

Transistor

11/04/2020 ①

→ Bipolar junction transistor (BJT)

1. 1948 - invention - John bardeen, william schokley
2. The conduction through electrons & holes.

3.

Region	E	C	operation
Active	F	R	Amplifier
saturation	F	F	close ckt
cut-off	R	R	open ckt
Inverse	R	F	Digital current

4. Transistor is a three terminal Electronic device.

Emitter: heavily doped

Base : lightly doped thin region

collector: Moderately doped, largest in size.

Emitter efficiency: it is the ratio of current reaching emitter junction, due to carriers from emitter region and the total current through emitter junction.

$$\boxed{\gamma = \frac{I_{PE}}{I_{PE} + I_{NE}}} \approx 1 \text{ in a good transistor}$$

Transport factor: - It is a measure of how efficiently carriers are transported from emitter to collector.

$$\beta^* = \frac{I_{PC}}{I_{PE}} \approx 1 \text{ for a good transistor.}$$

$$\boxed{I_C = -I_{PC} + I_{CO}} \rightarrow \begin{array}{l} \text{majority carrier} \\ \text{current} \end{array} \quad \begin{array}{l} \text{minority} \\ \text{carrier} \\ \text{current} \end{array}$$

Large signal current gain $[\alpha]$

(2)

"It is the ratio of negative change in collector current to change in emitter current from 0 to I_E ".

$$\alpha = -\left(\frac{\Delta I_C}{\Delta I_E}\right) \Big|_{I_E = 0 \text{ to } I_E}$$

$$\boxed{\alpha = \frac{I_{PC}}{I_E}}$$

$$\boxed{\alpha = \beta^* \cdot \gamma} \rightarrow \text{emitter efficiency}$$

$\downarrow$ Transport factor

CB	CE	CC
$\alpha = \frac{I_C}{I_E}$	$\beta = \frac{I_C}{I_B}$	$\gamma = \frac{I_E}{I_B}$
$I_E = I_C + I_B$	$I_E = I_C + I_B$	$I_E = I_C + I_B$
$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$	$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$	$\frac{I_E}{I_E} = \frac{I_C}{I_E} + \frac{I_B}{I_E}$
$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$	$\frac{1}{\alpha} - 1 = \frac{1}{\beta}$	$1 = \alpha + \frac{1}{\gamma}$
$\frac{1}{\alpha} = \frac{\beta + 1}{\beta}$	$\frac{1 - \alpha}{\alpha} = \frac{1}{\beta}$	$1 - \alpha = \frac{1}{\gamma}$
$\alpha = \frac{\beta}{1 + \beta}$	$\beta = \frac{\alpha}{1 - \alpha}$	$\gamma = \frac{1}{1 - \alpha}$
$\boxed{\alpha = \frac{\beta}{1 + \beta}}$	$\boxed{\beta = \frac{\alpha}{1 - \alpha}}$	$\boxed{\gamma = 1 + \beta}$

$$* \therefore I_C = \beta I_B + (1 + \beta) I_{CO}$$

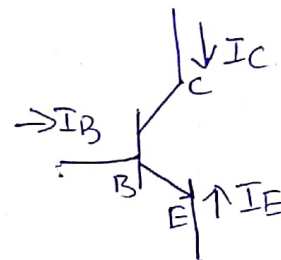
' β ' is called "common emitter large signal current gain"

"It is the ratio of change in collector current to change in Base current from "0- I_B " " $\beta = \frac{\Delta I_C}{\Delta I_B} \Big|_{I_B=0-I_B}$ " (3)

$$I_C = \beta I_B + I_{C0} + \beta I_{C0}$$

$$I_C - I_{C0} = \beta I_B + \beta I_{C0}$$

$$\beta = \frac{I_C - I_{C0}}{I_B - (-I_{C0})}$$



$$\text{KCL} \quad I_E + I_B + I_C = 0$$

$$0 + I_B + I_C = 0$$

$$I_B = -I_{C0}$$

when transistor is in cut-off, then

$$I_C = I_{C0} \quad \& \quad I_B = -I_{C0}$$

DC ' β ' of a transistor "It is the ratio of collector current = base current". $\beta_{DC} = \frac{I_C}{I_B}$

as I_{C0} is negligible; $\boxed{\beta_{DC} \approx \beta}$

→ Small signal ' β ' (or) AC ' β ' is the ratio of "change in collector current to change in base current, when base current changes by small amount".

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B} \Big|_{\Delta I_B \rightarrow 0} = \frac{\partial I_C}{\partial I_B}$$

$$I_C = \beta I_B + (1 + \beta) I_{C0}$$

(Treat ' β ' is also depends on I_B)

Differentiate w.r.t I_B

$$\frac{\partial I_C}{\partial I_B} = I_B \frac{\partial \beta}{\partial I_B} + \beta(1) + I_{C0} \frac{\partial \beta}{\partial I_B}$$

$$\beta_{ac} = I_B + (I_B + I_{C0}) \frac{\partial \beta}{\partial I_B}$$

(i) If ' β ' is independent of ' I_B '

$$\therefore \underline{\beta_{ac} = \beta_{dc}}$$

small signal & large signal ' β ' will be same.

(ii) $\frac{\partial \beta}{\partial I_B} = +ve$ Then $\beta_{ac} = \beta + (I_B + I_{C0})' + ve$

$\therefore \underline{\beta_{ac} > \beta_{dc}}$

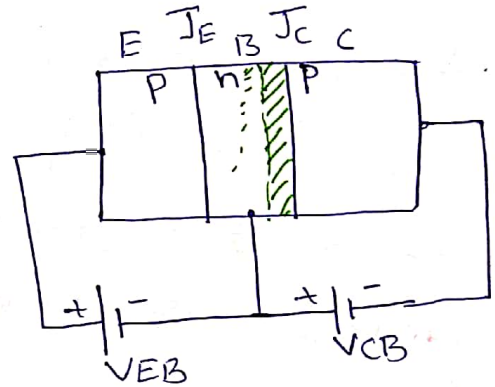
(iii) $\frac{\partial \beta}{\partial I_B} = -ve$ Then β_{ac} decreases with I_B

$\underline{\beta_{ac} < \beta_{dc}}$

* Early Effect:-

→ "Proposed by James Early"

→ when a transistor is operated in active mode, its collector junction is Reverse biased, by applying a voltage V_{CB} .



→ Then the depletion region width across collector junction increases. Since base is lightly doped the depletion region extends more into the base side [$N_A > N_D$ then $w_P < w_N$] and thus effective base width becomes smaller.

EX:- without V_{CB} Total Base width = $20 \mu m$
 when $V_{CB} = 1V \Rightarrow$ depletion region extend more into Base side
 $\hookrightarrow 10 \mu m$ [$B = 8$ collector side = $2 \mu m$]

Then Base width decrease that is

$$20 \mu m - 8 \mu m = 12 \mu m$$

$V_{CB} = 2V \Rightarrow$ depletion region $15 \mu m$ [Base side = $12 \mu m$
 $C = 3 \mu m$]

$$20 \mu m - 12 = 8 \mu m$$

V_{CB} is keep on increasing base width becomes smaller

→ This decrease in effective Base width, due to the reverse voltage V_{CB} applied across collector junction is called "Early effect" (i) "Base width modulation"

→ Early effect has 3 side effects:-

(5)

① Large signal current gain α' increases

EX:-	V_{CB}	emits Emitter	collects Collector	receives $\alpha = \frac{I_C}{I_E}$
	1V	1000 holes	950	$\alpha = \frac{950}{1000} = 0.95$
	2V	1000 holes	970	$\alpha = \frac{970}{1000} = 0.97$
	3V	1000 holes	990	$\alpha = 0.99 \rightarrow \beta = 99$
	4V	1000 holes	992	$\alpha = 0.992 \rightarrow \beta = 124$

consider $V_{CB} = 1V$ $\alpha = 0.95$

$V_{CB} = 2V$ $\alpha = 0.97$

difference @ change is
0.02 but β change
nearly doubles"

that means small change of α' there is a large change of β' .

If $V_{CB} \uparrow \rightarrow$ effective base width $\downarrow \rightarrow$ Recombination $\downarrow \rightarrow$ Transport factor (β) $\uparrow$
Ex 50 holes recombine

then $\alpha \uparrow (\beta^* \gamma)$

Due to Early effect, α' increases by small amount, but β' changes by large amount.

② current through emitter junction $I_E \uparrow$

EX: if $V_{CB} = 0V$ Base width = 20 μm [majority carriers travels within base region 20 μm]
if $V_{CB} = 1V$ Base width reduced to 15 μm [majority carriers travels within base region up to 15 μm]
then $I_E \uparrow$

$I_E \approx I_{PE}$ (current due to holes at J_E)



I_{PE} is a diffusion current (because @ Junction) (6)

$$\uparrow I_{PE} \propto \frac{dp_n}{dx} \approx \frac{\Delta p_n}{\Delta x}$$

If $V_{CB} \uparrow \rightarrow \Delta x \downarrow \rightarrow \frac{\Delta p}{\Delta x} \uparrow \rightarrow I_{PE} \uparrow \rightarrow I_E \uparrow$

$\Delta x \rightarrow$ effective base width

$\rightarrow$ Emitter current increases due to increases in the gradient in concentration of holes inside the base.

(3) "Punch-through (or) Reach-through" may takes place:-

when the applied Reverse voltage V_{CB} is made sufficiently large, the depletion region, will fully occupy the base region, making effective base width zero. This condition of effective base width becoming zero is called "reach through" because the negative voltage applied at collector region reaches through to the emitter junction.

when effective base width becomes zero, the gradient $\frac{dp}{dx}$ becomes infinite & therefore current through the emitter junction becomes dangerously large, which will spoil the transistor.

$dx \rightarrow$ effective base width = 0