

Explanation of symbols

● General symbols

The following symbols are used to indicate electrical characteristics and other parameters.

V : Voltage	f : Frequency
I : Current	C : Capacitance
P : Power	N : Noise
T : Temperature	t : Time

These letters will be upper case in the case of direct current, and lower case in the case of alternating current.

The following suffixes may be added to the letters.

Suffix type 1

- (1) Additional qualifier. Example : Tstg
- (2) Indication of terminal or lead. Example : Ic
- (3) Indication of direction.
 - i : Input
 - r : Reverse
 - f : Forward
 - o : Output

Suffix type 2

Indicates ground lead. Example : V_{CBO}

Suffix type 3

- (1) Condition of leads other those with suffix type 1 or 2.
 - S : Third lead is shorted to ground lead.
 - R : Specified resistor is connected between third lead and ground lead.
 - O : Third lead is open.
- (2) Electrical condition of device.
 - (sat) : Indicates that the device is saturated.
 - (off) : Indicates that the device is cut off.

● Explanation of symbols

V_{CBO} : (Collector-base voltage) The maximum voltage between the collector and base when the emitter is open-circuited. This is the electron avalanche breakdown voltage at the emitter-base junction, and occurs when 10^5 V/cm is applied to a PN junction.

V_{EBO} : (Emitter-base voltage) The maximum voltage between the emitter and base when the collector is open-circuited. This is the electron avalanche breakdown voltage or Zener breakdown at the emitter-base junction.

V_{CEO} : (Collector-emitter voltage) The maximum voltage between the collector and emitter when the base is open-circuited. It is determined by V_{CBO} and h_{FE} .

$$V_{CEO} = \frac{V_{CBO}}{m \sqrt{1+h_{FE}}} \quad m : \begin{array}{l} 3 \sim 4 \text{NPN} \\ 6 \sim 8 \text{PNP} \end{array}$$

V_{CER} : (Collector-emitter voltage). The maximum voltage between the collector and emitter when a resistor is connected between the base and emitter. It is determined by V_{CBO} and R_{BE} :

$$V_{CER} = V_{CBO} \sqrt[m]{1 - \frac{I_{CBO}(r_b + R_{BE})}{V_{TF}}}$$

r_b : Base resistance

V_{TF} : Forward rise voltage between base and emitter.

V_{CES} : (Collector-emitter voltage). The maximum voltage between the collector and emitter when the base and emitter are short-circuited.

$$V_{CES} = V_{CBO} \sqrt[m]{1 - \frac{I_{CBO} r_b}{V_{TF}}} \doteq V_{CBO}$$

I_C : (Collector current) The forward current which flows through the collector junction when a forward voltage is applied between the base and emitter. It consists of minority carriers injected from the emitter into the base and majority carriers generated in the collector depletion layer. ROHM normally takes this to be the current at which h_{FE} is reduced to 1/3 to 1/2 of its maximum value at $T_{j\text{max}}$, or less.

I_B : (Base current) The current which flows through the base when a forward voltage is applied between the base and emitter, and the emitter and collector are short-circuited. Normally 1/3 of the collector current in a single transistor.

P_C : (Collector dissipation) The power dissipated in the collector is equal to the power P_{in} entering the transistor minus the output power, and is called collector dissipation. It is normally equal to $V_{CE} \times I_C$ when the junction temperature is at a maximum. The standard temperature is 25°C.

- T_j : (Junction temperature) This is a combination of heat due to power dissipation in the device and the ambient temperature. The maximum allowable junction temperature (T_{jMax}) depends on device and package materials, and is determined by temperature and operating life tests.
- T_{stg} : (Storage temperature range) This is the temperature range at which a device can be stored without electrical load. The upper limit is determined by the maximum allowable junction temperature and the lower limit is determined by the package material.
- C_{ib} : (Emitter input capacitance) The input capacitance with the base grounded. More precisely, it is the capacitance measured between the emitter and base at a specified emitter-base voltage and frequency with the collector open-circuited. It includes the stray capacitance of the case.
- C_{ob} : (Output capacitance) The output capacitance with the base grounded. More precisely, it is the capacitance measured between the collector and base at a specified collector-base voltage and frequency with the emitter open-circuited. It includes the stray capacitance of the case.
- C_{re} : (Small signal reverse transfer capacitance) This is the imaginary part of the reverse transfer admittance Y_{re} .
- f_T : (Transition frequency) The frequency at which the grounded-emitter small signal current gain h_{FE} becomes 1 at a specified V_{CE} and I_C .
- $C_C \cdot r_{bb'}$: (Collector-base time constant) The product of the collector capacitance C_C and the base resistance $r_{bb'}$. The following relationship holds between the maximum oscillating frequency f_{Max} and the cutoff frequency α :

$$f_{Max}^2 \doteq \frac{f \alpha}{8 \pi C_C \cdot r_{bb'}}$$

- h_{FE} : (DC current transfer ratio) This is the ratio I_C/I_B at a specified V_{CE} and I_C .

- h_{ie} : (Closed circuit small signal short circuit input impedance) This is the ratio between the AC input voltage and the AC input current with the output short-circuited (grounded emitter). Normally $f = 270\text{Hz}$.
- h_{re} : (Reverse voltage transfer ratio) This is the ratio between the AC output current and the AC input current with the output short-circuited (grounded emitter). Normally $f = 270\text{Hz}$.
- h_{oe} : (Small signal short circuit output admittance) This is the ratio between the AC output current and the AC voltage applied to the output terminal with the input open-circuited (grounded emitter). Normally $f = 270\text{Hz}$.
- I_{CBO} : (Collector cutoff current) This is the collector current when a specified voltage is applied between the collector and base with the emitter open-circuited.
- I_{CEO} : (Collector cutoff current) This is the collector current when a specified voltage is applied between the collector and emitter with the base open-circuited. I_{CER} is the collector current when a specified resistor is connected between the base and emitter, and I_{CES} is the collector current when the base and emitter are short-circuited.
- I_{EBO} : (Emitter cutoff current) This is the emitter current when a specified voltage is applied between the emitter and base with the collector open-circuited.
- NF : (Noise figure) This is the measured ratio of the effective noise output power per unit bandwidth of the device and the noise output resulting from the signal source resistance connected to the input terminal. The noise figure is measured at a standard temperature of 290°K .

$$\begin{aligned} NF &= 10 \log \frac{\text{Effective noise output power}}{\text{Output noise power due to thermal noise of signal source resistance}} \\ &= 10 \log \frac{\text{Ratio of input signal to noise}}{\text{Ratio of output signal to noise}} = \frac{S_i N_i}{S_o N_o} \\ &= 10 \log \frac{E_{n_i}^2}{E_t^2} \end{aligned}$$

E_{ni} is the equivalent input noise and E_t is the thermal noise of the input resistance. The noise of the amplifier can be expressed by the voltage source e_n connected in series to the input terminal (zero impedance), the current source in (infinite impedance) connected in parallel to the input terminal, and the correlation coefficient C of the two (not shown in the diagram).

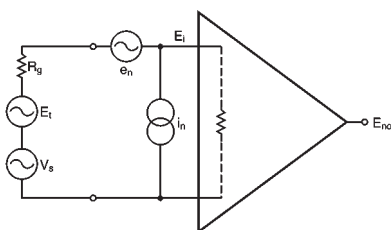


Fig.1

$$E_{ni}^2 = E_t^2 + e_n^2 + i_n^2 R_g^2$$

$$E_t^2 = 4KTR_g \Delta f$$

Thus,

$$NF = 10 \log \frac{4KTR_g + e_n^2 + i_n^2 R_g^2}{4KTR_g}$$

Also, the intermediate frequency noise without the transistor's 1/f noise is given by

$$e_n^2 = 4KT r_{bb'} + 2q I_{cre}^2$$

$$i_n^2 = 2q I_B$$

therefore a reduction of $r_{bb'}$ and an increase of h_{FE} are necessary for reducing noise.

NV₁ : (Noise voltage (RMS)) In a specified transistor (normally $G_V = 80\text{dB}$, $f = 20$ to 20kHz $_{-3}^0$ dB, FLAT AMP.), this is the effective value of the output noise voltage when a specified DC voltage and current with a specified signal source resistance are applied to the terminals of the transistor.

NV₂ : Noise voltage peak

The peak value of the output noise voltage of the same amplifier as NV₁.

PG : Power gain

This is the ratio of the power obtained from the output of the transistor to the power supplied to the input.

$$G = \left(\frac{i_o}{i_i} \right)^2 \cdot \frac{R_o}{R_i} = \frac{V_o i_o}{V_i i_i}$$

R_{BE} : (Base-emitter resistance) This is the value of the resistor connected between the base and emitter.

r_{bb'} : (Base resistance) This is the series base resistance which consists of the resistance of the non-active base region and the resistance of the active region which causes a transverse ohmic voltage drop.

t_d : (Delay time) The delay between the application of the input pulse and the point at which the output pulse reaches 10% of its maximum amplitude. (Fig.2)

t_r : (Rise time) The time needed for the output pulse to rise from 10% to 90% of its maximum amplitude. (Fig.2)

t_{stg} : (Storage time) The time needed for the output pulse to fall to 90% of its maximum amplitude after the input pulse ends. (Fig.2)

t_f : (Fall time) The time needed for the output pulse to fall from 90% to 10% of its maximum amplitude. (Fig.2)

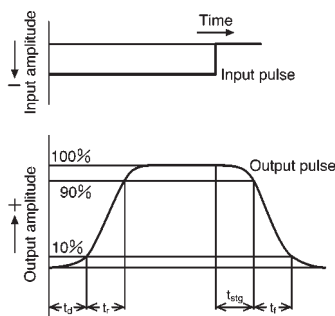


Fig.2 Pulse response (example of PNP common emitter)

$V_{CE(sat)}$: (Collector saturation voltage) When a sufficient base current flows into a common emitter amplifier circuit, this is the condition in which the collector-emitter voltage decreases and the base-collector junction is forward biased. Measured with the assumption that I_B is I_C/n , where n is an integer (usually 10), with a specified V_{CE} and I_C .

V_{BE} : (Base-emitter voltage) This is measured at a specified V_{CE} and I_C .

V_F : (Forward voltage) The forward voltage when a specified forward current flows.

y_{ie} : (Small signal, short-circuit input admittance) The ratio of the AC input current and the AC input voltage with the output short-circuited (grounded emitter).

$$y_{ie} = \frac{1}{r_{ie}} + j\omega C_{ie}$$

Y_{re} : Small signal, short-circuit, reverse transfer admittance

The ratio of the AC current appearing at the input when the input is short-circuited and the AC voltage applied to the output (grounded emitter).

$$Y_{re} = |y_{re}| \exp(j\phi_{re})$$

Y_{fe} : (Small signal, short-circuit forward transfer admittance) The ratio of the AC output current and the AC input voltage with the output short-circuited (grounded emitter).

$$Y_{fe} = |y_{fe}| \exp(j\phi_{fe})$$

Y_{oe} : (Small signal, short-circuit output admittance) The ratio of the AC output current and the AC voltage applied to the output with the input short-circuited (grounded emitter).

$$y_{oe} = \frac{1}{r_{oe}} + j\omega C_{oe}$$

SOA: (Safe operating area) This is the area in which a transistor can be used without damage or deterioration.

Range 1 : Current limiting range : This range is limited by the maximum collector current I_{CMax} .

Range 2 : Thermal resistance limiting range (P_C area). This range is limited by the thermal resistance. If the collector-emitter voltage is V_{CE} and the collector current is I_C , the transistor power dissipation is limited as follows : $P_C = V_{CE} \times I_C \leq P_{CMax}$.

Range 3 : Secondary breakdown range. This range is limited by the secondary breakdown of the transistor. As the voltage grows higher, current hot spots appear in non-uniform parts of chip junctions and in defects within the chip, and the transistor becomes susceptible to secondary breakdown. Differences in transistor resistance to damage become apparent in this region, thus it is used for control of normal resistance to damage.

Range 4 : Voltage limiting region. This range is limited by the maximum collector-emitter voltage V_{CEOMax} .

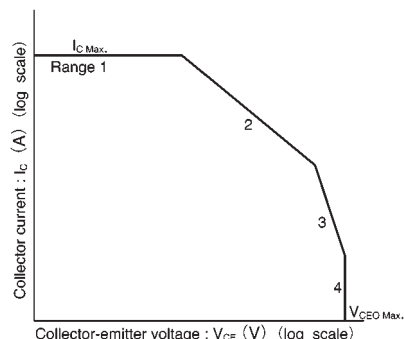


Fig.3 Safe operating area (SOA)

S parameters

The scattering matrix method can be used to express the equivalent circuit of an ultra-short wave band transistor as follows :

$$b_1 = S_{11a1} + S_{12a2}$$

$$b_2 = S_{21a1} + S_{22a2}$$

The four parameters S_{11} , S_{12} , S_{21} , and S_{22} appearing in this equation are called the S parameters.

- S_{11e} : Input reflection coefficient (grounded emitter).
- S_{12e} : Reverse transmission coefficient (grounded emitter).
- S_{22e} : Forward transmission coefficient (grounded emitter)
- S_{22e} : Output reflection coefficient (grounded emitter)

The above S parameters express the characteristics of a three dimensional microwave circuit, and are defined as reflected and transmitted waves as shown in Figure 4.

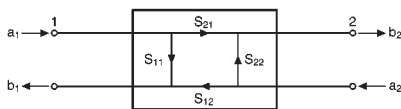


Fig.4

- $S_{11} = \left. \frac{b_1}{a_1} \right|_{a_2=0}$ Output 2 is terminated and expressed as the ratio of incident wave a_1 and reflected wave b_1 .
- $S_{12} = \left. \frac{b_1}{a_2} \right|_{a_1=0}$ Input 1 is terminated and expressed as the ratio of incident wave a_1 and transmitted wave b_1 .
- $S_{21} = \left. \frac{b_2}{a_1} \right|_{a_2=0}$ Output 2 is terminated and expressed as the ratio of incident wave a_1 and transmitted wave b_2 .
- $S_{22} = \left. \frac{b_2}{a_2} \right|_{a_1=0}$ Input 1 is terminated and expressed as the ratio of incident wave a_2 and reflected wave b_2 .

Conversions for S and Y parameters are shown in Table 1.

Table1

S_{11}	$\frac{(1-y_{11})(1+y_{22})-y_{12}y_{21}}{(1-y_{11})(1+y_{22})-y_{12}y_{21}}$	y_{11}	$\frac{(1+S_{22})(1-S_{11})+S_{12}S_{21}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$
S_{12}	$\frac{-2y_{12}}{(1+y_{11})(1+y_{22})-y_{12}y_{21}}$	y_{12}	$\frac{-2S_{12}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$
S_{21}	$\frac{-2y_{21}}{(1+y_{11})(1+y_{22})-y_{12}y_{21}}$	y_{21}	$\frac{-2S_{21}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$
S_{22}	$\frac{(1+y_{11})(1-y_{22})+y_{12}y_{21}}{(1+y_{11})(1+y_{22})-y_{12}y_{21}}$	y_{22}	$\frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{(1+S_{11})(1+S_{22})-S_{12}S_{21}}$

$|S_{21e}|^2$: (insertion gain) The square of the absolute value of the forward transmission coefficient (a complex number) expressed as a decibel.

●Digital transistor symbols

- V_{CC} : (Power supply voltage) This is the maximum voltage at which characteristics and operating levels can be guaranteed. This value includes both DC changes (primary power supply, load changes, temperature changes over time) and AC changes (ripple, noise, spike currents).
- V_{IN} : (Input voltage) The maximum input voltage at which device operation can be guaranteed.
- I_O : (Output current) The maximum allowed continual current which can flow through the OUT pin when a forward voltage V_i is applied between the IN pin and GND pin.
- $I_{C(Max.)}$: (Collector current) The maximum current that can flow in a component transistor by itself.
- $I_{O(OFF)}$: (Output cutoff current) The current which flows in the Outpin when a specified voltage (V_o) is applied between the OUT pin and GND pin with the IN pin open-circuited.
- P_d : (Power dissipation) The maximum power which can be continually dissipated while the device is in operation.

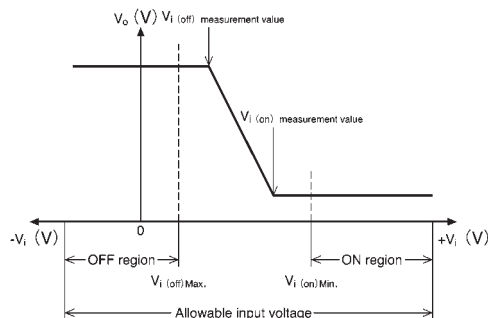


Fig.5 OFF region ON region

- $V_{I(ON)Min.}$: (Input on-voltage) With a forward voltage (V_o) applied between the OUT pin and the GND pin, this is the minimum input voltage needed to make the specified output current flow. In other words, it is the minimum input voltage needed to keep the digital transistor turned ON. To turn OFF the transistor it is necessary to lower the input voltage below this value, and thus the value of a good transistor will go below this. (See Figure 5)
- $V_{I(OFF)Max.}$: (Input off-voltage) This is the maximum input voltage obtained between the IN pin and GND pin when the specified output current (I_o) is applied and the specified supply voltage (V_{CC}) is applied between the OUT pin and GND pin. In other words, it is the maximum input voltage which can be applied and still keep the transistor turned OFF. To turn on the transistor, it is necessary to increase the input voltage above this maximum input voltage, and thus the value of a good transistor go above this. (See Figure 5)
- $V_{O(ON)}$: (Output voltage) The output pin voltage under any input conditions which do not exceed the absolute maximum ratings. When sufficient input current is made to flow in GND amplifier circuit, the output voltage will decrease and the IN and OUT junctions will be forward biased. It is measured as a fraction (usually 1/10 to 1/20) at a specified V_o and I_o .
- $I_{I(Max.)}$: (Input current) The maximum allowed input current which can continually flow through the IN pin when a forward voltage (V_i) is applied between the IN pin and GND pin.
- G_i : (DC current gain) The ratio I_o/I_i at a specified V_o and I_o .
- R_i : (Input resistance) The built-in resistor between the IN pin and transistor base. The allowed range of R_i is $\pm 30\%$.
- R_2/R_1 : (Resistance ratio) The ratio of the transistor base-emitter resistance to the built-in input resistor.

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