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Small Signal Transistor

Technical Symbols and Its Definitions

For the convenience of the users of this Document, the technical symbols such as for maximum ratings, electrical characteristics are shown below.

1. General Principles for the Symbols

In order to show DC characteristics, capital letter is used; and small letter is used to show AC characteristics and small-signal characteristics. But attention should be given to some exceptions. There are some symbols of capital letter which indicate other than DC characteristics; examples are such as: power output (Pout), power gain (PG), noise figure (NF), and storage quality factor (Qs).

The use of suffixes is as described in the following examples. There are some exceptions and conventional usages which depart from the principles.

Examples:

Symbol	First item	Second item	Third item	Description
T P	opr out			The first item gives a supplementary explanation of the contents of the symbol.
I h	F i	 e		The first item indicates the direction of transmission, and an example of a four-terminal parameter.
I V	C C	B E	X O	The third item indicates the state of the third electrode.
V V	C G1	E S	(sat) (off)	The third item indicates the state of the device.

The first item is divided up into the following three main categories.

(a) To provide a supplementary explanation of the contents indicated by the symbol. (In this case, the first item sometimes has three letters or more.)
(b) To indicate the electrode in question when the symbol refers to current or voltage.
(c) To indicate the direction of transmission, and in case four-terminal parameters are referred to.

I, i : Input parameter.
R, r : Reverse transmission parameter.
F, f : Forward transmission parameter.
O, o : Output parameter.

The second item indicates the grounding electrode (the reference electrode of the voltage).

The third item indicates the electrical state of the electrode (the third electrode) other than the first and the second item of the device itself.

The third item has the following meanings:

S: the third electrode is short-circuited to the grounding electrode.
R: the prescribed resistance is to be connected between third electrode and the grounding electrode.
O: the third electrode is left open.
X: the third electrode is in a state than other that of S, R, or O as given above. In this Document, this is always indicated with reverse bias.
(sat): indicates that the device is in the state of saturation as to the electrical characteristics.
(off): indicates that the device is in the cut-off state as to the electrical characteristics.

2. Symbols for the Maximum Ratings

In semiconductor products, the maximum ratings are usually defined in terms of the “absolute maximum ratings.” The strictest care must be taken to assure that the values given in the maximum rating tables for each type are never surpassed, even for an instant. Even momentary excess of these maximum ratings set leads to immediate deterioration or destruction of the device concerned. Even if the device should be able to operate the excess, it must be assumed that its life has been shortened extremely. In designing electronic circuits with semiconductor devices, the first step to circuit-design is to make sure that their maximum ratings should never be exceeded, no matter what electrical fluctuations due to the external conditions may occur.

In many cases these maximum ratings are closely interrelated, and careful attention must be paid to the fact that they are not compatible at the same time. For example, let us take it that current and voltage applied to a transistor are both within the range of their maximum ratings. In this case, the power consumption of the transistor will be given by the product of them. It must be within the range of the permissible collector dissipation of the given type. Furthermore, this permissible collector dissipation will decrease if the service temperature is higher; the service range will be reduced relatively.

The following table gives brief definitions of the various items of the maximum ratings prescribed for the different devices given in this Document.

Table 1 Maximum Ratings of Transistors

Item	Definitions of the maximum ratings
V_{CBO}	Maximum value (base grounded) of voltage which can be applied between the collector and base when the emitter is open.
V_{CBX}	Maximum value (base grounded) of voltage which can be applied between the collector and the base when the given bias has been applied between the emitter and the base (reverse bias to be used in this Document).
V_{CEX}	Maximum value (emitter grounded) of voltage which can be applied between the collector and emitter when the prescribed bias has been applied between the base and the emitter (this is always reverse bias in this Document).
V_{CES}	Maximum value (emitter grounded) of voltage which can be applied between the collector and emitter when the base and emitter have been D.C. short-circuited.
V_{CER}	Maximum value (emitter grounded) of voltage which can be applied between the collector and emitter when the prescribed D.C. resistance has been connected between the base and emitter.
V_{CEO}	Maximum value (emitter grounded) of voltage which can be applied between the collector and emitter when the base in open.
V_{EBO}	Maximum value (base grounded) of voltage which can be applied between the emitter and base when the collector is open.
i_C (peak)	Peak value of the A.C. collector current which can be applied within range wherein the mean current will not exceed the following I_C.
I_C (surge)	Maximum value of the surge current which can applied at the prescribed pulse width or the test circuit.
I_C	Maximum value of D.C. current which can be continuously applied to the collector within the permissible range of the collector dissipation of the mean value of the A.C. current.
I_E	Same definition as that of I_C with respect to the emitter current.
I_B	Same definition as that of I_C with respect to the base current.
P_C	Maximum value of the collector dissipation which can be consumed continuously by the transistor under the prescribed heat radiation conditions.
Tj	Upper limit value of the junction temperature which must not be surpassed by (Ta + θja • Pdiss), the sum of the ambient temperature during operation (Ta) and the temperature rise (θja • Pdiss) due to the inner loss within the transistor itself (Pdiss).
Tstg	Upper and lower limit values of the ambient temperature which must not be surpassed when the transistor out of operation is kept in storage.

Table 2 Maximum Ratings of Field-Effect Transistors (FET)

Item	Definitions of the maximum ratings
V_{DSX}	Maximum value of the voltage which can be applied between the drain and the source when the given bias is applied between the first gate and the source.
V_{DSS}	Maximum value of voltage which can be applied between the drain and the source when the gate and the source have been D.C. Short-circuited.
V_{GSS}	Maximum value of voltage which can be applied between the gate and the source when the drain and the source have been D.C. Short-circuited.
V_{GSX}	Maximum value of the voltage which can be applied between the gate and source when the given bias is applied between the drain and the source.
i_D (peak)	Peak value of the AC drain current which can be applied within range wherein the mean current will not exceed the following I_D.
I_D	Maximum value of the D.C. current which can be applied continuously to the drain with the permissible range of the channel dissipation.
I_{DR}	Maximum value of the reverse D.C. current which can be applied continuously to the immanent diode in source to drain with the permissible range of the channel dissipation.
i_{DR} (peak)	Peak value of the reverse AC drain current which can be applied with in range wherein the mean current will not exceed the following I_{DR}.
I_G	Maximum value of the D.C. current which can be applied continuously to the gate within the permissible range of the channel dissipation.
Pch	Same as P_C for transistors.
Tch	Same as Tj for transistors.
Tstg	Same as transistor.

3. Symbols for the Electrical Characteristics

As for the electrical characteristics of the various devices described in this Document, the limit values as well as the standard values are given whenever possible for all items which will be necessary in circuit design. These characteristics may be divided up into the following five categories.

(a) Withstand voltage characteristics
These are items laid down for the purpose of guaranteeing the maximum-rated voltage of the given product. The withstand voltages indicates the voltage between the two specified electrodes when the given current has been applied to the prescribed electrode (in transistors and FET, the given bias conditions are to be imposed upon the other electrode).

In most cases, testing is performed by means of a curve tracer, and adjustments are made so that the peak value of the A.C. (50 or 60 Hz) half-wave shall come to the value of the prescribed current. Care must be taken never to test these items by applying D.C. current; there shall be danger of thermal destruction of the device.

(b) Cut-off current characteristics
This refers to the D.C. current flowing into the prescribed electrode when the given voltage has been applied between the two prescribed electrodes (in transistors and FET, the given bias conditions are imposed upon the other electrode).

Of all the characteristics of semiconductor products, this value is the most sensitive to temperature, and has a temperature coefficient of approximately 10 (%/°C).

Therefore, when the device is to be operated at a higher ambient temperature, its operating range must be narrower and care must be taken of possible thermal runaway.

(c) D.C. characteristics
These characteristics give the bias point (h_{FE}, V_{CE}), the gain at the enlarged-amplitude operation (h_{FE}), the driving conditions ($V_{BE\ (sat)}$), as well as the width of the operating-region ($V_{CE\ (sat)}$) of the device in question. They also have an important significance when the device is applied for switching use.

(d) Small signal characteristics (Low-frequency, High-frequency)
These characteristics give the input-output and transmission characteristics of the devices to be used in small signal (low-frequency or high-frequency) operations in the recommended applications. For the device to be used in low

frequency, the characteristics are indicated at 270 (Hz). For the devices to be used in high-frequency, their characteristics are indicated with the frequency in which they are generally expected to operate.

(e) Operating characteristics
These characteristics are given under the standard operating conditions in which the devices are applied. The approximate performance characteristics in the operating conditions may be estimated from the characteristics in the preceding four sections. But the operating characteristics indicate the actual operating characteristics at the recommended operating point.

The measuring conditions and the definitions of these items are given in Table 3 and the following table.

Table 3 Electrical Characteristics of Transistors
(In all cases, common emitter is used unless otherwise specified.)

Category	Symbol	Prescribed measuring conditions and their definitions
(a)	$V_{(BR)CBO}$	Determines I_C. It is assumed that $I_E = 0$. (base grounded)
	$V_{(BR)CBX}$	Determines I_C and V_{EB}. (base grounded)
	$V_{(BR)CEX}$	Determines I_C and V_{BE}.
	$V_{(BR)CES}$	Determines I_C. It is assumed that $R_{BE} = 0$.
	$V_{(BR)CER}$	Determines I_C and R_{BE}.
	$V_{(BR)CEO}$	Determines I_C. It is assumed that $R_{BE} = \infty$.
	$V_{(BR)EBO}$	Determines I_E. It is assumed that $I_C = 0$. (base grounded)
	V_{CEO} (sus)	Determines I_C which is higher than $I_{(BR)CEO}$. It is assumed that $R_{BE} = \infty$.
	V_{CEX} (sus)	Determines I_C which is higher than $I_{(BR)CEX}$ and V_{BE}.
(b)	I_{CBO}	Determines V_{CB}. It is assumed that $I_E = 0$. (base grounded)
	I_{CBX}	Determines V_{CB} and V_{EB}. (base grounded)
	I_{CEX}	Determines V_{CE} and V_{BE}.
	I_{CES}	Determines V_{CE}. It is assumed that $R_{BE} = 0$.
	I_{CER}	Determines V_{CE} and R_{BE}.
	I_{CEO}	Determines V_{CE}. It is assumed that $R_{BE} = \infty$.
	I_{EBO}	Determines V_{EB}. It is assumed that $I_C = 0$. (base grounded)
(c)	h_{FE}	Determines V_{CE} and I_C.
	V_{BE}	
	V_{CE} (sat)	Determines I_C and I_B.
	V_{BE} (sat)	
(d)	<h-parameters> h_{ie} h_{re} h_{fe} h_{oe}	Determines V_{CE}, I_C (or I_E) and f. (At low frequencies, usually f = 270 Hz.) When these parameters are used, the relationships between the input and output current and voltage will be expressed with the following equation; $\begin{pmatrix} v_i \\ i_o \end{pmatrix} = \begin{pmatrix} h_{ie}, h_{re} \\ h_{fe}, h_{oe} \end{pmatrix} \begin{pmatrix} i_i \\ v_o \end{pmatrix}$
	h_{ie} (real)	This is the pure resistant component when the input impedance at high frequencies is given parallel indication as C.R. this was formerly called r_{bb}'.
	<y-parameters> y_{ie} y_{re} y_{fe} y_{oe}	Determines V_{CE}, I_C (or I_E) and f. $= g_{ie} + jb_{ie} = g_{ie} + j\omega C_{ie}$ $= g_{fe} + jb_{fe} = \lvert y_{re} \rvert ej\phi fe, \quad \lvert y_{fe} \rvert = \sqrt{g_{fe}^2 + b_{fe}^2}, \phi_{fe} = \tan^{-1} \frac{b_{fe}}{g_{fe}}$ $= g_{fe} + jb_{fe} = \lvert y_{re} \rvert ej\phi fe, \quad \lvert y_{fe} \rvert = \sqrt{g_{fe}^2 + b_{fe}^2}, \phi_{fe} = \tan^{-1} \frac{b_{fe}}{g_{fe}}$ $= g_{oe} = jb_{oe} = g_{oe} + j\omega C_{oe}$ When these parameters are used, the relationships between the input and output current and voltage will be expressed as follows: $\begin{pmatrix} i_i \\ i_o \end{pmatrix} = \begin{pmatrix} y_{ie}, y_{re} \\ y_{fe}, y_{oe} \end{pmatrix} \begin{pmatrix} v_i \\ v_o \end{pmatrix}$

Table 3 Electrical Characteristics of Transistors (cont)
(In all cases, common emitter is used unless otherwise specified.) (cont)

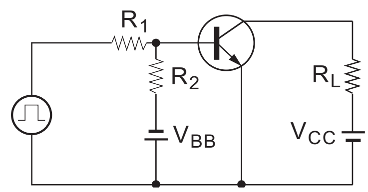
Cate-gory	Symbol		Prescribed measuring conditions and their definitions
(d)	<r-parameters>		Determines V_{CE}, I_C (or I_E) and f, The expression uses parallel indication of the input-output impedance.
	r_{ie}	= $1/g_{ie}$	Measurements are taken with the output terminal in an A.C. short circuit state.
	C_{ie}	= b_{ie}/ω	
	r_{oe}	= $1/g_{oe}$	Measurements are taken with input terminal in an A.C. short circuit state.
	C_{oe}	= b_{oe}/ω	
	<S-parameters>		$E_{r1} = S_{11}E_{i1} + S_{12}E_{i2}$ $E_{r2} = S_{21}E_{i1} + S_{22}E_{i2}$ Relationship between equivalent circuit of microwave transistors and S-parameters. S_{11}: Input reflection coefficient S_{21}: Forward transfer coefficient S_{12}: Reverse transfer coefficient S_{22}: Output reflection coefficient
	<Junction capacitance>		
	Cib		Determines V_{EB} and f. It is assumed that $I_C = 0$. (base grounded)
	Cob		Determines V_{CB} and f. It is assumed that $I_E = 0$. (base grounded) In some cases the shield terminal is grounded, and in other cases it is opened.
	Cre		Determines V_{CB} and f. Measurements are taken with a balance type capacitance meter assuming that $I_E = 0$. The emitter and the shield terminal are connected to the grounded terminal of the meter.
	<Cut-off frequency>		
	$f_{\alpha b}$		At this frequency, the small signal current gain at the prescribed V_{CB}, I_C (or I_E) is 3 dB lower than the value at the low frequency. (base grounded)
	$f_{\alpha e}$		The same definition as of $f_{\alpha b}$ at the prescribed V_{CE} and I_C (or I_E). (emitter grounded)
	f_T		The frequency at which the small signal current gain will be 1 (0 dB) at the prescribed V_{CE} and I_C (or I_E). (emitter grounded)
	<Others>		
	$r_{bb}' \bullet C_C$		The base time constant at the prescribed V_{CE}, I_C (or I_E), and f. It forms part of the figure of merit.
	NF		The noise figure at the prescribed V_{CE}, I_C (or I_E), f and Rg.
	ΔV_{BE}		Change of V_{BE} between P_C on and off ($\Delta V_{BE} = V_{BE1} - V_{BE2}$)
(e)	<Switching properties>		
	t_d t_r t_{stg} t_f		Determines V_{CC}, I_C, I_{B1} and I_{B2}. The measuring circuits are specified. When the measuring circuit not prescribed, measurements have been taken with the circuit shown below: 
	t_{on}		= $t_d + t_r$
	t_{off}		= $t_{stg} + t_f$

Table 3 Electrical Characteristics of Transistors (cont)
(In all cases, common emitter is used unless otherwise specified.) (cont)

Cate-gory	Symbol	Prescribed measuring conditions and their definitions
(e)	<Power gain>	Determines V_{CE} (or V_{CC}), I_C (or I_E), f, Rg, and R_L. Measurements are made with the prescribed circuit. The values include the transformer insertion loss.
	PG	(Power gain)
	CG	(Conversion gain)
	MAPG	(Maximum available power gain) Complete neutralization is performed at the prescribed operating point, and the input and output are matched. At this matched state, the MAPG is obtained from the small signal constant by the following formula. $\text{MAPG} = 10 \log \frac{\lvert yfe \rvert^2}{4g_{ie} \bullet g_{oe}}$ (dB)
	MAG	(Maximum available gain) $\text{MAG} = \frac{\lvert S_{21} \rvert}{\lvert S_{12} \rvert}$ (at $k \le 1$) $k = \frac{1 - \lvert S_{11} \rvert^2 - \lvert S_{22} \rvert^2 + \lvert S_{11}S_{22} - S_{12}S_{21} \rvert^2}{2\lvert S_{12}S_{21} \rvert}$
	MSG	(Maximum stable gain) $\text{MSG} = \frac{\lvert S_{21} \rvert}{\lvert S_{12} \rvert} \times (k - \sqrt{(k^2 - 1)})$ (at $k > 1$)
	$\lvert S_{21} \rvert^2$	(Insertion power gain in a 50 Ω system without matching at input and output.) $(\lvert S_{21} \rvert^2)_{dB} = 10 \log (\lvert S_{21} \rvert^2)$
	Γ_{opt}	Reflection coefficient for minimum noise.
	NF_{min}	Minimum noise figure.
	<Large signal output characteristics>	
	P_{out}	Determines V_{CC} (or V_{CE}), I_C (or I_E), Pin (RF), f, Rg and R_L. Designates the operating circuit.
	η_D, η_C	Drain efficiency, Corrector efficiency. $\eta_D, \eta_C = \frac{\text{Pout}}{P_{DC}}$
	η_{add} (PAE)	Power added efficiency $\eta_{add} = \frac{\text{Pout} - \text{Pin}}{P_{DC}}$
	OIP_3	Third order intercept point refer to output power.
	P_{-1dB}	RF output power at 1 dB compression point.
	$P_{o(sat)}$	Saturation output power.

Table 4 Electrical Characteristics of FET
(In all cases, common source is used unless otherwise specified.)

Category	Symbol	Prescribed measuring conditions, contents of definitions
(a)	$V_{(BR)DSS}$	Determines I_D. It is assumed that $V_{GS} = 0$.
	$V_{(BR)DSX}$	Determines I_D and V_{GS}.
	$V_{(BR)GSS}$	Determines I_G. It is assumed that $V_{DS} = 0$.
(b)	I_{GSS}	Determines V_{GS}. It is assumed that $V_{DS} = 0$.
(c)	I_{DSS}	Determines V_{DS}. It is assumed that $V_{GS} = 0$.
	I_{DSX}	Determines V_{DS}, V_{GS}.
	$I_{D(op)}$	Determines V_{DS}, V_{G2S}, V_{G1S} and R_G.
	$R_{DS\ (on)}$	Determines I_D, V_{GS}.
	$V_{DS\ (on)}$	Determines I_D, V_{GS}.
	V_{DF}	Determines I_F. It is assumed that $V_{GS} = 0$.
	$V_{GS\ (off)}$	Determines V_{DS} and I_D.
	R_{ON}	Determines $V_{DS.}$ It is assumed that $V_{GS} = 0$.
	R_{OFF}	Determines V_{DS} and V_{GS}.
(d)	V_n	(Output noise voltage.) Measurements are made with the prescribed circuit.
	NF	Determines V_{DS}, I_D, Rg and f.
	$\vert y_{fs} \vert$	Determines V_{DS} and f. It is assumed $I_D = I_{DSS}$, unless otherwise notice.
	C_{iss}	Determines V_{DS} and f.
	C_{rss}	Determines V_{DS} and f.
	C_{oss}	Determines V_{DS}, V_{GS} and f.
	GR	(Gain reduction) determines V_{DS}, V_{G2S}, V_{G1S}, R_G and f.
(e)	$t_{d\ (on)}$ t_r $t_{d\ (off)}$ t_f	Determines V_{DD}, R_L, V_{GS} and I_D. Designate the measuring circuit.
	t_{on}	$= t_d$ (on) $+ t_r$
	t_{off}	$= t_d$ (off) $+ t_f$

4. Indications of Units and Power

The units and power used in this document with which to show the maximum ratings and the various characteristics are as follows.

(a) Indications of units*1

Quantities	Symbols	Abbreviation
Current	I, i	A
Voltage	V, v	V
Power	P	W
Charge	Q, q	C
Resistance	R, r	Ω
Capacitance	C	F
Inductance	L	H
Admittance	y	S
Conductance	g	S
Susceptance	b	S
Gain, attenuation	–	dB
Time	t	s
Frequency	f	Hz
Angle	(φ)	°
Temperature	T	°C
Length	(*l*)	mm
Efficiency	η	%

(b) Indications of power*2

Power	Abbreviation
10^{9}	G
10^{6}	M
10^{3}	k
10^{0}	–
10^{-3}	m
10^{-6}	μ
10^{-9}	n
10^{-12}	p
10^{-15}	f

Notes: 1. All of the units shown here are to be applied to the power product of 10^{0}. When indicating the power product in connection with time t (s) or frequency f (Hz), the following indications are to be used:
t (μs), f (kHz), etc.

2. Nowadays the power products of 10^{9} to 10^{-15} is used for semiconductor products. But it does not follow that all of them are used for all other different quantities; 10^{-3} (m) and 10^{-9} (n) are not customarily used for capacitance.

Revision Record

Rev.	Date	Description	
		Page	Summary
1.00	Jun.18.04	—	First edition issued

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