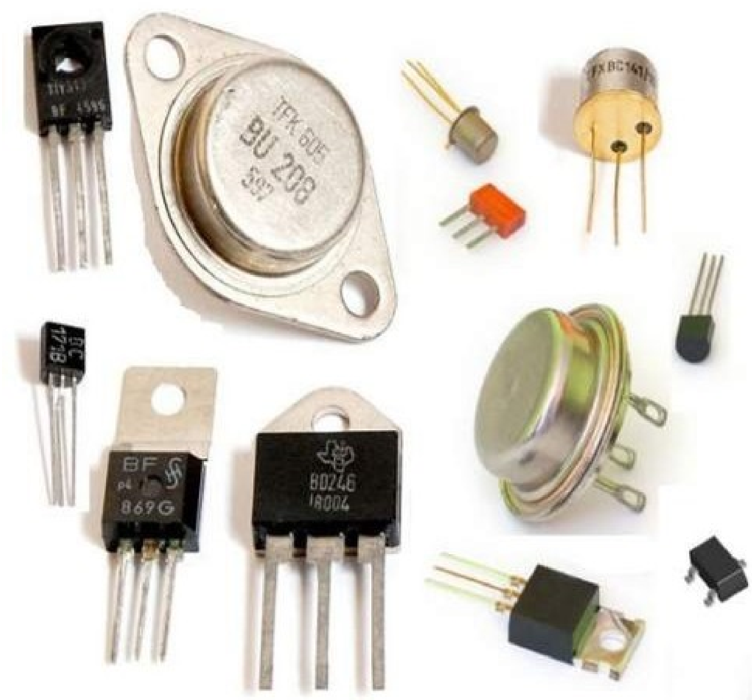
Semiconductor Electronics- II



Transistors

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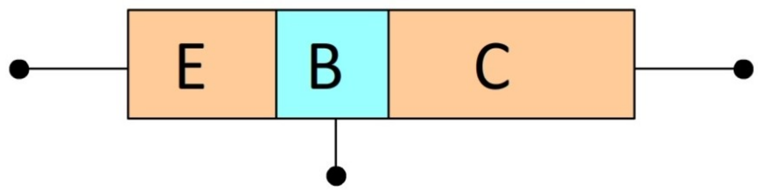
Transistor (construction)

A transistor is three terminal device made up of semiconducting materials.
Transistor consists of three regions (emitter, base and collector)

Emitter

(a) Emitter supplies the majority charge carriers
(b) Emitter is heavily doped
(c) Emitter is of moderate size



Base

(a) Base is the mid region of a transistor
(b) Base is very lightly doped
(c) Base is very thin

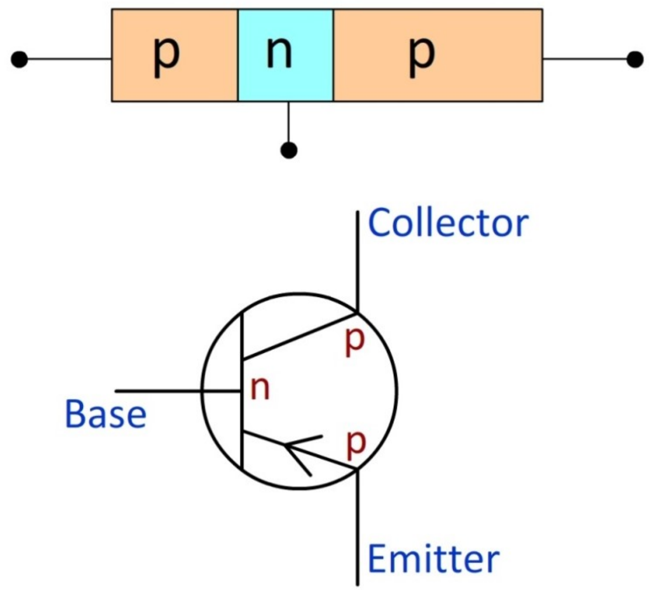
Collector

(a) Collector collects the majority charge carriers crossing over the base
(b) Collector is moderately doped
(c) Collector is largest in size

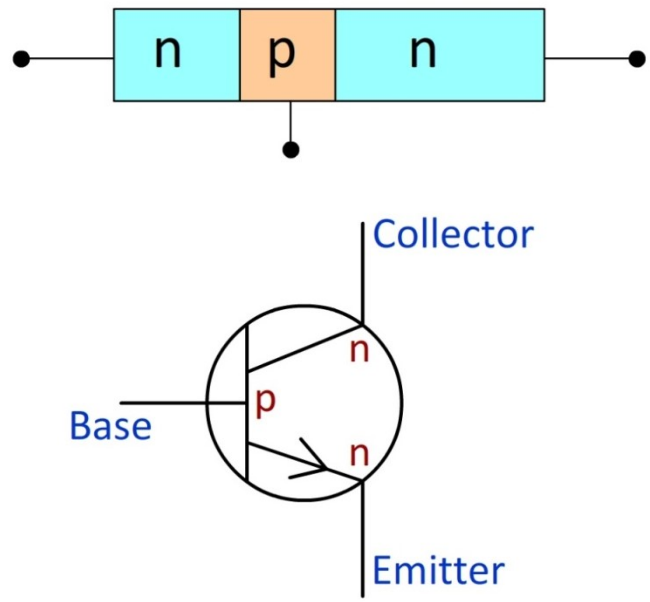
Transistor types and circuit symbol

Depending on the type of semiconductor material used in the regions, transistors are of two types

pnp transistor



npn transistor



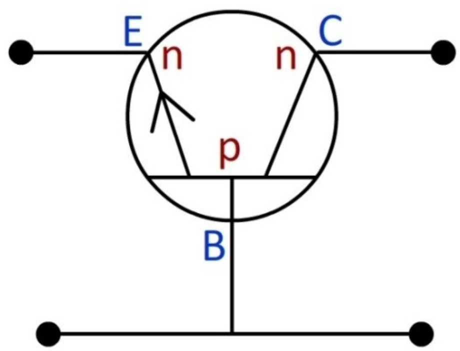
note

(a) Position of arrow indicates the location of emitter

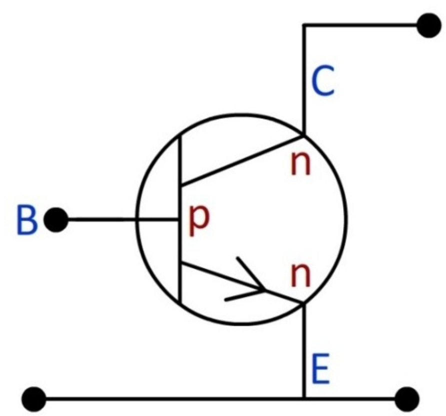
(b) Direction of arrow indicates type of transistor (*pnp* or *npn*). Direction of arrow is based on the conventional direction of flow of current i.e. direction of movement of holes.

Transistor configurations

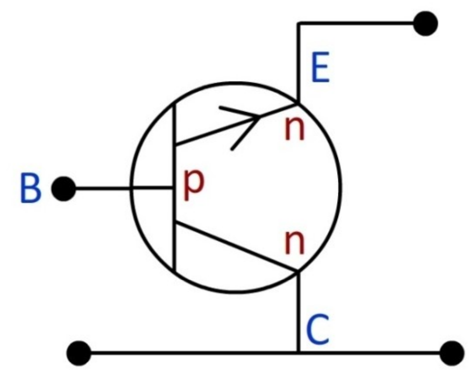
Based on specific requirements, transistors may be used in any one of the following configurations:



Common base



Common emitter



Common collector

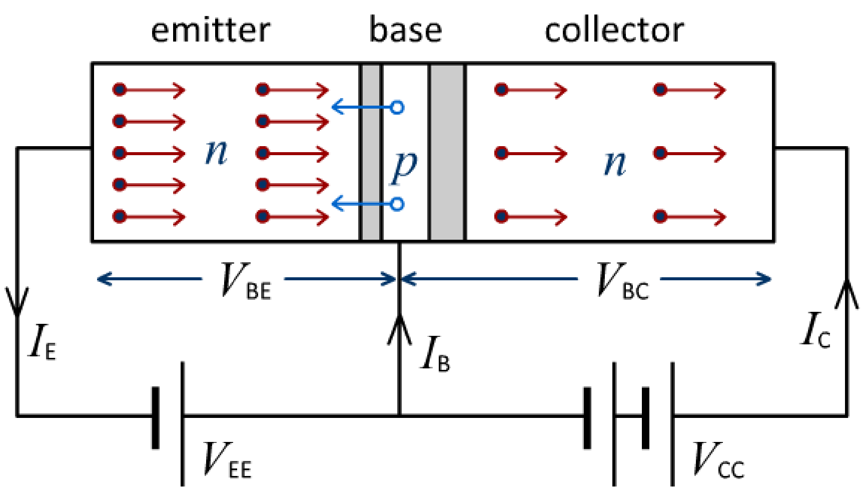
In any of the above configurations, two terminals on LHS are for input and two on the RHS are for the output.

Working of a transistor (movement of majority charge carriers)

Consider a *npn* transistor connected in a common base configuration. In the active region, B-E region is forward biased and B-C region is reverse biased

- Electrons enter the base region in large numbers due to forward bias of BE region
- Only a small number of electrons recombine with holes in the base (due to very light doping of base)
- Due to reverse bias of BC region, a large number of electrons easily cross the junction and enter the collector
- Though total current is due to holes and electrons ($i = i_e + i_h$), current in this case is predominantly due to electrons (majority charge carriers in *n*-type emitter) and hence $i_e >> i_h$
- Applying Kirchhoff's junction law

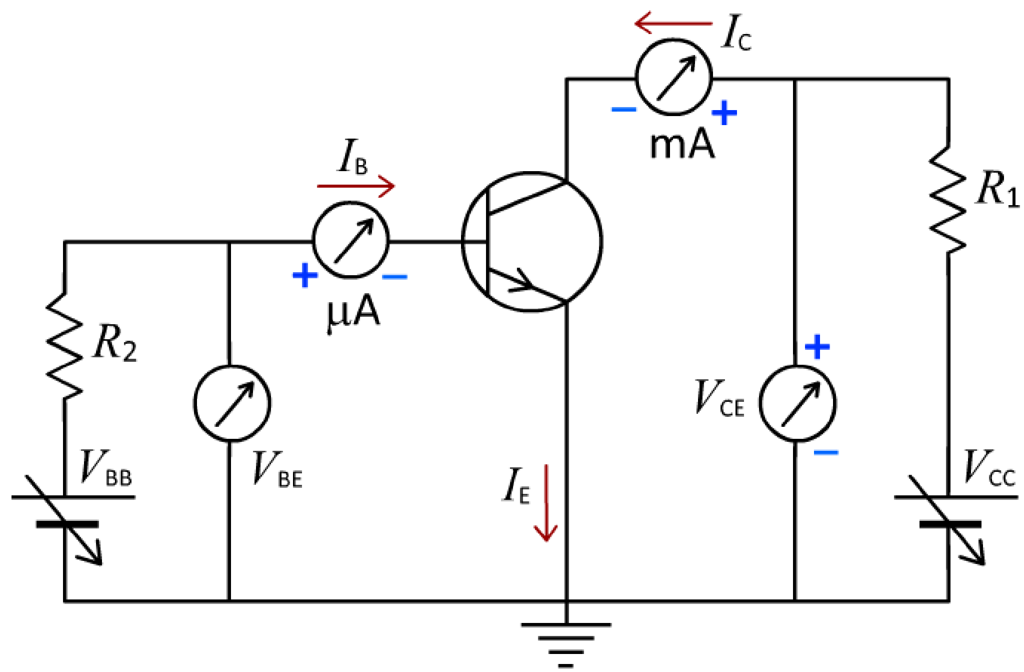
$$i_E = i_C + i_B$$



V_{BE} = P.D. across the B-E region
V_{BC} = P.D. across the B-C region
V_{EE} = power supply B-E region
V_{CC} = power supply B-C region

I/O characteristics of a transistor

Consider a *npn* transistor connected in a common emitter configuration.

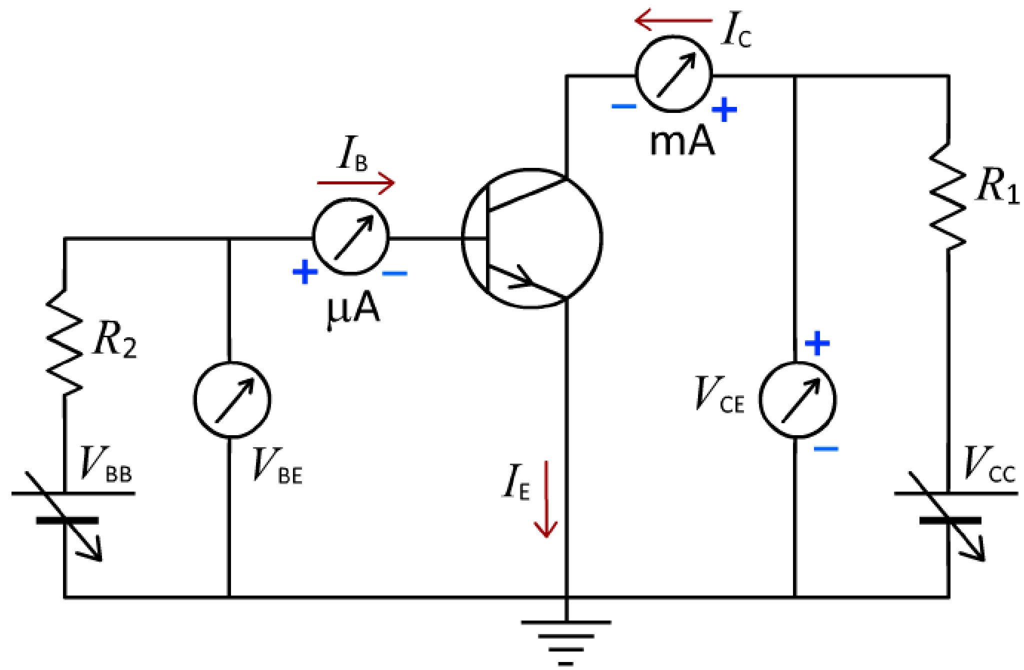


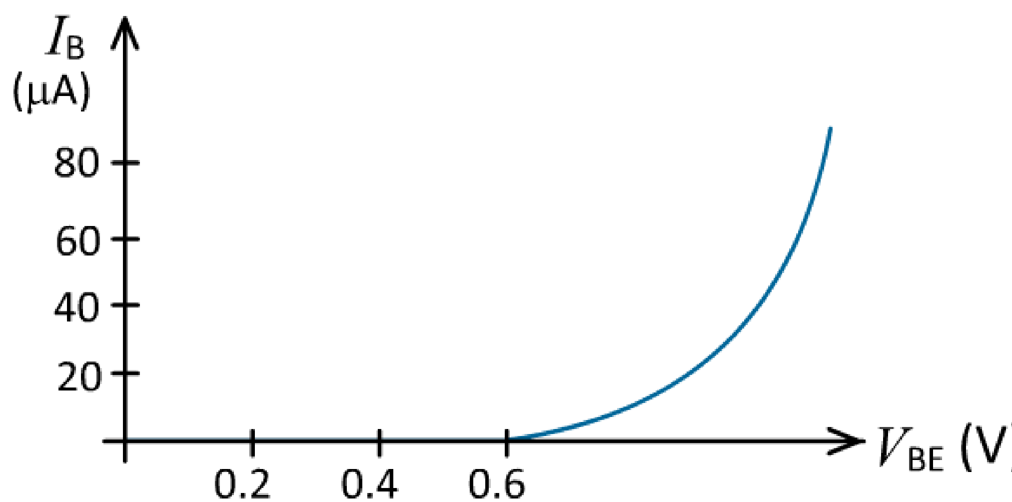
- V_{BB} is base biasing voltage and V_{CC} is collector basing voltage due variable power supplies
- A micro-ammeter measures base current and a milli-ammeter measures collector current.
- A voltmeter measures the base-emitter voltage i.e. V_{BE}
- A voltmeter measures the collector-emitter voltage i.e. V_{CE}
- R_1 and R_2 are biasing resistors used to regulate current in the circuit.

I/O characteristics of a transistor

Input characteristics

- Graph is plotted for input current (I_B) as a function of input voltage (V_{BE}).
- Output voltage (V_{CE}) is kept large to maintain the transistor in the active state.
- Increase in V_{CE} appears as increase in V_{CB}, its effect on I_B is negligible.
- Initially the I_B is zero as barrier potential across it prevents diffusion of charges .
- With increase in V_{BE} the barrier potential is overcome and there is an increase in I_B

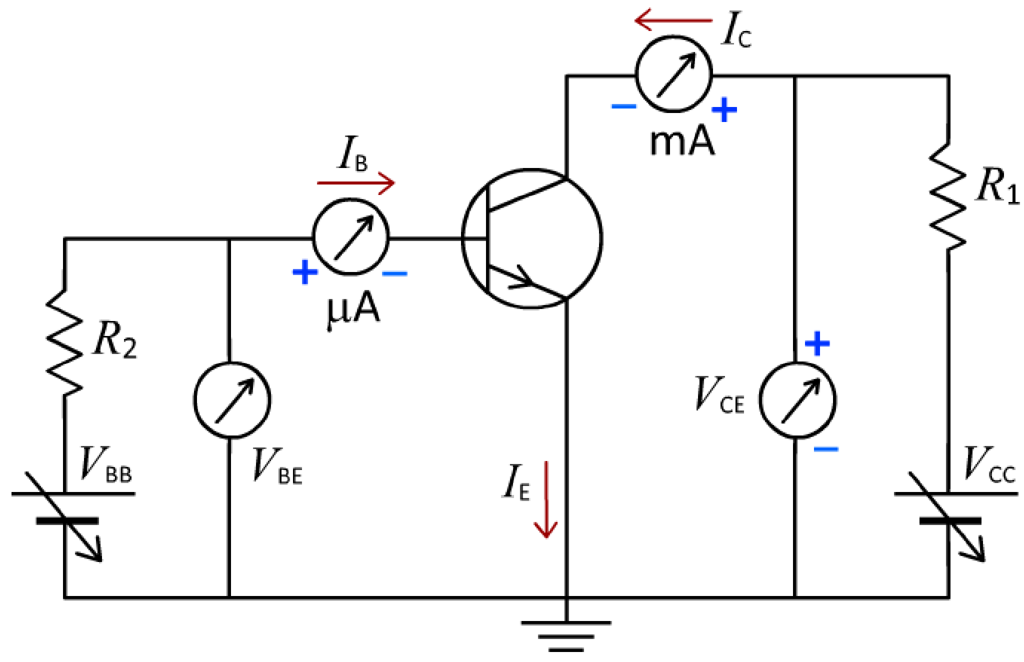


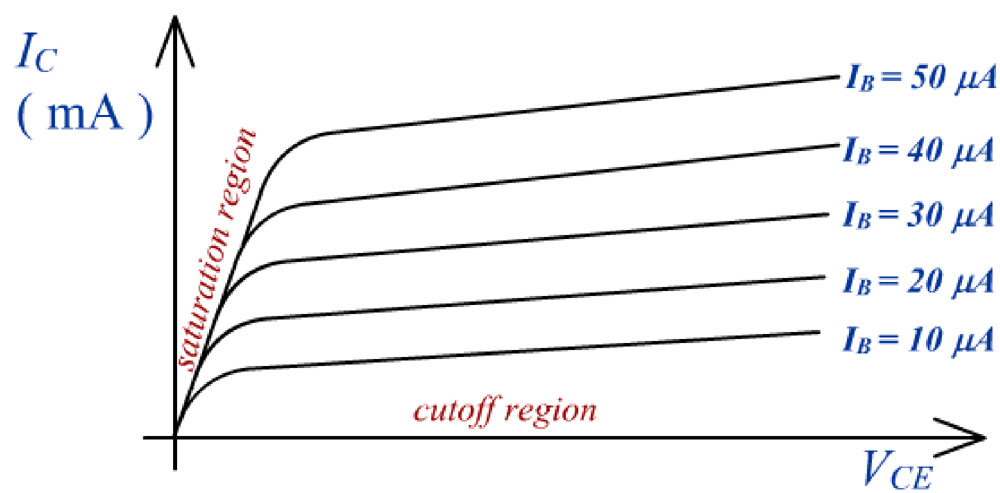


I/O characteristics of a transistor

Output characteristics

- Graph is plotted for output current (I_C) as a function of output voltage (V_{CE}).
- Input current (I_B) is kept constant





I/O characteristics of a transistor

Output characteristics

<u>Saturated state :</u>

A state in which I_C increases linearly and depends only on applied V_{CE} and is independent of I_B.

<u>Cutoff state :</u>

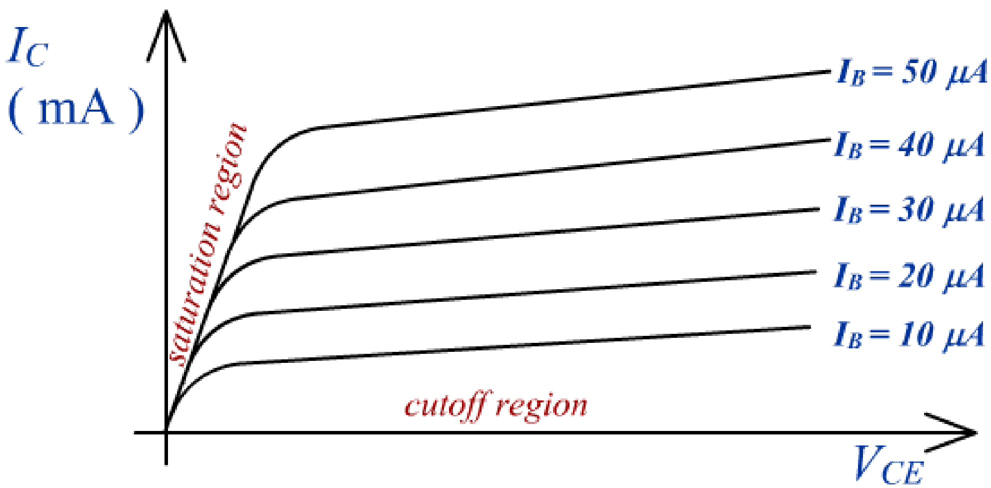
A state in which I_C is zero and independent of applied V_{CE}.

When I_B is nearly zero, I_C is also zero and independent of V_{CE} (because zero I_B implies that B-E region is not suitably forward biased)

<u>Active state:</u>

I_C is nearly independent of V_{CE} and depends only on I_B.

A small change in I_B (of the order of μA) results in a large change in I_C (of the order of mA).



Parameters associated with transistor operation

Input resistance (r_i)

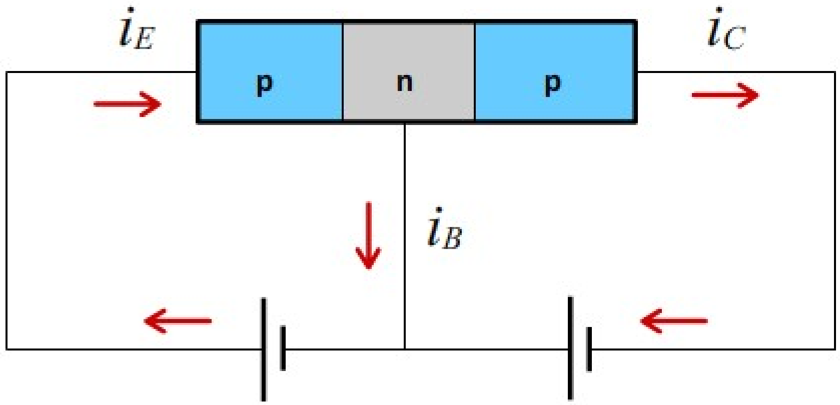
$$r_i = \left[\frac{\Delta V_{\mathrm{BE}}}{\Delta I_{\mathrm{B}}}\right]_{V_{\mathrm{CE}}}$$

Output resistance (r_o)

$$r_o = \left[\frac{\Delta V_{\mathrm{CE}}}{\Delta I_{\mathrm{C}}}\right]_{I_{\mathrm{B}}}$$

Current amplification(β)

$$\beta = \frac{\Delta I_{\mathrm{C}}}{\Delta I_{\mathrm{B}}}$$



$$I_{\mathrm{E}} = I_{\mathrm{B}} + I_{\mathrm{C}}$$

$$V_{\mathrm{CE}} = V_{\mathrm{EB}} + V_{\mathrm{BC}}$$

Current gains : α , β and γ

Current amplification(β) – common emitter configuration

$$\boxed{\beta = \frac{\Delta I_C}{\Delta I_B}}$$

β is always greater than 1

Current gain(α) – common base configuration

$$\boxed{\alpha = \frac{\Delta I_C}{\Delta I_E}}$$

α is always lesser than 1

Current gain(γ) – common collector configuration

$$\boxed{\gamma = \frac{I_E}{I_B}}$$

γ is always greater than 1

Relation between α, β and γ

$$I_E = I_B + I_C$$

$$\beta = \frac{I_C}{I_B}$$

$$\beta = \frac{I_C}{I_E - I_C}$$

$$\frac{1}{\beta} = \frac{I_C}{I_E} - 1$$

$$\frac{1}{\beta} = \frac{1}{\alpha} - 1$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

$$\frac{1}{\alpha} = \frac{1}{\beta} + 1$$

$$\frac{1}{\alpha} = \frac{1+\beta}{\beta}$$

$$\boxed{\alpha = \frac{\beta}{1+\beta}}$$

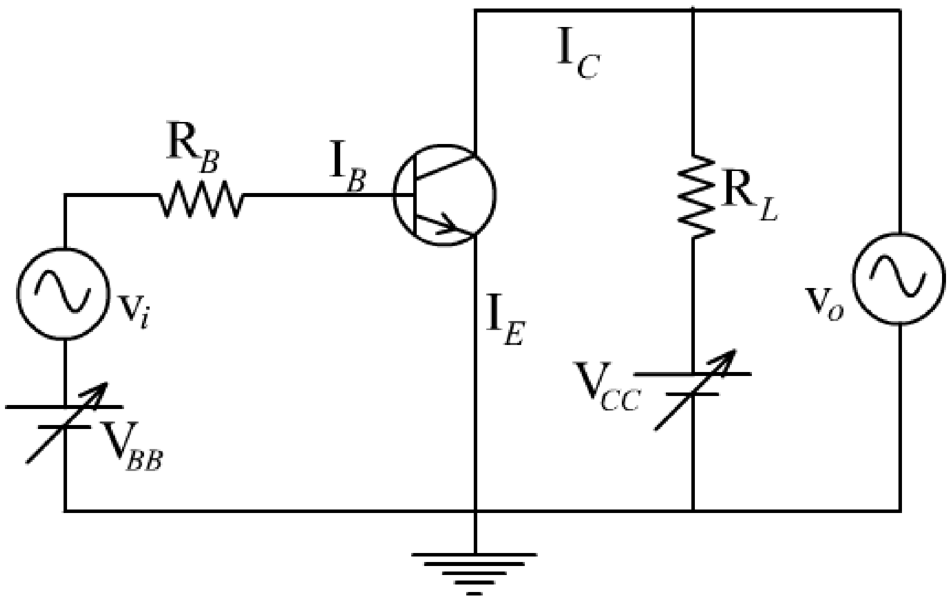
$$\gamma = \frac{I_E}{I_B}$$

$$\gamma = \frac{I_B + I_C}{I_B}$$

$$\gamma = 1 + \frac{I_C}{I_B}$$

$$\boxed{\gamma = 1 + \beta}$$

Transistor as an amplifier



$a.c.$ signal to be amplified is connected in the input section of the transistor.

V_{CE} is taken as the output

Transistor is operated in the active region only.

A small change in I_B (μA) results in a large change in I_C (mA).

Output and input are out of phase by π. (negative slope of V_O - V_I plot in the active region)

Voltage gain

$$A_V = \frac{V_o}{V_i}$$

$$A_V = \frac{I_C R_L}{I_B R_B}$$

Using the relation

$$\beta = \frac{I_C}{I_B}$$

$$\boxed{A_V = \beta \frac{R_L}{R_B}}$$

Using the $P = VI$

$$\boxed{\text{Power gain} = \beta^2 \frac{R_L}{R_B}}$$

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