emitter terminal

3.3.3
common collector
circuit configuration in which the collector terminal is common to the input circuit and to the output circuit and in which the input terminal is the base terminal and the output terminal is the emitter terminal

3.3.4
inverse common collector
circuit configuration in which the collector terminal is common to the input circuit and to the output circuit and in which the input terminal is the emitter terminal and the output terminal is the base terminal

3.3.5
common emitter
circuit configuration in which the emitter terminal is common to the input circuit and to the output circuit and in which the input terminal is the base terminal and the output terminal is the collector terminal

3.3.6
inverse common emitter
circuit configuration in which the emitter terminal is common to the input circuit and to the output circuit and in which the input terminal is the collector terminal and the output terminal is the base terminal

3.4 Terms related to ratings and characteristics

3.4.1
punch-through voltage
value of the collector-base voltage above which the open-circuit emitter-base voltage increases almost linearly with increasing collector-base voltage

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

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

3.4.2
saturation voltages

3.4.2.1
collector-emitter saturation voltage
voltage between the collector and emitter electrodes under conditions of base current or base-emitter voltage beyond which the collector current remains essentially constant as the base current or voltage is increased

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

3.4.2.2
base-emitter saturation voltage
voltage between the base and emitter electrodes under conditions of base current or base-emitter voltage beyond which the collector current remains essentially constant as the base current or voltage is increased

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

3.4.3
cut-off current (reverse current)
reverse current of the base-collector junction (or base-emitter junction) when the emitter (or the collector) is open-circuited, the reverse voltage being specified

3.4.4
collector series resistance
resistance between the collector terminal and the internal inaccessible collector point in an equivalent circuit

3.4.5
emitter series resistance
resistance between the emitter terminal and the internal inaccessible emitter point in an equivalent circuit

3.4.6
saturation resistance
resistance between collector and emitter terminals under specified conditions of base current and collector current when the collector current is limited by the external circuit

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

3.4.7
extrinsic base resistance
resistance between the base terminal and the internal inaccessible base point in an equivalent circuit

3.4.8
emitter depletion layer capacitance
part of the capacitance across an emitter-base junction that is associated with its depletion layer

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

3.4.9
collector depletion layer capacitance
part of the capacitance across a collector-base junction that is associated with its depletion layer

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

3.4.10
delay-time (of a switching transistor)
time interval between the application at the input terminals of a pulse which is switching the transistor from a non-conducting to a conducting state and the appearance at the output terminals of the pulse induced by the charge carriers

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

3.4.11
rise time (of a switching transistor)
time interval between the instants at which the magnitude of the pulse at the output terminals reaches specified lower and upper limits, respectively, when the transistor is being switched from its non-conducting to its conducting state

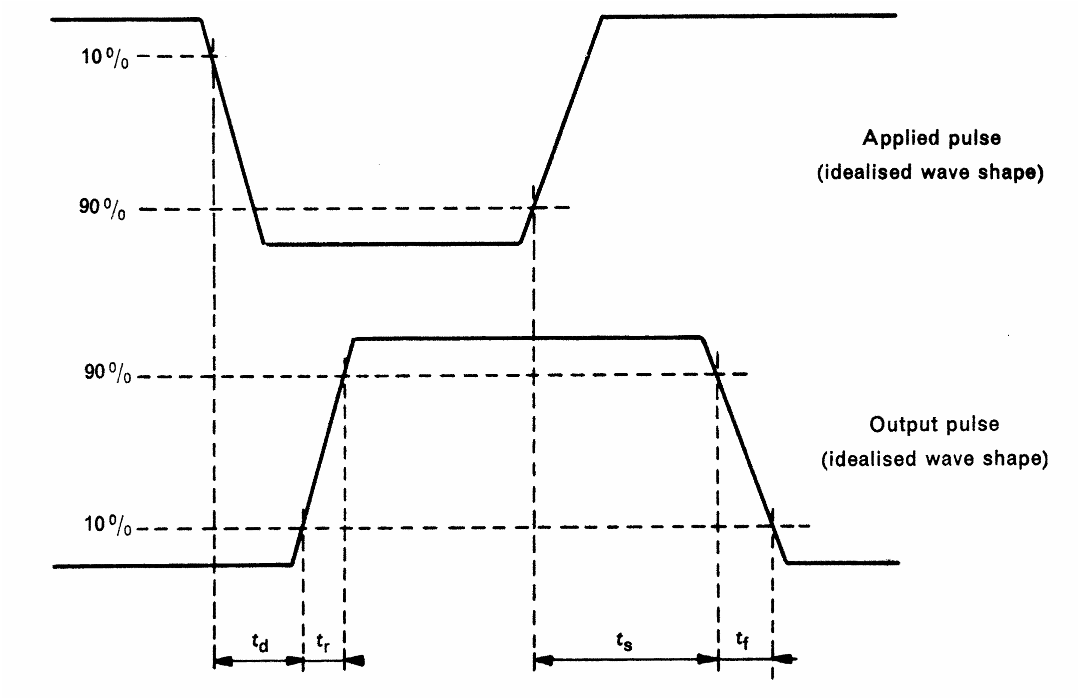
NOTE The lower and upper limits are usually 10 % and 90 % respectively of the amplitude of the output pulse (see figure 1).

3.4.12
carrier storage time (of a switching transistor)
time interval between the beginning of the fall of the pulse applied to the input terminals and the beginning of the fall of the pulse generated by charge carriers at the output terminals

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

3.4.13
fall time (of a switching transistor)
time interval between the instants at which the magnitude of the pulse at the output terminals reaches specified upper and lower limits respectively, when the transistor is being switched from its conducting to its non-conducting state

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



t_d = delay time t_r = rise time

t_f = fall time t_s = carrier storage time

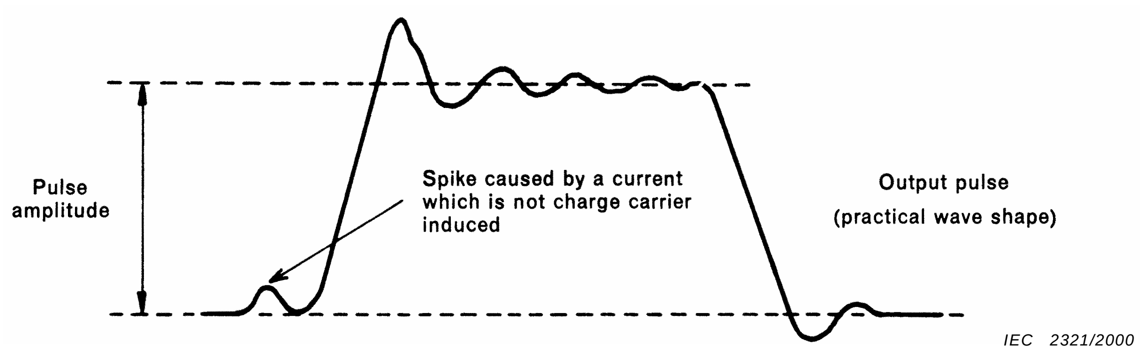


Figure 1 – Switching transistor pulse characteristic

3.4.14
maximum frequency of oscillation
maximum frequency at which a transistor can be made to oscillate under specified conditions

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

3.4.15
transition frequency (f_T)
product of the modulus of the common-emitter small-signal short-circuit forward current transfer ratio $|h_{21e}|$ and the frequency of measurement, this frequency being so chosen that $|h_{21e}|$ is decreasing at a slope of approximately 6 dB per octave

3.4.16
frequency of unity current transfer ratio (f_1)
frequency at which the modulus of the common-emitter small-signal short-circuit forw current transfer ratio $|h_{21e}|$ has decreased to unity

3.4.17
current transfer ratio; current amplification factor

3.4.17.1
small-signal short-circuit forward current transfer ratio
ratio between the alternating output current and the small sinusoidal input current producir under small-signal conditions, the output being short-circuited to a.c.

3.4.17.2
static value of the forward current transfer ratio
ratio between the continuous (direct) output and the continuous (direct) input current, output voltage being held constant

3.4.17.3
inherent (large-signal) forward current transfer ratio
difference between the continuous (direct) collector current and the collector-base cut current divided by the sum of the continuous (direct) base current and the collector-base off current at a specified constant value of the collector-emitter voltage

3.4.18
small-signal open-circuit reverse voltage transfer ratio
ratio of the alternating voltage appearing at the input terminals, when they are a.c. op circuited, to the alternating voltage applied to the output terminals, under small-sig conditions

3.4.19
transient current ratio in saturation (of a switching transistor)
quotient of the collector current suddenly demanded from a transistor and the minimum b current necessary to hold it in saturation

3.4.20
Early voltage V_{EY} (for computer-aided circuit design)
voltage corresponding to the point derived from the graph of collector current versus collec to-emitter voltage, with the base current as a parameter, where the output characteri extrapolates back to the voltage axis

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

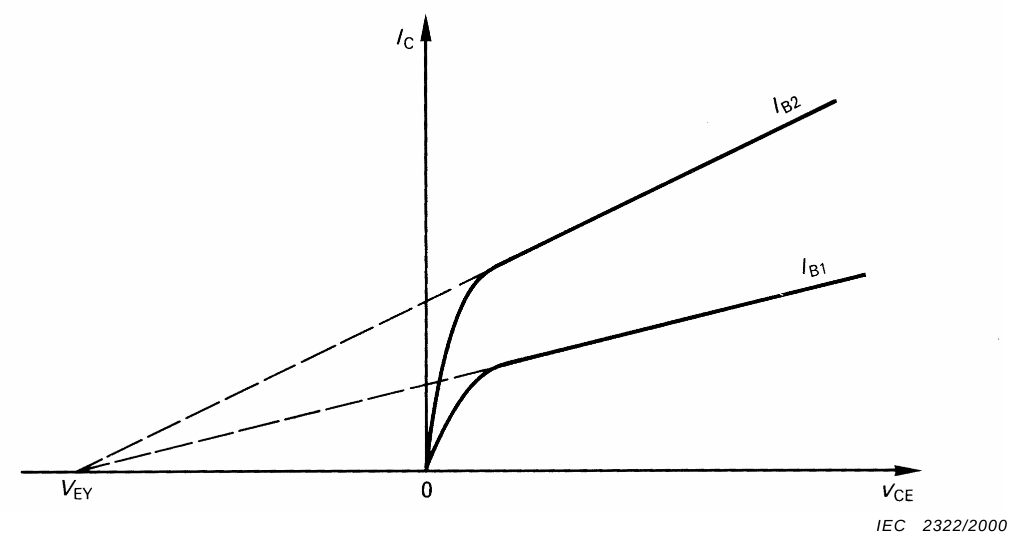


Figure 2 – Early voltage

3.5 *s* parameters

3.5.1 General introduction

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

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

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

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

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

where

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

$Z_{0i} = R_{0i} + \mathrm{j}X_{0i}$;

$Z_{0i}^{*} = R_{0i} - \mathrm{j}X_{0i}$.

(See figure 3.)

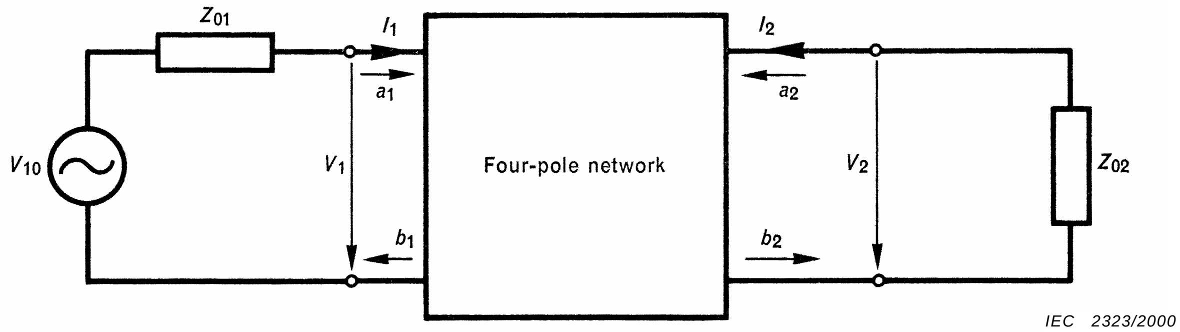


Figure 3 – Circuit with four-pole network

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

In the general case, they are complex quantities.

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

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

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

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

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

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

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

Analogously:

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

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

In addition:

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

$$= \left(\frac{V_2 - R_0 I_2}{V_1 + R_0 I_1}\right)_{\text{with } (V_2 = -R_0 I_2)} = \left(\frac{V_2}{½\, V_{10}}\right) \quad \text{with } \left(-\frac{V_2}{I_2} = R_0\right)$$

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

Analogously:

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

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

3.5.2 Definitions

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

3.5.2.1
input reflection coefficient (s_{11})
ratio of the complex-value of the reflected wave at the input to that of the incident wave at the input, under small-signal conditions, the output terminating resistance and the source resistance each having the value R_0

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

3.5.2.2
output reflection coefficient (s_{22})
ratio of the complex value of the reflected wave at the output to that of the incident wave at the output, under small-signal conditions, the input terminating resistance and the source resistance each having the value R_0

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

3.5.2.3
forward transmission coefficient (s_{21})
ratio of the complex value of the transmitted wave at the output to that of the incident wave at the input, under small-signal conditions, the output terminating resistance and the source resistance each having the value R_0

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

3.5.2.4
reverse transmission coefficient (s_{12})
ratio of the complex value of the transmitted wave at the input to that of the incident wave at the output, under small-signal conditions, the input terminating resistance and the source resistance each having the value R_0

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

General note

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

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

3.5.2.5
frequency of unity forward transmission coefficient (f_s, f_{1s})
frequency at which the modulus of the forward transmission coefficient s_{21} has decreased to unity

3.5.3 Application of the *s* parameters

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

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

The following matrix equivalences hold:

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

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

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

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

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

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

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

The following equivalences hold:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Conditions of unconditional stability:

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

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

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

4 Letter symbols

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

4.1 Letter symbols for currents, voltages and powers

4.1.1 General

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

4.1.2 Additional subscripts

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

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

4.2 Letter symbols for electric parameters

4.2.1 General

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

4.2.2 Additional subscripts

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

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

4.3 Letter symbols for other quantities

4.3.1 General

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

4.4 List of letter symbols

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

4.4.1 Voltages

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

4.4.2 Currents

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

4.4.3 Powers

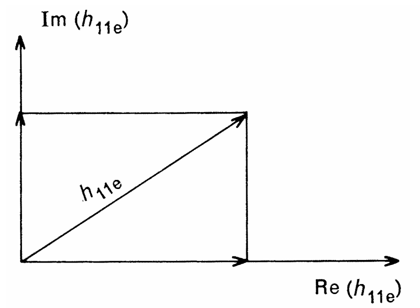
Name and designation	Letter symbol	Remarks
Collector power dissipation with T_{amb} or T_{case} specified	P_C	
Total input power (d.c. or average) to all electrodes with T_{amb} or T_{case} specified	P_{tot}	

4.4.4 Electrical parameters

4.4.4.1 Static parameters (specified for bias conditions)

Name and designation	Letter symbol	Remarks
Static value of the forward current transfer ratio (in common-emitter configuration)	h_{21E} or h_{FE}	$h_{21E} = \frac{I_C}{I_B} = \frac{I_E}{I_B} - 1$ with V_{CE} = 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} = 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} = constant

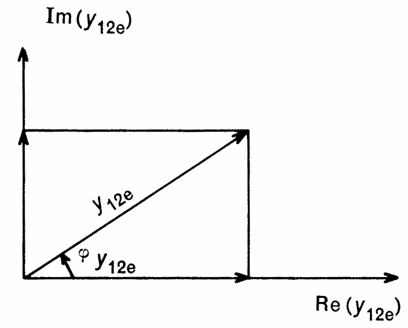
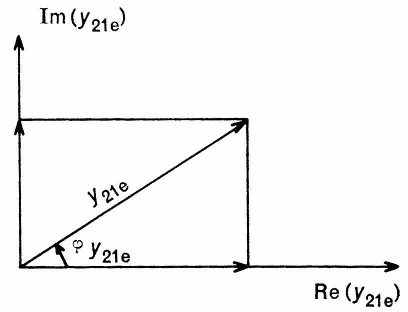
4.4.4.2 Small-signal parameters (specified for bias and frequency conditions)

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

4.4.4.2 *(continued)*

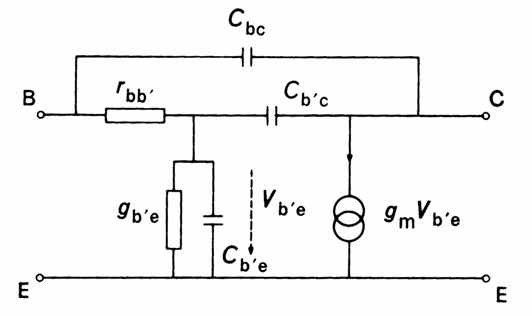
Name and designation	Letter symbol	Remarks
Output capacitance, input open-circuited to a.c.: – in common-emitter configuration – in common-base configuration	 C_{22eo} or C_{oeo} C_{22bo} or C_{obo}	 $h_{22e} = \mathrm{Re}(h_{22e}) + \mathrm{j}\omega C_{22eo}$ $h_{22b} = \mathrm{Re}(h_{22b}) + \mathrm{j}\omega C_{22bo}$
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}	 $y_{22e} = \mathrm{Re}(y_{22e}) + \mathrm{j}\omega C_{22es}$ $y_{22b} = \mathrm{Re}(y_{22b}) + \mathrm{j}\omega C_{22bs}$
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} = constant and $y_{11e} = \frac{1}{h_{11e}}$ $y_{11b} = \frac{I_e}{V_{eb}}$ with V_{cb} = 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} = constant $y_{12b} = \frac{I_e}{V_{cb}}$ with V_{eb} = 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} = constant $y_{21b} = \frac{I_c}{V_{eb}}$ with V_{cb} = 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} = constant $y_{22b} = \frac{I_c}{V_{cb}}$ with V_{eb} = constant

4.4.4.2 *(continued)*

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

4.4.4.3 Modified hybrid π equivalent circuit parameters

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



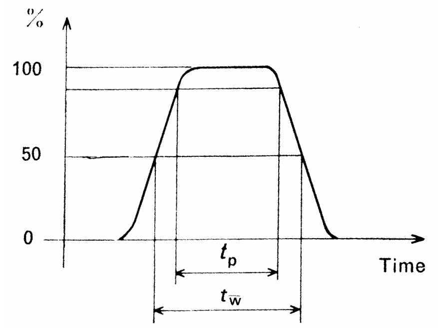
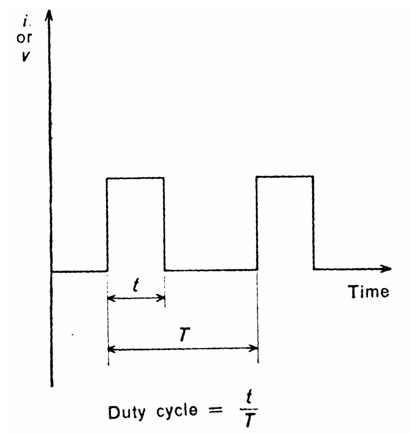
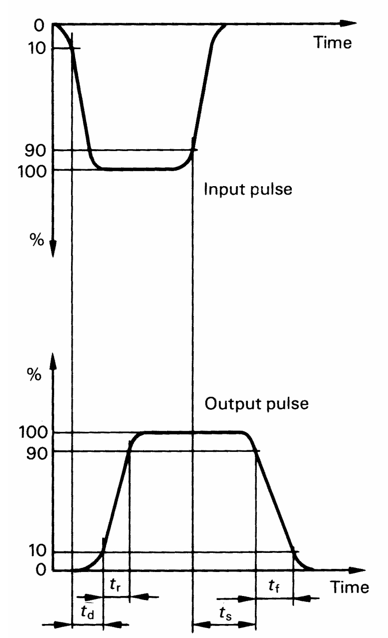
IEC 2324/2000

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

4.4.5 Frequency parameters

Name and designation	Letter symbol	Remarks
Cut-off frequency:		
– in common-emitter configuration	f_{h21e} or f_{hfe}	
– in common-base configuration	f_{h21b} or f_{hfb}	
– in common-collector configuration	f_{h21c} or f_{hfc}	
Frequency of unity current transfer ratio	f_1	$f_1 = f$ for $\lvert h_{21e}\rvert = 1$
Transition frequency	f_T	$f_T = f \times \lvert h_{21e}\rvert$ (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 – in common-base configuration – in common-collector configuration	 f_{se}, f_{1se} f_{sb}, f_{1sb} f_{sc}, f_{1sc}	 $f_{se} = f$ for $\lvert s_{21e}\rvert = 1$ $f_{sb} = f$ for $\lvert s_{21b}\rvert = 1$ $f_{sc} = f$ for $\lvert s_{21c}\rvert = 1$

4.4.6 Switching parameters

Name and designation	Letter symbol	Remarks
Pulse average time	t_w	
Pulse time	t_p	
Duty cycle	D, δ	
Delay time	t_d	
Rise time	t_r	
Carrier storage time	t_s	
Fall time	t_f	

4.4.6 *(continued)*

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

4.4.7 Sundry quantities

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

4.4.8 External circuit parameters

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

4.4.9 Matched-pair bipolar transistors

Name and designation	Letter symbol	Remarks
Ratio of static values of common-emitter forward current transfer ratio	h_{FE1}/h_{FE2} 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	$\left\|\Delta\left(V_{BE1} - V_{BE2}\right)\right\|_{\Delta T}$	

5 Essential ratings and characteristics

5.1 Low-power signal transistors (excluding switching applications)

5.1.1 General

5.1.1.1 Range of application

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

5.1.1.2 Rating methods

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

5.1.1.3 Recommended temperatures

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

5.1.2 Ratings (limiting values)

The following ratings shall be stated.

5.1.2.1 Temperatures

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

5.1.2.1.2 Range of storage temperatures (T_{stg})

5.1.2.2 Voltages and currents

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

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

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

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

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

5.1.2.2.4 Maximum collector current (I_C)

5.1.2.2.5 Maximum emitter current (where appropriate) (I_E)

5.1.2.2.6 Maximum base current (where appropriate) (I_B)

5.1.2.3 Power dissipation

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

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

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

5.1.3 Characteristics

5.1.3.1 General

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

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

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

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

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

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

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

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

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

5.1.3.5 Base-emitter voltage (V_{BE})

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

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

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

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

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

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

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

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

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

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

Either:

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

or:

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

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

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

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

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

5.1.3.9.1 Three-terminal transistors

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

5.1.3.9.2 Four-terminal transistors

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

5.1.3.10 Noise factor (where appropriate)

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

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

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

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

5.1.3.11.1 General purpose applications

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

The parameters should be specified as follows:

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

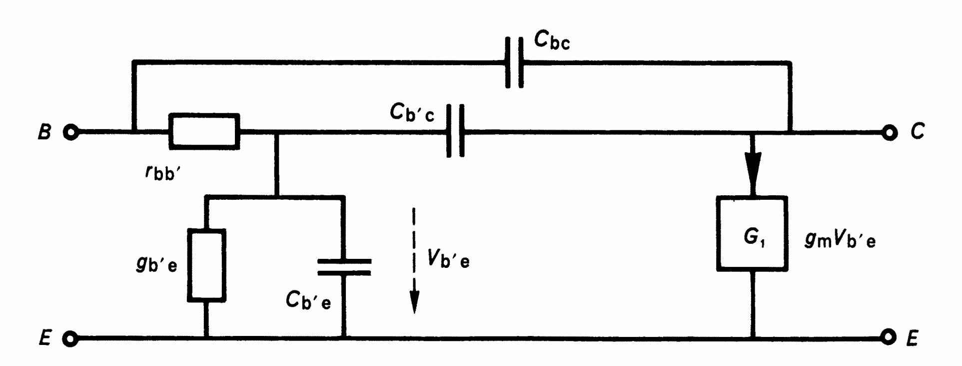
  This parameter shall be specified in the same way as in 5.1.3.9.

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

The four characteristic values:

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:



G_1 = current generator

Figure 4 – Equivalent circuit

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

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

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

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

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

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

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

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

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

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 in the above formulae. (The values used in the above formulae are defined in 6.1.11.3.2).

5.1.3.11.2 Special purpose applications

a) *y parameters*

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

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

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

either first set:

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

or second set:

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

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

b) *s parameters*

As an alternative to the y parameters, the following s parameters may be given in a complex form. They shall be stated with reference to a resistive load of 50 Ω 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".

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

5.1.3.12.1 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.

5.1.3.12.2 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).

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

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

Maximum absolute value of the change in the difference of the base-emitter voltages (as in 5.1.3.12.2) between two specified temperatures, at specified voltage (V_{CE}) and current (I_C).

5.1.4 Application data

Under consideration.

5.2 Power transistors (excluding switching and high-frequency applications)

5.2.1 General

5.2.1.1 Range of application

The following subclauses give the requirements applicable to power transistors (excluding switching and high-frequency applications).

5.2.1.2 Rating methods

Power transistors should be specified either as ambient-rated or case-rated devices or, where appropriate, as both.

5.2.1.3 Recommended temperatures

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

5.2.2 Ratings (limiting values)

The following ratings should be stated.

5.2.2.1 Temperatures

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

5.2.2.1.2 Range of storage temperatures (T_{stg})

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

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

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

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

5.2.2.2.4 Maximum collector current (I_C)

5.2.2.2.5 Maximum emitter current (where appropriate) (I_E)

5.2.2.2.6 Maximum base current (I_B)

5.2.2.3 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 should be specified.

5.2.3 Characteristics

5.2.3.1 General

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

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

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

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

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

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

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

Maximum value at 25 °C at a specified high value of collector current and a specified base current

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

Minimum and maximum values at 25 °C 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.

5.2.3.6 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-emitting 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 $\times$ 10^n Hz and should be such that $|h_{21e}|$ is in the range of 2 to 10.

5.2.3.7 Output capacitance C_{22b} (where appropriate)

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

5.2.4 Application data

Under consideration.

5.3 High-frequency power transistors for amplifier and oscillator applications

5.3.1 Type

Case-rated high-frequency power transistor for amplifier and oscillator applications

5.3.2 Semiconductor material

Germanium, silicon, etc.

5.3.3 Polarity

PNP/NPN

5.3.4 Outline

5.3.4.1 IEC reference

(National references may be added.)

5.3.4.2 Case material

5.3.4.3 Terminal identification and indication of any connection between a terminal and the case

5.3.5 Limiting values (absolute maximum system) over the operating temperature range, unless otherwise stated

Any qualification such as time, frequency, pulse duration, humidity, etc. must be stated.

5.3.5.1 Minimum and maximum case operating temperatures (T_{case})

5.3.5.2 Minimum and maximum storage temperatures (T_{stg})

5.3.5.3 At least, one of the following should be specified. It is recommended that V_{CB} should be stated as a first priority.

5.3.5.3.1 Maximum collector-base voltage (V_{CB})

5.3.5.3.2 Maximum collector-emitter voltage with specified reverse base voltage (V_{CEX})

5.3.5.3.3 Maximum collector-emitter voltage with the base short-circuited to the emitter (V_{CES})

5.3.5.4 Maximum collector-emitter voltage with the base open-circuited (V_{CEO})

and/or

maximum collector-emitter voltage with the specified external resistance (V_{CER})

5.3.5.5 Maximum emitter-base reverse voltage (V_{EB})

5.3.5.6 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 $I_{E(AV)}$)

5.3.5.7 Either:

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

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

5.3.5.9 Power dissipation

5.3.5.9.1 Maximum total power dissipation as a function of case temperature (P_{tot}), or

5.3.5.9.2 Maximum virtual (equivalent) junction temperature and maximum total power dissipation ($T_{(vj)}$ and P_{tot})

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

5.3.5.11 Where appropriate, capability of sustaining a mismatch under specified conditions

5.3.6 Characteristics

Reference	Characteristics	Conditions at T_{case} = 25 °C, unless otherwise stated	Note	Symbol	Requirements	
5.3.6.1	Static value of common-emitter forward current transfer ratio	V_{CE} specified, I_C specified (typical value), d.c. or pulse as specified		h_{21E}	min.	max.
5.3.6.2	Where appropriate, static value of common-emitter forward current transfer ratio	V_{CE} = specified low value, I_C = specified high value, d.c. or pulse as specified		h_{21E}	min.	–
5.3.6.3	Transition frequency	V_{CE}, I_C and f specified		f_T	min.	max.*
	or: modulus of the forward transmission coefficient	V_{CE}, I_C, f, source and load impedances (preferably 50 Ω) specified		$\|s_{21e}\|$	min.	
5.3.6.4	Cut-off currents					
5.3.6.4.1	Preferably, collector-base cut-off current	V_{CB} specified, preferably maximum value Emitter open-circuited		I_{CBO}	–	max.
	or otherwise collector-emitter cut-off current	V_{CEX} specified, preferably maximum value, V_{BE} specified		I_{CEX}	–	max.
5.3.6.4.2	Where appropriate, collector-emitter cut-off current	V_{CER} specified, preferably maximum value. Specified base-emitter resistance		I_{CER}	–	max.
5.3.6.4.3	Where appropriate, collector-emitter cut-off current	V_{CES} specified, preferably maximum value. Base short-circuited to emitter		I_{CES}	–	max.

5.3.6 *(continued)*

Reference	Characteristics	Conditions at T_{case} = 25 °C, unless otherwise stated	Note	Symbol	Requirements	
5.3.6.4.4	Where appropriate, collector-emitter cut-off current	V_{CEO} specified, preferably maximum value. Base open-circuited		I_{CEO}	–	max.
5.3.6.5	Cut-off currents at high temperature					
5.3.6.5.1	Preferably, collector-base cut-off current	V_{CB} specified, preferably between 65 % and 85 % of maximum value V_{CB} T_{case} specified, preferably high value		I_{CBO}	–	max.
	or otherwise collector-emitter cut-off current	V_{CE} specified, preferably between 65 % and 85 % of maximum value V_{CEX} V_{BE} specified, T_{case} specified, preferably high value		I_{CEX}	–	max.
5.3.6.5.2	Where appropriate, collector-emitter cut-off current	V_{CE} specified, preferably between 65 % and 85 % of maximum value V_{CER}. specified. T_{case} specified, preferably high value		I_{CER}	–	max.
5.3.6.5.3	Where appropriate, collector-emitter cut-off current	V_{CE} specified, preferably between 65 % and 85 % of maximum value V_{CES} T_{case} specified, preferably high value		I_{CES}	–	max.
5.3.6.5.4	Where appropriate, collector-emitter cut-off current	V_{CE} specified, preferably between 65 % and 85 % of maximum value V_{CEO} T_{case} specified, preferably high value		I_{CEO}	–	max.
5.3.6.6	Collector-emitter saturation voltage	I_C = specified high value, I_B specified, d.c. or pulse as specified		V_{CEsat}	–	max.
5.3.6.7	Either: output power into the load	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		P_{out}	min.	–
	or: power gain	Same conditions as for output power		G_p	min.	–
5.3.6.8	Where appropriate, overall efficiency	Same conditions as for output power	1	η_{tot}	min.	–
	alternatively, collector efficiency	Same conditions as for output power	1	η_c	min.	–
5.3.6.9	Capacitances:					
5.3.6.9.1	Output capacitance	V_{CB} and f specified, I_E = 0		C_{22b}	–	max.
5.3.6.9.2	Where appropriate, input capacitance	V_{EB} and f specified, I_C = 0		C_{11b}	–	max.
5.3.6.9.3	Where appropriate, reverse transfer capacitance	V_{CE} and f specified, I_B = 0		C_{12e}	–	max.
5.3.6.10	Where appropriate, inter-modulation factor or other linearity criterion	Conditions to be specified			min.*	max.*
5.3.6.11	Thermal resistance (junction to case)	Conditions to be specified		$R_{th(j\text{-}case)}$	–	max.

* Where appropriate.

NOTE $\eta_{tot} = \dfrac{P_{out}}{P_{in} + P_{(d.c.)}}$ $\eta_c = \dfrac{P_{out}}{P_{C(d.c.)}}$

5.3.7 Supplementary information

5.3.7.1 Where appropriate, curves of maximum transient thermal impedance under pulse conditions

5.3.7.2 Mounting torque (where appropriate)

5.3.8 Environmental and/or endurance test information

Under consideration.

5.4 Switching transistors

5.4.1 General

5.4.1.1 Range of application

The following subclauses give the requirements applicable to transistors intended for switching applications.

5.4.1.2 Rating methods

Switching transistors should be specified either as ambient-rated or case-rated devices or, where appropriate, as both.

5.4.1.3 Recommended temperatures

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

5.4.2 Ratings (limiting values)

The following ratings shall be stated.

5.4.2.1 Temperatures

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

5.4.2.1.2 Range of storage temperatures (T_{stg})

5.4.2.2 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.

5.4.2.2.1 Maximum continuous collector current (I_C)

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

5.4.2.2.3 Maximum continuous base current (I_B)

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

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

5.4.2.3 Voltages

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

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

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

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

Maximum rated value at specified collector current and specified base-emitter (reverse) voltage

5.4.2.4 Power dissipation

5.4.2.4.1 Maximum total power dissipation (without additional cooling for ambient-rated devices) up to ambient or case temperature of 25 °C (P_{tot})

5.4.2.4.2 Derating factor above 25 °C or, for case-rated devices, derating curve

5.4.2.5 Safe operating areas

5.4.2.5.1 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

Conditions to be specified:

– case temperature (T_{case})
– pulse time (t_p)
– duty cycle (δ)

5.4.2.5.2 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

Conditions to be specified:

– case temperature (T_{case})
– reverse base current (I_{B2})
– conditions in the drive circuit

5.4.3 Characteristics

5.4.3.1 General

The values should be preferably stated at one of the voltages and/or currents given in clause 6 of IEC 60747-1, chapter VI.

5.4.3.2 Static characteristics

5.4.3.2.1 Cut-off currents

NOTE One or more of these currents should be stated.

5.4.3.2.1.1 Collector-base current (I_{CBO})

– Maximum value at 25 °C, preferably at the maximum rated value of the collector-base voltage and with the emitter open-circuited
– Maximum value at a high operating temperature, at a voltage preferably between 65 % and 85 % of the maximum rated collector-base voltage, and with the emitter open-circuited

5.4.3.2.1.2 Collector-emitter current (I_{CEX})

– Maximum value at 25 °C, preferably at the maximum rated value of collector-emitter voltage and under specified base-emitter bias conditions
– Maximum value at a high operating temperature, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage and under specified base-emitter bias conditions

5.4.3.2.1.3 Collector-emitter current (I_{CES})

– Maximum value at 25 °C, preferably at the maximum rated value of the collector-emitter voltage and with the base short-circuited to the emitter
– Maximum value at a high operating temperature, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage and with the base short-circuited to the emitter

5.4.3.2.1.4 Collector-emitter current (I_{CEO})

– Maximum value at 25 °C, preferably at the maximum rated value of the collector-emitter voltage and with the base open-circuited
– Maximum value at a specified high operating temperature, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage and with the base open-circuited

5.4.3.2.1.5 Collector-emitter current (I_{CER})

– Maximum value at 25 °C, preferably at the maximum rated collector-emitter voltage and with a specified base-emitter resistance
– Maximum value at a high operating temperature, at a voltage preferably between 65 % and 85 % of the maximum rated collector-emitter voltage and with a specified base-emitter resistance

5.4.3.2.1.6 Emitter-base current (I_{EBO})

– Maximum value at 25 °C at a specified high value of the emitter-base voltage and with the collector open-circuited
– Maximum value at a high operating temperature and at a specified emitter-base voltage, and with the collector open-circuited

5.4.3.2.2 Emitter-base cut-off current (reverse current)

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

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

Minimum value at 25 °C, at specified collector current and collector-emitter voltage

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

Maximum value at 25 °C, for at least one specified collector current and specified base current

5.4.3.2.5 Base-emitter saturation voltage (V_{BEsat})

Maximum value at 25 °C, at specified collector and base currents, preferably the same as in 5.4.3.2.4

5.4.3.3 Switching characteristics at 25 °C (see 5.4.3.3.3, note 1)

5.4.3.3.1 Output capacitance (C_{22b})

Maximum value, at specified collector-base voltage and frequency, with zero emitter current

5.4.3.3.2 Switching times (see 5.4.3.3.3, note 2)

5.4.3.3.2.1 Rise time (t_r)

Maximum value, at nominal values of collector current (I_C) and base forward current (I_{B1}).

5.4.3.3.2.2 Turn-on time (t_{on})

Maximum value, at nominal values of collector current (I_C), base forward current (I_{B1}) and base-emitter voltage (V_{BE}) prior to turn-on pulse

5.4.3.3.2.3 Storage time (t_s)

Maximum value, at nominal values of collector current (I_C) and base forward and reverse currents (I_{B1} and I_{B2})

5.4.3.3.2.4 Turn-off time (t_{off})

Maximum value, at nominal values of collector current (I_C) and base forward and reverse currents (I_{B1} and I_{B2})

5.4.3.3.3 Transition frequency (f_T)

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

In specifying f_T, the frequency should 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.

NOTE 1 The following characteristics should be specified:

a) C_{22b} (see 5.4.3.3.1) and

b) preferably t_r, t_{on}, t_s, t_{off} (see 5.4.3.3.2.1 to 5.4.3.3.2.4), or
   t_r and t_s (see 5.4.3.3.2.1 and 5.4.3.3.2.3), or
   t_{on} and t_{off} (see 5.4.3.3.2.2 and 5.4.3.3.2.4), or
   t_s and f_T (see 5.4.3.3.2.3 and 5.4.3.3.3).

NOTE 2 In the data sheets, the circuit component values, bias and driving voltages should be specified.

5.4.3.4 Additional characteristics for computer-aided circuit design

The following additional characteristics should be given for transistors intended to be used in circuits designed using computer-aided techniques. These characteristics, together with the appropriate ones selected from the essential characteristics, are applicable for use in the Beaufoy and Sparkes equivalent circuit of a transistor.

5.4.3.4.1 C_{ib}: maximum common-base input capacitance, at specified value of reverse base-emitter voltage and zero collector current

5.4.3.4.2 f_T: minimum transition frequency, at specified values of collector current and collector-emitter voltage

5.4.3.4.3 Either:

a) h_{22e}, h_{oe}: maximum value of the common-emitter output admittance with input open-circuited to a.c., at specified values of collector current and collector-emitter voltage

or:

b) V_{EY}: minimum Early voltage

5.4.3.5 Thermal characteristics

5.4.3.5.1 Thermal resistance junction-case (R_{thjc}) (for case-rated transistors)

Maximum value

5.4.3.5.2 Thermal resistance junction-ambient (R_{thja}) (for ambient-rated transistors, if applicable)

Maximum value

5.4.3.5.3 Transient thermal impedance junction-case (Z_{thjc}) (for case-rated transistors, if applicable)

Diagram showing Z_{thjc} against the time which has elapsed after a step change in power dissipation

5.4.3.5.4 Thermal impedance junction-case under pulse conditions ($Z_{(thjc)p}$) (for case-rated transistors, if applicable)

Diagram showing ($Z_{(thjc)p}$) against the pulse duration t_p for various duty cycles, at least 1/2

5.4.4 Application data

Under consideration.

6 General and reference measuring methods

6.1 General measuring methods

6.1.1 General

The polarities of the generators shown in the circuits in this subclause are applicable to NPN devices. However, these circuits can be adapted for PNP devices by changing the polarities of the meters and power supplies.

6.1.2 Collector-base and emitter-base cut-off currents

6.1.2.1 Collector-base cut-off current (d.c. method) (I_{CBO})

The collector-base cut-off current is measured in the same way as the collector-emitter cut-off current (see 6.1.3), except that the emitter and base terminals are interchanged. The emitter is left open-circuit.

6.1.2.2 Emitter-base cut-off current (d.c. method) (I_{EBO})

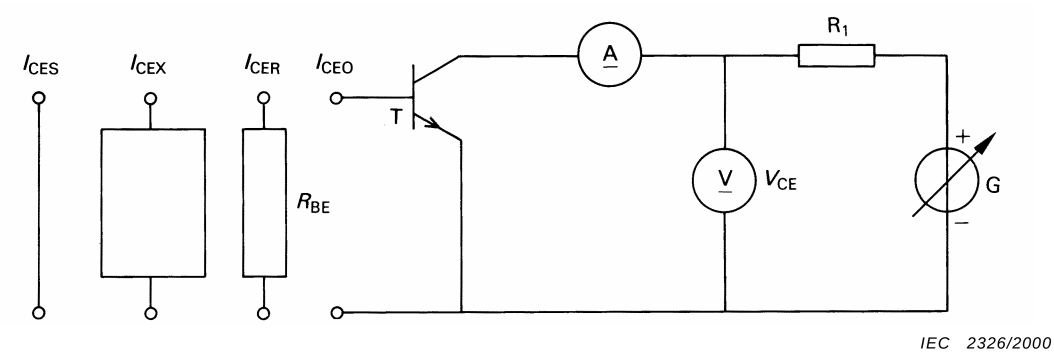
The emitter-base cut-off current is measured in the same way as the collector-emitter cut-off current (see 6.1.3), except that the emitter is connected to the ammeter and the base is connected to the common line. The collector is left open-circuit.

6.1.3 Collector-emitter cut-off currents (d.c. method) (I_{CEO}, I_{CER}, I_{CEX}, I_{CES})

a) Purpose

To measure the collector-emitter cut-off currents of a transistor under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 5 – Basic circuit for the measurement of collector-emitter cut-off currents

c) Circuit description and requirements

Resistor R_1 is a current-limiting resistor. The base-emitter configuration should be as specified.

d) Measurement procedure

The temperature is set to the specified value. The voltage is increased until V_{CE} reaches the specified value.

The cut-off current is read on ammeter A.

e) Specified conditions

- Ambient or case temperature (T_{amb} or T_{case})
- Collector-emitter voltage (V_{CE}).
- Terminations to be applied:

for I_{CEO}	$I_B = 0$
for I_{CER}	R_{BE} = ... Ω
for I_{CEX}	V_{BB} = ...V, R = ... Ω
	or
	V_{BE} = ... V
for I_{CES}	$V_{BE} = 0$

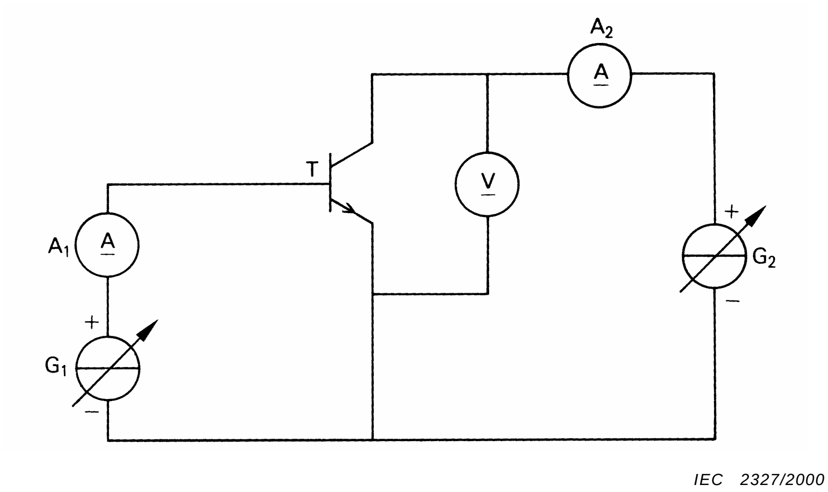
6.1.4 Collector-emitter saturation voltage (V_{CEsat})

6.1.4.1 Collector-emitter saturation voltage (d.c. method)

a) Purpose

To measure the collector-emitter saturation voltage of a transistor under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 6 – Basic circuit for the measurement of the collector-emitter saturation voltage (d.c. method)

c) Precautions to be observed

Because of the risk that the maximum power dissipation P_{tot} could be exceeded, it is important to follow the order of the measurement procedure.

It may be necessary to modify the measurement circuit, for example by connecting a voltage-limiting circuit across the generator G_2.

d) Measurement procedure

The temperature is set to the specified value.

The base current is adjusted to the specified value read on ammeter A_1.

The collector current is adjusted to the specified value read on ammeter A_2.

The collector-emitter saturation voltage is measured on voltmeter V.

e) Specified conditions

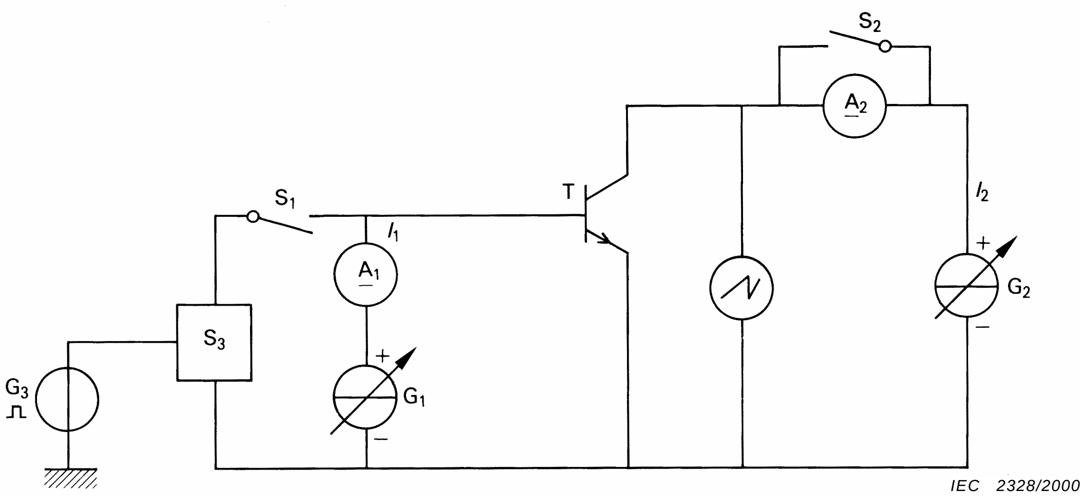
- Ambient or case temperature (T_{amb} or T_{case})
- Base current (I_B)
- Collector current (I_C)

6.1.4.2 Collector-emitter saturation voltage (pulse method)

a) Purpose

To measure the collector-emitter saturation voltage of a transistor under pulse conditions.

b) Circuit diagram



T = transistor being measured

Figure 7 – Basic circuit for the measurement of the collector-emitter saturation voltage (pulse method)

c) Circuit description and requirements

Electronic switch S_3 is normally closed, and opened only when pulses are applied to it by pulse generator G_3.

The value of the internal resistance of constant-current generator G_1 should be much greater than the input impedance of the transistor being measured.

The value of the internal resistance of constant-current generator G_2 should be much greater than the value of V_{CEsat}/I_C.

d) Precautions to be observed

The time for the direct-current generators to respond to changes in load should be less than the "on" period of the transistor being measured.

The specified width and duty cycle of the pulse generator should be so small that no significant heat dissipation occurs in the transistor being measured.

The maximum voltage supplied by direct current generator G_2 should not exceed the collector-emitter breakdown voltage of the transistor.

e) Measurement procedure

The temperature is set to the specified value.

With switch S_1 open, with no transistor in the measurement socket and with a short circuit inserted between emitter and base terminals, current generator G_1 is adjusted until the reading of ammeter A_1 is equal to the specified value I_B.

With switch S_2 open, with no transistor in the measurement socket, and with a short circuit inserted between emitter and collector terminals, current generator G_2 is adjusted until the reading of ammeter A_2 is equal to the specified value I_C.

With the transistor being measured in the measurement socket, switches S_1 and S_2 closed, and switch S_3 operated by G_3, the value of the steady voltage of the flat part of the waveform in the "on" period as observed on the oscilloscope is V_{CEsat}.

f) Specified conditions

- Ambient or case temperature (T_{amb} or T_{case})
- Base current (I_B)
- Collector current (I_C)
- Pulse time and duty cycle of pulses (t_p, δ, preferably t_p = 300 μs, $\delta \leq 2$ %)

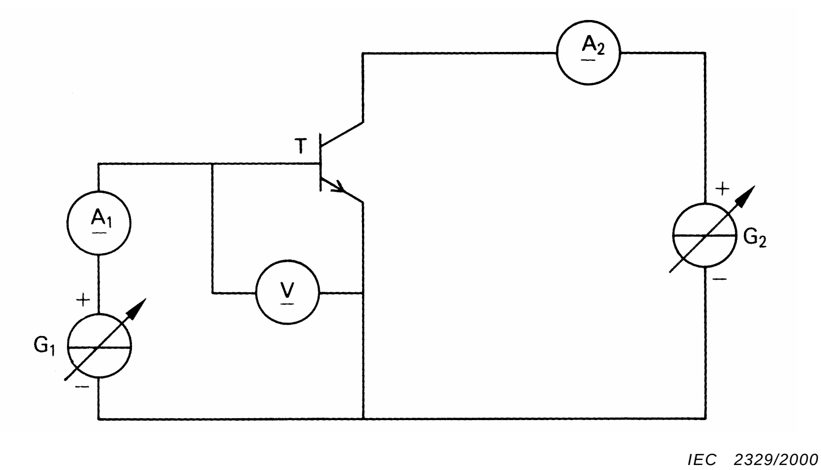
6.1.5 Base-emitter saturation voltage (V_{BEsat})

6.1.5.1 Base-emitter saturation voltage (d.c. method)

a) Purpose

To measure the base-emitter saturation voltage of a transistor under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 8a – Basic circuit for the measurement of the base-emitter saturation voltage (d.c. method)

c) Precautions to be observed

Difficulty may be experienced in setting up the specified electrical conditions and, in some cases, there is a risk that the maximum dissipation of the transistor may be exceeded. Therefore, it is important to follow the order of the measurement procedure.

It may be necessary to modify the measurement circuit, for example by connecting a voltage-limiting circuit across generator G_2.

d) Measurement procedure

The temperature is set to the specified value.

The base current is adjusted to the specified value read on ammeter A_1.

The collector current is adjusted to the specified value read on ammeter A_2.

The base-emitter saturation voltage is measured on voltmeter V.

e) Specified conditions

– Ambient or case temperature (T_{amb} or T_{case})

– Base current (I_B)

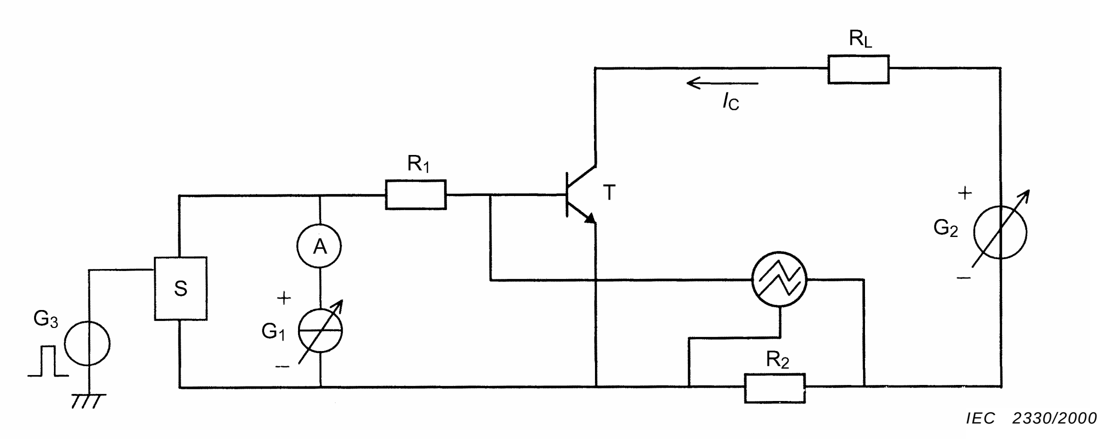
– Collector current (I_C)

6.1.5.2 Base-emitter saturation voltage (pulse methods)

a) Purpose

To measure the base-emitter saturation voltage under pulse conditions.

b) Circuit diagram



T = transistor being measured

Figure 8b – Basic circuit for the measurement of the base-emitter saturation voltage (pulse methods)

c) Circuit description and requirements

Current generator G_1 supplies the base current.

Electronic switch S is normally closed and opened only when a pulse is applied to it by pulse generator G_3. The repetition frequency and duty cycle of the pulses should be chosen so as to avoid significant heating of the transistor being measured (see clauses 2, 3 and 6 of IEC 60747-1, chapter VII, section one).

The value of resistor R_1 is chosen so that the specified collector current is achieved with voltage generator G_2. The collector current is measured by means of resistor R_2 which is connected to the oscilloscope.

d) Measurement procedure

The temperature is set to the specified value.

The base current, read on ammeter A, is set to the specified value.

The collector current, shown on the oscilloscope, is set to the specified value.

The base-emitter saturation voltage is measured using the oscilloscope.

e) Specified conditons

– Ambient or case temperature or virtual junction temperature (T_{amb} or T_{case}) or (T_{vj})

– Base current (I_B)

– Collector current (I_c)

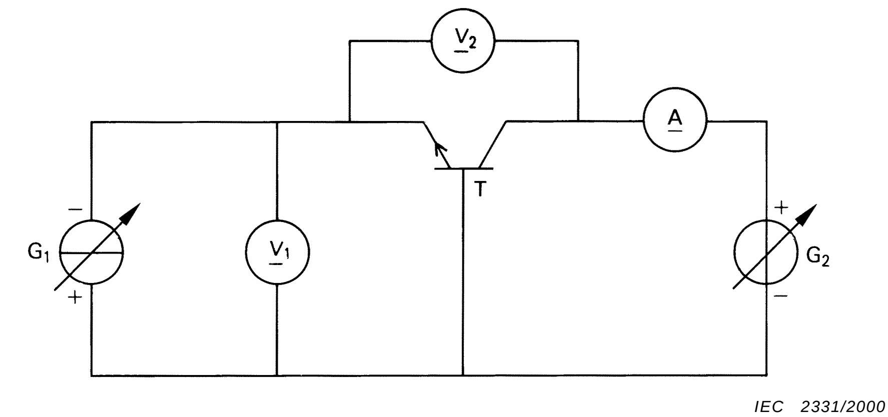
– Pulse time (t_p) and duty cycle (δ), preferably t_p = 300 μs, δ < 2 %

6.1.6 Base-emitter voltage (d.c. method) (V_{BE})

a) Purpose

To measure the base-emitter voltage of a transistor under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 9 – Base circuit for the measurement of base-emitter voltage (d.c. method)

c) Measurement procedure

The temperature is set to the specified value.

The outputs of variable generators G_1 and G_2 are adjusted until the specified collector-emitter voltage is read from voltmeter V_2 and the specified collector current is read from ammeter A.

The base-emitter voltage is read from voltmeter V_1.

d) Specified conditions

– Ambient or case temperature (T_{amb} or T_{case})

– Collector current (I_C)

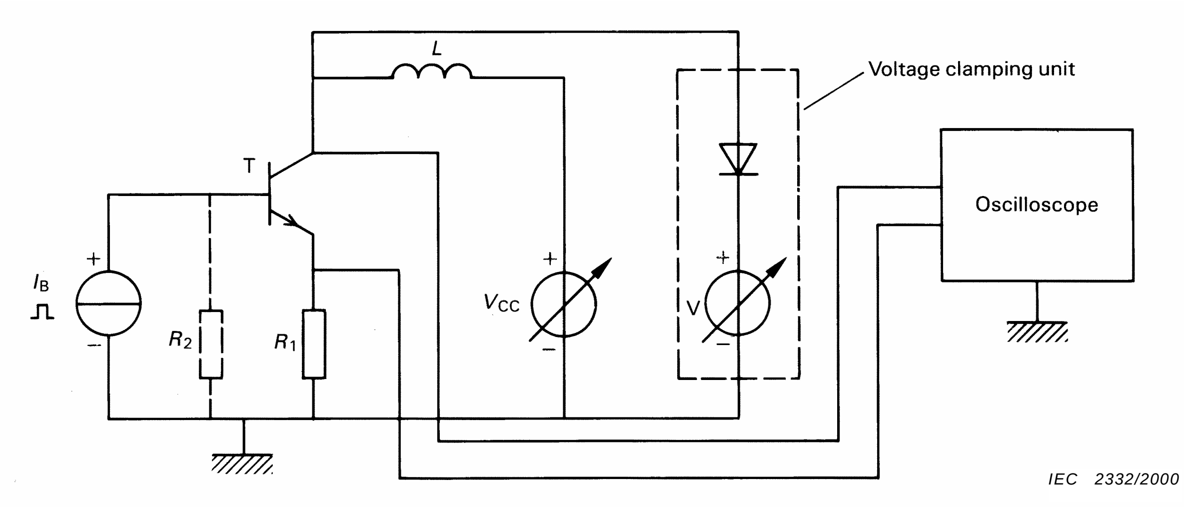
– Collector-emitter voltage (V_{CE})

6.1.7 Collector-emitter sustaining voltage ($V_{CEO(sus)}$, $V_{CER(sus)}$)

a) Purpose

Rating verification method to verify that a transistor will sustain the maximum rated value of the collector-emitter sustaining voltage under specified conditions without being damaged.

b) Circuit diagram



T = transistor being measured

Figure 10 – Basic circuit for the measurement of the collector-emitter sustaining voltage

c) Circuit description and requirements

The transistor is operated in a saturated condition under pulse operation.

Due to inductance L, the switching of the base current causes the transistor to be swept through a current-voltage cycle.

Resistor R_2 is required for the measurement of $V_{CER(sus)}$.

Generator V_{CC} is adjustable; it enables the collector current to be set to the specified value.

R_1 is a current measuring resistor.

A voltage clamping unit, indicated in figure 10 as a variable voltage source in series with a diode, limits the voltage V_{CE} at the maximum rated value $V_{CEO(sus)}$ or $V_{CER(sus)}$.

The minimum value of inductance L may be given in the detail specification; otherwise, it may be calculated from:

$$L_{min} = (V - V_{CC})\frac{t_{off}}{0,1\ I_C}$$

This ensures that I_C does not drop by more than 10 % during t_{off}.

d) Measurement procedure

1) The clamping unit is adjusted to operate at the maximum rated value $V_{CEO(sus)}$.

2) With voltage V_{CC} set at 0, current I_B is adjusted (for example 1/10 or 1/5 of the specified current I_C), so that the specified current I_C can be reached with a V_{CE} value of less than a few volts (point A in figure 11) (that is, in the saturated condition).

3) The voltage V_{CC} is progressively increased until the specified current I_C is reached for the maximum rated value of voltage $V_{CEO(sus)}$ (point B in figure 11).

As a result, the current at which the cycle starts may reach a value I_O slightly higher than the specified value of I_C (point A′ in figure 11).

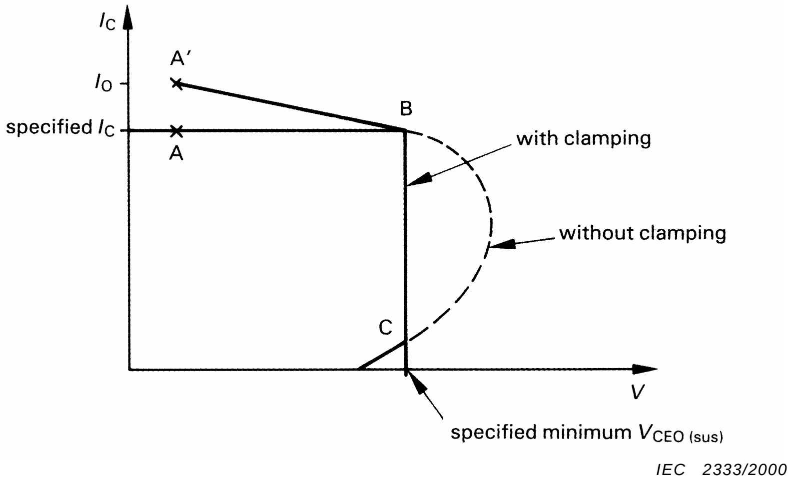


Figure 11 – I_C versus V_{CE} characteristic

e) Precautions to be observed

In a preliminary test, the action of the clamping unit should be verified by decreasing its adjustable voltage; then the clamping unit should be adjusted to the desired value of V_{CEO} that corresponds to the specified current I_C (point B of figure 11).

f) Requirements

1) The transistor is satisfactory when the trace moving from point B to point C does not pass to the left of the line BC.

2) When the clamping unit is not used, the transistor is satisfactory if the trace effectively turns around point B, as shown in figure 11.

g) Specified conditions

– Case or ambient temperature (T_{case} or T_{amb})
– Collector current (I_C)
– Minimum sustaining voltage ($V_{CEO(sus)}$ or $V_{CER(sus)}$)
– Value of inductance L, where appropriate
– Frequency of pulse generator I_B, if different from 50 Hz.

6.1.8 Capacitances

6.1.8.1 Common-base output capacitance (C_{22b} or C_{ob})

a) Purpose

To measure the output capacitance of a transistor under specified conditions.

Two methods are given:

- method 1, using a two-terminal bridge;
- method 2, using a three-terminal bridge. This method is particularly appropriate for the accurate measurement of small output capacitances.

In method 1, the bridge must be able to pass the d.c. bias current, whereas in method 2 (three-terminal bridge) this is not required.

6.1.8.1.1 Method 1: two-terminal bridge

b) Circuit diagram

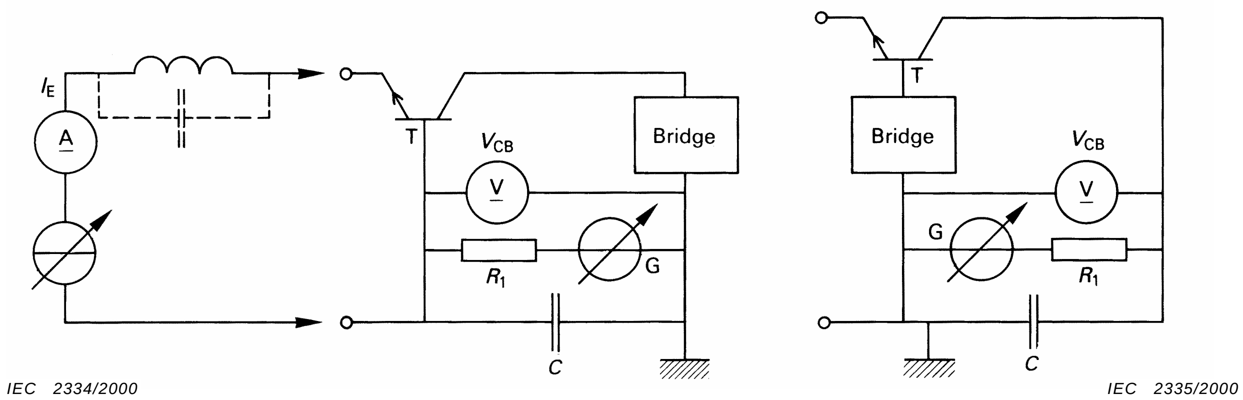


Figure 12a – Transistor with base terminal connected to case

Figure 12b – Transistor with collector terminal connected to case

Figure 12 – Basic circuit for the measurement of the common-base output capacitance using a two-terminal bridge

c) Circuit description and requirements

The bridge should be capable of carrying the required collector current without affecting the accuracy of measurement. Alternatively, an inductor could be connected across the bridge terminals. Capacitor C should provide a short circuit at the measurement frequency. A bias circuit is connected between the emitter and base terminals if the measurement of capacitance for conditions other than open-emitter is required.

d) Measurement procedure

The temperature is set to the specified value.

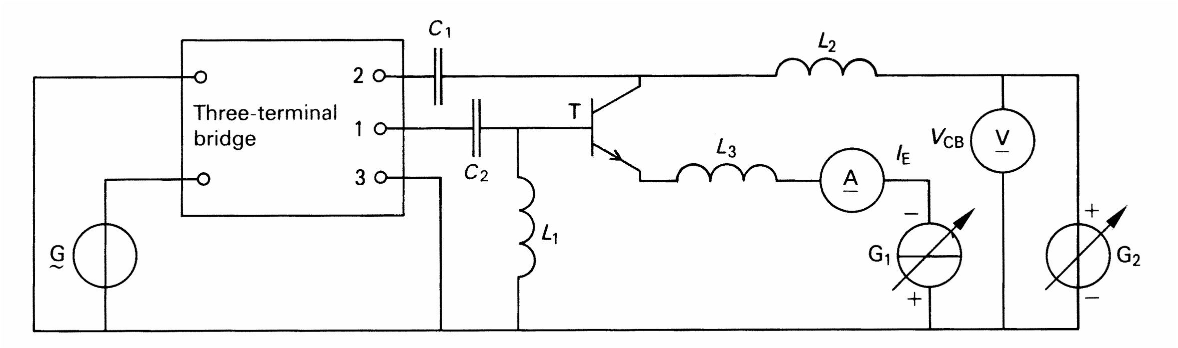
The bridge is adjusted to obtain a zero reading, with the measurement circuit connected.

The transistor being measured is inserted into the measurement socket and, with the specified bias conditions applied, the output capacitance is measured.

e) Specified conditions
- Ambient or case temperature (T_{amb} or T_{case})
- Collector-base voltage (V_{CB})
- Emitter current (I_E), usually zero
- Measurement frequency (f), if different from 1 MHz
- Mounting conditions of the transistor, if necessary

6.1.8.1.2 Method 2: three-terminal bridge

b) Circuit diagram



T = transistor being measured

Figure 13 – Basic circuit for the measurement of C_{22b} using a three-terminal bridge

c) Circuit description and requirements

The three-terminal bridge should be capable of providing a measurement of the capacitance between terminals 1 and 2 independent of any impedance present between either terminal and the grounded guard terminal (3).

Capacitors C_1 and C_2 should provide a short circuit at the measurement frequency. Inductors L_1, L_2 and L_3 should have a high impedance at the measurement frequency.

The figure shows the case for which it is impossible or undesirable to pass direct current through the bridge. If the bridge is capable of carrying the required bias current without affecting the accuracy of measurement, the circuit can be simplified so that the direct current bias is supplied through the bridge terminals.

If the emitter current is specified as zero, the emitter bias circuit is omitted.

If the transistor being measured is a four-terminal device (the metallic case is isolated electrically from the three other terminals), the fourth terminal (case) should be connected to the ground terminal of the bridge.

d) Precautions to be observed

Stray capacitances should be reduced as much as possible.

For the measurement, a plane of reference of the device must be defined and the screening of the device leads extended to this plane.

The method of mounting the transistor should be specified in considerable detail if accurate and reproducible results are to be obtained. For example, a measurement socket should be specified so that the capacitance measurement is independent of the lead length of the transistor and so that the resulting capacitance is referred to the reference plane of measurement.

e) Measurement procedure

The temperature is set to the specified value.

The bridge is set to the specified measurement frequency and, with the circuit connected and with no transistor in the measurement socket, the bridge is adjusted to obtain a zero reading.

The transistor being measured is then inserted into the measurement socket and, with the specified bias conditions applied, the output capacitance is determined by balancing the bridge.

f) Specified conditions

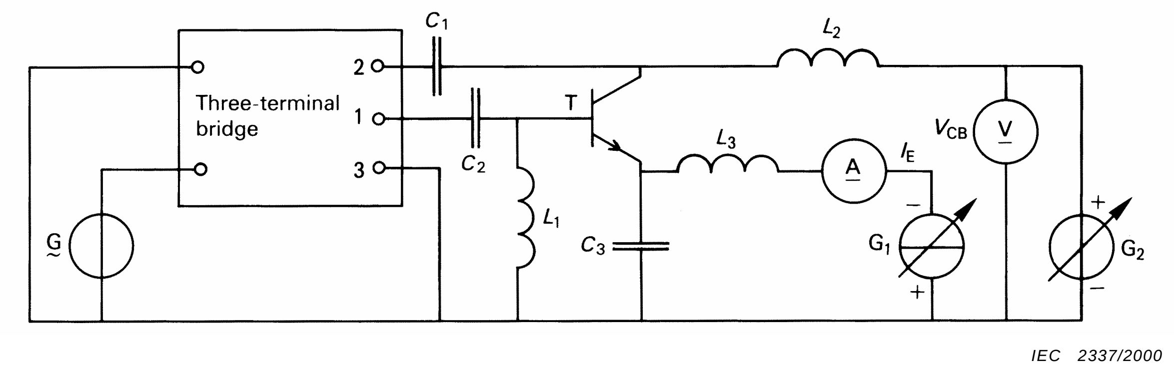
- Ambient or case temperature (T_{amb} or T_{case})
- Collector-base voltage (V_{CB})
- Emitter current (I_E), usually zero
- Measurement frequency (f), if different from 1 MHz
- Reference plane of measurement
- Mounting conditions, if necessary

6.1.8.2 Collector-base capacitance (C_{cb})

a) Purpose

To measure the collector-base capacitance of a transistor under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 14 – Basic circuit for the measurement of C_{cb} using a three-terminal bridge

c) Circuit description and requirements

Capacitor C_3 between the emitter terminal and ground should provide a short circuit at the measurement frequency.

d) Measurement procedure

The method of measurement of common-base output capacitance by method 2 (three-terminal bridge), as described in 6.1.8.1.2, may be used for this measurement.

6.1.9 Hybrid parameters (small-signal and large-signal)

Although clause 3 (dealing with essential ratings and characteristics) requires common-emitter parameters to be quoted, it is sometimes preferable to measure the common-base parameters and to calculate the common-emitter parameters (except in the case of h_{21e} where a common-collector configuration may be used and h_{21e} calculated in terms of h_{21c}).

(Expressions relating common-base and common-emitter parameters are given in 6.1.9.5.)

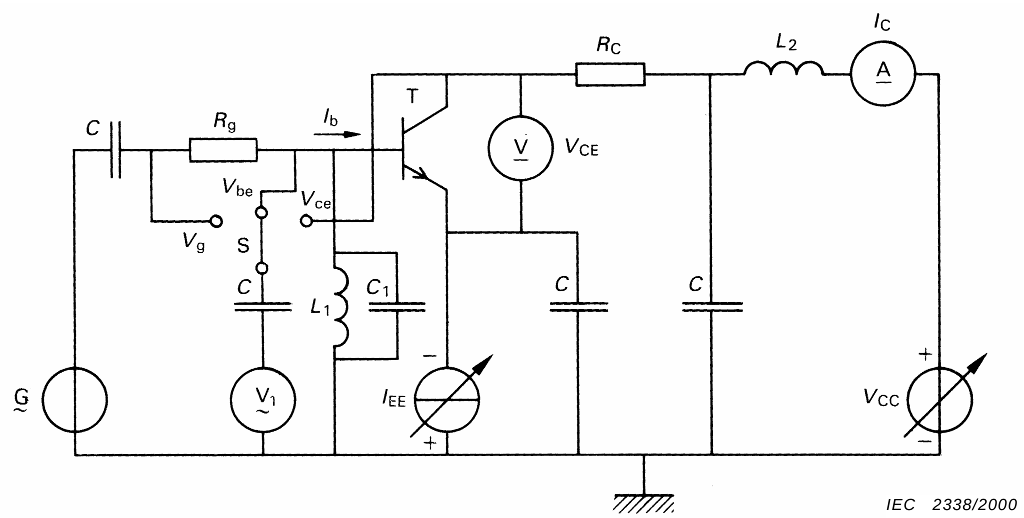
The measuring methods described in this subclause are intended to measure the four hybrid parameters in the frequency range where their reactive components compared with their non-reactive components are negligible. In order that these conditions may be satisfied, the frequency of measurement must be sufficiently low so that the effects of the reactive components are negligible. However, at a relatively low frequency such as 1 000 Hz, the reactive components may be quite appreciable.

6.1.9.1 Common-emitter small-signal short-circuit input impedance h_{11e} Common-emitter small-signal short-circuit forward current transfer ratio h_{21e}

a) Purpose

To measure the common-emitter small-signal input impedance and forward current transfer ratio with the output short-circuited to alternating current, under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 15 – Basic circuit for the measurement of h_{11e} and h_{21e}

c) Circuit description and requirements

Capacitors C shall present short-circuits at the measurement frequency. Resistor R_C is an accurate standard resistor of low value compared to $1/h_{22e}$. R_g shall be accurately calibrated. V_1 is an a.c. electronic voltmeter.

The stray capacitance between base to ground and collector to ground shall be small.

The inductance L_1 shall have a high reactance compared with h_{11e} and may be resonated with a parallel capacitor C_1 at the measurement frequency.

d) Measurement procedure

The collector voltage and then the emitter current are increased in sequence until the specified bias conditions are applied to the device, care being taken not to exceed the device ratings during adjustment.

Signal generator G is set to the specified frequency; V_{CE}, V_g and V_{be} are measured by means of the high-impedance electronic voltmeter V_1.

h_{11e} is calculated as follows:

$$h_{11e} = \frac{V_{be}}{I_b} \qquad I_b = \frac{V_g - V_{be}}{R_g} \qquad h_{11e} = R_g \frac{V_{be}}{V_g - V_{be}}$$

If R_g is large compared with h_{11e}, $V_g >> V_{be}$

then:

$$h_{11e} \simeq R_g \frac{V_{be}}{V_g}$$

If V_g is maintained at a constant value, the meter indicating V_{be} can be calibrated directly in terms of h_{11e}.

h_{21e} is calculated as follows:

$$h_{21e} = \frac{I_c}{I_b} \qquad I_c = \frac{V_{ce}}{R_c} \qquad I_b = \frac{V_g - V_{be}}{R_g}$$

$$h_{21e} = \frac{V_{ce}}{R_c} \cdot \frac{R_g}{V_g - V_{be}}$$

If R_g is large compared with h_{11e}, $V_g >> V_{be}$

then:

$$h_{21e} \simeq \frac{V_{ce}}{V_g} \cdot \frac{R_g}{R_c}$$

If V_g is maintained at a constant value, the meter indicating V_{ce} can be calibrated directly in terms of h_{21e}.

e) Specified conditions

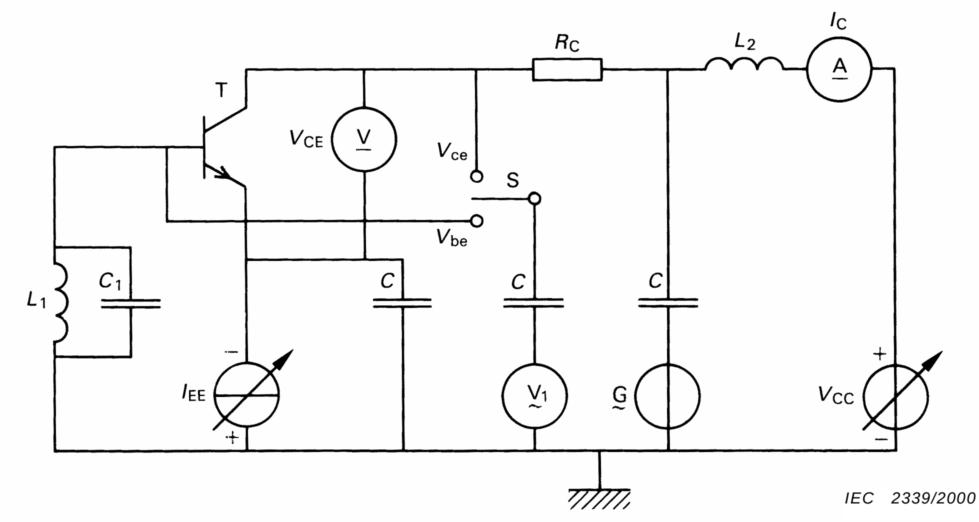
- Ambient or case temperature (T_{amb} or T_{case})
- Measurement frequency (f)
- Collector current (I_C)
- Collector-emitter voltage (V_{CE})

6.1.9.2 Common-emitter small-signal open-circuit reverse voltage transfer ratio h_{12e}

a) Purpose

To measure the common-emitter small-signal reverse voltage transfer ratio of a transistor, with the input open-circuited to alternating current, under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 16 – Basic circuit for the measurement of h_{12e}

c) Circuit description and requirements

V_{be} and V_{ce} are measured on electronic voltmeter V_1.

Capacitors C shall present short circuits at the measurement frequency.

The inductance L_1 shall have a high reactance compared with h_{11e} and may be resonated with a parallel capacitor C_1 at the measurement frequency.

At the measurement frequency, the reactance of L_2 shall be large compared to the output impedance of the generator G.

d) Measurement procedure

The output of the collector voltage source V_{CC} is increased until the specified collector-emitter voltage is reached.

The output of the emitter current source is increased until the specified collector current is indicated on ammeter A. The collector-emitter voltage should be checked and adjusted, if necessary.

The output of the signal generator G is increased until the a.c. collector voltage is approximately equal to one tenth of the specified value of the collector-emitter voltage. This shall be measured on electronic voltmeter V_1 reading V_{ce}.

h_{12e} is calculated using the formula: $h_{12e} = \dfrac{V_{be}}{V_{ce}}$

If V_{ce} is maintained at a constant value, the meter indicating V_{be} can be calibrated directly in terms of h_{12e}.

e) Specified conditions

– Ambient or case temperature (T_{amb} or T_{case})

– Measurement frequency (f)

– Collector current (I_C)

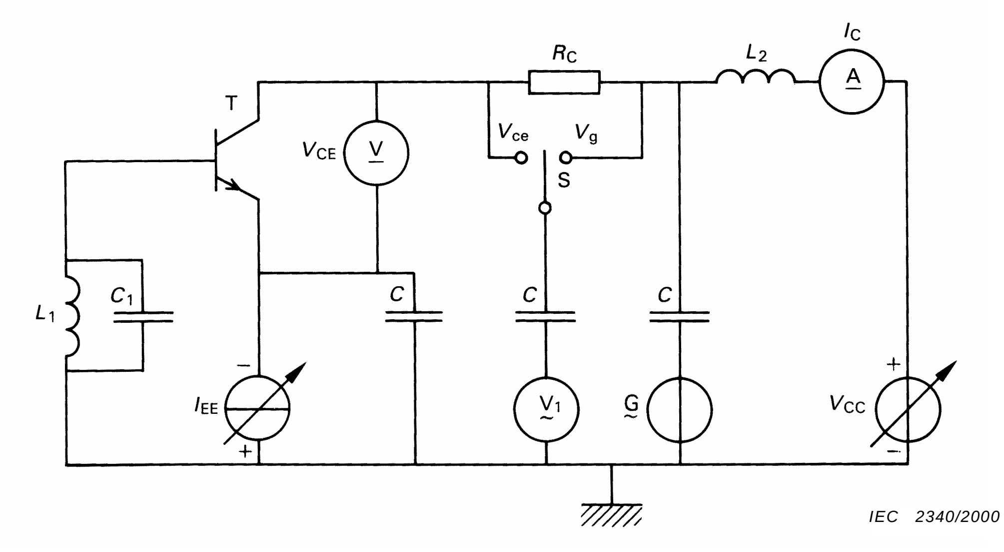
– Collector-emitter voltage (V_{CE})

6.1.9.3 Common-emitter small-signal open-circuit output admittance h_{22e}

a) Purpose

To measure the common-emitter small-signal output admittance of a transistor with the input open-circuited to alternating current, under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 17 – Basic circuit for the measurement of h_{22e}

c) Circuit description and requirements

Capacitors C shall present short circuits at the measurement frequency. Resistor R_C is an accurate standard resistor of low value compared to $1/h_{22e}$. The inductance L_1 shall have a high reactance compared with h_{11e} and may be resonated with a parallel capacitor C_1 at the measurement frequency.

V_{ce} and V_g are measured by means of an electronic voltmeter V_1. The impedance of the electronic voltmeter used to measure V_{ce} shall be large compared with $1/h_{22e}$.

d) Measurement procedure

The output of the collector voltage source V_{CC} is increased until the specified collector-emitter voltage is reached.

The output of the emitter current generator is increased until the specified collector current is indicated on ammeter A. The collector-emitter voltage should be checked and adjusted, if necessary.

The output of the signal generator G is increased until the a.c. collector voltage is approximately equal to one tenth of the specified value of the collector-emitter voltage.

$$h_{22e} = \frac{I_c}{V_{ce}} \qquad I_c = \frac{V_g - V_{ce}}{R_c}$$

$$h_{22e} = \frac{V_g - V_{ce}}{V_{ce}\, R_c}$$

If V_g is maintained at a constant value, the meter indicating V_{ce} can be calibrated directly in terms of h_{22e}.

e) Specified conditions

– Ambient or case temperature (T_{amb} or T_{case})

– Measurement frequency (f)

– Collector current (I_C)

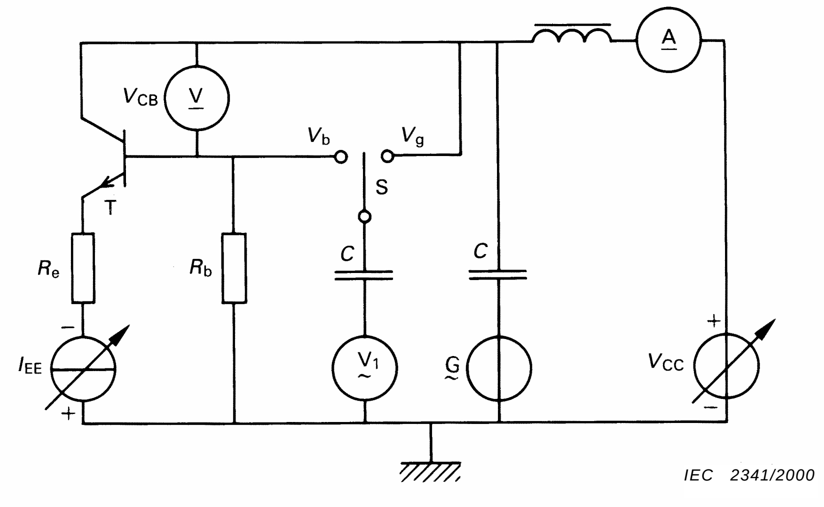
– Collector-emitter voltage (V_{CE})

6.1.9.4 Common-base small-signal open-circuit output admittance h_{22b}

a) Purpose

To measure the common-base small-signal output admittance of a transistor with input open-circuited to alternating current, under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 18 – Basic circuit for the measurement of h_{22b}

c) Circuit description and requirements

Capacitors C shall present short-circuits at the measurement frequency.

R_e shall be large relative to z_{11b} + R_b. V_b and V_g are measured on an electronic voltmeter V_1.

d) Measurement procedure

The output of the collector voltage V_{CC} is increased until the specified collector-base voltage is reached.

The output of the emitter current source is increased until the specified collector current is indicated on ammeter A. The collector-base voltage shall be checked and adjusted, if necessary. The voltmeter V_{CB} is then disconnected.

The output of signal generator G is increased until the a.c. collector voltage is approximately equal to one tenth of the specified value of the collector-emitter voltage.

$$h_{22b} = \frac{I_c}{V_{cb}} \qquad I_c \simeq I_B \text{, since the emitter is open circuited}$$

Then:

$$h_{22b} \simeq \frac{I_b}{V_{cb}} \qquad I_b = \frac{V_b}{R_b} \qquad V_{cb} = V_g - V_b \qquad h_{22b} \simeq \frac{V_b}{R_b(V_g - V_b)}$$

If R_b is small compared with $1/h_{22b}$, $V_g >> V_b$

then:

$$h_{22b} \simeq \frac{V_b}{V_g \cdot R_b}$$

If V_g is maintained at a constant value, the meter indicating V_b can be calibrated directly in terms of h_{22b}.

e) Specified conditions

- Ambient or case temperature (T_{amb} or T_{case})
- Measurement frequency (f)
- Collector current (I_C)
- Collector-base voltage (V_{CB})

6.1.9.5 Expressions relating common-base and common-emitter *h* parameters

6.1.9.5.1 Small-signal value of the short-circuit input impedance

$$h_{11e} = \frac{h_{11b}}{1 - h_{12b} + h_{21b} + \Delta h_b} \qquad (\Delta h = h_{11} \cdot h_{22} - h_{12} \cdot h_{21})$$

If $\Delta h_b - h_{12b} << 1 + h_{21b}$ $\qquad h_{11e} \simeq \dfrac{h_{11b}}{1 + h_{21b}}$

6.1.9.5.2 Small-signal value of the short-circuit forward current transfer ratio

$$h_{21e} = \frac{-\Delta h_b - h_{21b}}{1 - h_{12b} + h_{21b} + \Delta h_b} \qquad h_{21e} \simeq \frac{-h_{21b}}{1 + h_{21b}}$$

$$h_{21b} = \frac{-\Delta h_e - h_{21e}}{1 - h_{12e} + h_{21e} + \Delta h_e} \qquad h_{21b} \simeq \frac{-h_{21e}}{1 + h_{21e}}$$

$$h_{21b} \simeq -\frac{h_{21c} + 1}{h_{21c}}$$

$$1 + h_{21e} = \frac{1}{1 + h_{21b}} \qquad \text{and} \qquad h_{11e} \simeq h_{11b}(h_{21e} + 1)$$

6.1.9.5.3 Small-signal value of the open-circuit reverse voltage transfer-ratio

$$h_{12e} = \frac{\Delta h_b - h_{12b}}{1 - h_{12b} + h_{21b} + \Delta h_b} \qquad h_{12e} \simeq \frac{h_{b11} \cdot h_{22b} - h_{12b}(h_{21b} + 1)}{1 + h_{21b}}$$

$$\text{or} \qquad h_{12e} \simeq h_{11b} \cdot h_{22b}(1 + h_{21e}) - h_{12b}$$

It must be appreciated that there is a risk of considerable error in the result obtained from this calculation, because the two terms of the difference may be of comparable magnitude.

6.1.9.5.4 Small-signal open-circuit output admittance

$$h_{22e} = \frac{h_{22b}}{1 - h_{12b} + h_{21b} + \Delta h_b} \qquad h_{22e} \simeq \frac{h_{22b}}{1 + h_{21b}}$$

$$\text{or} \qquad h_{22e} \simeq h_{22b} \cdot (1 + h_{21e})$$

6.1.9.6 Common-emitter forward current transfer ratio (h_{21E})
(output voltage held constant) (d.c. and pulse methods)

a) Purpose

To measure the static value of the common-emitter forward current transfer ratio of a transistor under specified conditions.

b) Circuit diagram

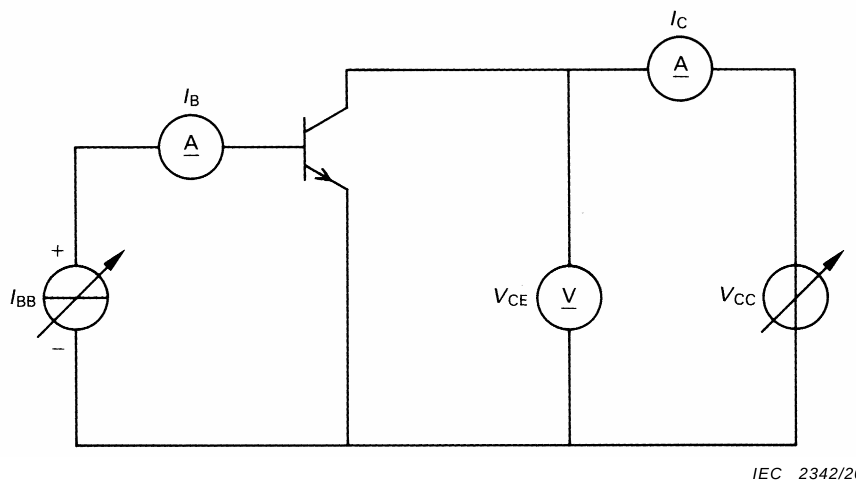


Figure 19 – Basic circuit for the measurement of h_{21E}

c) Circuit description and requirements

For a fixed value of I_C, the ammeter indicating the base current I_B can be calibrated directly in terms of h_{21E}. The constant-current source can be replaced by a pulse generator, in which case both ammeters should be peak-reading instruments.

d) Measurement procedure

The temperature is set to the specified value.

The voltage supply V_{CC} is adjusted to obtain the specified voltage V_{CE} indicated on voltmeter V.

The current from the current generator I_{BB} is increased until the specified collector current I_C is indicated on the ammeter.

The collector-emitter voltage V_{CE} should be checked and adjusted, if necessary.

$$h_{21E} = \frac{I_C}{I_B}$$

e) Precautions to be observed

When a pulse method is used, care should be taken that transients do not affect the accuracy of the measurement.

f) Specified conditions

- Ambient or case temperature (T_{amb} or T_{case})
- Collector current (I_C)
- Collector-emitter voltage (V_{CE})

If a pulse method is used:

- Pulse duration and duty cycle of the pulse generator (t_p, δ), preferably t_p = 300 μs, $\delta \leq$ 2 %.

6.1.10 Voltage ratings and measurable characteristics limiting the working voltages ($V_{(BR)CBO}$, $V_{(BR)EBO}$, $I_{S/B}$)

6.1.10.1 Introduction

Information on the maximum voltages which may be applied to transistors may take the form of ratings determined by the manufacturer, e.g.:

- Maximum collector-base voltage V_{CB} max.
- Maximum collector-emitter voltage V_{CE} max.
- Maximum emitter-base reverse voltage V_{EB} max.

or of data on characteristics which will limit the operating voltage in a circuit, e.g.:

- Collector-base breakdown voltage with zero emitter current $V_{(BR)CBO}$
- Emitter-base breakdown voltage with zero collector current $V_{(BR)EBO}$
- Collector-emitter breakdown voltage $V_{(BR)(CE)}$

Ratings are based on a considerable amount of experience and take into account both voltage-limiting parameters and life failure mechanisms. It is not possible to measure such ratings. When the information given is in the form of data on characteristics, which would have the effect of limiting the voltages which may be applied across the transistor in a circuit, this implies that measurements may be made under controlled conditions.

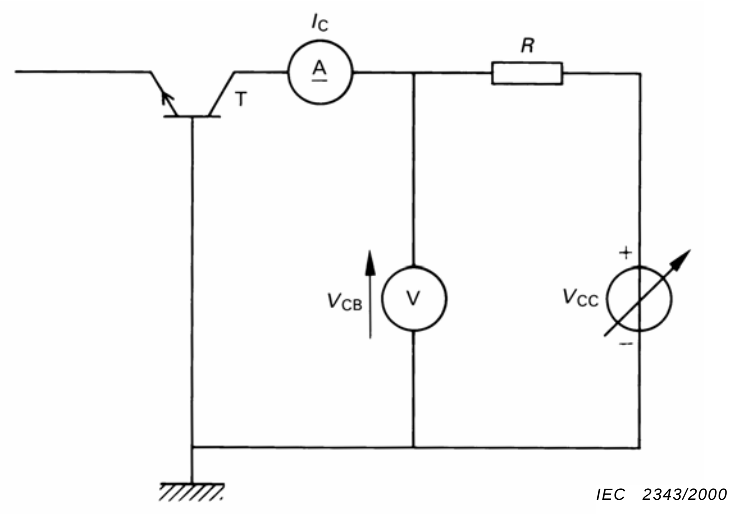
6.1.10.2 Collector-base breakdown voltage with zero emitter current $V_{(BR)CBO}$ Emitter-base breakdown voltage with zero collector current $V_{(BR)EBO}$

a) Purpose

To verify the breakdown ratings of a transistor under specified conditions.

The description given is for verifying the collector-base breakdown voltage rating, but the method can be applied to the emitter-base breakdown voltage rating by suitably interchanging the collector and emitter terminals.

b) Circuit diagram



T = transistor being measured

Figure 20 – Circuit for the measurement of $V_{(BR)CBO}$

c) Circuit description and requirements

Resistor R is a current-limiting resistor and should be of sufficiently high value to avoid excessive current flowing through the transistor and ammeter A.

Ammeter A should present a short-circuit and voltmeter V should present an open-circuit.

d) Measurement procedure

The temperature is set to the specified value.

The voltage generator should be increased until either:

– the specified maximum voltage is reached before the maximum current is reached, in which case the rating is verified;

or:

– the specified maximum current is reached before the specified maximum voltage is reached, in which case the rating is not verified and the transistor is rejected.

e) Specified conditions

– Ambient or case temperature (T_{amb} or T_{case})

– Collector current (or emitter current) (I_C or I_E)

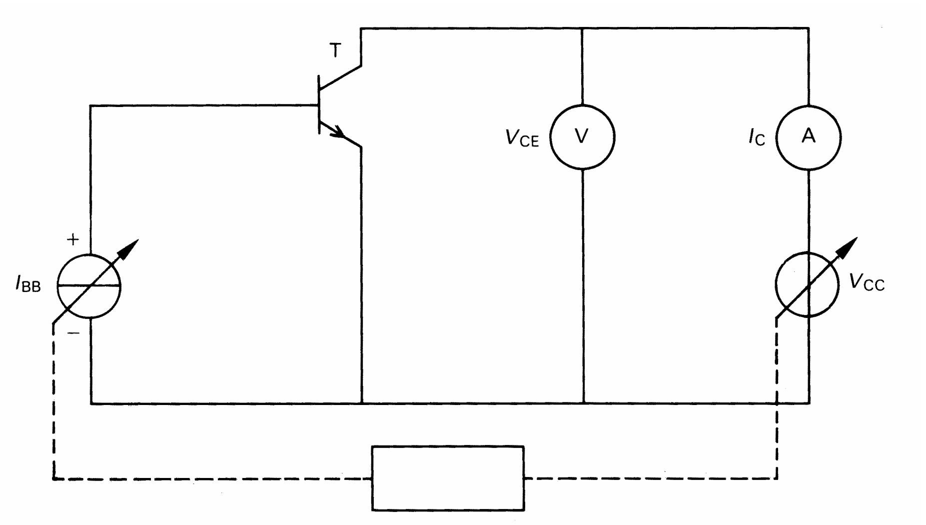
6.1.10.3 Verification method for the second breakdown current rating ($I_{S/B}$)

a) Purpose

At the specified case temperature, the specified collector voltage and current are simultaneously applied for a given time. The specified final measurements are then carried out to verify that the transistor is still satisfactory.

NOTE This test may be destructive.

b) Circuit diagram



T = transistor being measured

I_{BB} = base current generator (d.c. or pulse)

V_{CC} = collector voltage generator (d.c. or pulse)

Figure 21 – Circuit for the measurement of $I_{S/B}$

c) Circuit description and requirements

Generators I_{BB} and V_{CC} should be provided with fast, adjustable threshold, circuit-breakers (for instance operating in less than one microsecond) to prevent destruction of the transistor.

A synchronous switch enables the specified current I_B (to obtain I_C) and the specified voltage V_{CC} to be applied simultaneously.

Voltmeter V and ammeter A should be suitable for this verification method.

Overvoltages due to stray inductance in the collector circuit should be avoided.

A feedback circuit to automatically adjust base current in order to maintain the collector current may be added.

NOTE A circuit for carrying out this test with the transistor in common-base configuration can also be used.

d) Measurement procedure

The case of the transistor is maintained at the specified temperature.

Generator V_{CC} is set to obtain the specified voltage V_{CE}.

With generator I_{BB} at 0, the synchronous switch is set to the specified time (in the case of d.c., a duration of 10 s is considered sufficient to reach thermal equilibrium).

Generator I_{BB} is set so that the specified value I_C is obtained and kept constant during the conduction time of the transistor.

e) Requirements

The transistor is satisfactory if the specified value of I_C is reached for the specified time (without operating the circuit-breakers) and if the final measurements are satisfactory.

f) Specified conditions

- Case temperature (T_{case})
- Collector-emitter voltage (V_{CE})
- Collector current (I_C)
- Duration of I_C (t_p)
- If more than one cycle is required, number of cycles and maximum duty cycle (δ)
- If a common-base configuration is used, this should be stated
- Final measurements, required limits

6.1.11 Thermal resistance

6.1.11.1 Introduction

The measurement of thermal resistance R_{th} involves the measurement of T_j and T_{amb} (or T_{case}) while a known power is being dissipated in the transistor.

To measure the junction temperature, a temperature-sensitive device parameter must be used.

The two parameters that are commonly used are:

1) the d.c. forward characteristic of the collector junction;
2) the d.c. forward characteristic of the emitter junction.

The forward voltage drop decreases with the increase of temperature. Hence, the forward current at a fixed voltage or the forward voltage at a fixed current (or an intermediate condition) can be calibrated as a function of junction temperature.

The methods of measuring the junction temperature require that very little power is dissipated in the transistor while the calibration is being carried out, in order that the junction temperature-sensitive parameter may be calibrated as a function of ambient temperature. Therefore, since power must be dissipated in the transistor, the measurement of thermal resistance requires a system of alternately applying power to the transistor and measuring the junction temperature.

It should be noted that this method of measurement assumes that there is the same uniform distribution of temperature over the junction when power is dissipated in the transistor as there is when the transistor is being calibrated. This assumption may not be valid.

6.1.11.2 General procedure for thermal resistance measurements

6.1.11.2.1 Switching times

Power is dissipated in the transistor for the majority of the time and is switched off for short periods to enable the junction temperature to be measured.

The measuring time must be short compared to the thermal response time of the device being measured, so that the device does not cool appreciably during the temperature measurement.

The ratio of power dissipating time to measuring time should be sufficiently high so that the mean power dissipation is approximately equal to that dissipated in the "on" condition.

Measuring times of about 1 ms and "on" times of about 20 ms to 40 ms have been found suitable for most low power and power transistors. With fast switch-over times and short measuring periods, care should be taken to avoid capacitive and carrier storage effects.

6.1.11.2.2 Switching methods

The following methods may be used:

– mechanical switching techniques (i.e. relays, motor driven commutators);

– electronic switching techniques.

NOTE When measuring power transistors, the high currents flowing in the emitter and collector circuits can be troublesome, and it is preferable to carry out switching in the base circuit.

6.1.11.2.3 Measurement procedure

Two basic measurement procedures may be used.

Procedure I:

The device is placed in a variable temperature enclosure and the value of the temperature-sensitive parameter is measured as a function of temperature with negligible power dissipated in the device. The device is then placed in a fixed temperature enclosure and power is supplied. The resultant junction temperature is obtained by measuring the value of the temperature-sensitive parameter.

The thermal resistance is given by:

$$R_{\mathrm{th}} = \frac{T_{\mathrm{j}} - T_{\mathrm{ref}}}{P_1}$$

where

T_{ref} is either the ambient temperature or the case temperature;

P_1 is the power supplied to the device, and is given by:

$$P_1 = I_{\mathrm{C}} V_{\mathrm{CB}} + I_{\mathrm{E}} V_{\mathrm{EB}}$$

Procedure II:

The device is placed in an enclosure at an elevated temperature T_2 and the temperature-sensitive parameter is observed. The device is then transferred to an enclosure at a lower temperature T_1 and power is applied until the original value of the temperature-sensitive parameter is obtained; then:

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

6.1.11.3 Examples of practical circuits

6.1.11.3.1 Emitter-base forward voltage method

6.1.11.3.1.1 Introduction

The method of the thermal resistance measurement presented here is the easiest method for the inspection of the die attachment, which may affect the reliability primarily of the power devices. The emitter-base forward voltage is a good temperature sensitive parameter. The thermal resistance can be calculated by using the emitter-base forward voltage variation (ΔV_{EB}) caused by a single heating pulse.

This single pulse method has the following merits compared to the method using a high duty cycle:

a) the thermal resistance from the junction to the case can be measured easily and rapidly, making this method applicable to a 100 % inspection of the die attachment of the devices in the fabrication process;

b) the degradation of the die attachment of the devices during the reliability test, especially during the thermal fatigue test, can easily be found;

c) it is possible to apply high power to the device, thus permitting the measurement of the second breakdown point (S/B) and the safe operating area (SOAR).

6.1.11.3.1.2 Purpose

To measure the thermal resistance from the junction to any specified reference point of single element transistors by using the emitter-base junction temperature characteristic in the emitter-only switching mode.

6.1.11.3.1.3 List of symbols

$R_{th(j-x)}$ = thermal resistance from the junction to a reference point x (in millivolts per degree Celsius)

ΔP_T = power dissipation variation of the device under test (in watts)

ΔT_j = junction temperature variation caused by ΔP_T (in degrees Celsius)

I_M = measuring current (in amperes)

I_H = heating current (in amperes)

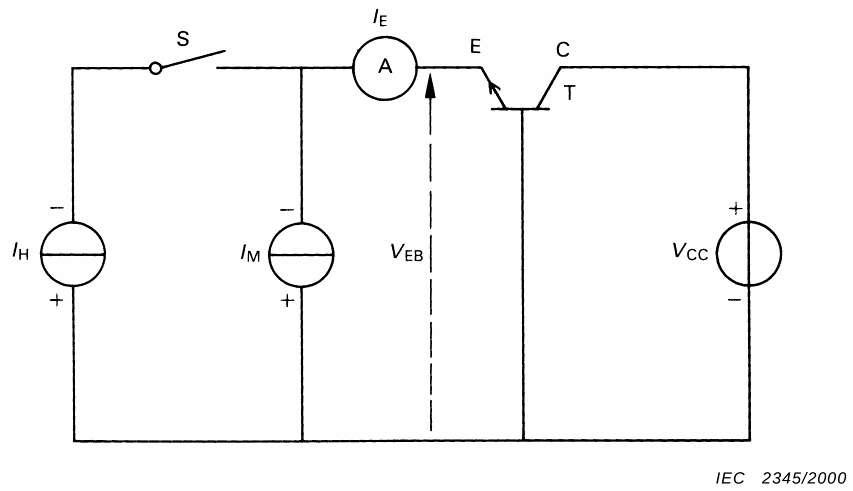
t_p = heating pulse duration (in seconds)

αV_{EB} = temperature coefficient of the emitter-base forward voltage (in millivolts per degree Celsius)

$\left.\begin{array}{l}\Delta V_{EB}(1)\\ \Delta V_{EB}(2)\end{array}\right\}$ = emitter-base forward voltage variation measured at I_M (in millivolts)

6.1.11.3.1.4 Principle of the measuring method

The thermal resistance $R_{th(j-x)}$ between the junction and any reference point x is measured by selecting an appropriate heating pulse duration (t_p) and using the temperature characteristic of the emitter-base forward voltage (V_{EB}) to know the junction temperature.



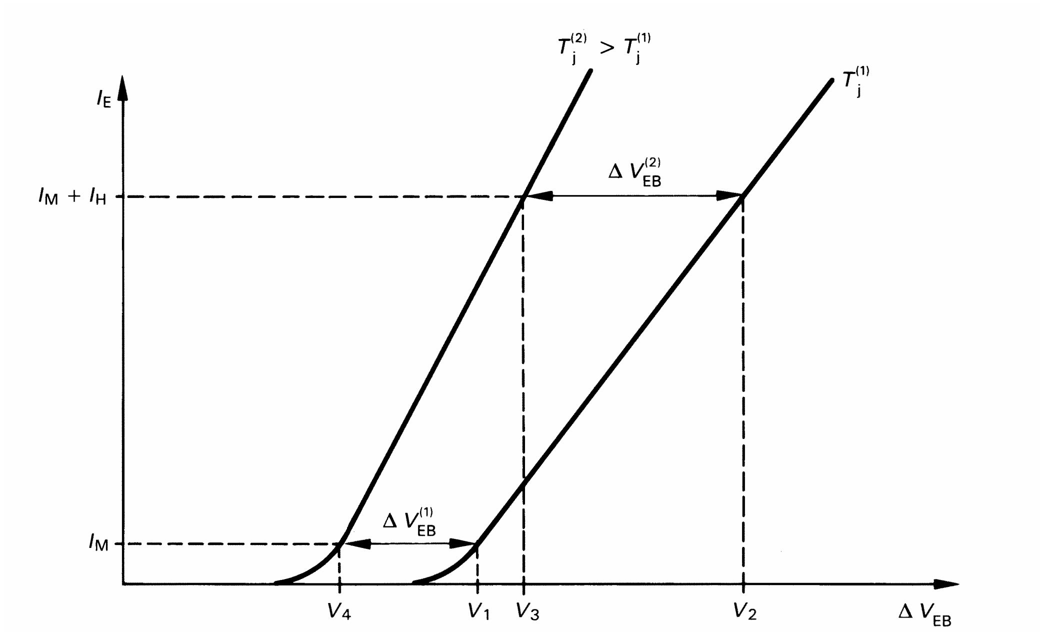
T = transistor being measured

I_E = current probe

Figure 22 – Basic test circuit for measuring the thermal resistance of NPN transistors

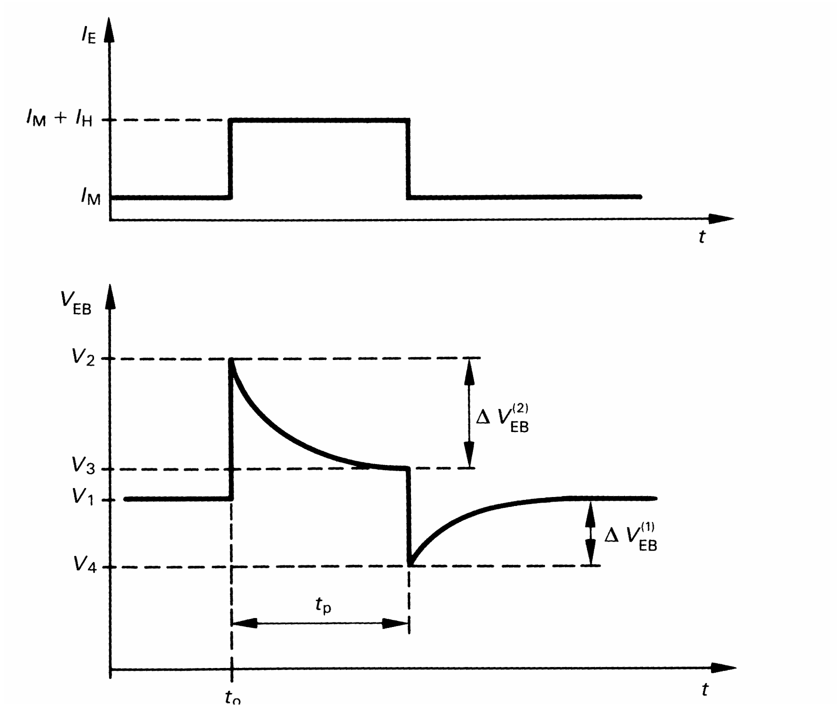
Figure 22 shows a basic test circuit for measuring the thermal resistance of NPN transistors. For PNP transistors, invert the polarity of the collector voltage supply (V_{CC}) and the current direction (I_H, I_M) in figure 23. The following applies to NPN transistors, unless otherwise stated.

The grounded-base test circuit consists of two current generators supplying the measuring current (I_M) and the heating current (I_H), a voltage supply (V_{CC}) providing the collector-base voltage (V_{CB}) and a switch (S) switching the heating current. DC or pulse switching conditions can be used for this measurement.



IEC 2346/2000

Figure 23 – Emitter current (I_E) versus emitter-base voltage (V_{EB}) for the junction temperatures $T_j^{(1)}$ and $T_j^{(2)}$



IEC 2347/2000

Figure 24 – I_E and V_{EB} change with time

With switch S open, only the measuring current (I_M) flows into the transistor being measured (T); the emitter-base forward voltage is V_1 and the junction temperature is $T_j(1)$, as shown in figure 23. With switch S closed, the sum of the heating current and measuring current flows into the transistor. The emitter-base forward voltage rise from V_1 up to V_2 immediately, while the junction temperature rises from $T_j(1)$ up to $T_j(2)$ during the heating pulse (t_p).

The emitter-base forward voltage decreases from V_2 to V_3 because of the negative temperature coefficient of the emitter-base forward voltage as the junction temperature rises.

Then, with switch S open, the emitter current and the emitter-base forward voltage decrease to I_M and V_4 respectively. As the junction temperature is still high, the emitter-base forward voltage at the measuring current remains less than the initial value V_1, increasing as the function temperature decreases and finally rises up to the initial V_1 at I_M.

NOTE The accuracy of the measurement is basically determined by the accuracy of measurement of voltage V_4.

To calculate the thermal resistance, $V_{EB}(1)$ is observed on the oscilloscope. The changes with time of the emitter current (I_E) and of the emitter-base forward voltage (V_{EB}), observed on the oscilloscope, are schematically shown in figure 24. First of all, the magnitudes of the emitter-base forward voltage, at the measuring current, at the times t_0 and $t_0 + t_p$ are recorded (V_1 and V_4).

The difference of these two values is $\Delta V_{EB}(1)$. Hence, the thermal resistance from the junction to a fixed-temperature reference point x is given by:

$$R_{th(j-x)} = \frac{\Delta T_j}{\Delta P_T} = \frac{\Delta V_{EB}^{(1)} / \alpha V_{EB}}{I_H V_{EB} + h_{FB} I_H V_{CB}} \qquad (1)$$

where h_{FB} is the common-base current gain of the transistor.

In general, V_{CB} is much larger than V_{EB} and h_{FB} is approximately equal to 1.

Therefore to a good approximation:

$$R_{th(j-x)} = \frac{\Delta V_{EB}^{(1)} / \alpha V_{EB}}{I_H V_{CB}} \qquad (2)$$

The thermal resistance from the junction to a reference point is thus measured. However, according to the location of the reference point and the material of the transistor, the operator must choose an appropriate heating-pulse duration so that the junction is fully heated but the temperature of the reference point does not change significantly.

For example, to measure the thermal resistance from the junction to the silicon chip, t_p is chosen less than the thermal time constant of the chip itself, experimentally several tens of microseconds.

Similarly, to measure the thermal resistance from junction to case $R_{th(j-c)}$, a pulse duration of about 100 ms is chosen because of the thermal time constant of the material. To measure the thermal resistance between the junction and ambient $R_{th(j-a)}$, t_p is chosen large enough for the package to be in a state of equilibrium; experimentally more than several tens of minutes are needed for most transistors.

By using the temperature coefficient of V_{EB} that applies for a current equal to the sum of the measuring current and the heating current, and by using $\Delta V_{EB}(2)$ shown in figure 24, the thermal resistance can also be calculated in the same manner using equation (1) or (2). But the temperature coefficient at such a large current is inaccurate due to the voltage drop in the device and so this method is not generally used.

6.1.11.3.1.5 Measurement procedure

a) The bias supply is set to the specified value V_{CB}.

b) Measurement of the temperature coefficient αV_{EB}.

   The temperature coefficient of the temperature-sensitive parameter is obtained by measuring the emitter-base forward voltage as a function of the temperature, under operating conditions, with the specified measuring current (I_M) and the collector-emitter voltage (V_{CE}), by externally heating the device under test in a temperature-controlled oven. Care should be taken that thermal equilibrium is reached between the measured device and the oven system in the measurement of αV_{EB}.

   A measuring current ranging from 1 mA to 50 mA. Note that the temperature coefficient αV_{EB} is negative and depends on the magnitude of the measuring current.

c) The heating current I_H is applied.

   The specified emitter current must flow for the specified period (t_p) to cause the junction temperature to rise.

d) Thermal resistance calculation

   The emitter-base forward voltage variation ($\Delta V_{EB}(1)$) at the measuring current is measured on the oscilloscope or by another method or a more accurate method; the thermal resistance is calculated using equation (1) or (2).

6.1.11.3.1.6 Specified conditions

– Measuring current (I_M)
– Junction heating emitter current (I_H)
– Heating pulse duration (t_p)
– Collector-base voltage (V_{CB})
– Mounting arrangement

6.1.11.3.2 Current dependence of the thermal coefficient of the emitter-base forward voltage

The thermal coefficient αV_{EB} of the emitter-base forward voltage is a function of the emitter current density. The relationship between the emitter current and the emitter-base forward voltage for the transistor, where current gain h_{FB} is nearly unity, is given theoretically by Schockley:

$$I_E \approx \frac{q D_B n_i^2 A_E}{N_B W_B} \exp\left(qV_{EB}/kT\right) \quad (3)$$

where

N_B is the concentration of impurities in the base region;

D_B is the diffusion coefficient of minority carriers in the base region;

n_i is the intrinsic carrier concentration;

W_B is the base width;

T is the absolute temperature;

A_E is the emitter-base junction area;

q is the magnitude of electronic charge = 1,60 × 10^{-19} C;

k is the Boltzmann constant = 1,380 × 10^{-23} J/K.

Taking logarithms of both sides and rearranging, one obtains:

$$V_{EB} = \frac{kT}{q} \ln\left(\frac{q D_B n_i^2 I_E}{N_B W_B A_E} \right) \quad (4)$$

Differentiation of equation (4) with respect to temperature gives the temperature coefficient αV_{EB}. k/q is calculated using numerical values. αV_{EB} is given by:

$$\alpha V_{EB} = \frac{dV_{EB}}{dT} = \frac{k}{q} \ln(J_E) + c$$

$$= -8{,}63 \times 10^{-2} \ln(J_E) + c \qquad \text{(mV/°C)} \quad (5)$$

where

$$J_E = \frac{I_E}{A_E} \qquad \text{(A/cm}^2\text{)}$$

$$c = \frac{k}{q} \ln\left(q \frac{D_B n_i^2}{N_B W_B} \right) \qquad \text{(mV/°C)}$$

It is now clear that αV_{EB} is proportional to the logarithm of J_E. Experimental measurements of αV_{EB} are shown in figure 25. There is a good agreement between equation (5) and the experimental measurements.

Note that constant c is also thermal dependent, but it can be shown experimentally that its temperature dependency is negligible within a temperature range from 0 °C to 200 °C and its value is around 2,2 mV/K.

For large currents, αV_{EB} may not be proportional to the logarithm of J_E, because the voltage drop in the resistance of the device is not negligible. The measuring current shall then be chosen small enough to ensure an accurate measurement of αV_{EB}.

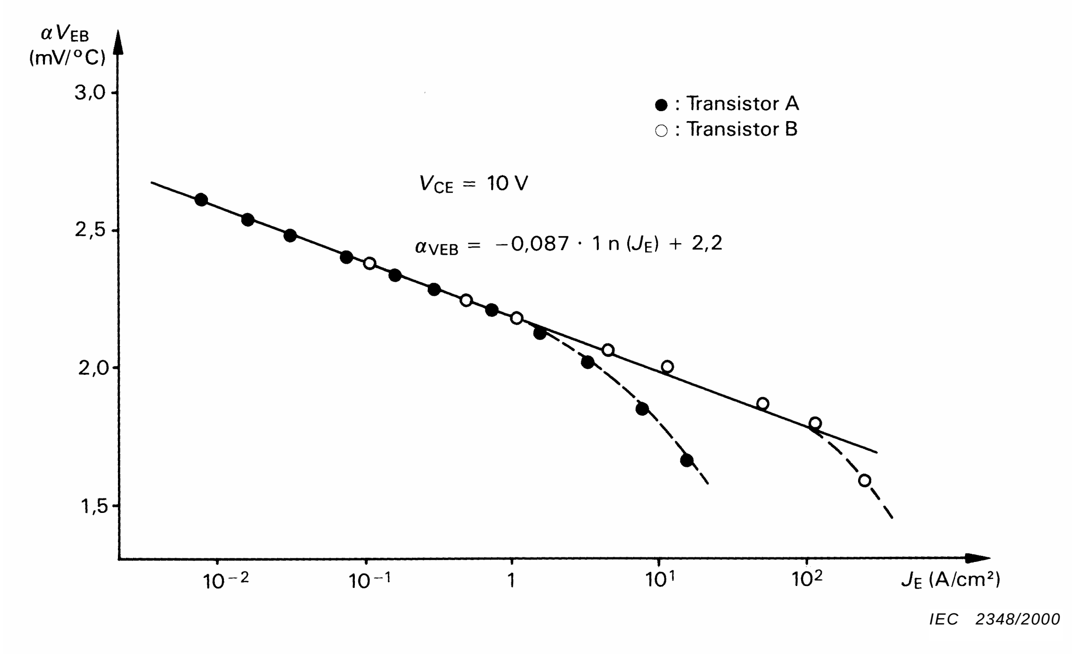


Figure 25 – Temperature coefficient (αV_{EB}) versus typical emitter current density (J_E)

6.1.11.3.3 Measurement of transient thermal resistance

There are many materials with different physical constants in the heat path from junction to ambient. Figure 26a shows the cross-section of a typical transistor in metallic case (cavity). Most of the heat occurring at the junction flows first into the chip, then into the solder to the header and finally into the ambient surroundings. The total thermal equivalent circuit is therefore considered as a series combination of individual parallel circuits, each consisting of the thermal resistance concerning the thermal conductivity of the material and the thermal capacitance concerning its volume. Figure 26b shows an example of the thermal equivalent circuit.

Approximate values for the thermal resistance of each transistor component such as chip, solder, package can be found from the transient thermal resistance characteristic which is the relationship between the heating pulse duration and the thermal resistance.

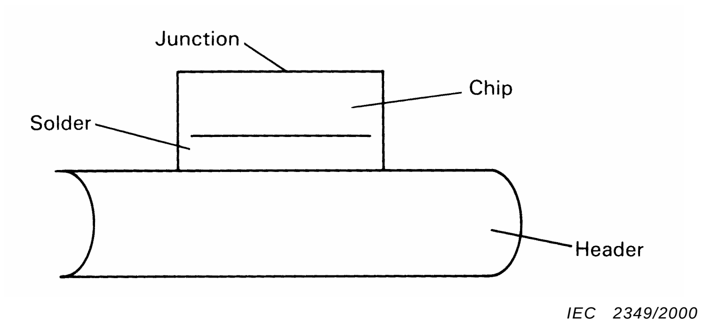
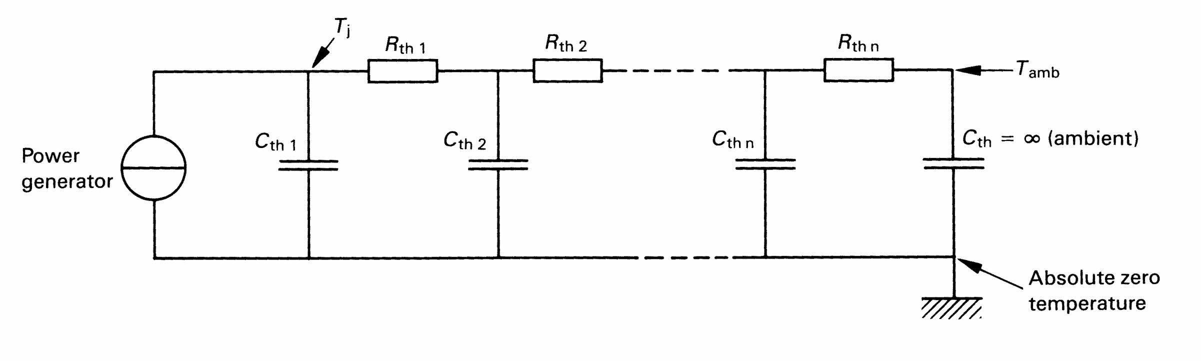


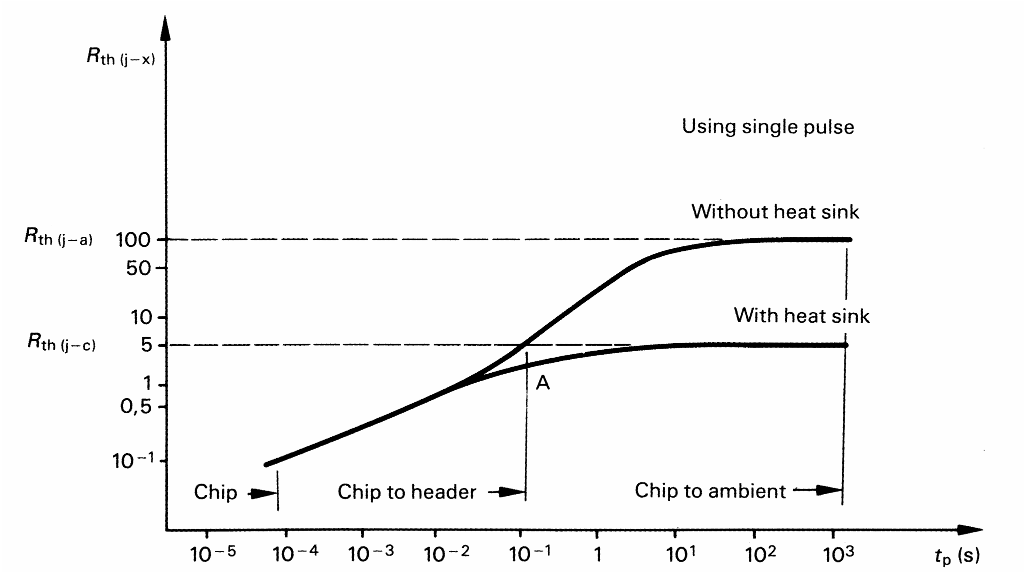
Figure 26a – Cross-section of a typical transistor in metallic case (cavity)



IEC 2350/2000

Figure 26b – Thermal equivalent circuit

A typical transient thermal resistance characteristic is shown in figure 27.



IEC 2351/2000

Figure 27 – Typical transient thermal resistance characteristic versus heating pulse duration

The transistor junction temperature variation as a function of time is known as the Mortenson's theory. The method of thermal resistance measurement using ΔV_{EB} gives the thermal resistance from the junction to a reference point which is determined by the heating pulse duration. Hence the only significant thermal resistance for a small pulse duration is that from the junction to the silicon chip. In figure 27, this region corresponds to the thermal resistance at $t < 10^{-4}$ s. The thermal resistance from the junction to a farther point is determined by the use of a longer pulse duration. The thermal resistance at point A is the thermal resistance from junction to case $R_{th(j-c)}$ and the thermal resistance from junction to ambient $R_{th(j-a)}$, with or without a heat sink, is shown by the diverging curves to the right of point A.

It is only sufficient to choose an appropriate t_p for $R_{th(j-c)}$ for the inspection of the die attachment, which is especially important for power transistors.

6.1.11.3.4 Application to the determination of the safe operating area

Even when the device is operated within its ratings, it may sometimes run away because of the second breakdown (S/B). It is then important, especially for power transistors, to specify the safe operating area (SOAR).

The safe operating area (from short pulse operation to d.c. operation) is determined easily by using the thermal resistance measurement. The following procedure is used: the value of ΔV_{EB} increases when increasing the collector-base voltage V_{CB} for a given I_H and t_p conditions. It increases rapidly at a certain value of V_{CB}; this is an indication of the onset of the second breakdown. Further increase may run the transistor into the second breakdown and destroy it. These phenomena are shown in figure 28.

In general, SOAR is specified at values less than the conditions for the rising point of ΔV_{EB}. The same result will also be obtained by changing the magnitude of the heating current I_H for a fixed V_{CB}.

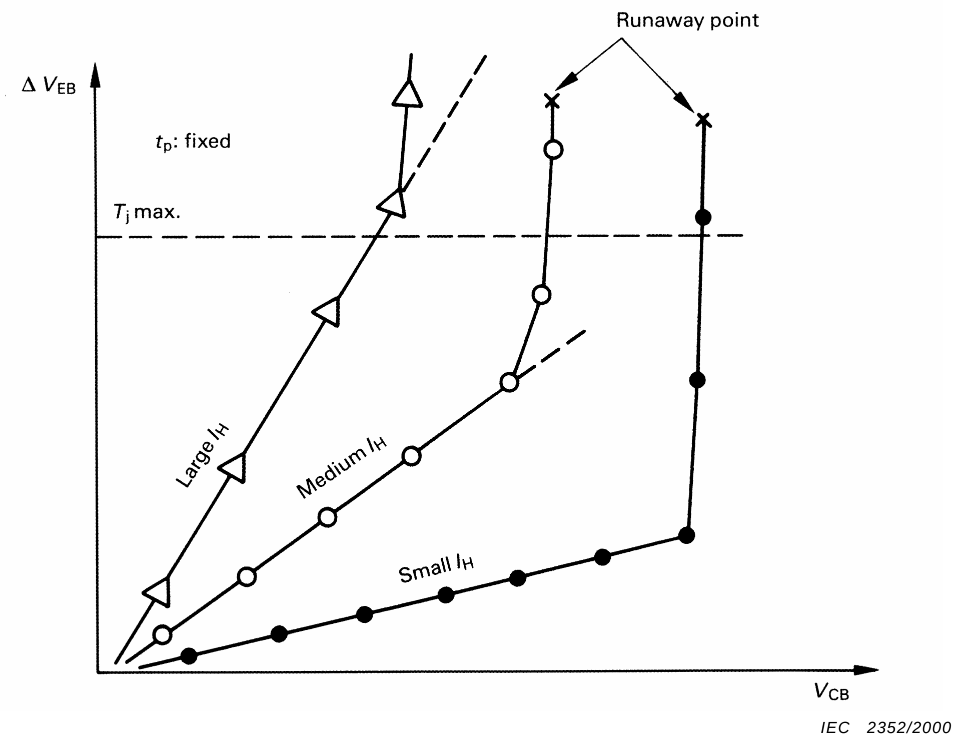


Figure 28 – Typical ΔV_{EB} versus collector-base (V_{CB}) characteristic

Figure 29 shows a typical SOAR at various t_p, within specified maximum values of I_C and V_{CB}.

At smaller V_{CB}, the SOAR determined by the second breakdown usually exceeds the maximum power dissipation (P_{tot}). So the SOAR at smaller V_{CB} is determined by the maximum power dissipation rating.

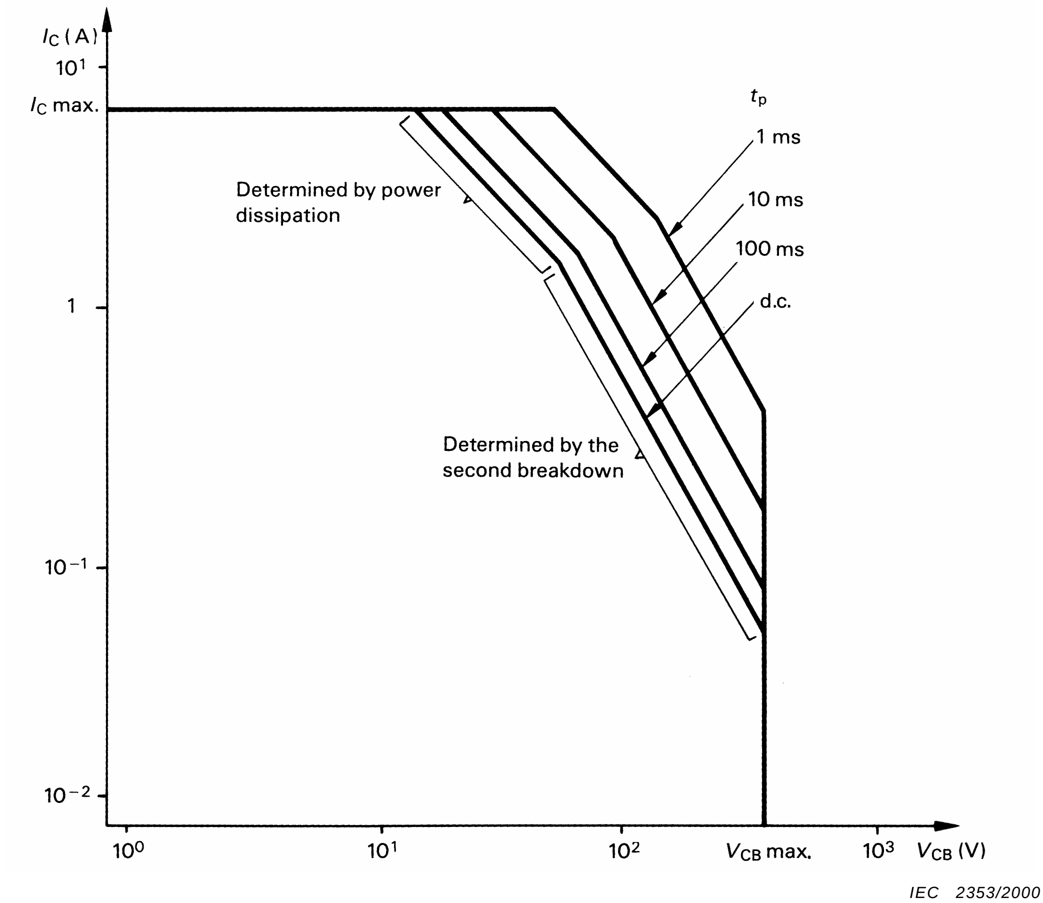


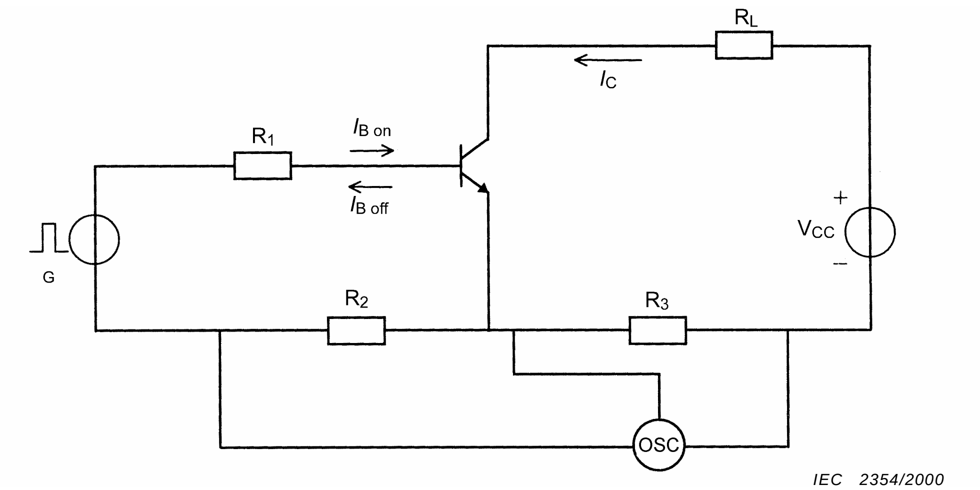
Figure 29 – Typical safe operating area

6.1.12 Switching times (t_d, t_r, t_{on}, t_s, t_f, t_{off})

a) Purpose

To measure the delay, rise, turn-on, storage, fall and turn-off times of a transistor when pulsed from the off-state to the saturated on-state and vice-versa.

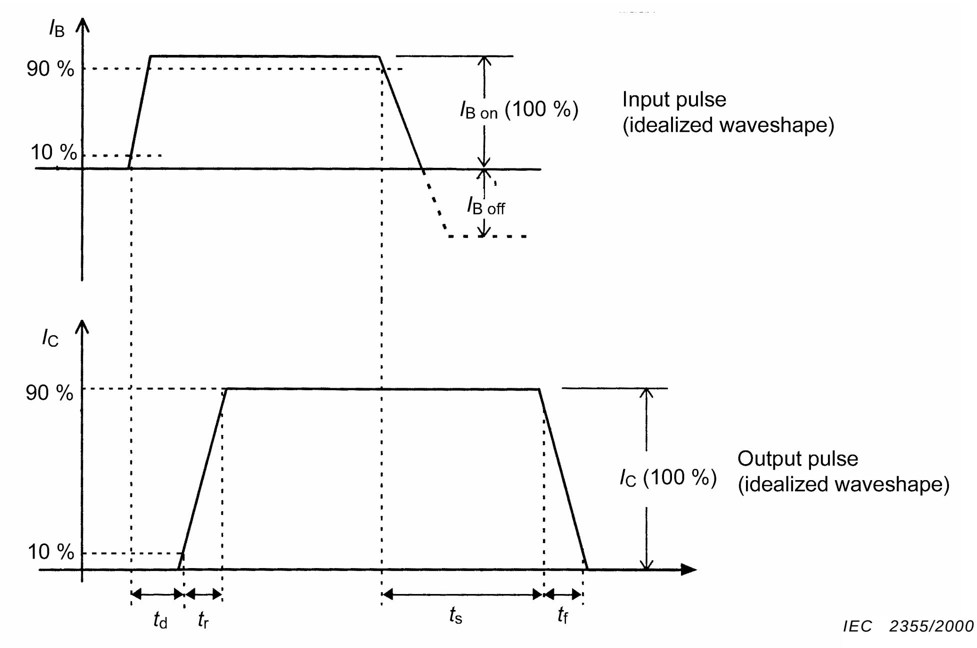
b) Circuit diagram and waveforms



T = transistor being measured

OSC = dual beam oscilloscope

Figure 30 – Circuit diagram



t_d	=	delay time	t_r	=	rise time
t_f	=	fall time	t_s	=	carrier storage time

Figure 31 – Switching times

c) Circuit description and requirements

R_1 and R_L may be replaced by equivalent circuits provided these circuits present the same specified impedance and voltage conditions to the transistor being measured, immediately before and during the measurement.

d) Precautions to be observed

See also 2.3.6 on pulse measurements in IEC 60747-1, chapter VII, section one.

Switching time measurements are critically dependent on the overall frequency response of the complete circuit. For measurements involving very short time intervals, the techniques of construction of the circuit must be adequate for the frequencies involved.

The frequency response, triggering and rise time of the oscilloscope must be carefully evaluated to ensure adequate performance. A double-beam oscilloscope is normally used, and care should be taken to ensure exactly equal delay times in the dual signal connections to the oscilloscope.

All resistors should be low-inductance types and have ±1 % tolerance.

Screened sockets for transistor leads may be necessary and the reference plane for measurements may have to be specified.

Additional circuitry may be necessary to prevent the transistor ratings (V_{EB} in particular) from being exceeded outside the measuring period.

e) Measurement procedure

Temperature conditions are set to the specified value. The specified collector supply voltage (V_{CC}) and input waveform are applied.

The required switching times are measured between the relevant points on the input and output waveforms as specified in figure 31.

f) Specified conditions

– Ambient or case temperature (T_{amb} or T_{case})
– Collector current (I_C nominal)
– Base current during the pulse ($I_{B\ on}$ nominal)
– Peak reverse base current ($I_{B\ off}$ nominal < 0) (for t_s, t_f and t_{off} only)
– Input voltages (V_1 and V_2)
– Maximum pulse edge transition times
– Collector supply voltage (V_{CC})
– Resistances (R_1 and R_L)

6.1.13 High-frequency parameters (f_T, C_{22b}, Re (h_{11e}), $y_{..e}$, $s_{..}$)

6.1.13.1 Introduction

Methods of measurement are given for the following high-frequency parameters of transistors:

a) For transistors intended for general purpose applications:

1) Real part of the short-circuit, common-emitter input impedance:

$$\mathrm{Re}\ (h_{11e})$$

2) Magnitude of the common-base open-circuit reverse voltage transfer ratio at a medium frequency:

$$|h_{12b}|$$

3) Magnitude of the short-circuit common-emitter forward current transfer ratio at a high frequency:

$$|h_{21e}|$$

4) Open-circuit common-base output capacitance:

$$C_{22b}$$

b) For transistors intended for special purpose applications, e.g. at a standard intermediate frequency, one complete set of the following parameters in the complex form at a specified frequency and for specified bias conditions:

$$\left.\begin{matrix} y_{11e} \\ y_{12e} \\ y_{21e} \\ y_{22e} \end{matrix}\right\} \text{ or } \left\{\begin{matrix} y_{11b} \\ y_{12b} \\ y_{21b} \\ y_{22b} \end{matrix}\right.$$

Precautions

1) For general precautions, see clause 2 of IEC 60747-1, chapter VII, section one. Except as indicated, all capacitors should be effective short-circuits at the frequency of measurement.

2) Additional precautions

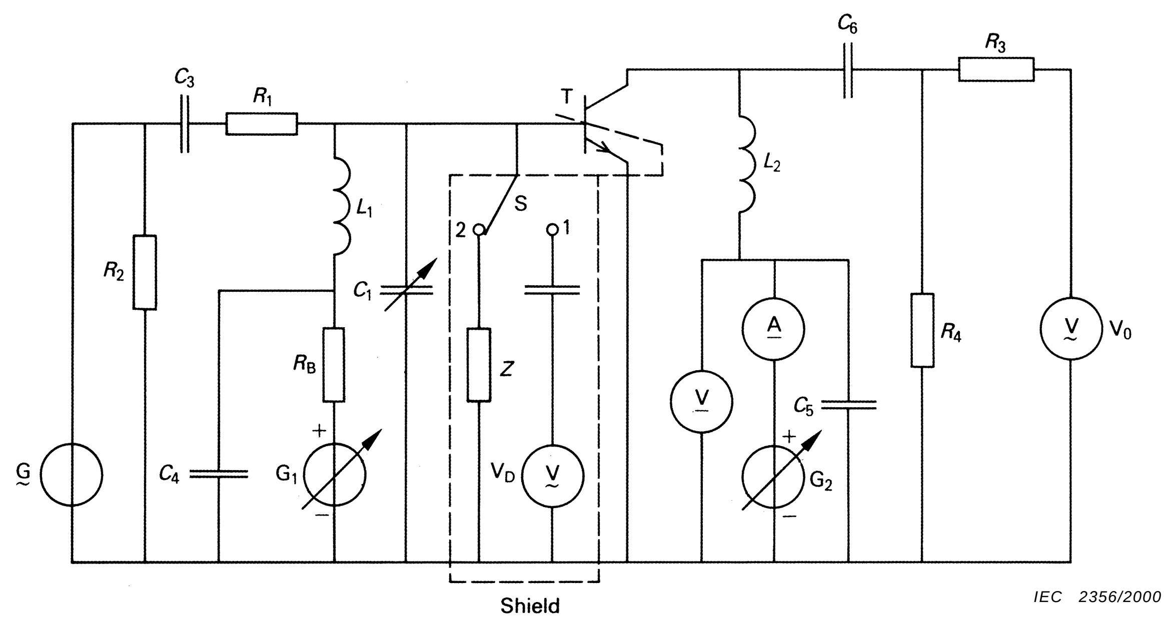
If the results of high-frequency measurements are likely to be influenced by the length of the terminals of the device (e.g. leads or pins), the reference plane for the measurement with respect to the device should be specified.

6.1.13.2 Transition frequency (f_T)

a) Purpose

To measure the transition frequency of a transistor under specified conditions.

b) Circuit diagram



T = transistor being measured

Figure 32 – Circuit for the measurement of the transition frequency

c) Circuit description and requirements

V_0 is an electronic voltmeter.

V_D is a signal detector.

The value of R_1 is large compared with the impedance of the transistor.

The value of R_2 is chosen to match the characteristic impedance of the generator.

R_3 is the internal impedance of voltmeter V_0 and should be of large value compared with that of R_4.

The value of R_4 must be small compared with the output impedance of the transistor.

The value of R_B should be large compared with V_{BE}/I_B.

L_1 and L_2 should have a high impedance at the measurement frequency and the impedance of L_2 should be at least 100 times greater than R_4.

Capacitances C_4 and C_5 should present a short circuit at the measurement frequency. Capacitances C_3 and C_6 should have a low impedance compared with R_1 and R_4.

d) Precautions to be observed

1) Stray capacitance shunting the base-emitter terminals of the transistor must be avoided as much as possible.

   At very high frequencies, it may be necessary to tune out such stray capacitance, which is done as follows.

   With the transistor removed, a signal detector V_D of high impedance is connected between the base and earth (position 1 of switch S).

   The capacitor C_1 is then adjusted until parallel resonance of L_1 and C_1 plus the stray capacitance occurs as indicated on the detector.

   The detector is then replaced by an impedance Z having a value equal to the detector impedance, by changing the position of switch S to 2.

2) It is particularly important that stray inductance in the emitter lead be avoided.

3) Transmission of the measuring signals between base and collector without passing through the transistor must be avoided by screening as shown in the circuit.

   The following test may be used to confirm that the screening between the base and collector sockets is adequate.

   The transistor is removed and a resistor having a value approximately equal to the input impedance of the transistor is inserted between the base and emitter sockets. The collector socket is left open-circuit.

   The reading obtained should be so low that it does not influence the accuracy of the measurement.

4) If the transistor being measured is a four-terminal device (including the case of a metal case which is isolated electrically from the three other terminals), the electrical connection to the fourth terminal should be made as specified.

e) Measurement procedure

With the collector and base voltage generators G_1 and G_2 set to zero, a short circuit is inserted between the base and collector sockets.

With signal generator G tuned to the specified measurement frequency, the signal generator output is adjusted to give the lowest convenient reading $V_0^{(1)}$ on the output electronic voltmeter V_0 compatible with an adequate signal-to-noise ratio.

The short circuit is removed. The transistor to be measured is then inserted into the test socket.

The collector and base voltage generators G_1 and G_2 respectively are adjusted in sequence until the specified bias conditions are applied to the device, care being taken not to exceed the device ratings during adjustment.

Temperature conditions are set to the specified values, and any necessary adjustments are made to the bias conditions.

With the same signal generator conditions, the reading $V_0^{(2)}$ on the output electronic voltmeter is noted.

The transition frequency is calculated using the expression:

$$f_T = f \frac{V_0^{(2)}}{V_0^{(1)}}$$

where f is the frequency of the measurement.

f) Specified conditions
   - Ambient or case temperature (T_{amb} or T_{case})
   - Measurement frequency (f)
   - Collector-emitter voltage (V_{CE})
   - Collector current (I_C)

6.1.13.3 Open-circuit common-base output capacitance (C_{22b})

6.1.13.3.1 For a three-terminal device, the measuring method is given in 6.1.8.1.2 and described in figure 13 is applicable.

6.1.13.3.2 If the transistor being measured is a four-terminal device (including the situation of a metallic case, which is electrically isolated from the three other terminals), the electrical connection to the fourth terminal should be made as specified.

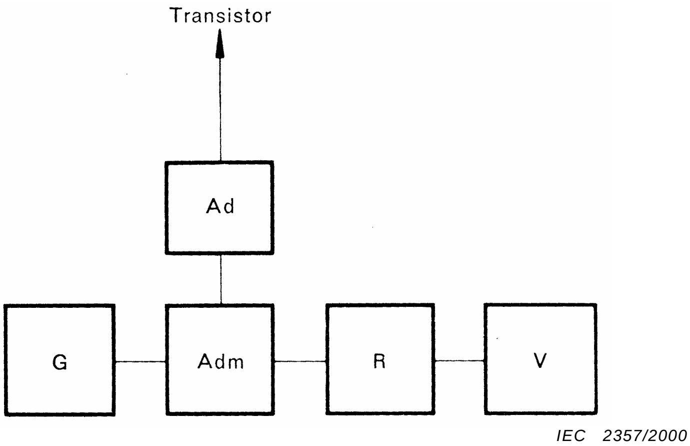
For such a device:

a) If the specification requires that the fourth terminal be connected to either the emitter, base or collector terminal, the method for a three-terminal device is applicable.
b) If this is not the case, the method of measurement to be used is under consideration.

6.1.13.4 Real part of the short-circuit common-emitter input impedance (Re(h_{11e}))

6.1.13.4.1 General

The resistive and reactive components of the short-circuit common-emitter input impedance h_{11e} can be measured by means of the circuit shown in block diagram form in figure 33.

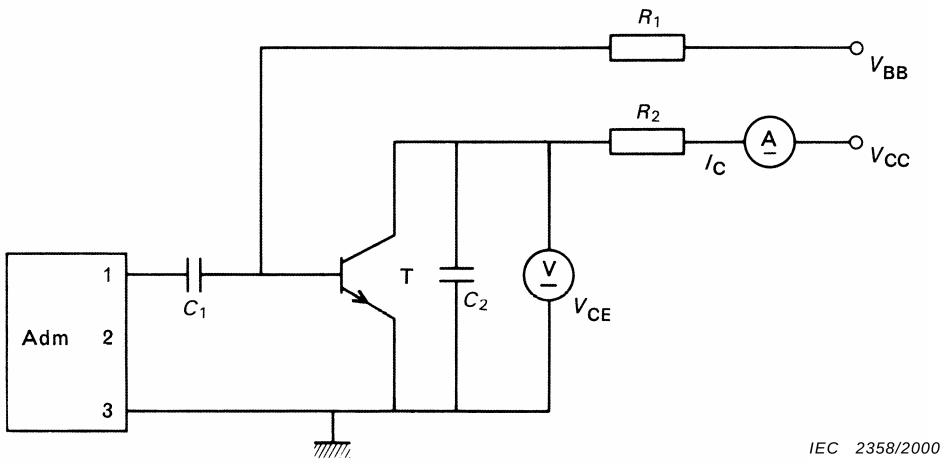


G = modulated signal generator
Ad = adaptor
Adm = admittance bridge
R = receiver
V = electronic voltmeter

Figure 33 – Block-diagram of the circuit for the measurement of the resistive and reactive components of h_{11e}

Any of several different types of bridge may be used, e.g. a VHF admittance bridge, an RX meter or a transadmittance bridge. In all cases, an adaptor is necessary to provide the bias to the device and to connect the transistor input terminals to the bridge terminals, with the transistor output terminals short-circuited for a.c.

A circuit of a suitable adaptor for this measurement is shown in figure 34. The values of capacitors C_1 and C_2 should be chosen to be effective short circuits at the frequency of measurement.



Adm = admittance bridge
1 = measurement terminal
2 = neutral (if present)
3 = measurement terminal
T = transistor being measured

Figure 34 – Circuit of the adaptor shown in figure 33

6.1.13.4.2 Special precautions

a) Care must be taken that leads connecting the transistor to the bridge are of low inductance, since the error due to stray inductance may be serious, even at relatively low frequencies.

b) Since the parameter h_{11e} is particularly sensitive to the signal voltage level, attention is called to the general precaution given in 2.3.3 of IEC 60747-1, chapter VII, section one.

6.1.13.4.3 Measurement procedure

The bridge is first balanced with the transistor removed, and the admittance or impedance arising from the biasing circuit and adaptor is either balanced out by a preset adjustment of the bridge or its value recorded.

The transistor is then inserted and the bias conditions are adjusted. The bridge is balanced again and the readings are taken.

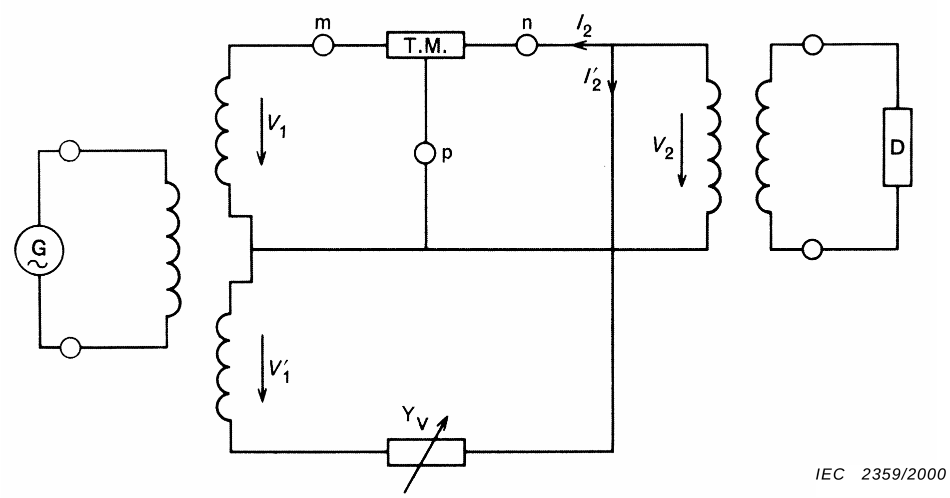
The value of Re(h_{11e}) is then obtained from the last readings either directly or after correction, using the recorded value arising from the initial adjustment.

6.1.13.5 Common-emitter *y* parameters

The methods of measurement for the four complex common-emitter *y* parameters are described below. These methods are applicable for frequencies less than about 50 MHz.

The *y* parameters can be measured by using a bridge of the differential transformer type.

The method of measurement is shown in figure 35.



D = detector

T.M. = three-pole being measured

Figure 35 – Circuit for the measurement of complex common-emitter *y* parameters

When the bridge is adjusted for a null, then the following conditions are fulfilled:

$$-I_2 = I'_2 \quad \text{and} \quad V_2 = 0$$

Furthermore, since $V_1 = V'_1$, the following relation holds:

$$-y_{mn} = Y_V$$

where y_{mn} is the short-circuit forward transadmittance of the three-pole to be measured.

This three-pole represents the transistor to be measured including the suitable biasing circuitry and adequate by-passing. The three-pole circuit has to be chosen according to the various y parameters of the transistor.

The correspondence between the transistor terminals and the bridge terminals m, n and p, for the various y parameters, is shown in figures 37, 38 et 39.

Figure 36 shows the three-pole circuit for the measurement of y_{11e}.

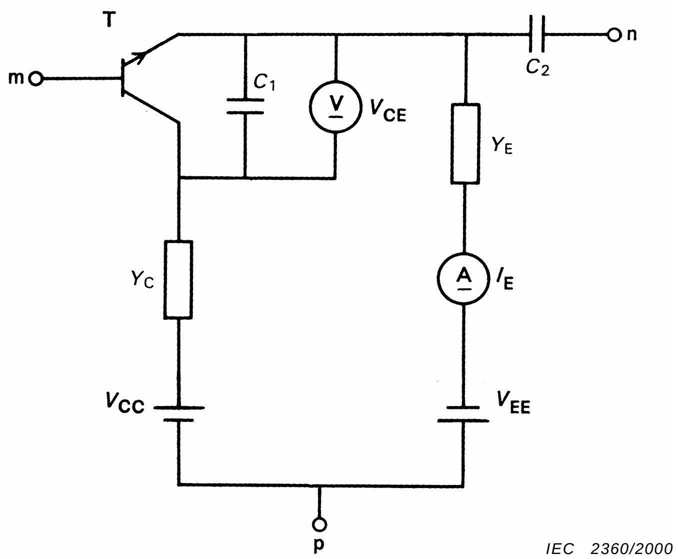


Figure 36 – Three-pole circuit for the measurement of y_{11e}

The admittances Y_E and Y_C must satisfy the following conditions:

$$\omega C_2 >> |Y_C|$$

$$\omega C_2 >> |Y_E|$$

These conditions can be obtained, for instance, by using a resistor in series with an inductor or by a parallel tuned circuit.

In addition, the following conditions must be satisfied:

$$\omega C_1 >> |Y_C| \times |h_{21e}|$$

$$\omega C_1 >> |y_{21e}| \times |h_{21e}|$$

Figure 37 shows the three-pole circuit for the measurement of y_{22e}.

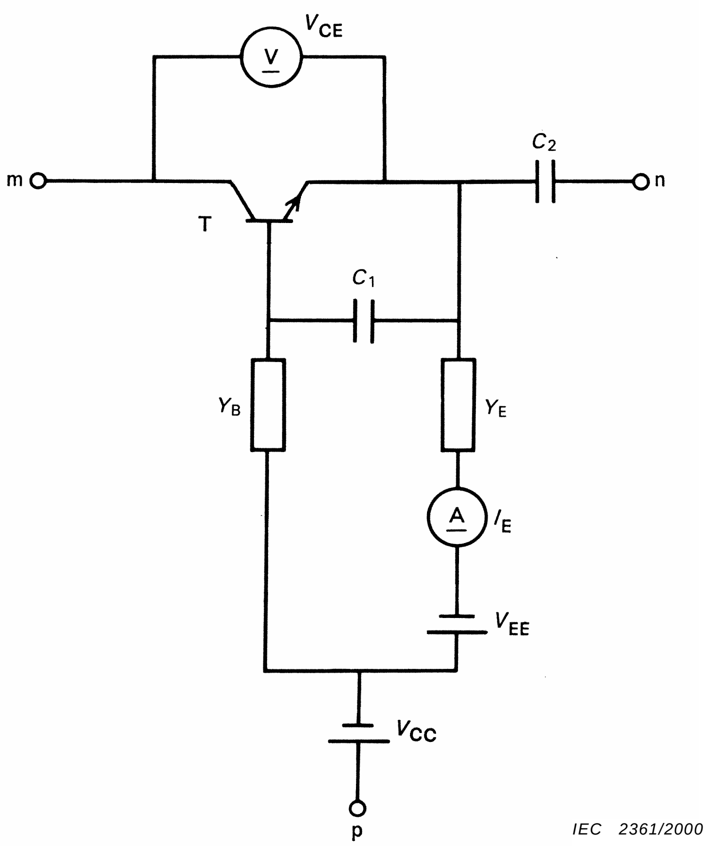


Figure 37 – Three-pole circuit for the measurement of y_{22e}

Conditions:

$$\omega C_1 \gg \left| \frac{y_{12e} \cdot y_{21e}}{y_{22e}} \right|$$

$$\omega C_1 \gg \left| \frac{y_{12e} \cdot Y_B}{y_{22e}} \right|$$

$$\omega C_2 \gg \left| y_{22e} \right|$$

Figure 38 shows the three-pole circuit for the measurement of y_{21e}.

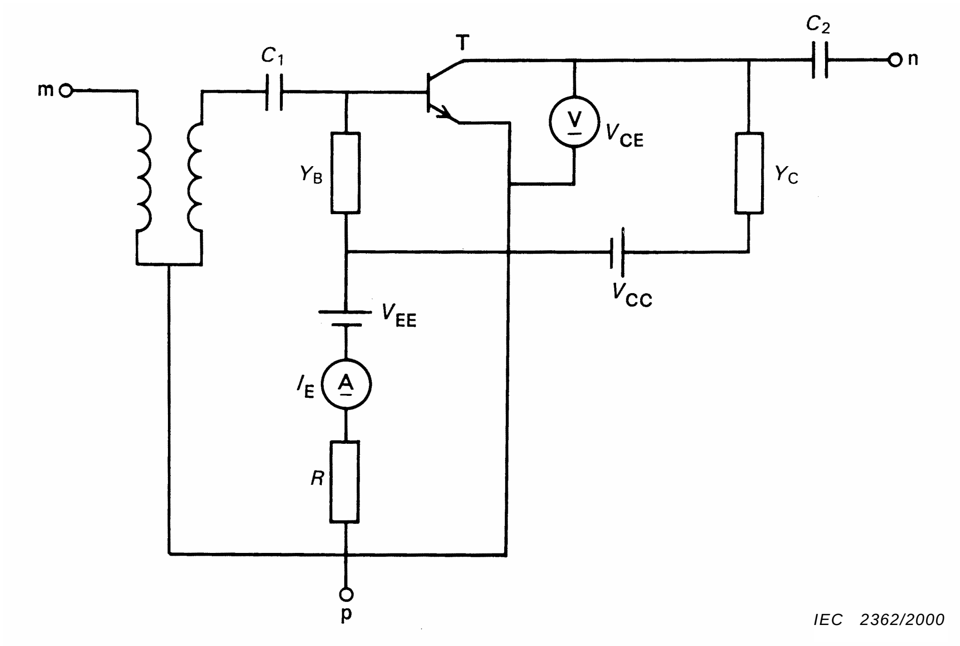


Figure 38 – Three-pole circuit for the measurement of y_{21e}

Conditions:

$$\omega C_1 >> |y_{11e}|$$

$$\omega C_1 >> |Y_B|$$

$$\omega C_2 >> |y_{22e}|$$

$$\omega C_2 >> |Y_C|$$

NOTE A phase reversing transformer (shown in the figure) needs to be added if the bridge is not capable of measuring a negative conductance.

Figure 39 shows the three-pole circuit for the measurement of y_{12e}.

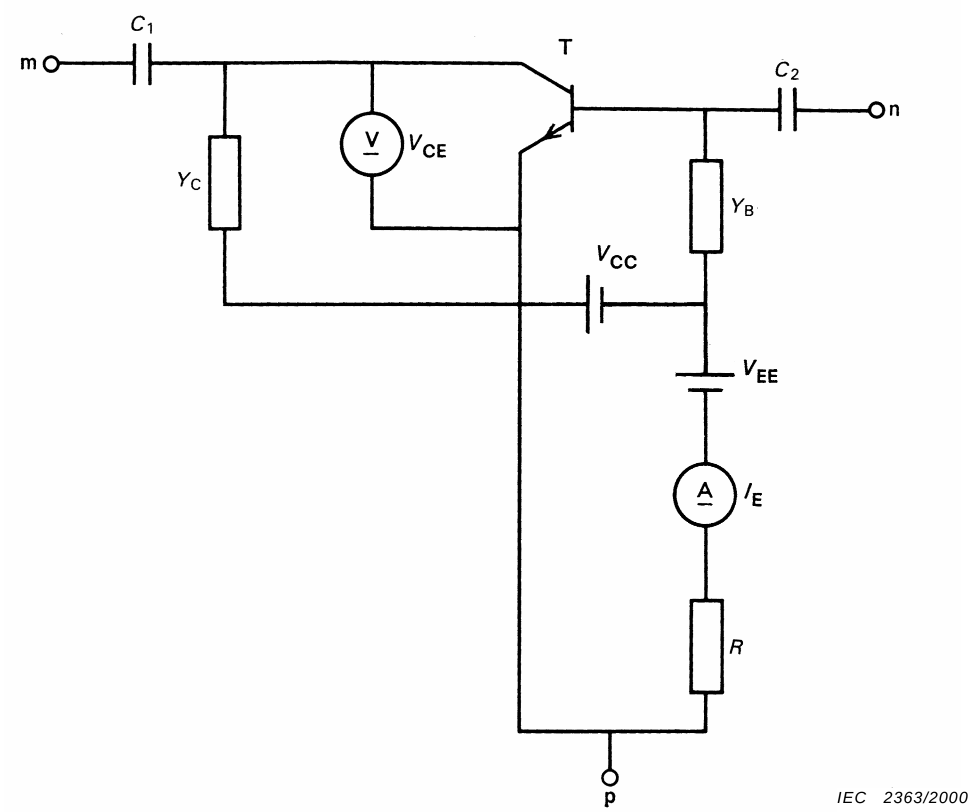


Figure 39 – Three-pole circuit for the measurement of y_{12e}

Conditions:

$$\omega C_1 >> |y_{22e}|$$

$$\omega C_1 >> |Y_C|$$

$$\omega C_2 >> |y_{11e}|$$

$$\omega C_2 >> |Y_B|$$

The methods of biasing shown in these figures are given for illustration only, other methods consistent with good engineering practice may also be used.

6.1.13.6 *s* parameters

6.1.13.6.1 Input (s_{11}) and output (s_{22}) reflection parameters

a) Purpose

To measure transistor parameters s_{11} and s_{22} at a specified frequency.

b) Circuit diagram

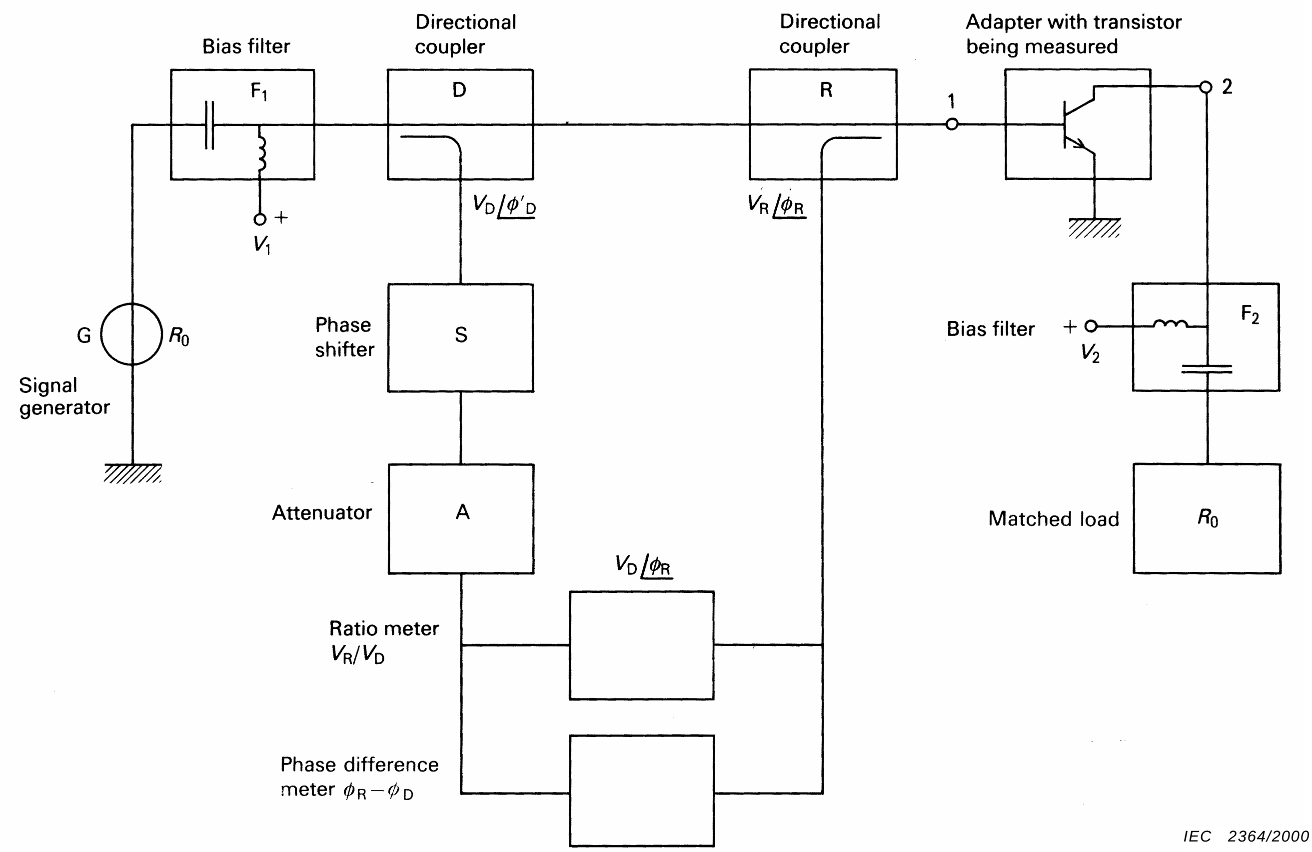


Figure 40 – Block diagram of the circuit for the measurement of s_{11} and s_{22} parameters

c) Circuit description and requirements

The methods specified below refer to both bipolar (NPN and PNP) and unipolar (N-channel and P-channel, both depletion and enhancement types) transistors for any type of configuration.

The circuit shown is valid for NPN transistors in the common-emitter configuration. For other types of transistors and/or configurations, the polarities of bias voltage and current are changed appropriately.

Two measuring methods are possible in connection with the circuit shown in figure 40:

1) *direct reading method*, when ratio and phase difference meters are direct reading meters. In this method, attenuator A and phase shifter S are not necessary and, for single-frequency measurements, they must be set to read a minimum value A_0 (if possible 0 dB) and S_0 (if possible 0 degree);

2) *null method*, when calibrated ratio and phase meters are not available.

d) Precautions to be observed

Small-signal conditions must be maintained; see 2.3.3 of IEC 60747-1, chapter VII, section one.

The adaptors for the transistors should be designed so that connectors or transitions between different types of waveguides, if any, do not show appreciable mismatching, with adequate decoupling between input and output lines.

For the adaptor, a drawing should be given and the reference plane indicated.

The lines connected to terminals 1 and 2, including those inside the adaptor, should have a characteristic impedance equal to the purely resistive reference impedance chosen for the measurement of the *s*-matrix. The load resistance must have the same value. The attenuation of the lines should be negligible and the directional couplers must have adequate directivity.

If the signals from the terminals of D and R are of too small amplitude with respect to the sensitivity of the meters, two amplifiers having identical characteristics may be inserted in the two lines coming from these terminals.

If the ratio V_R/V_D and phase meters (or the null detector) are unsuitable for the measurement frequency, two mixers having identical characteristics and driven by a single local oscillator may be inserted in the two lines coming from terminals of D and R to make a frequency conversion.

When amplifiers or mixers are incorporated, care should be taken to operate them in a linear range. It is therefore advisable to use the procedure given under e)1) or to use the null method of measurement under e)2).

The bias filters must be such that line mismatching is minimized.

If there is a separate terminal connected to the case, this must be grounded, unless otherwise specified.

e) Measurement procedure

1) Direct reading method

With $V_1 = 0$ and the transistor removed, a short circuit is inserted between the input terminals of the adaptor (point 1) at the reference plane at which the measurement is to be made.

Under these conditions, the ratio meter should be adjusted to read unity and the phase meter to read 180°.

Differences observed between measurements of phase difference, when switching from short-circuit to open-circuit conditions, indicate a lack of accuracy in implementing short-circuit or open-circuit conditions at the reference plane. The observed differences should be taken into account when determining the accuracy of the measurements.

The transistor is then inserted into the adaptor, taking care that the input terminals (point 1) coincide with the input port for the measurement of parameter s_{11} or with the output port for the measurement of parameter s_{22}. The specified bias voltages are applied to the appropriate terminals.

The amplitude ratio (V_R/V_D) and the phase difference ($\Phi_R - \Phi_D$) are then measured by means of the two meters.

The value of the parameter s_{11} (or s_{22}) is calculated using the expression:

$$s_{11} \text{ (or } s_{22}) = V_R / V_D \angle \Phi_R - \Phi_D \tag{6}$$

NOTE If the ratio V_R/V_D is lower than the minimum usable reading of the ratio meter, the setting of the attenuator A can be varied from the initial value A_0 to a value A_{01}, so that the ratio V_R/V_D falls within the range of the meter readings. In a similar way, to obtain a more precise phase difference indication, the setting of the phase shifter S can be varied from the initial position S_0 to a new position S_{01}.

This procedure is valid provided that the attenuator has a constant phase-shift and the phase shifter has constant attenuation, in which case the value of the parameter s_{11} (or s_{22}) is calculated using the expression:

$$s_{11} \text{ (or } s_{22}) = \frac{V_R / V_D}{\text{anti}\log\left[\left(A_{01} - A_0\right)/20\right]} \angle \Phi_R - (\Phi_D + S_{01} - S_0) \tag{7}$$

2) Null method

The measurement is made by means of a calibrated attenuator A having a constant phase shift, a graduated phase shifter S having a constant attenuation and a null detector which replaces the ratio meter and the phase meter of the previous method.

In this case, the measurement procedure is as follows.

With V_1 = 0 and the transistor removed, a short circuit is inserted between the input terminals (point 1) of the adaptor at the reference plane at which the measurement is to be made.

Attenuator A and phase shifter S are then varied until a null is observed and the readings A_0 (decibels) and S_0 (degrees) are recorded.

The transistor is inserted in the adaptor, taking care that the input terminals (point 1) coincide with the input port for the measurement of the parameter s_{11} or with the output port for the measurement of the parameter s_{22}.

The specified bias voltages are applied to the appropriate terminals.

The null condition is then obtained by means of variations of attenuator A and phase shifter S; the values A_1 (decibels) and S_1 (degrees) are recorded.

The value of the parameter s_{11} (or s_{22}) is calculated using the expression:

$$s_{11} \text{ (or } s_{22}) = \text{anti}\log\left[(A_1 - A_0)/20\right] \angle 180° + S_1 - S_0 \tag{8}$$

f) Specified conditions

- Ambient temperature (T_{amb})
- Bias conditions
- Frequency (f)
- Reference plane
- Purely resistive reference impedance

6.1.13.6.2 Measurement of forward (s_{21}) and reverse (s_{12}) transfer parameters

a) Purpose

To measure transistor parameters s_{21} and s_{12} at a specified frequency.

b) Circuit diagram

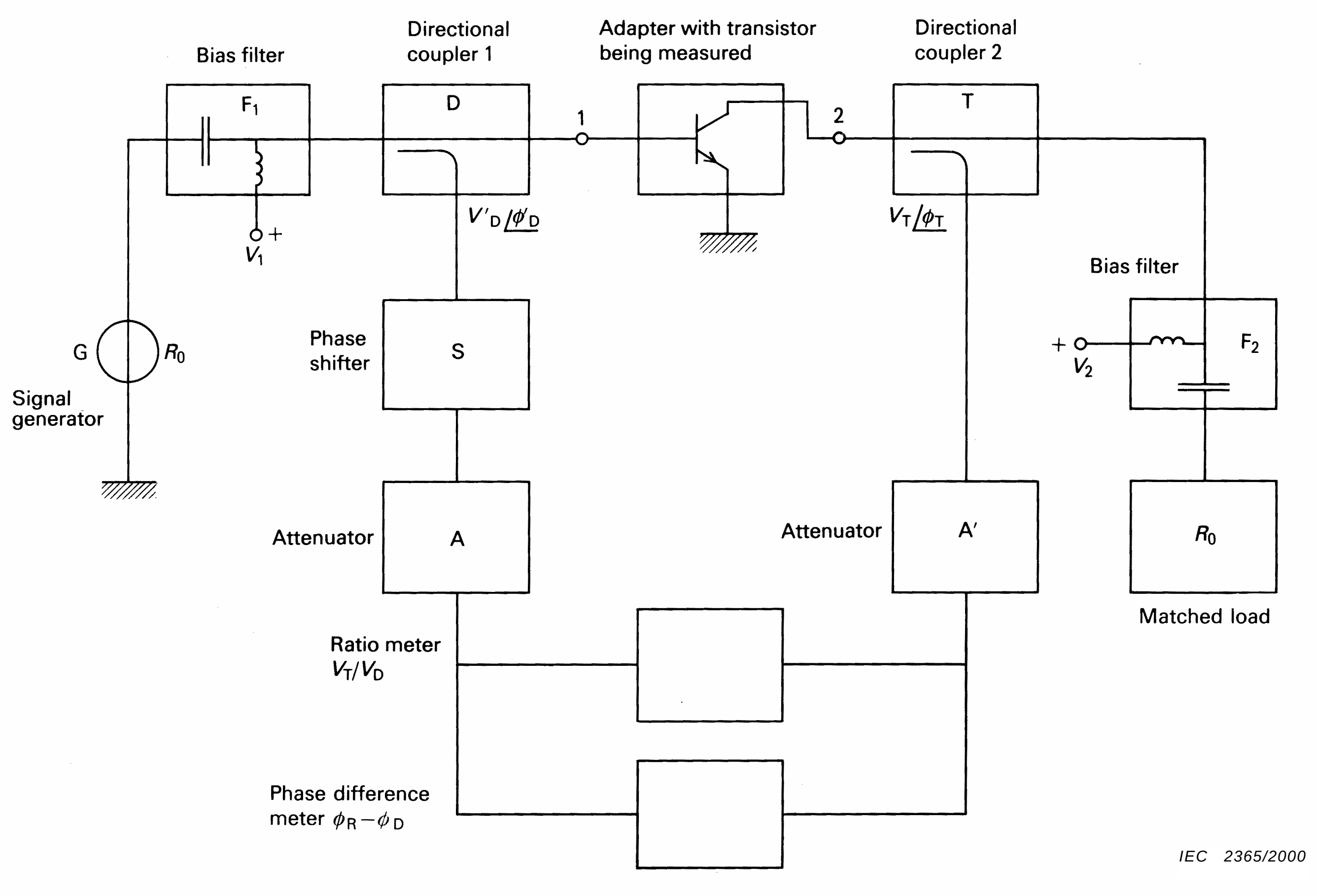


Figure 41 – Block diagram of the circuit for the measurement of s_{12} and s_{21} parameters

c) Circuit description and requirements

The methods specified below refer to both bipolar (NPN and PNP) and unipolar (N-channel and P-channel, both depletion and enhancement types) transistors for any type of configuration.

The circuit shown is valid for NPN transistors in the common-emitter configuration. For other types of transistors and/or configuration, the polarities of bias voltage and current are changed appropriately.

Two measuring methods are possible in connection with the circuit shown in figure 41:

1) *direct reading method*, when ratio and phase difference meters are direct reading meters;

2) *null method*, when calibrated ratio and phase difference meters are not available.

d) Precautions to be observed

Small-signal conditions must be maintained, see 2.3.3 of IEC 60747-1, chapter VII, section one.

The adaptors for the transistors should be designed so that connectors or transitions between different types of waveguides, if any, do not show appreciable mismatching with adequate decoupling between input and output lines.

For the adaptor, a drawing should be given and the reference plane indicated.

The lines connected to terminals 1 and 2, including those inside the adaptor, should have a characteristic impedance equal to the purely resistive reference impedance chosen for the measurement of the scattering matrix. The load resistance must have the same value as in item d) of 6.1.13.6.1. The attenuation of the lines should be low and the directional couplers must have adequate directivity.

If the signals from the terminals of D and T are of too small amplitude with respect to the sensitivity of the meters, two amplifiers having identical characteristics may be inserted in the two lines coming from these terminals.

If the ratio and phase meters (or the null detector) are unsuitable for the measurement frequency, two mixers having identical characteristics and driven by a single local oscillator may be inserted in the two lines coming from the terminals of D and T to make a frequency conversion.

When amplifiers or mixers are incorporated, care should be taken to operate in a linear range. It is therefore advisable to use the procedure given under e)1) or to use the null method of measurement under e)2).

The bias filters must be such that line mismatching is minimized.

If there is a separate terminal connected to the case, this must be grounded, unless otherwise specified.

e) Measurement procedure

1) Direct reading method

With $V_1 = V_2 = 0$, the input and output terminals are linked so that the characteristic impedance of the line is maintained through the adaptor; the ratio and phase meters are so adjusted as to obtain a reading of unity on the ratio meter and of 0 degree on the phase meter.

The transistor is then inserted into the adaptor, taking care that terminal 1 coincides with the input port for the measurement of parameter s_{21} or with the output port for the measurement of parameter s_{12}. The specified bias voltages are applied to the appropriate terminals.

The amplitude ratio (V_T/V_D) and the phase difference ($\Phi_T - \Phi_D$) are measured by means of the two meters (see note below).

This procedure is valid provided that the attenuator has a constant phase shift and the phase shifter has a constant attenuation, in which case, the value of the parameter s_{21} (or s_{12}) is calculated using the expression:

$$s_{21}\ (\text{or } s_{12}) = V_T / V_D \angle \Phi_R - \Phi_D \qquad (9)$$

NOTE If the ratio V_T/V_D is lower than the minimum usable reading of the ratio meter, the setting of the attenuator A can be varied from initial value A_0 to a value A_{01}, so that the ratio V_T/V_D falls within the range of the meter readings.

Similarly to the above, for values of the ratio V_T/V_D higher than the maximum usable reading of the meter, the setting of the attenuator A' can be varied from the initial value A'_0 to a value A'_{01} so that the ratio V_T/V_D falls within the range of the meter readings. In a similar way, to obtain a more precise phase-difference indication, the setting of the phase shifter S can be varied from its initial position S_0 to a new position S_{01}.

In this case, the value of the parameter s_{21} (or s_{12}) is calculated using the expression:

$$s_{21}\ (\text{or } s_{12}) = \frac{V_T / V_D}{\text{antilog}\left\{[(A_{01} - A_0) - (A'_{01} - A'_0)] / 20\right\}} \angle \Phi_T - (\Phi_D + S_{01} - S_0) \qquad (10)$$

2) Null method

The measurement is made by means of two calibrated attenuators A and A′ having a constant phase shift, a graduated phase shifter S having a constant attenuation and a null detector which replaces the ratio meter and the phase meter of the previous method.

In this case, the measurement procedure is as follows.

With $V_1 = V_2 = 0$, a short circuit is inserted between the isolated points of terminals 1 and 2 of the adaptor.

Attenuator A and phase shifter S are then varied until a null is observed, and the readings A_0 and S_0 are recorded.

Attenuator A′ is set at its minimum reading A'_0.

The transistor is inserted into the adaptor, taking care that terminal 1 coincides with the input port for the measurement of parameter s_{21} or with the output port for the measurement of parameter s_{12}.

The specified bias voltage are applied to the appropriate terminals.

The null condition is then obtained by means of variations of attenuators A and, where necessary, A′ and phase shifter S. The values A_1, A'_1 and S_1 are recorded.

The value of the parameter s_{21} (or s_{12}) is calculated using the expression:

$$s_{21} \text{ (or } s_{12}) = \text{antilog}\left\{\left[\left(A_{01} - A_0\right) - \left(A'_{01} - A'_0\right)\right]/20\right\} \angle S_1 - S_0 \qquad (11)$$

f) Specified conditions

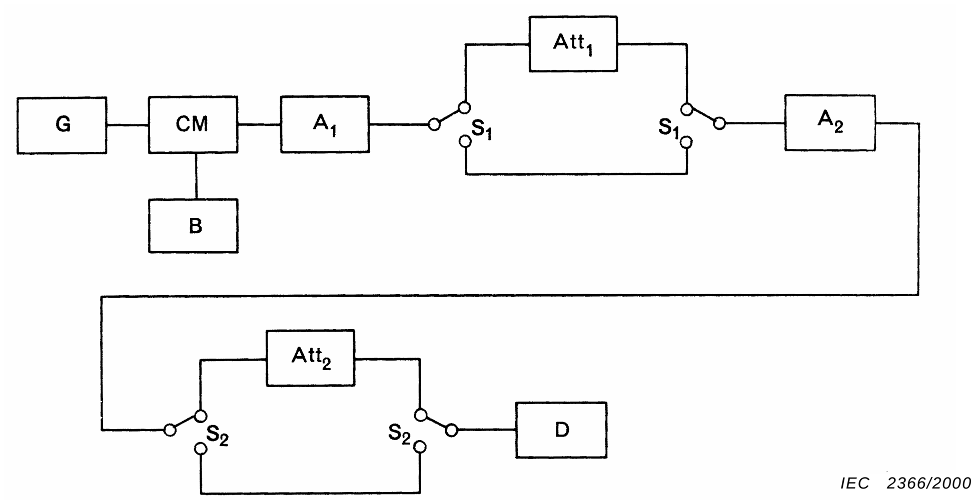
- Ambient temperature (T_{amb})
- Bias conditions
- Frequency (f)
- Reference plane
- Purely resistive reference impedance

6.1.14 Noise (F)

6.1.14.1 Introduction

The noise characteristics of a transistor should be measured in terms of noise figure (F). This noise figure is defined as the ratio of the total available noise power output from the transistor when connected to a source to that which is generated solely by the source.

The measurement is made in the circuit as outlined in the block diagram of figure 42 using either a noise diode or a signal generator as described in 6.1.14.3, 6.1.14.4 and 6.1.14.5.



G	=	generator	A_1, A_2	=	amplifiers
CM	=	transistor measurement circuit	Att_1, Att_2	=	attenuators
B	=	bias	D	=	detector with specified response time

Figure 42 – Basic block diagram for the measurement of the noise figure

The value of the transistor source impedance, the d.c. operating conditions, the circuit configuration, the frequency of measurement, the amplifier bandwidth and the detector time constant should be specified. If the input network must be adjusted to give optimum noise performance, this should be indicated.

Where possible, the noise diode method should be used, but for frequencies less than 1 kHz a suitable noise diode may not be available, in which case the signal generator method should be used.

6.1.14.2 General requirements

6.1.14.2.1 Shielding of measuring equipment

The measuring equipment must be very well shielded and grounded in order to prevent pick-up of unwanted signals.

6.1.14.2.2 Generator

A suitably calibrated generator should be used. All resistors which form part of the effective noise source for the transistor being measured should be of a low-noise type, such as deposited metal film resistors, in order to minimize contact and breakdown noise. For measurements in the HF and VHF range, care should be taken to avoid errors due to series inductance in the generator, which can be particularly serious at the higher frequencies.

6.1.14.2.3 Bias supplies

Batteries or low ripple d.c. supplies should be used. Any bias applied should be decoupled for both radio frequencies and audio frequencies.

6.1.14.2.4 Preamplifier (amplifier no. 1)

A preamplifier can be inserted between the transistor being measured and the attenuator no. 1, if desired. If this is done, the preamplifier must meet the linearity and other relevant requirements given in 6.1.14.2.6.

The preamplifier should include an impedance matching network between the output of the transistor and the input of the preamplifier, in order to reduce the contribution of second stage noise.

6.1.14.2.5 Attenuators

Attenuator no. 1 is used to minimize the effect of non-linearities in the post amplifier and the noise indicator, by controlling the gain of the system.

Attenuator no. 1 can also be used at higher frequencies to determine the effect of the noise caused by amplifier no. 2 when the transistor gain is low. A switch S_1 is connected across the attenuator, as shown in figure 42. The use of this switch will be described in 6.1.14.4.3.

6.1.14.2.6 Amplifier no. 2 (post amplifier)

The amplifier noise should be such that, with the noise generator turned off, any transistor being measured gives an increase of at least 15 dB above the reading due to the post amplifier itself with no transistor in the circuit. If this is not achieved, the effect of the amplifier on the overall noise figure must be considered. This can be done conveniently by means of attenuator no. 1 (see 6.1.14.4.3).

Heterodyne type amplifiers may be used, but careful attention must be paid to the image and other spurious responses which can be encountered with such amplifiers. These spurious responses must be made negligible or must be specified and accounted for in the measurement.

The amplifier should have an input impedance which matches attenuator no. 1 for the attenuation to be known accurately.

The amplifier must be essentially linear from the r.m.s. level used to a minimum of 20 dB above this level, in order to take into account the crest factor of the noise.

Additional flexibility may be provided by making the gain of the amplifier variable.

Theoretical analysis and empirical experiments have shown that, if the overall amplifier bandwidth relative to the centre frequency is 15 % or less, the measured noise figure will be within a few per cent of the noise figure referred to a bandwidth of 1 Hz.

6.1.14.2.7 Detector and output voltmeter

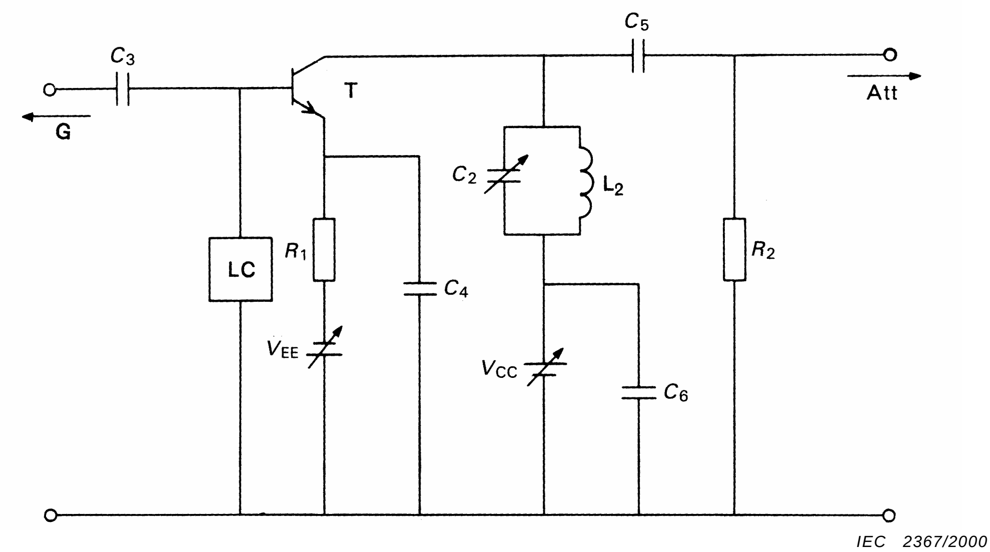
The voltmeter in the detector must respond to the true r.m.s. value of the applied signal and must be able to handle a crest factor of at least 12 dB.

The product of the overall bandwidth and the detector time constant should be large enough to reduce fluctuations in the voltmeter reading, so that adequate discrimination can be obtained in the measurement.

6.1.14.3 Noise figure in the frequency range up to 3 MHz (*F*)

6.1.14.3.1 General

The noise figure is measured with the transistor connected in an amplifier circuit having the general configuration shown in figure 43. A similar configuration in which the transistor is operated in the common-base or common-collector connection may be used.



G = input from noise generator
LC = tuned circuit, or resistance
T = transistor being measured
Att = attenuator

Figure 43 – Basic circuit for the measurement of the noise figure up to 3 MHz

In figure 43, the input and output circuits are two tuned circuits, or a resistor and a tuned circuit, respectively. With the transistor connected into the circuit, the input and/or output circuits are tuned for maximum power gain at the frequency for which the value of the noise figure is to be determined. The noise output is read under the conditions of tuning. The blocking and bypass capacitors, C_3, C_5 and C_4, C_6 must have a low impedance at the frequency of measurement. The values of V_{EE} and R_1 are determined by the specified emitter current for the transistor, and the value of V_{CC} depends upon the specified collector-base voltage.

The equivalent parallel resistance of the input circuit should be large compared with the generator resistance.

6.1.14.3.2 Method of measurement (see figure 42)

The bias of the transistor is adjusted to the specified values. With the noise generator output set to zero and with attenuator no. 2 switched out of the circuit, a reference level is obtained on the noise indicator.

Attenuator no. 2 is then switched into the circuit. Next the noise generator is turned on and its output is increased until the noise indicator returns to the reference level.

The recorded value of the output of the noise generator is then used to compute the noise figure. For example, if a thermionic noise diode is used as the noise generator at 25 °C, the noise figure is:

$$F\ (\mathrm{dB}) = 10\log\frac{19{,}4\times I_\mathrm{D}\,R_\mathrm{g}}{M-1}$$

where

I_D is the noise diode d.c. anode current, in amperes;

R_g is the source resistance, in ohms;

M is the antilogarithm of one tenth of the attenuator reading, in decibels.

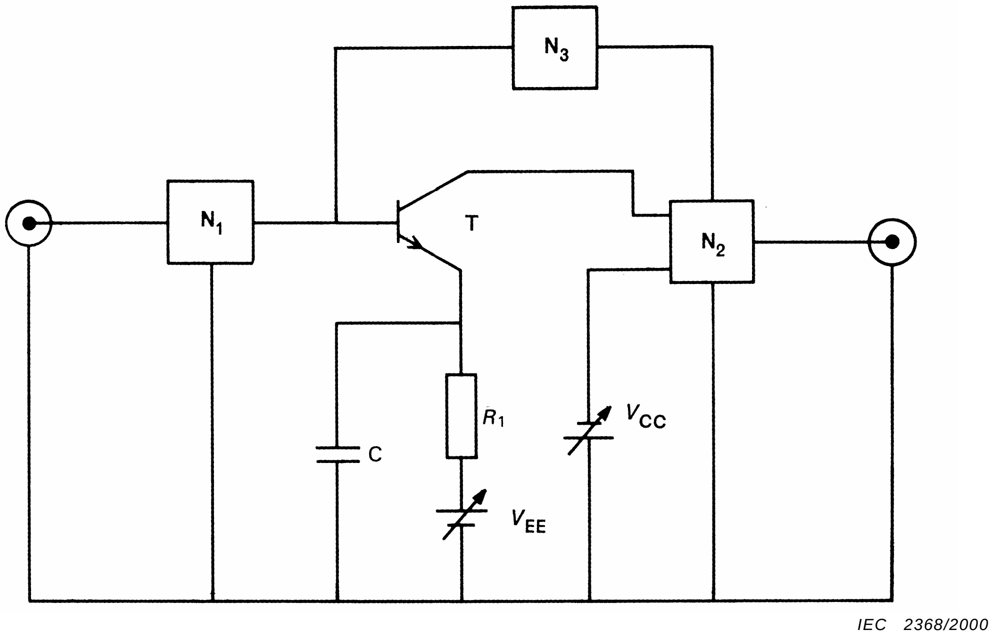
A value of M = 2, corresponding to an attenuator setting of 3 dB, is often used.

In this case, the noise output of the diode is equivalent to the noise power of the transistor being measured.

6.1.14.4 Noise figure in the HF or VHF range (3 MHz-300 MHz)

6.1.14.4.1 General

The transistor being measured is inserted into an amplifier circuit having the general configuration shown in figure 44. A similar configuration in which the transistor is operated in the common-base or common-collector configuration may be used.



T = transistor being measured
N_1 = input network, tuned
N_2 = output network, tuned
N_3 = optional neutralization network

Figure 44 – Basic circuit for the measurement of the noise figure from 3 MHz to 300 MHz

The values of V_{EE} and R_1 are determined by the specified emitter current for the transistor and the value of V_{CC} depends upon the specified collector-base voltage.

The input network should have a bandwidth sufficiently large to ensure that the accuracy of measurement is not affected. Alternatively, the input bandwidth may be selected as desired, and the contribution of the input network should be taken into account in the calculation of the noise figure. The input network should provide an effective bypass for audio frequencies. The tuning conditions for input and output networks must be stated.

The use of a neutralization network is optional. It should be used, if necessary, to maintain stability of the amplifier.

6.1.14.4.2 Method of measurement

The procedure is the same as given in 6.1.14.3.2.

6.1.14.4.3 Effect of amplifier noise

At higher frequencies, where the noise output of the transistor being measured is less than 15 dB above the amplifier noise, attenuator no. 1 may be used to obtain the correct value for F_1, the noise figure of the transistor alone, in terms of the overall noise figure F_{12}.

To do this, the input impedance of amplifier no. 2 must be matched to the attenuator.

The correction for the amplifier noise is based on the well-known equation for the noise figure of cascaded amplifiers:

$$F_{12} = F_1 + (F_2 - 1)\frac{1}{G_1}$$

where

F_1 is the true noise figure of the transistor alone,

G_1 is its available gain,

F_2 is the noise figure of amplifier no. 2,

and where the values of gain and noise figure are expressed numerically.

This equation is valid only if the output impedance of the transistor has been matched to the input impedance of the following stage.

However, in order to avoid having to measure F_2 and G_1, two measurements of the overall noise figure can be made. In this case, the preamplifier must not be used. First, the overall noise figure F_{12} is measured with attenuator no. 1 switched out of the circuit. Then attenuator no. 1 is switched in the circuit and set to an arbitrary loss, L (e.g. a factor of 4) and a second measurement of the overall noise figure F'_{12} is made.

In the second case, F'_{12} is given by the equation:

$$F'_{12} = F_1 + (L\ F_2 - 1)\frac{1}{G_1}$$

where L is expressed numerically.
Solving the above two equations for F_1 leads to:

$$F_1 = \frac{L\,F_{12} - F'_{12}}{L - 1} + \frac{1}{G_1}$$

$$F_1 \cong \frac{L\,F_{12} - F'_{12}}{L - 1}$$

$$\text{for } F_1 >> \frac{1}{G_1}$$

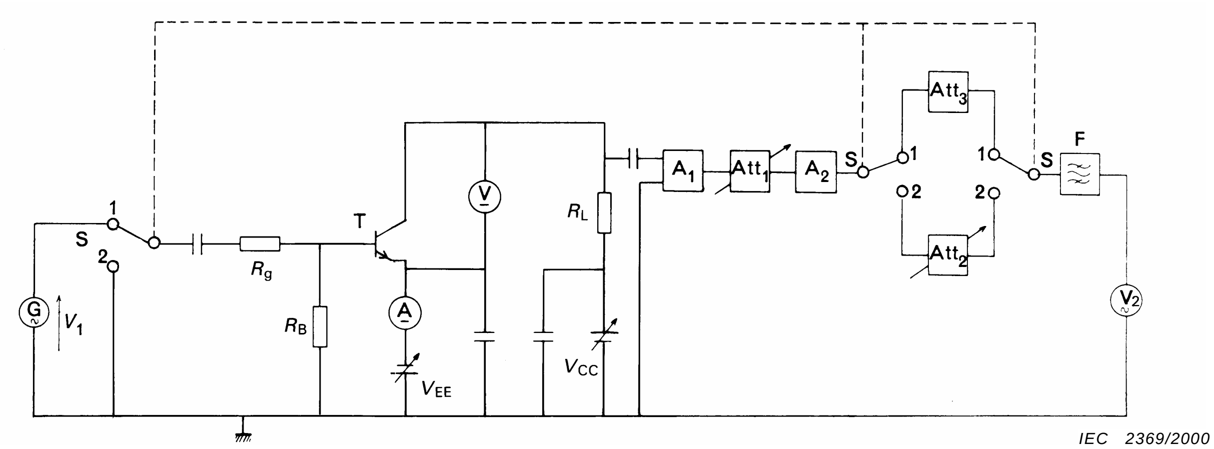
In terms of decibel representation of the noise figure, the equation for F_1 becomes:

$$F_1 = 10 \log (LF_{12} - F'_{12}) - 10 \log(L - 1) \qquad \text{(dB)}$$

6.1.14.5 Noise figure in the frequency range below 1 000 Hz (signal generator method)

6.1.14.5.1 General

Figure 45 shows a suitable circuit.



T	=	transistor being measured	F	=	selective filter
A_1, A_2	=	amplifiers	V_2	=	square-law voltmeter
Att_1, Att_2, Att_3	=	attenuators			

Figure 45 – Basic circuit for the measurement of the noise figure below 1 kHz (signal generator method)

The circuit is essentially identical to that outlined in figure 42, and its components should meet the requirements described in 6.1.14.2, but an attenuator no. 3 having a fixed attenuation and a selective filter is added.

The amplifiers should have a bandwidth sufficiently large to ensure that the overall noise bandwidth is determined by the selective filter, and should be capable of linear operation over a range of signals at least equal to the setting of attenuator no. 3.

The selective filter should be a high *Q* band-pass type with a centre frequency at the frequency of measurement. For noise figure measurements over a narrow frequency band, the effective noise bandwidth should be 15 % or less of the centre frequency. The equivalent noise bandwidth should be accurately determined. The frequency characteristics of the filter must be specified. The frequency of the generator should be adjusted to the centre frequency of the filter.

The system should be checked for spurious responses over the entire frequency range of the detector.

The value of R_g should be large compared with the output impedance of the generator, but small compared with the value of R_B.

6.1.14.5.2 Method of measurement

In this method, the amplifiers need not be calibrated and only the output voltage V_1 of the sinewave generator G and the effective noise bandwidth *B* of the system need be known. With switch S in position 1, attenuator no. 1 is adjusted to give a reference reading on the output square-law voltmeter. With switch S in position 2, the same reading is obtained by adjusting attenuator no. 2. The bandwidth of the amplifiers must be sufficiently large to ensure that the system bandwidth *B* is determined by the filter.

The noise figure is computed by means of the following formula:

$$F = 10 \log \left(\frac{V_1^2}{4\mathrm{k}\ TBR_g} \right) - X_3 + X_2 \quad \text{(dB)}$$

where

V_1 is the output voltage of the signal generator, in volts r.m.s.;

k is the Boltzmann constant = $1{,}38 \times 10^{-23}$ J/K;

T is the absolute temperature of R_g, in kelvins;

B is the effective noise bandwidth, in hertz;

R_g is the generator resistance, in ohms;

X_3 is the attenuation of attenuator no. 3 (fixed), in decibels;

X_2 is the attenuation of attenuator no. 2, in decibels.

By choosing the following values for V_1, T, etc., the noise factor F (in decibels) is nearly equal to X_2:

V_1 = 28,5 μV

B = 100 Hz

X_3 = 60 dB

T = 298 K

R_g = 500 Ω

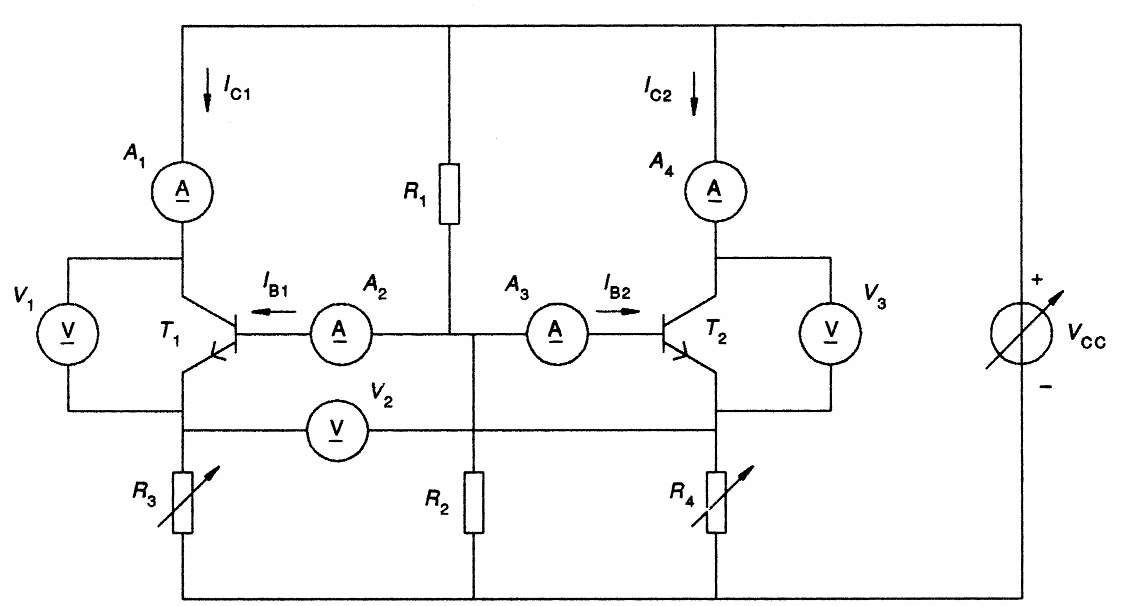
6.1.15 Measuring methods for matched-pair bipolar transistors

6.1.15.1 Ratio of static values of common-emitter forward current transfer ratios h_{21E1}/h_{21E2}

6.1.15.1.1 Purpose

To measure the ratio of static values of common-emitter forward current transfer ratios of matched-pair bipolar transistors under specified conditions.

6.1.15.1.2 Circuit diagram



T_1, T_2 = matched-pair transistors being measured

V_3 = This voltmeter may be omitted.

NOTE R_3 and R_4 may be replaced by current sources.

Figure 46 – Basic circuit for the measurement of h_{21E1}/h_{21E2}

6.1.15.1.3 Measurement procedure

The temperature is set to the specified value.

V_{CC}, R_3 and R_4 are adjusted so that, for each transistor, the specified values of V_{CE} and I_C are reached.

The base currents I_{B1} and I_{B2} are measured.

The ratio of static values of common-emitter forward current transfer ratios h_{21E1}/h_{21E2} is then calculated

$$\text{either as } \frac{I_{B2}}{I_{B1}} \text{ (for } I_{B2} < I_{B1}\text{)}$$

$$\text{or as } \frac{I_{B1}}{I_{B2}} \text{ (for } I_{B2} > I_{B1}\text{)}$$

The ratio is the smaller value divided by the larger value.

6.1.15.1.4 Specified conditions

– Ambient or case temperature
– Collector current (I_C)
– Collector-emitter voltage (V_{CE})

6.1.15.2 Difference of base-emitter voltages ($V_{BE1} – V_{BE2}$)

6.1.15.2.1 Purpose

To measure the value of the difference between the base-emitter voltages of matched-pair transistors under specified conditions.

6.1.15.2.2 Circuit diagram

See figure 46.

6.1.15.2.3 Measurement procedure

The temperature is set to the specified value.

V_{CC}, R_3 and R_4 are adjusted so that, for each transistor, the specified values of V_{CE} and I_C are reached.

The value of the difference of the base-emitter voltages is read from voltmeter V_2.

6.1.15.2.4 Specified conditions

– Ambient or case temperature
– Collector current (I_C)
– Collector-emitter voltage (V_{CE})

6.1.15.3 Change in difference of base-emitter voltages between two temperatures $\left|\Delta\left(V_{BE1} - V_{BE2}\right)\right|_{\Delta T}$

6.1.15.3.1 Purpose

To measure the value of the change of the difference of the base-emitter voltages of matched-pair transistors between two specified temperatures under specified conditions.

6.1.15.3.2 Circuit diagram

See figure 46.

6.1.15.3.3 Measurement procedure

The temperature is set to the specified value T_1, preferably 25 °C.

V_{CC}, R_3 and R_4 are adjusted so that, for each transistor, the specified values of V_{CE} and I_C are reached.

The value of the difference of the base-emitter voltages is noted from voltmeter V_2.

The temperature is then set to a higher specified value, T_2.

If necessary, the collector currents are readjusted to the original value.

The value of the difference of the base-emitter voltages is noted from voltmeter V_2.

The absolute value of the difference of the value measured at T_2 and the value measured at T_1 is calculated.

6.1.15.3.4 Specified conditions

– Ambient or case temperature T_1, if different from 25 °C
– Ambient or case temperature T_2
– Collector current (I_C)
– Collector-emitter voltage (V_{CE})

6.2 Reference measuring methods

6.2.1 General

6.2.1.1 Introduction

The polarities of the sources shown in this subclause are applicable to PNP devices. However, the circuits can be adapted for NPN devices by changing the polarities of the meters and the sources.

The terms accuracy, repeatability and reproducibility, with their associated definitions, which are used in this subclause are still under consideration.

6.2.1.2 General requirements and precautions

The general precautions given in clause 2 of IEC 60747-1, chapter VII, section one, still apply, unless otherwise specified.

The conditions of measurement for these reference methods should be, as far as possible, the same as those specified in the published data:

a) Where limitations have to be imposed on the range of measurement conditions for which the reference method is applicable, these are given in the subclause to which they apply.
b) In order to achieve accurate and reproducible results, the following precautions should be observed.

   Where the parameter is very temperature dependent, the ambient or reference point temperature must be accurately measured and controlled within a close tolerance.

For current measurements, the errors due to ammeters should be less than:

±1 % for currents above 1 μA

±3 % for currents from 0,1 μA to 1 μA

±5 % for currents from 10 nA to 0,1 μA

±10 % for currents from 1 nA to 10 nA

The internal resistance of ammeters should not cause a voltage drop greater than 2 % of any relevant voltage.

The accuracy of the voltmeters should be better than ±1 %.

For any measurement, care must be taken to ensure that the maximum dissipation of the device being measured is not exceeded. In the case where a d.c. method would involve a high power dissipation, the alternative pulse method should be used.

For any device carrying appreciable currents, separate current carrying and voltage measuring contacts should be used. Meters used to measure voltage parameters of the device should be connected as near to the terminals of the device as possible.

If necessary, devices should be protected from all electromagnetic, optical and radioactive radiation, while being measured.

Where high voltage supplies are used, precautions may need to be taken to protect the device during insertion into the circuit by using diodes or switches.

Care must be taken in the construction of the measurement circuit to avoid parasitic oscillations, particularly when measuring high-frequency transistors.

6.2.1.3 Reasons governing the use of static and pulse reference methods of measurement

Under consideration.

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

6.2.2.1 The circuit to be used for this measurement is shown in figure 47.

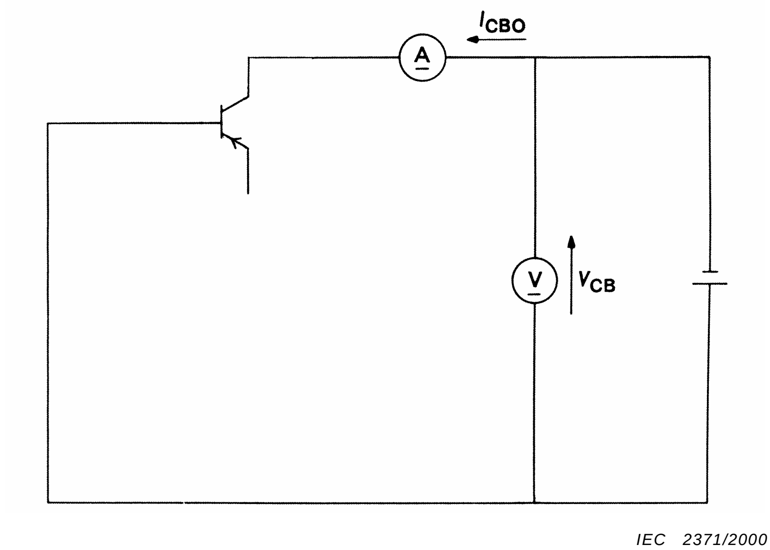


Figure 47 – Circuit for the measurement of I_{CBO}

This parameter is very temperature dependent. For the purpose of making reference measurements, ambient rated devices should be treated as case-related devices by controlling the case temperature to an accuracy better than ±0,5 °C, for example by immersing them in an oil bath. For case-rated or forced cooled devices, the temperature of the reference point should be controlled to within ±0,5 °C.

A higher accuracy can be achieved if the reference point temperature can be controlled to a smaller tolerance.

6.2.2.2 The accuracy predicted in 6.2.2.4 will only be achieved if the measurement is carried out below the breakdown region. This may be verified by making two measurements, the first at 1,05 times the specified voltage V and the second at the specified voltage V.

The measured values of I_{CBO} at the two values of V and 1,05 V should not differ by more than 20 %.

NOTE The specified voltage V should be less than 0,9 times the rated maximum collector-base reverse voltage.

6.2.2.3 With some transistors, the value of I_{CBO} may be unstable for a period after applying the specified voltage V. In such instances, a suitable time interval between applying the voltage and taking the reading of I_{CBO} should be specified.

6.2.2.4 The following accuracies should be achieved.

Current range	Accuracy	Main limitations
1 nA to 10 nA	±30 %	Noise, temperature control, meter inaccuracies
Greater than 10 nA	±25 %	Temperature control, meter inaccuracies

6.2.2.5 Repeatability

In some cases, there may be a drifting of I_{CBO}, in which case no meaningful value can be given for the repeatability of the result. When I_{CBO} does not drift, a repeatability of ±15 % should be possible.

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

The emitter-base cut-off current is measured in the same way as the collector-base cut-off current, except that the emitter and collector terminals are interchanged.

The precaution with respect to operation below the breakdown region is particularly important for the measurement of I_{EBO} (see 6.2.2.2).

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

6.2.4.1 DC method

6.2.4.1.1 The circuit to be used for this measurement is shown in figure 48.

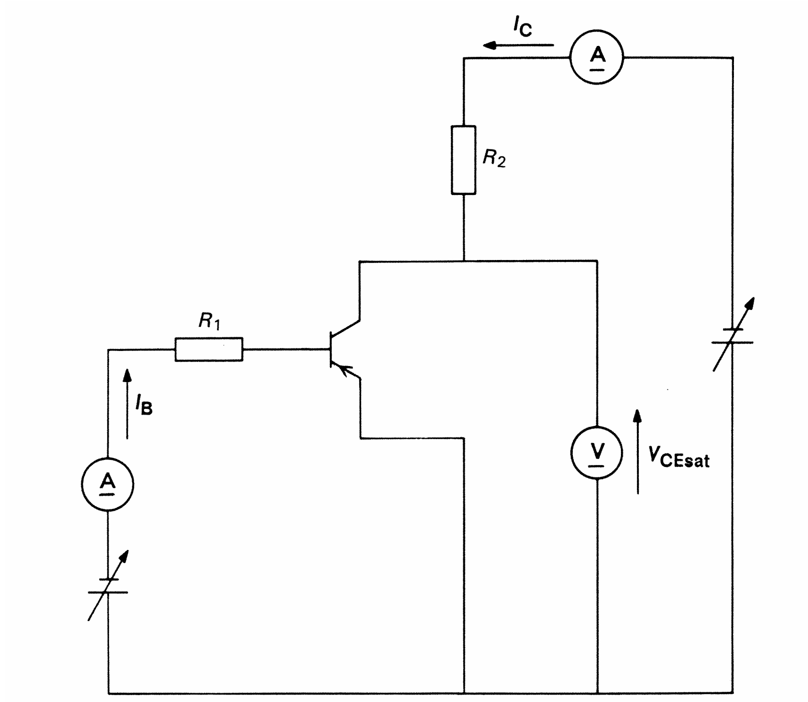


Figure 48 – Basic circuit for the measurement of the collector-emitter saturation voltage (d.c. method)

6.2.4.1.2 I_C and I_B are adjusted to the specified values by means of adjustable high-voltage sources, each in series with a resistor of high value.

6.2.4.1.3 The accuracy predicted below may be achieved only if the transistor is operated sufficiently in saturation. In case of doubt, a check may be made by increasing the value of I_B by 10 %, holding I_C constant; the measured value of V_{CEsat} should not change by more than 10 %.

6.2.4.1.4 The internal resistance of the voltmeter should be greater than:

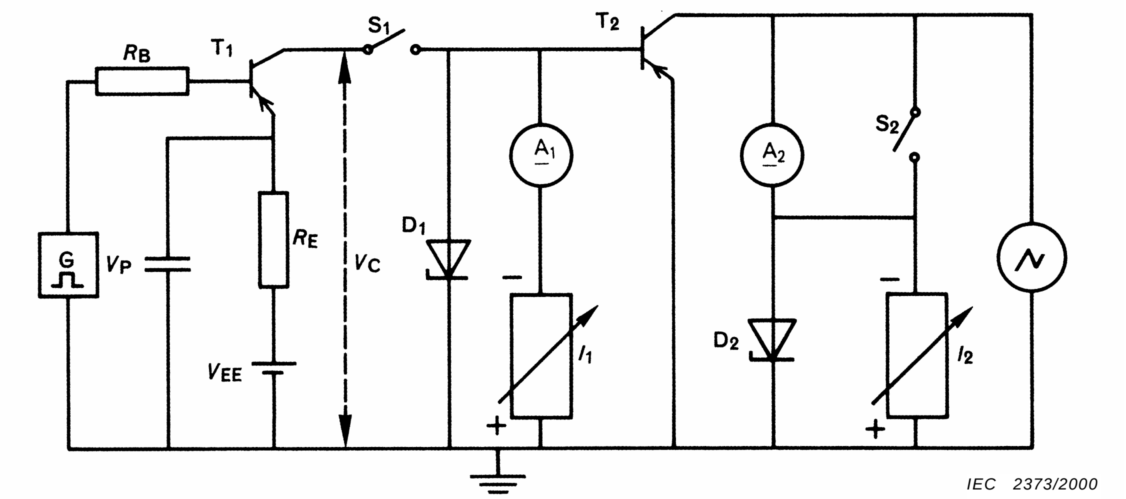
$$\frac{100\ V_{CEsat}}{I_C}$$

where V_{CEsat} is the maximum value specified for the type of transistor being measured.

An accuracy of ±10 % should be achieved.

6.2.4.2 Pulse method

Circuit diagram



T_2 = transistor being measured

Figure 49 – Basic circuit for the measurement of the collector-emitter saturation voltage (pulse method)

Circuit description and requirements

a) I_1 is a current supply whose equivalent internal resistance R_{11} is such that $R_{11}I_B$ is larger than 100 V_{BE}; I_B is the base current and V_{BE} is the maximum base-emitter voltage of the transistor being measured at the reference values of I_C and I_B.

b) I_2 is a current supply whose equivalent internal resistance R_{12} is such that $R_{12}I_C$ is larger than 100 V_{CEsat}; I_C is the reference value of the collector current and V_{CEsat} is the collector-emitter saturation voltage of the transistor being measured. The response time of the supply must be less than the "ON" period of the transistor being measured.

c) Transistor T_1 is a chopper transistor. It must be ensured that the value of V_C is less than V_{BE}, V_{BE} being the minimum base-emitter voltage of the transistor being measured at a collector current equal to 1 % of the reference value used for the measurement. The value of I_{CBO} of transistor T_1 should be less than 0,01 times the value of I_B required by the transistor being measured.

d) Pulse generator: the duration and duty cycle of the pulse waveform used to drive transistor T_1 should be so small that no significant heat dissipation occurs in the transistor being measured. Pulse duty cycles of about 0,01 and pulse widths between 10 μs and 500 μs are usually used (see also precaution a)).

   The value of the pulse voltage amplitude V_P should be chosen in combination with the limiting resistor R_B to be large enough to switch off transistor T_1.

e) Oscilloscope: an oscilloscope, calibrated by means of a reference voltage, should be connected directly at the ends of the transistor terminals.

   A high degree of accuracy can be achieved by using a reference voltage in combination with an oscilloscope which incorporates a differential amplifier having a high offset voltage.

f) Voltage reference diodes D_1 and D_2: voltage reference diode D_1 is used to protect against a collector-emitter breakdown of transistor T_1. Voltage reference diode D_2 is used to protect against a collector-emitter breakdown of the transistor being measured and against overdriving of the oscilloscope amplifier. The working voltage of diode D_2 should be less than the lower of these two limitations and this diode must be capable of carrying the reference value of collector current I_C used in the measurement.

Diodes D_1 and D_2 should have reverse currents at least 100 times smaller than the reference values of I_B and I_C respectively.

NOTE Diodes D_1 and D_2 may be omitted provided the current generators have suitable voltage limiting characteristics.

Measurement procedure

a) With switch S_1 opened and the transistor being measured out of the circuit, and with a shorting link between emitter and base terminals, the current supply I_1 is adjusted until the reading of A_1 is equal to the reference value of I_B.

b) With switch S_2 opened and the transistor being measured out of the circuit, and with a shorting link between emitter and collector terminals, the current supply I_2 is adjusted until the reading of A_2 is equal to the reference value of I_C.

c) With the transistor being measured in the circuit and with switches S_1 and S_2 closed, the waveform is as shown in figure 50. The value of the steady voltage of the flat part of the waveform in the "ON" period is V_{CEsat}.

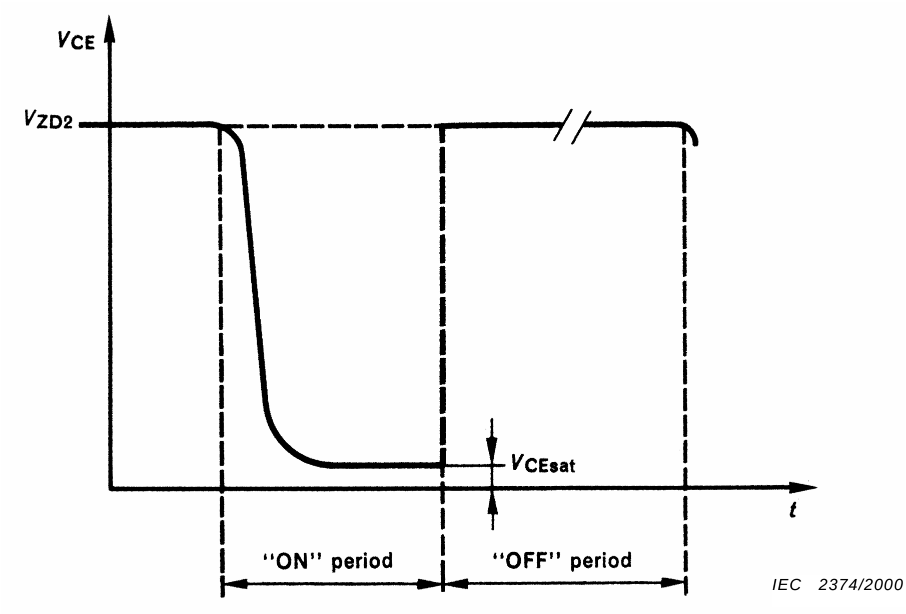


Figure 50 – V_{CE} changes with time

Precautions to be observed

a) The duration and duty cycle of the pulse waveform used to drive transistor T_1 should be chosen such that no difference in the measured value of V_{CEsat} occurs:

   1) when the duty cycle is doubled;

   2) when the pulse duration is doubled and the pulse repetition frequency halved (i.e. when the duty cycle is held constant).

b) Special care should be taken to keep the inductances of supply leads small.

c) The accuracy given below can only be achieved if the transistor is operated well in saturation. In case of doubt, a check may be made by increasing the value of I_B by 10 %, holding I_C constant; the measured value of V_{CEsat} should then not change by more than 10 %.

d) The reference temperature conditions should be controlled as described in clause 2 of IEC 60747-1, chapter VII, section two.

Accuracy

Provided the circuit requirements are fulfilled and the precautions observed, an accuracy of ±10 % should be achieved.

6.2.5 Base-emitter saturation voltage (V_{BEsat})

The base-emitter saturation voltage is measured under the same d.c. conditions as V_{CEsat} (see 6.2.4.1).

The measurement is made by means of a high-resistance d.c. voltmeter connected between the base and emitter terminals in the circuit of figure 48. The internal resistance of this voltmeter should be greater than:

$$\frac{100\ V_{BEsat}}{I_B}$$

where V_{BEsat} is the maximum value specified for the type of transistor measured.

An accuracy of ±10 % should be achieved.

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

The circuit to be used for this measurement is shown in figure 51.

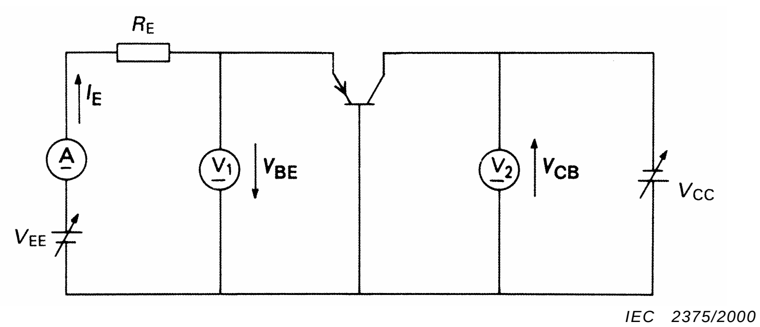


Figure 51 – Basic circuit for the measurement of the base-emitter forward voltage

The measurement of V_{BE} is made at the specified reference values of I_E and V_{CB} by adjustment of R_E and V_{CC} respectively.

The internal resistance of voltmeter V_1 should be greater than:

$$\frac{100\ V_{BE}\ \text{max.}}{I_E}$$

where V_{BE} max. is the maximum value specified for the type of transistor being measured.

It is convenient if the values of R_E and V_{EE} are chosen so that the value of V_{EE} is much greater than the value of V_{BE}, or at least much greater than the expected spread in the value of V_{BE}.

An accuracy of ±10 % should be achieved.

NOTE An alternative measurement may be made for specified values of I_C and V_{CE} by inserting the ammeter into the collector circuit and by connecting the voltmeter between collector and emitter rather than between collector and base terminals. In this case, the internal resistance of voltmeter V_2 should be greater than:

$$\frac{100\ V_{CE}\ \text{max.}}{I_C}$$

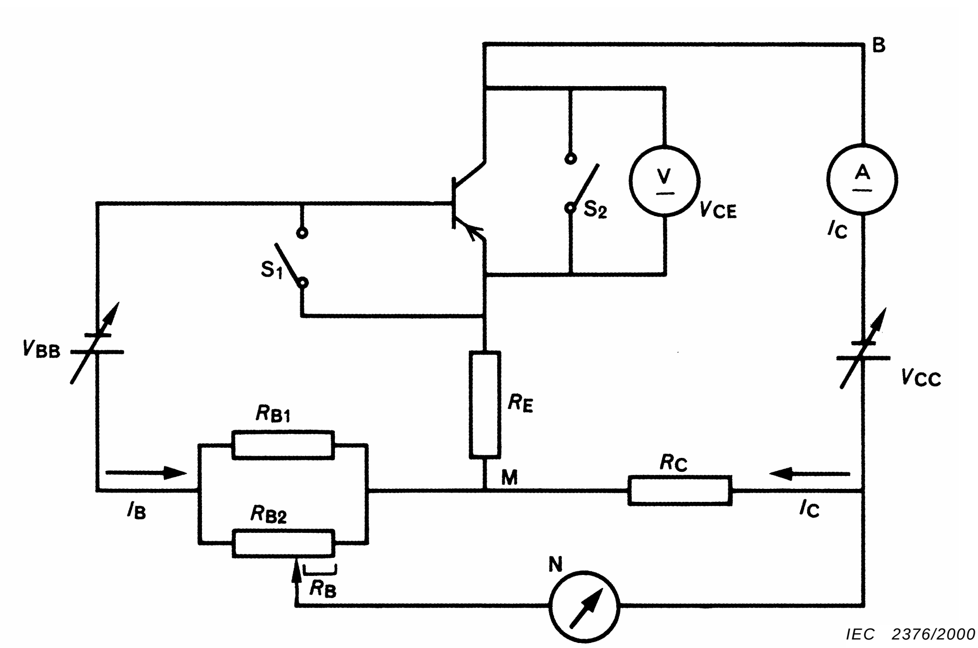
where $V_{CE\ max.}$ is the maximum value specified for the type of transistor being measured.

6.2.7 Static value of common-emitter forward current transfer ratio (h_{21E}) (d.c. method)

Purpose

This measuring method gives the static value of the common-emitter forward current transfer ratio, h_{21E}, for specified values of the continuous collector current and collector-emitter voltage, at a specified operating temperature.

Circuit diagram



N = null indicator

Figure 52 – Basic circuit for the measured of h_{21E} (d.c. method)

Circuit description and requirements

The principle of this measurement is to obtain a null on the null indicator. Under this condition:

$$a \cdot I_B \cdot R_B = I_C R_C$$

where a is a known fraction dependent on the value of R_{B1}, and R_B is the value of the resistance which appears between the tap on R_{B2} and the circuit node M.

The value of R_{B1} should be chosen in accordance with the specified value of I_C and is normally such that the factor a takes a value in the series 1, $1/10$, $1/100$, etc. By this means, very low values of R_C (for high values of I_C) can be avoided.

R_C is a known standard resistor, R_{B1} and R_{B2} are calibrated resistors. The values of R_E and R_C should be chosen commensurate with the specified values of I_C and the value of V_{CC}. The effective value of R_{B1} and R_{B2} in parallel must be such that, in conjunction with the chosen value of V_{BB}, an adequately large value of I_B is obtained when a transistor having the lowest expected value of h_{21E} is being measured.

The values of R_B, R_C, R_{B1} and R_{B2} should be accurate to ±0,5 %.

V_{BB} and V_{CC} are the chosen values of the adjustable constant voltage sources.

V_{CE} is a voltmeter having a high input resistance, e.g. an electronic digital voltmeter. Its maximum error, and that of ammeter A, should not exceed ±1 %.

Measurement procedure

a) The temperature conditions are set to the specified values, in accordance with clause 2 of IEC 60747-1, chapter VII, section two.
b) With switches S_1 and S_2 closed, and no transistor in the circuit, the value of V_{BB} is set to a low value (usually zero). The value of V_{CC} is adjusted until the specified value of I_C is obtained.
c) The transistor being measured is inserted into the circuit, and switch S_1 then switch S_2 are opened.
d) V_{BB} is increased in value until the specified value of I_C is obtained again. The value of V_{CC} and, if necessary, also of V_{BB} is then adjusted until the specified values of I_C and V_{CE} are obtained simultaneously.
e) The slider on R_{B2} is then adjusted until a null is obtained on the null indicator.
f) The value of h_{21E} is then given by:

$$h_{21E} = a \cdot \frac{R_B}{R_C}$$

where $a = \dfrac{R_{B1}}{R_{B1} + R_{B2}}$

Precautions to be observed

Thermal equilibrium must be reached before readings are taken.

The specified electrical conditions of measurement may not be obtained if the transistor used has a value of h_{21E} below the specified minimum value. It is therefore advisable to ensure that the values used for R_E and the maximum available supply voltage V_{CC} max. are such that the maximum dissipation rating for the transistor type cannot be exceeded under any circumstances.

If necessary, the circuit can be modified by connecting a clamping diode in series with a suitable additional constant voltage supply having a value lower than V_{CC} max. between B and node M. To reduce errors, the clamping diode should have a very low value of reverse current and should be preferably a silicon planar type.

If high values are used for the specified collector current I_C (e.g. larger than 1 A), separate voltage and current terminal contacts to the transistor should be provided.

Accuracy

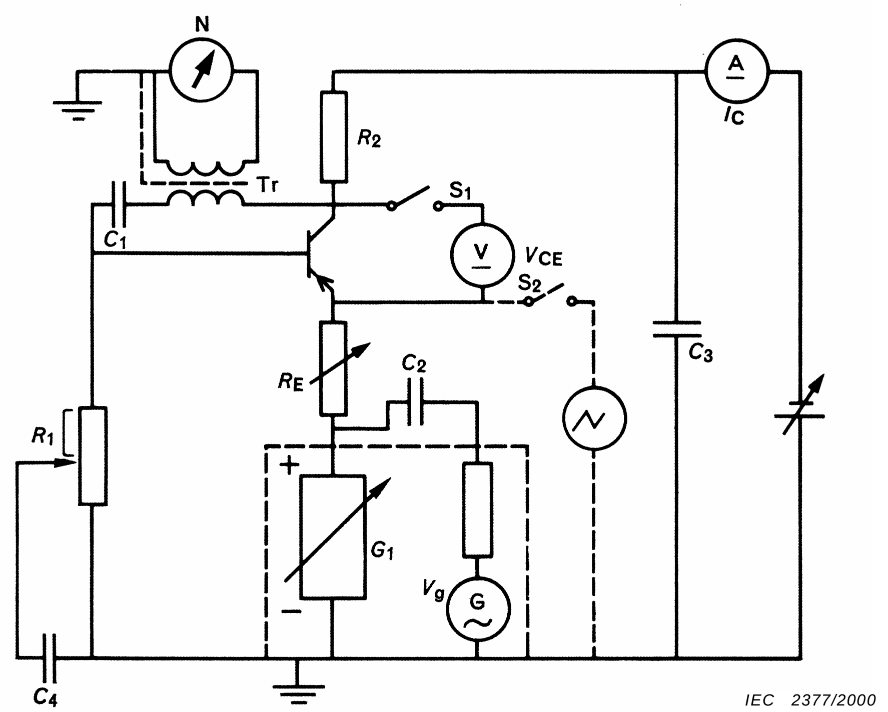
Provided the circuit requirements are fulfilled and the precautions observed, an accuracy of ±5 % should be achieved.

6.2.8 Small-signal common-emitter forward current transfer ratio at low frequencies (h_{21E})

Purpose

This method gives the value of the small-signal common-emitter forward current transfer ratio, for specified values of collector current and collector-emitter voltage, at specified values of low frequency and operating temperature.

Circuit diagram



G_1 = adjustable constant current supply
G = signal generator
N = null indicator

Figure 53 – Basic circuit for the measurement of h_{21E} at low frequencies

Circuit description and requirements

The principle of the measurement is to obtain a null on the null indicator.

Under this condition: $$h_{21e} = \frac{R_1}{R_2} - \frac{h_{11e} \cdot h_{22e}}{1 - h_{12e}}$$

Because the measurement is carried out at a low frequency, the second term normally is negligibly small, and thus:

$$h_{21e} = \frac{R_1}{R_2}$$

The value of R_2 should be low, and the values of resistors R_1 and R_2 should be accurate to ±0,5 %. The range of values of R_1 must correspond to the anticipated range of values of h_{21e}.

The reactances of C_2, C_3 and C_4 must be small at the frequency of measurement.

The capacitances between collector and ground, and between base and ground, must be small enough not to affect the accuracy of the measurement.

The details of transformer Tr and capacitor C_1 are only of importance with regard to the measurement sensitivity, since at balance the collector-base signal voltage is zero.

Voltmeter V_{CE} is a voltmeter having a high input impedance, e.g. an electronic digital voltmeter. Its input resistance should be at least 200 R_2, or 200 V_{CE}/I_C, whichever is the larger. Its maximum error and that of ammeter A should not exceed ±1 %.

Measurement procedure

a) The temperature conditions are set to the specified values in accordance with clause 2 of IEC 60747-1, chapter VII, section two.
b) With the signal generator voltage V_g set to zero and switch S_1 closed, the collector current I_C and the collector-emitter voltage V_{CE} are adjusted to the specified values by means of the constant current and constant voltage sources respectively; when correct bias conditions are established, switch S_1 is opened.
c) A check should be made to ensure that no parasitic oscillations are occurring in the circuit. This is done by closing switch S_2 and checking for such oscillations on a suitable oscilloscope, which must have a high input impedance. If such oscillations occur, it is necessary to increase the value of R_E and readjust the bias conditions, as stated in step b), until such oscillations cease.
d) With switch S_2 open, a small-signal voltage V_g at a specified low frequency (usually 1 000 Hz) is applied from the signal generator and the value of R_1 is adjusted until a null is obtained on the null indicator.
e) It should be ensured that no change occurs in the null conditions when the input from the signal generator is doubled in amplitude. If a change occurs, the initial value of V_g should be reduced and the measurement repeated.

Precautions to be observed

The range of values of the constant current and constant voltage supplies should be such that no rating of the transistor may be exceeded under any condition of the measurement.

Accuracy

Provided the circuit requirements are fulfilled and the precautions observed, an accuracy of ±5 % should be achieved.

6.2.9 Switching parameters

Under consideration.

7 Acceptance and reliability – Electrical endurance tests

7.1 General requirements

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

7.2 Specific requirements

7.2.1 List of endurance tests

A choice of endurance tests is given in table 2, which are applicable for all subcategories of bipolar transistors.

7.2.2 Conditions for endurance tests

Test conditions and test circuits are listed in table 2. The relevant specification will state which test(s) will apply.

7.2.3 Failure-defining characteristics and failure criteria for acceptance tests

Failure-defining characteristics, their failure criteria and measurement conditions are listed in table 1.

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

7.2.4 Failure-defining characteristics and failure criteria for reliability tests

Under consideration.

7.2.5 Procedure in case of a testing error

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

Table 1 – Failure-defining characteristics for acceptance after endurance tests

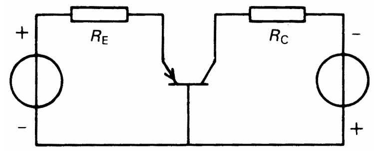
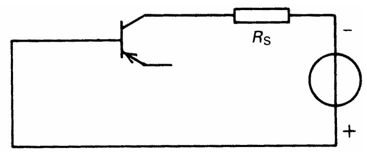
Device categories or subcategories	**Failure-defining characteristics**	**Failure criteria (note 1)**	**Measurement conditions**
Bipolar transistors	I_{CBO}	>2 × USL	Highest V_{CB} specified for I_{CBO}
	h_{21E} (h_{21e}) (note 2)	<0,8 × LSL >1,2 × USL	A value of I_C for which a h_{21E} (h_{21e}) tolerance (lower and upper limits) is specified
	V_{CEsat}	>1,2 × USL	Highest I_C specified for V_{CEsat}
	F (note 3)	>USL + 3 dB	Lowest I_C specified for F

NOTE 1 USL = upper specification limit; LSL = lower specification limit.

NOTE 2 Only where no h_{21E} tolerances are specified or where h_{21E} is unspecified.

NOTE 3 Where applicable.

Table 2 – Conditions for endurance tests

Device categories or subcategories	Tests	Operating conditions			Test circuits	Remarks
		Current	Voltage	Temperature		
Bipolar transistors	Operating life	$I_C = \dfrac{P_{tot}\ \text{max.}}{V_{CE}}$ (note 3)	$V_{CE} = 0{,}7\ V_{CEO}$ max. (note 1)	(note 4)	 (note 2)	$R_E \geq \dfrac{10 V_{EB}}{I_E}$ $R_C \approx \dfrac{V_{CB}}{I_C}$
	High temperature reverse bias		$V_{CB} = V_{CBO}$ max.	Highest operating temperature, T_{amb} max. or T_{case} max. as specified	 (note 2)	R_S = current-limiting resistor

NOTE 1 Test conditions shall be within the safe operating area if one is specified. The voltage is to be lowered below 0,7 V_{CEO} max. only as much as necessary to remain within the safe operating area.

NOTE 2 Change circuit appropriately for NPN transistor.

NOTE 3 See 2.1.5 of IEC 60747-1, chapter VIII, section three.

NOTE 4 See 2.1.3 of IEC 60747-1, chapter VIII, section three.