Bipolar Junction Transistor
Unit - III

Junction TXR:- In 1951, william invented the first junction transistor, A semiconductor device that can amplify electronic s/n such as radio and telivision s/n.

Transistor is a three terminal Device; Base, Emitter, and Collector. can be operated in three configurations common, base, common Emitter and common collector.

Transistor was invented Dr. william shockley and Dr. John Bardeen at belllaboratory in 1951. It is a three terminal device, The output voltage, current or power are controlled by input current in a transistor. Therefore it is called a current controlled device. In short transistor is also called as BJT stands for Bipolar junction transistor because the transistor operation is cared out by two types of charge carriers i.e majority carriers and minority carriers.

* There are 2 types of transistors.

① unipolar junction transistor :- Current conduction is only due to one type of carriers. i.e maj carriers

② Bipolar junction transistor :- The current conduction in BJT is because of both the types of charge carriers. electrons and holes.

*BJT are 2 types:-

1. n-p-n types
2. p-n-p types.

Formed by Sandwiching

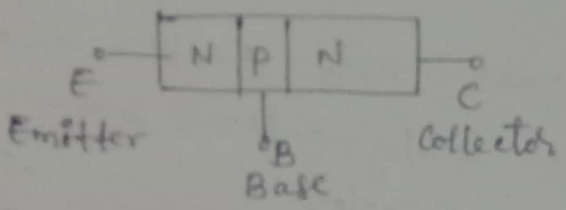
1. **N-P-N TXR:-** A single P-region b/w two n-regions.

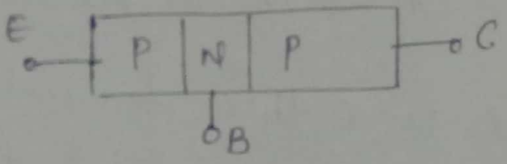
Unbia

unbiased

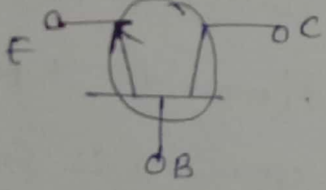
app

P-N-P TXR:- is formed by Sandwiching a single n-region b/w two P-regions.

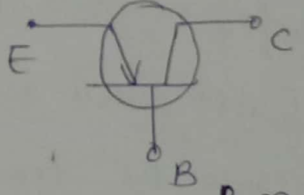




The middle region is always Base of the tXR. This region is very thin and lightly doped. The remaining two regions are called Emitter and Collector are heavily doped. But The doping level in emitter is slightly greater then Collector. And Collector Area is slightly more then Emitter.

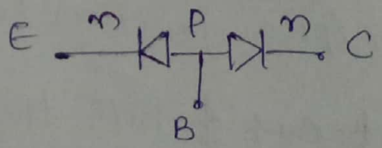


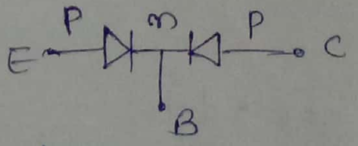
N-p-n TXR



P-n-p. TXR.

A transistor has two P-n junctions. one junction is b/w emitter and base and is called emitter base junction (J_E) The other junction is b/w the base and Collector Called Collector base junction (J_C) Thus transistor is like two p-n junction diodes Connected back-to-back.





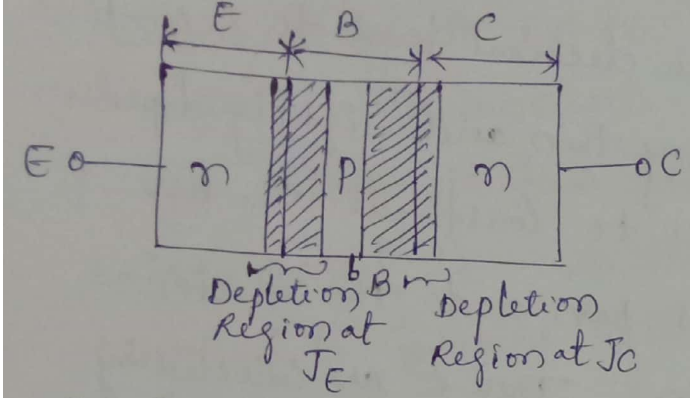
Emitter:- The function of emitter is to inject charge carriers ($e^{\ominus}$ and holes) to the base region.

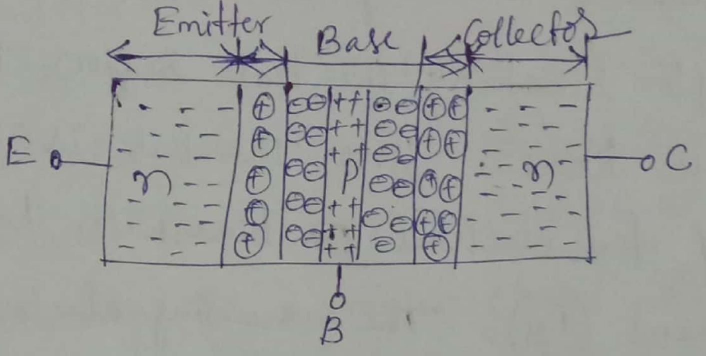
Base:- The function of base ~~is~~ to pass all the charge carriers onto the Collector

Collector:- The function of Collector is to Collect charge carriers.

Unbiased transistor :-

unbiased TXR means, transistor with no External Voltage is applied. There will be no current flowing from any of the transistors. Since transistor is like a two p-n junction diodes Connected back to back, there are depletion regions at both the junctions. at Emitter junction and Collector junction.

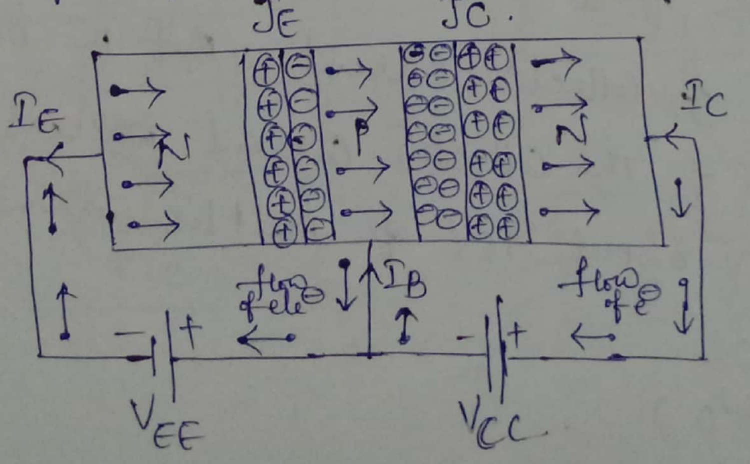




During diffusion process, depletion region penetrates more deeply into lightly doped side in order to include an equal number of impurity atoms in the each side of the junction.

⊛ Working of N-p-n Transistor :-

let us Consider n-p-n TXR, the base Emitter junction is forward biased by dc Source V_{EE} Thus The depletion depletion region width is reduced, The Collector base junction is reverse biased increasing depletion region at collector to base junction.



The forward bias of on Emitter base junction pushes a large no. of free electrons in the N- type Emitter towards the base. This makes the emitter Current (I_E). A very few holes also pass from base to emitter region. This flow of electrons and holes Constitute a Current I_E. The direction of conventional Current is always taken opposite to the flow of electrons.

After reaching the base region the electrons tend to recombine with holes. Since the base is very thin and lightly doped only few electrons combine with holes to Constitute the base Current (I_B). The remaining electrons pass on to the Collector which is positively biased N-region. These $e^{\ominus}$ are Collected by Collector to Constitute the Collector current.

There is an another Current (Collector Current) due to the thermally generated minority carriers (Holes in This Case) which pass towards the base. This small Current is called reverse Saturation Current.

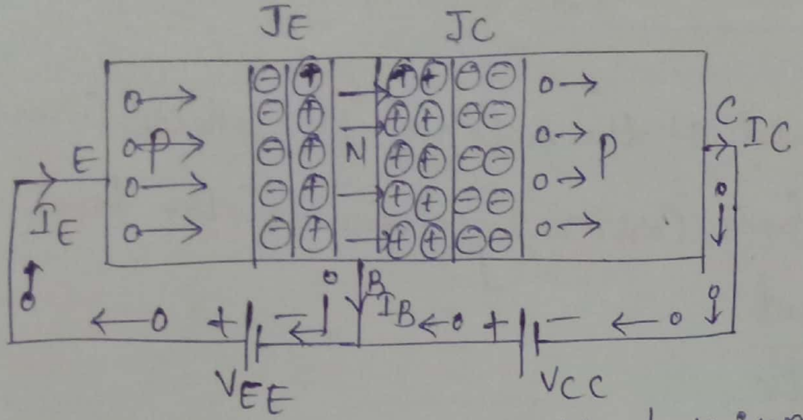
It is clear Emitter Current is sum of base Current plus Collector Current

$$I_E = I_B + I_C$$

The Emitter Current of a transistor Consists of two Components These are base Current & Collector Current. But the base current is only about 2% of the Collector Current whereas the Collector Current is about 98% of Emitter Current.

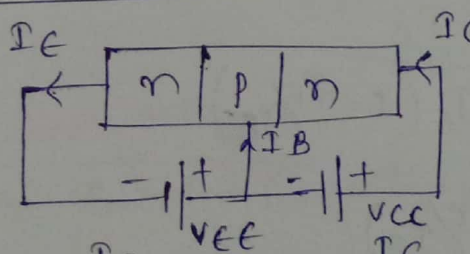
$$\because \quad I_E \simeq I_C .$$
$$(I_B \simeq 0)$$

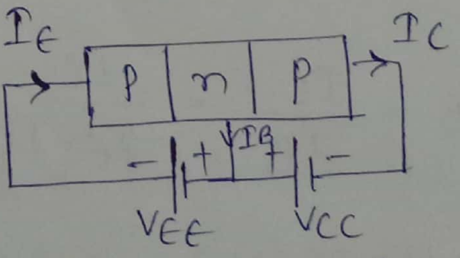
Working of PNP TxR:-

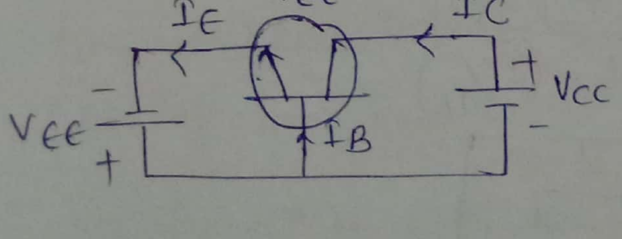


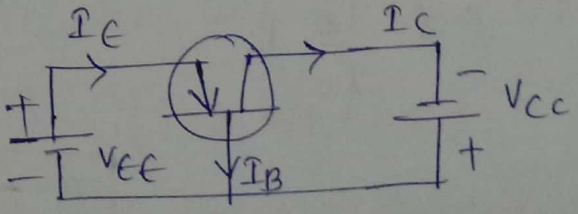
This is necessary to F.B the emitter base junction and reverse bias The Collector base junction. The F.B J_E Causes the holes in the P-type emitter to flow towords the base. This Constitutes the emitter current I_E. As these holes flow through the n-type base, they tend to Combine with electrons in n-region (base). As the base is very thin and lightly doped, very few of the holes injected into the base from the emitter recombine with electrons to Constitute base Current, I_B remaining large no. of holes Cross the depletion region and move through the Collector region to the negative terminal of the External d.c Source. This Constitute Collector Current I_C. Thus the holes flow constitute the dominent current in an p-n-p TxR.

* Transistor Currents:-









ⓐ Defination of α_{dc} and β_{dc} :-

α_{dc} :- It is defined as the ratio of the Collector Current resulting from Carrier injection to the total Emitter Current.

$$\alpha \simeq \alpha_{dc} \simeq \frac{I_C}{I_E}$$

∴ α is less than unity i.e 0.95 to 0.995. Coz $I_C < I_E$.
It represents in CB Configuration.

β_{dc} :- It is defined as the ratio of the collector current to the base current.

$$\beta_{dc} \simeq \beta = \frac{I_C}{I_B}.$$

⊕ Relation ship b/w α_{dc} and β_{dc} :-

we know that, $\beta = \frac{I_C}{I_B}$, $\alpha = \frac{I_C}{I_E}$

∴ we have $I_E = I_B + I_C$

i.e $I_B = I_E - I_C$

$$\therefore \beta = \frac{I_C}{I_B} = \frac{I_C}{I_E - I_C} = \frac{I_C}{I_E(1 - I_C/I_E)}$$

$$\therefore \left(\alpha = \frac{I_C}{I_E}\right) \qquad = \frac{(I_C/I_E)}{1-(I_C/I_E)}$$

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

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

By dividing $(1+\beta)$ on both sides,

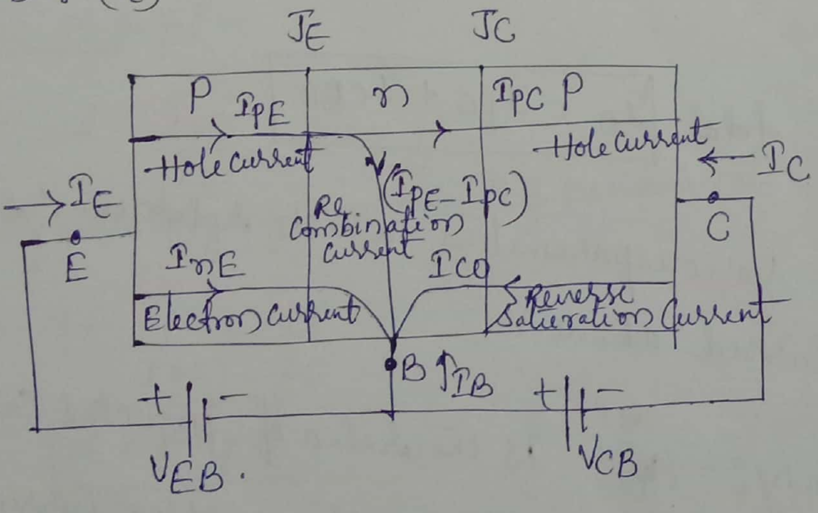
$$\frac{\beta}{(1+\beta)} = \frac{\alpha/(1-\alpha)}{(1+\beta)}$$

$$\frac{\beta}{1+\beta} = \frac{\frac{\alpha}{1-\alpha}}{1+\frac{\alpha}{1-\alpha}} \Rightarrow \frac{\frac{\alpha}{\cancel{(1-\alpha)}}}{\frac{1-\cancel{\alpha}+\cancel{\alpha}}{\cancel{(1-\alpha)}}} \Rightarrow \alpha$$

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

⊛ Transistor Current Components :-

Various Current Components in p-n-p transistor which flow across the Forward biased emitter base junction (J_E) and the reverse biased Collector base (J_C).



$J_E = F \cdot B$
$J_C = R \cdot B$.

I_{pE}, I_{nE}, and I_{pC} :-

The Emitter Current I_E Consists of hole current I_{pE} (Holes Crossing from emitter into base) and electron current I_{nE} (electron Crossing from base to emitter). $(I_E = I_{pE} + I_{nE})$.

In transistor Emitter is heavily doped as Compared to base, Thus, electron current is negligible as Compared to Current.

Thus Emitter Current in PNP transistor is mainly due the flow of holes from emitter to base.

All the holes Crossing the emitter base junction donot reach the Collector junction. because some of them Combine with electron in N-type base.

Since width of the base is verysmall, most of holes cross the Collector junction I_C and very few electrons recombine, Constitute the base Current $I_B = (I_{pE} - I_{pC})$

Reverse Saturation Current:-

Since Collector ~~Current~~ Junction is R.B, which acts as reverse biased PN junction diode, a reverse Saturation Current I_{CO} flows across this junction. Called I_{CBO} (~~Base~~ Emitter is open Circuitary, i.e $I_E = 0$) ~~and~~

So total $\boxed{I_C = I_{pC} + I_{CBO}}$.

Now, we define Variousparameters which relate the Current Components discussed above.

Emitter efficiency:- (γ): is the ratio of injected Carriers at Emitter base junction to total Emitter emitter Current.

$$\gamma = \frac{\text{Current of injected carriers at } J_E}{\text{Total Emitter Current}}$$

Incase p-n-p TXR

$$\boxed{\gamma = \frac{I_{pE}}{I_{pE} + I_{nE}} = \frac{I_{pE}}{I_E}}$$

($\because I_{pE} \gg I_{nE}$ Since γ nearly Equal to 1)

Transport Factor (β):-

It is the ratio of injected carriers current reaching at collector base junction J_C to injected carriers at emitter base junction J_E

$$\boxed{\beta = \frac{I_{pC}}{I_{pE}}}$$

Large s/n Current Gain (α_{dc}):-

It is the ratio of current due to the injected carriers I_{pC} to total emitter current I_E.

$\because I_C = I_{pC} + I_{CO}$

$I_{pC} = I_C - I_{CO}$

$$\alpha_{dc} = \frac{I_{pC}}{I_E} = \frac{I_C - I_{CO}}{I_E}$$

$$\alpha_{dc} \cdot I_E = I_C - I_{CO}.$$

$$\boxed{I_C = \alpha_{dC} \cdot I_E + I_{CO}}$$

Relation b/w α, β, γ:-

$$\therefore \alpha = \frac{I_{pC}}{I_E}$$

By multiplying numerator & Denominator by I_{pE}

$$\alpha = \frac{I_{pC}}{I_{pE}} \times \frac{I_{pE}}{I_E}$$

$$\boxed{\alpha = \beta * \gamma} \qquad \left(\because \beta = \frac{I_{pC}}{I_{pE}}, \ \gamma = \frac{I_{pE}}{I_E}\right) //.$$

The transistor alpha is the product of transport factor and emitter efficiency.

① a) Find 'α' for each of the following values of $\beta = 50$ and 190.

b) Find β for each of the value of $\alpha = 0.995$ and 0.9765

Sol:- a) $\alpha = \frac{\beta}{1+\beta}$.

$\therefore \beta = 50; \quad \alpha = \frac{50}{1+50} = 0.9804$

$\therefore \beta = 190; \quad \alpha = \frac{190}{1+190} = 0.9947$

b) $\because \alpha = 0.995; \quad \beta = \frac{\alpha}{1-\alpha} = \frac{0.995}{1-0.995} = 199$

$\because \alpha = 0.9765; \quad \beta = \frac{\alpha}{1-\alpha} = \frac{0.9765}{1-0.9765} = 41.55$

② If the base current in a transistor is 20μA when the emitter current is 6.4mA, what are the values of α_{dc} and $\beta_{d.c}$? Also calculate the collector current?

Sol:- $I_B = 20\mu A, \quad I_E = 6.4mA$

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

$\because I_E = I_B + I_C$

$\because I_C = \beta I_B$

$I_B + \beta I_B$

$I_E = (1+\beta) I_B$

$(1+\beta) = \frac{I_E}{I_B}$

$\beta = \frac{I_E}{I_B} - 1 \Rightarrow \frac{6.4 \times 10^{-3}}{20 \times 10^{-6}} - 1$

$\beta = 320 - 1$

$\boxed{\beta = 319}$

$\alpha = \frac{319}{1+319}$

$\boxed{\therefore \alpha = 0.9968}$

$\because I_C = \beta I_B.$

$= 319 \times 20 \times 10^{-6}$

$= 6380 \mu A$

$\boxed{I_C = 6.38mA}$

$\because I_C = \alpha I_E$

$= 0.9968 \times 6.4 \times 10^{-3}$

$\boxed{I_C = 6.379mA}$

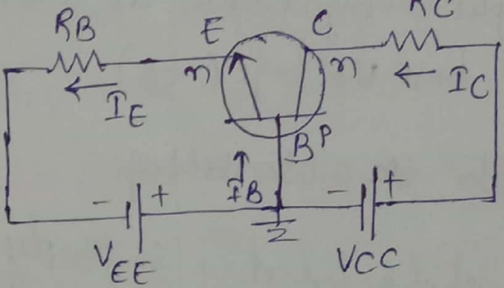
BJT Configuration:-

Txr Canbe connected in a ckt in the following three Configurations.

1. Commonbase Configuration
2. Common Emitter Configuration
3. Common Collector Configuration.

① Commonbase Configuration:-

In this Configuration input is applied b/w Emitter and base and o/p is taken from the Collector and base. Hence base of the transistor is Common to both input and output Circuits and hence the name Common base Configuration.



Here $\boxed{I_C = \alpha_{dc} I_E + I_{CBO}}$.

ICBO is reverse Saturation Current is temperature Sensitive and it doubles for every 10°C rise in temperature. Since ICBO is negligible i.e Small in practical Cases.

$$\therefore \quad I_C = \alpha_{dc} I_E$$

$$\alpha_{dc} = \frac{I_C}{I_E}$$

For a transistor, $I_E = I_B + I_C$

$$I_E = I_B + \alpha_{d.c} I_E + I_{CBO}$$

$$I_B = I_E - \alpha_{dc} \cdot I_E - I_{CBO}$$

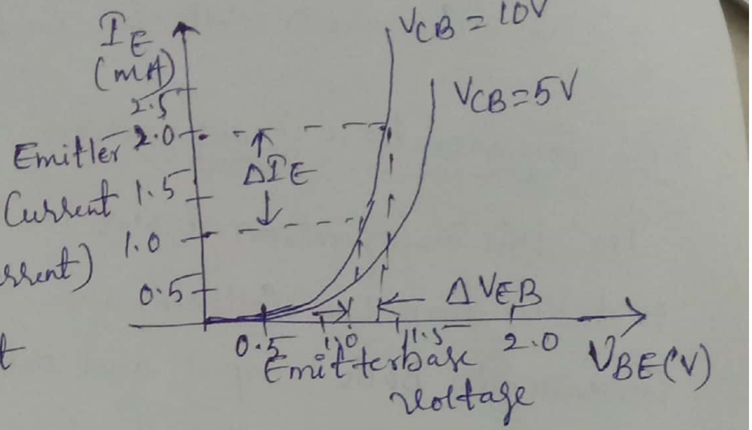
$$\boxed{I_B = I_E(1-\alpha_{d.c}) - I_{CBO}}$$

By neglecting ICBO, Can be written as

$$\boxed{I_B = I_E(1-\alpha_{d.c})}$$

Common Base V-I Characteristics:-

To understand the complete electrical behaviour of the Txr it is necessary to study the interrelation of the various currents and voltage. These relationships can be plotted graphically which are commonly known as the characteristics of transistor. i.e i/p & o/p characteristics.



* Input Characteristics:-

It is the curve b/w I_E (input current) and input voltage (V_{EB}) at constant collector base voltage (V_{CB}).

*. ~~After the cutin Voltage~~

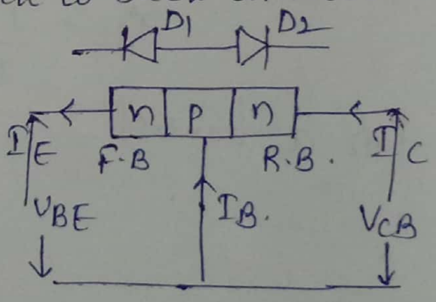
→ The i/p characteristics is simply characteristics of F.B diode

→ Graphical relation of i/p I Vs i/p V for diff o/p ~~Values~~ Voltages.

$i/p\ I = I_E$ $o/p\ I = I_C$

$i/p\ V = V_{BE}$ $o/p\ V = V_{CB}$.

→ we can consider a transistor as two diodes, back to back connection for active mode.

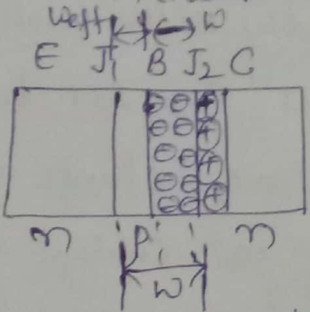


→ The i/p characteristic is similar to F.B ~~i/p~~ characteristic of diode.

But important point is here the effect on i/p characteristic by changing V_{CB}.

→ To understand this effect, first understand early effect.

Ealy Effect:- Known as base width modulation. It is named after James M. Easly. This Effect found when we increase in V_{CB}.



→ Here J_1 F.B, J_2 R.B in R.B the width of depletion region is more and mostly penetrate in to the Base region Because base is lightly doped.

→ The depletion Region has immobile ion's and -ve immobile ion's at Base and the immobile ions at Collector because it is npn Tx R.

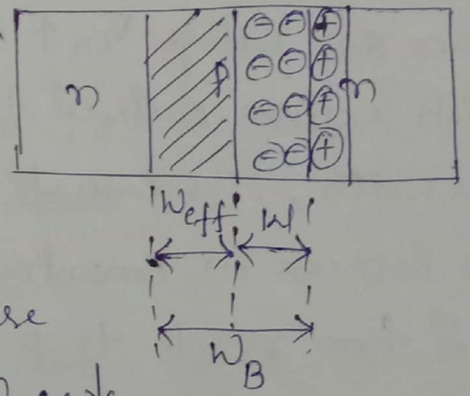
→ let say W_B = width of base (or) Metallergical base width

W = width of depletion Layer penetrate into the Base region

$W_{effective}$ = Width of Base with no depletion region.

$W_B = W_{eff} + W$.

$W_{eff} = W_B - W$.



Now if we increase V_{CB} ↑ the reverse Voltage potential; 'W' will ↑, when W ↑ W_{eff} ↓. where W_{eff} is the region where recombination takes place. ~~Wid~~ when W_{eff} ↓ The chance of recombination at Base region ↓. In this situation I_E ↑.

→ The other reason is increase in concentration gradient ↑. The e^- in 'n' side move ~~from~~ to Base, as the area decrease the concentration gradient increases. So more no. of e^- move towards base This will also increase I_E. ↑. i.e if we increase V_{CB} ↑ o/p voltage, the i/p current I_E ↑. And The remaining characteristis ~~of~~ are similar to F.B of Pn junction.

i/p Characteristics:-

1) After cut in voltage (0.7) for Si, The emitter Current I_E i rapidly with small increase in Emitter base Voltage (V_{EB}). It means i/p. resistance is very small. Because i/p resistance is a ratio of change in emitter base Voltage (ΔV_{EB}) to resulting change in Current (ΔI_E) at constant V_{CB}. This resistance is Also known as dynamic i/p resistance of TxR in CB configuration.

$$r_i = \frac{\Delta V_{EB}}{\Delta I_E}\bigg|_{V_{CB} = \text{Const}}$$

2) It can be observed That, there is slight ~~change~~ increase in Emitter Current (I_E) with increase in V_{CB}. is due to change in width of depletion region in the base region under the reverse bias condition.

When R.B Voltage V_{CB} ↑, The width of depletion region also ↑, which reduses electrical base width. Due to reduction of The electrical base width, The concentration gradient ↑ in The base region. This increase in concentration of charge carriers causes more diffusion of $e^{\ominus}$ from n side to p side, That increase in I_E slightly.

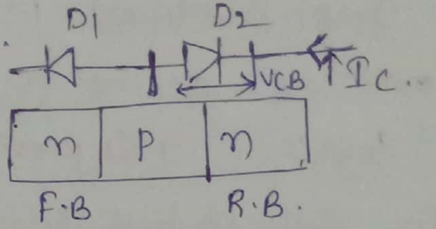
<u>Early Effect</u>:- When R.B V_{CB} ↑, The width of depletion ↑ which reduces ↓ The electrical base width. This effect is known as early Effect (or) Base width modulation.

This ↓ in base width has two Consequences:

1. There is less chance for recombination within The base region. Hence The transport factor α and β ↑ with in collector junction voltage.

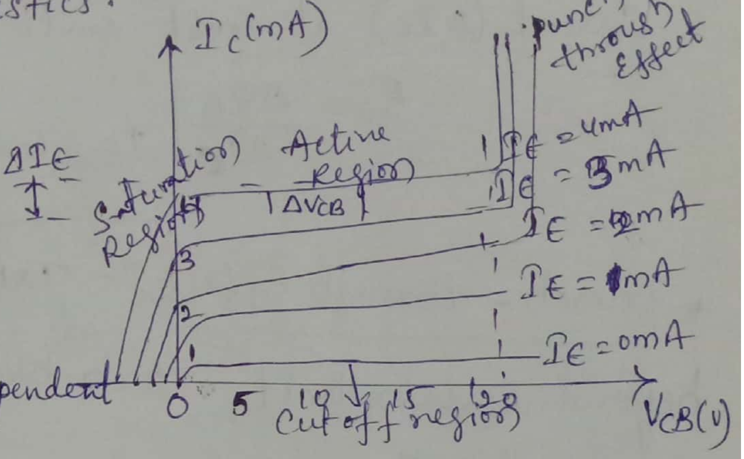
2. The charge gradient increases within The base, & The current of minority carriers injected across the junction increases.

O/p characteristics:- It is the curve b/w O/p voltage V_{CB} and o/p current I_C at const emitter current I_E.



→ at diode D_2 the o/p current I_C and voltage across diode is V_{CB}. So o/p characteristics simply the R.B of diode characteristics.

→ on X-axis $V_{CB}(V)$,
Y-axis $I_C(mA)$



→ We know $\boxed{I_C \cong \alpha I_E + I_{CBO}}$.

I_{CBO} is reverse leakage current which is negligable and it is independent of V_{CB}.

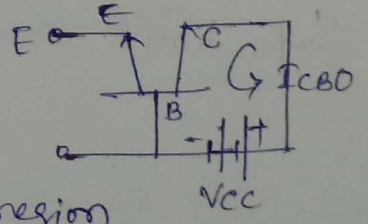
$$\boxed{I_C \cong \alpha I_E}$$

$I_C = I_E$ ($\because \alpha \cong 0.95$ to 0.995 Equal to 1)

→ i.e O/p current depending on i/p current I_E. When $I_E = 0mA$. This small current is reverse saturation current I_{CBO}.

O/p characteristics has 3 basic regions:-

Cutoff region: If the emitter current is zero, the collector current is simply I_{CBO}., this current is very small in magnitude compared to the vertical curve. The region below the curve $I_E = 0$ is known as cutoff region. When collector current $I_C = 0$. When J_E, J_C are R.B.



Saturation region:- This region is left of $V_{CB} = 0$. Exponential increase in collector current as the voltage V_{CB} increases towords zero 0V. in this region the J_E, J_C are both F.B.

Active region :- The Collector Current is Almost Const, and graph is Almost parallel with x-axis. The Ic is Always in on VCB. depend on IE So almost TxR acts as Const-Current Source : This provides high dynamic resistance [i.e. The ratio of change in Collector base Voltage (ΔVCB) to resulting change in Collector Current (ΔIc) at Const emitter Current IE.

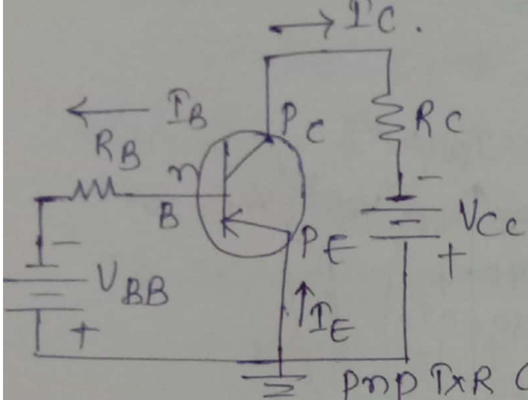
$$R_0 = \frac{\Delta V_{CB}}{\Delta I_C}\Big|_{I_E = Const}$$

* punch-through Effect :- TxR breakdown occurs when VCB ↑ beyond certain limit. Such break down known as punch through or reach-through.

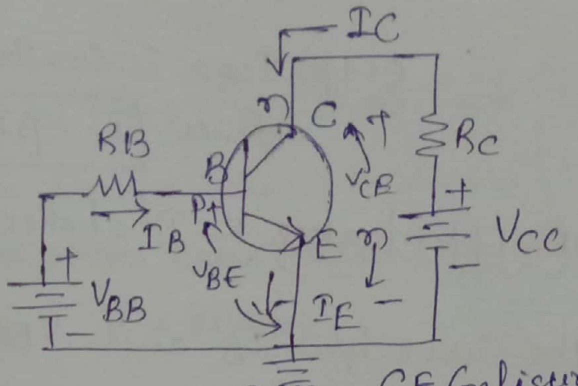
→ The potential barriers at the junction of transistor when EB junction is F.B and CB junction is R.B. The F.B EB junction ↓ the potential barrier by |VEB| and R.B of CB junction ↑. When CB Junction ↑, The Effective base width reduces ↓. When CB Junction ↑ beyond certain limit effective base width reduces ↓ to zero. Thus result Emitter & Collector shorted. Thus Cause large increase in Emitter Current (IE) resulting Breakdown. ∴ It is necessary to keep of the VCB within Safe limit to avoid punch through (or) reach through breakdow

Common Emitter transistor :- Configuration

In this Configuration i/p is applied b/w base and Emitter, and output is taken from the Collector and emitter. Here Emitter of transistor is Common ~~for~~ to both input and output ckts. and hence name is Called Common Emitter Configuration.



pnp TxR CE Configuration.



npn– CE Configuration

As shown in fig: J_E = F.B by V_{BB} and J_C is R.B by V_{CC}.

The input voltage in the CE Configuration is the base Emitter voltage V_{BE}, and o/p voltage is the Collector emitter voltage. The i/p Current is I_B and o/p Current is I_C.

∴ Now how the o/p Current is relate with the i/p Current I_B.

∵ We have seen

$$I_C = \alpha I_E + I_{CBO}$$

$$I_C - I_{CBO} = \alpha I_E$$

$$\frac{I_C}{\alpha} - \frac{I_{CBO}}{\alpha} = I_E \qquad (\because I_E = I_B + I_C)$$

$$\frac{I_C}{\alpha} - \frac{I_{CBO}}{\alpha} = I_B + I_C$$

$$I_C\left(\frac{1}{\alpha} - 1\right) = I_B + \frac{I_{CBO}}{\alpha}$$

$$I_C\left(\frac{1-\alpha}{\alpha}\right) = I_B + \frac{I_{CBO}}{\alpha}$$

$$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \frac{I_{CBO}}{1-\alpha} \qquad \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

$$\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}} \qquad \left(\because (1+\beta) = \frac{1}{1-\alpha}\right)$$

∵ The term $(1+\beta) I_{CBO}$ is the reverse leakage cur

Common Emitter Configuration.

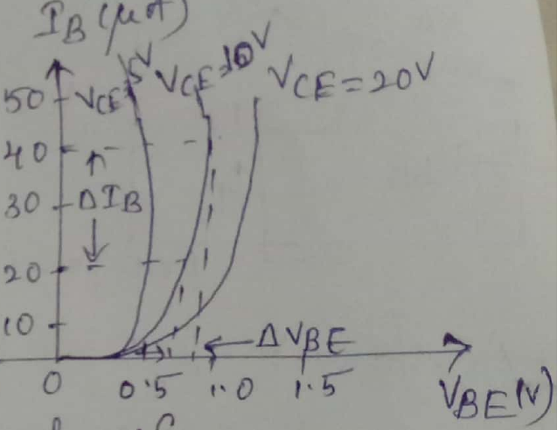
$$\boxed{\because I_{CEO} = (1+\beta) I_{CBO}}$$

∵ The value of $\alpha = 0.995$ which is less then 1. and the value β is from 20 to hundreds. $\beta = \frac{\alpha}{1-\alpha} = \frac{0.995}{1-0.995} = 199$.

∴ $(1+\beta) I_{CBO}$ is smaller then βI_B.

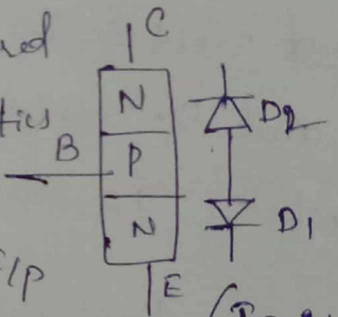
Hence $\boxed{I_C = \beta I_B}$

④ Common Emitter ~~leakag~~ V-I characteristics :-



→ It is the curve b/w I_B and V_{BE} at constant o/p voltage V_{CE}.
V_{BB} & V_{CC} are biasing potentials.

→ we can also consider an npn TXR as two diodes back to back, i.e diode D_1 in F.B can considered as i/p characteristics of CE TXR is characteristics of F.B diode.



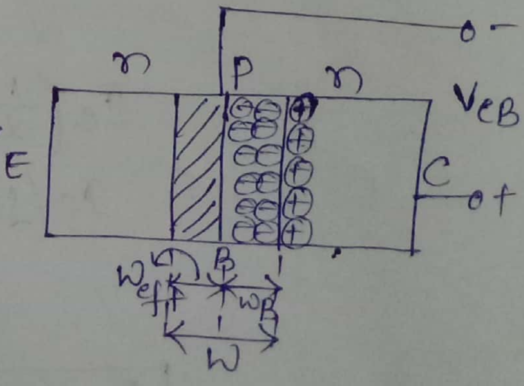
→ But important point, the variation of V_{CE} on I/p characteristics of TXR.

(I_B is current through the diode V_{BE} voltage across diode)

→ The current I_B exponentially increases when i/p voltage > barrier potential ~~greater than~~ voltage. $(V_{BE} > V_b)$; Dynamic i/p resistance $r_i = \frac{\Delta V_{BE}}{\Delta I_B}\Big|_{V_{CE} = \text{const}}$.

→ The effect of V_{CE} on I_B due to early effect. i.e for a fixed V_{BE} value, I_B decreases as V_{CE} increases.

→ Since In Active region J_E forward biased, J_C reverse biased. Due to R.B of J_C The width of depletion region increases at J_C and more widely penetrate in to lightly doped Base region.



W_B = Width of base region
W = Width of depletion region in Base
W_{eff} = Effective base width without depletion region.

$$W_B = W_{eff} + W$$

$$\boxed{\downarrow W_{eff} = \underset{const}{W_B} - W \uparrow}$$

and V_{CE} is o/p Voltage is $V_{CB} + V_{BE}$ if we increase V_{CE}, V_{CB} also increases. $\uparrow V_{CE} = \uparrow V_{CB} + V_{BE}$

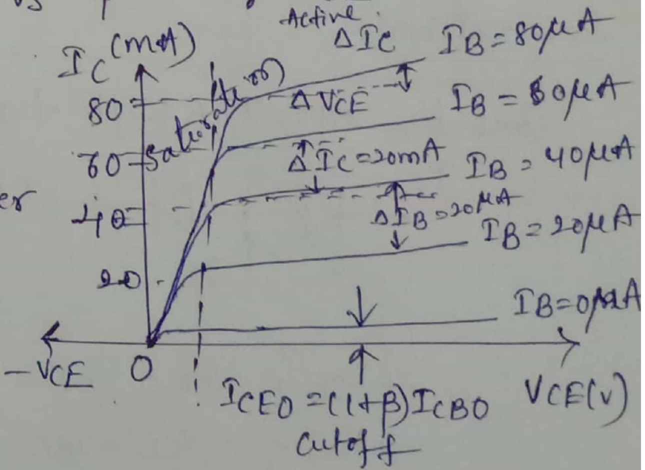
i.e $V_{CE} \uparrow \Rightarrow V_{CB} \uparrow \Rightarrow W \uparrow \Rightarrow W_{eff} \downarrow \Rightarrow I_B \downarrow$ (i/p current)

When $W_{effe} \downarrow$, The region which recombination reduces, The $\bar{e}$ from Emitter are not recombine with holes present in Base it will reduce Base current I_B. ~~Viceversa~~.

When $V_{CE} \uparrow \rightarrow I_B \downarrow$ lly.
Viceversa $\boxed{V_{CE} \downarrow \rightarrow I_B} \uparrow$. In V-I characteristics we can observe, by decreasing o/p Voltage $V_{CB} \downarrow$, it increase i/p current $I_B \uparrow$

O/p - characteristics:-

Graphical relation b/w o/p current I_C Vs o/p Voltage V_{CE} for different levels of I_B.



The o/p characteristics of Common Emitter Configuration consists of three regions Active, Saturation and Cutoff.

1. **Cutoff region:-** when the i/p base current is made Equal to zero, The Collector Current is reverse leakage current I_{CEO}. to make TXR cut off region. it is not enough to reduce $I_B = 0$ instead, it is necessary to R.B the emitter base junction slightly. Here in this situation Collector current Equal to reverse saturation current.

$\because I_C = \beta I_B + (1+\beta) I_{CBO}$.

$\because I_B = 0$

$\boxed{I_C = (1+\beta) I_{CBO}}$ Small current R.S.C.

Active region:— In the active region the curve is approximately horizontal is "active" region of CE Configuration. In the active region the collector junction is R.B. As V_{CE} increased, R.B ↑. This causes depletion to spread more in base than in collector reducing the chances of recombination in the base. This increases the value of α_{dc}. This ~~collector current~~ early effect causes, I_C to rise more sharply with increase in V_{CE} in the active region of o/p characteristics.

$\text{when } \uparrow V_{CE} = \uparrow \overset{\text{R.B b/w C \& B.}}{V_{CB}} + V_{BE}$

$\text{When } V_{CB} \uparrow \Rightarrow \text{The } W_{eff} \downarrow \Rightarrow I_B \downarrow \Rightarrow I_C \uparrow$

$$\left[\because \beta = \frac{\Delta I_C}{\Delta I_B} = \frac{(40-20)\,mA}{(40-20)\,\mu A} = \frac{\cancel{20} \times 10^{-3}}{\cancel{20} \times 10^{-6}} \right.$$

$\boxed{\beta \Rightarrow 1000}$

When $I_B = 20\mu A$

$I_C = \beta I_B$.

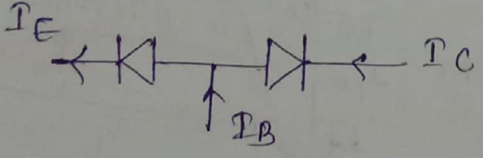
$= 1000 \times 20 \times 10^{-6}$

$I_C = 20mA$]

Amplifies.

Saturation:—

Consider npn TxR with two diodes.



$-V_{CE} = V_{CB} + V_{BE}$

$\swarrow V_{CB} = -V_{CE} - V_{BE}$.

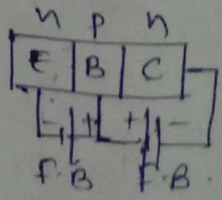
is F.B potential.

Here V_{CE} is very small in this region.

where. $\boxed{V_{CB} = \downarrow V_{CE} - V_{BE}}$

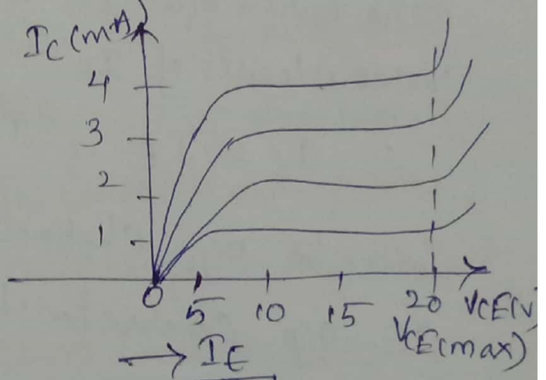
When V_{CE} is very small, V_{CB} is -ve.

make D_2 diode also F.B.



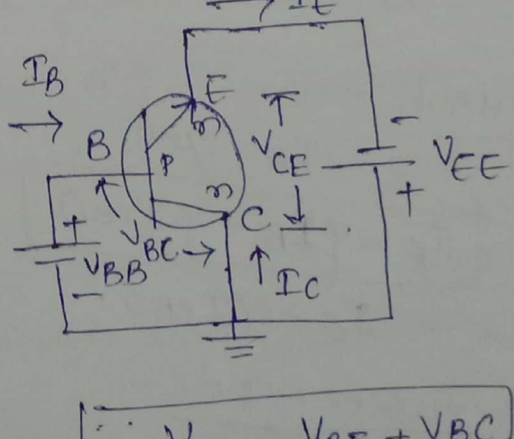
Saturation Region:- If V_{CE} is reduced to small value i.e 0.2V, the collector base junction becomes F.B, since Emitter base junction is already F.B by 0.7V, the i/p junction in CE configuration is base to Emitter junction. which is always forward to operate transistor in active region. when both the junctions are in FB, Transistor operates in Saturation region. which is indicated in o/p characteristics. The saturation value of V_{CE}, is $(V_{CE})_{sat}$ usually ranges b/w 0.1V and 0.3V.

punchthrough:- In the active region, the collector base junction is reversebiased, for every transistor there is a limit on maximum value of R.B voltage. If the limit increases (exceeded) breakdown occurs. in the TxB this effect is known as punchthrough effect.



③ Common Collector Configuration:-

In this configuration I/p is applied b/w Base and collector and o/p is taken from Emitter and collector. Here collector is common to both i/p & o/p called Common collector configuration.



$$\boxed{\because V_{CE} = V_{BE} + V_{BC}}$$

o/p Voltage.

$\because I_E = I_B + I_C$.

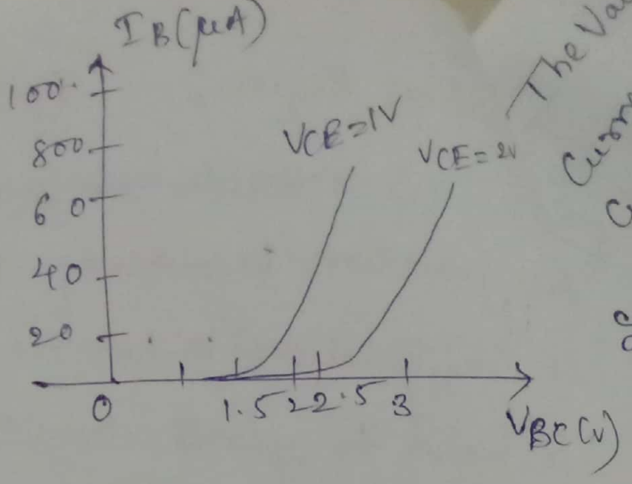
$\div I_B$.

$$\frac{I_E}{I_B} = 1 + \frac{I_C}{I_B}.$$

$$\boxed{\gamma = 1+\beta} = 1 + \frac{\alpha}{1-\alpha} = \frac{1-\alpha+\alpha}{1-\alpha} = \boxed{\frac{1}{1-\alpha} = \gamma} \;//$$

I/p Characteristics :-

I/p Voltage (V_{BC}) Vs I/p Current I_B for different Values of V_{CE}.



$\because$ $V_{CE} = V_{CB} - V_{BE}$

$\therefore$ $\boxed{\gamma = (1+\beta) = \frac{1}{(1-\alpha)}}$

$\boxed{\therefore\ I_E = (1+\beta) I_B + (1+\beta) I_{CBO}.}$

$\because$ $I_E = I_C + I_B$ —①

$I_C = \alpha I_E + I_{CBO}$ —②

② in ①

$I_E = \alpha I_E + I_{CBO} + I_B.$

$(1-\alpha) I_E = I_B + I_{CBO}$

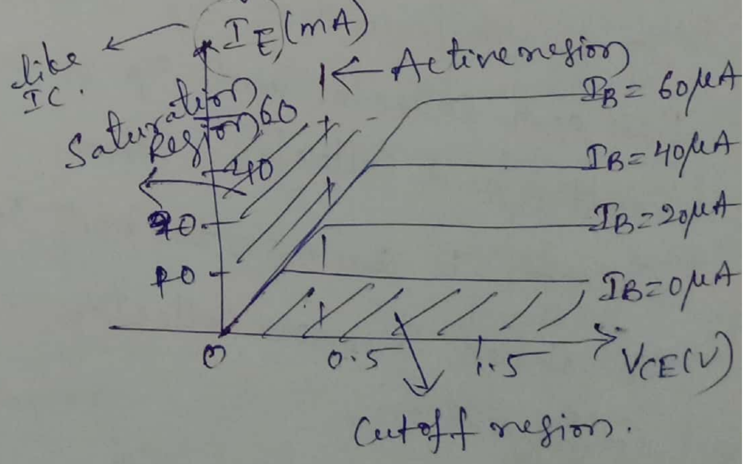
$I_E = \frac{I_B}{(1-\alpha)} + \frac{I_{CBO}}{(1-\alpha)}$

$\boxed{I_E = \gamma I_B + \gamma I_{CBO}}$

O/p characteristics:-

The Curve b/w I_E & V_{CE} for various levels of I_B.

$\therefore$ $I_C \cong I_E$; I_C is approximately I_E, The Common Collector o/p Characteristics are practically similar to those of CE o/p characteristics.



① Cutoff:-

$\because$ $I_B = 0\mu A$

$\boxed{I_E = \gamma I_B + \gamma I_{CBO}}$

$I_E = \gamma I_{CBO}.$

② Active Region:-

$I_E \cong \gamma I_B.$

We know $I_C = \alpha I_E + I_{CBO}$ → By neglecting I_{CBO}.

$I_C = \alpha I_E$

$\alpha = 0.95$ to 0.995

$\boxed{I_C \cong I_E}$ //.

General procedure to obtain stability factor :- (S)

①

⑭

for Common Emitter Configuration, Collector Current Equation.

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

Apply '∂' on both sides.

$$\partial I_C = \beta \cdot \partial I_B + (1+\beta)\, \partial I_{CBO}.$$

$$1 = \beta \cdot \frac{\partial I_B}{\partial I_C} + (1+\beta) \frac{\partial I_{CBO}}{\partial I_C}.$$

$$1-\beta \cdot \frac{\partial I_B}{\partial I_C} = (1+\beta) \frac{\partial I_{CBO}}{\partial I_C}.$$

$$\frac{\partial I_{CBO}}{\partial I_C} = \frac{1-\beta \cdot \frac{\partial I_B}{\partial I_C}}{1+\beta}. \qquad \left(\because S = \frac{\partial I_C}{\partial I_{CBO}}\right)$$

$$\frac{1}{S} = \frac{1-\beta \cdot \frac{\partial I_B}{\partial I_C}}{1+\beta}.$$

$$S = \frac{(1+\beta)}{1-\beta \cdot \left(\frac{\partial I_B}{\partial I_C}\right)} \;//.$$

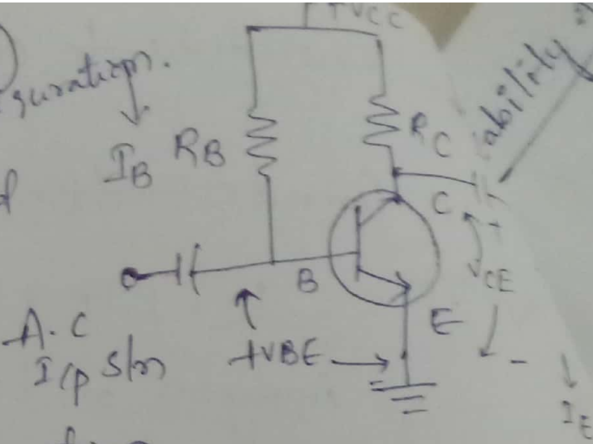
(*) Biasing Circuits :-

Need :- Transistor should be operated in the middle of the active region. (or) operating point should be in the centre of the active region.

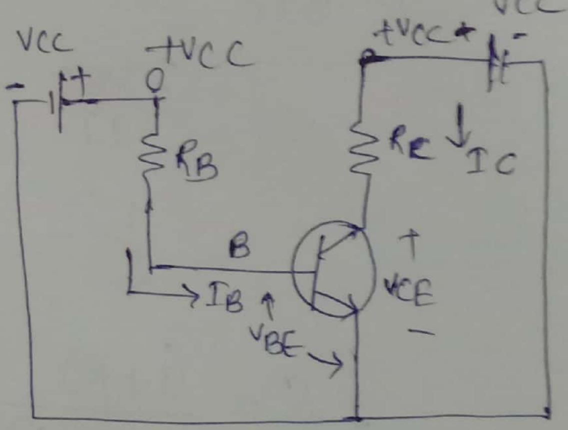
Basically, 4 types of Biasing ckts.

1. Fixed Bias ckt
2. Collector to Base bias ckt
3. Voltage divider Bias / Self bias
4. Emitter Stabilized bias ckt

① Fixed bias circuit :- (Base bias configuration).



Here the base current I_B is controlled by the value of R_B. and I_C is related to I_B by a constant β. The magnitude of I_C is not a function of resistance R_C. changing R_C to any level will not affect the level of I_B & I_C as long as we remain in the active region.



Apply KVL at i/p side.

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_B.}} \quad — ①$$

Apply K.V.L at o/p side.

$$V_{CC} - I_C \cdot R_C - V_{CE} = 0$$

$$\boxed{I_C = \frac{V_{CC} - V_{CE}}{R_C}}$$

$$I_C = -\frac{1}{R_C} \cdot V_{CE} + \frac{V_{CC}}{R_C}.$$

Stability factor:-

$$\because \quad I_B = \frac{V_{CC}}{R_B} - \frac{V_{BE}}{R_B}.$$

when I_B Changes by ∂I_B, Vcc and VBE are uneffected

$$\therefore \quad \frac{\partial I_B}{\partial I_C} = 0$$

∵ I_C is not present in the Equation.

$$\therefore \quad S = \frac{(1+\beta)}{1-\beta\cdot\left(\frac{\partial I_B}{\partial I_C}\right)} = \frac{1+\beta}{1-0} = (1+\beta) \;//$$

bility factor (s'):

$$S' = \left.\frac{\partial I_C}{\partial V_{BE}}\right|_{I_{CO},\ \beta\ \text{const}}$$

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

Now representing I_B interms of V_{BE}

$$I_C = \beta \cdot \left(\frac{V_{CC} - V_{BE}}{R_B}\right) + (1+\beta) I_{CBO}.$$

$$I_C = \beta \cdot \frac{V_{CC}}{R_B} - \frac{\beta \cdot V_{BE}}{R_B} + (1+\beta) I_{CBO}.$$

$$\partial I_C = \beta \cdot \frac{V_{CC}}{R_B} - \beta \cdot \frac{V_{BE}}{R_B} + (1+\beta)\, \partial I_{CBO}.$$

$$\frac{\partial I_C}{\partial V_{BE}} = 0 - \frac{\beta}{R_B} + 0 \Rightarrow -\beta/R_B.$$

$$\boxed{S' = \frac{-\beta}{R_B}.}$$

Relation b/w S and s' :-

We know that $S = (1+\beta)$, $S' = \frac{-\beta}{R_B}.$

$S' = -\beta/R_B.$ multiply & divide with $(1+\beta)$

$$S' = \frac{-\beta(1+\beta)}{R_B(1+\beta)} = \frac{-\beta \cdot S}{R_B \cdot (1+\beta)}$$

Sability factor (s''):-

$$S'' = \left.\frac{\partial I_C}{\partial \beta}\right|_{V_{BE},\ I_{CBO}\ \text{const.}}$$

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

$$I_C = \beta\left(\frac{V_{CC} - V_{BE}}{R_B}\right) + (1+\beta) I_{CBO}$$

$$I_C = \beta\cdot\frac{V_{CC}}{R_B} - \beta\frac{V_{BE}}{R_B} + (1+\beta)I_{CBO}.$$

$$\partial I_C = \beta\cdot\frac{V_{CC}}{R_B} - \beta\cdot\frac{V_{BE}}{R_B} + (1+\beta)\, I_{CBO}.$$

$$\frac{\partial I_C}{\partial \beta} = \left(\underbrace{\frac{V_{CC}}{R_B} - \frac{V_{BE}}{R_B}}\right) + I_{CBO}.$$

$$\frac{\partial I_C}{\partial \beta} = I_B + I_{CBO}. \qquad (\because I_B \gg I_{CBO})$$

$$S'' = \boxed{\frac{\partial I_C}{\partial \beta} = I_B. \Rightarrow I_C/\beta.}$$

Relation b/w S and S'':—

We know $S=(1+\beta)$, $S'' = I_C/\beta$.

Multiplying numerator and denominator by $(1+\beta)$

$$S'' = \frac{I_C(1+\beta)}{\beta(1+\beta)} = \frac{I_C\cdot S}{\beta\cdot(1+\beta)} \;//.$$

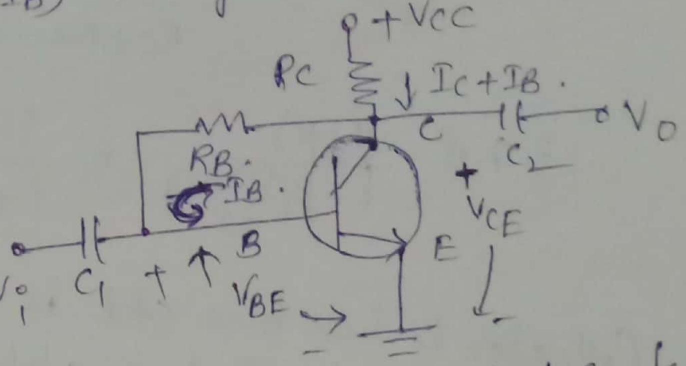
* Disadvantages:— since $I_C=\beta I_B$. and I_B is already fixed

I_C depends on β which changes unit to unit and shifts the operating point.

Thus stabilization of operating point is very poor in the fixed bias circuit.

Collector to base bias :- (Collector feedback bias)

In this biasing resistor is connected b/w Collector and Base of the transistor. to provide feedback path ∴ Thus I_B flows through R_B and (I_C+I_B) through R_C.



D.C bias with voltage feed back.

By Applying KVL to the base ckt.

$$V_{CC} - (I_B+I_C)R_C - I_B.R_B - V_{BE} = 0$$

$$V_{CC} = (R_B+R_C)I_B + I_C.R_C + V_{BE}$$

$$V_{CC} = (R_B+R_C)I_B + \beta.I_B.R_C + V_{BE}$$

$$I_B = \frac{V_{CC}-V_{BE}}{(1+\beta)R_C+R_B} \qquad (\beta >> 1)$$

$$\boxed{I_B = \frac{V_{CC}-V_{BE}}{R_B+\beta R_C}}$$

By Applying KVL to Collector ckt

$$V_{CC} - (I_C+I_B)R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - (I_C+I_B)R_C.$$

$$V_{CC} - V_{CE} = (I_C+I_B)R_B.$$

$$\boxed{I_C = \frac{V_{CC}-V_{CE}-I_BR_B}{R_B}}$$

Stability factor for Collector to base bias :-

$$V_{CC} - (I_C+I_B)R_C + I_B.R_B - V_{BE} = 0$$

$$V_{CC} = I_CR_C + (R_C+R_B)I_B + V_{BE}.$$

Apply '∂' on both sides.

$$0 = \partial I_C R_C + \partial I_B (R_C + R_B)$$

$$-\partial I_C \cdot R_C = \partial I_B \cdot (R_C + R_B)$$

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_C}{R_C + R_B}$$

$$\therefore S = \frac{(1+\beta)}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)} = \frac{(1+\beta)}{1+\beta\left(\frac{R_C}{R_C+R_B}\right)}$$

Collector to base bias ckt is having lesser stabily factor than for fixed bias ckt. Hence this ckt provides better stability then fixed bias.

Stability factor (S') :-

$$S' = \left.\frac{\partial I_C}{\partial V_{BE}}\right| I_{CO}, \beta \text{ Const}$$

From base ckt

$$V_{CC} - (I_C + I_B) R_C - I_B R_B + V_{BE} = 0 \Rightarrow V_{CC} - I_C R_C - I_B (R_B + R_C) + V_{BE} = 0.$$

$$I_B = \frac{V_{CC} - V_{BE} - I_C R_C}{R_B + R_C}$$

$$\frac{I_C}{\beta} = \frac{V_{CC} - I_C R_C - V_{BE}}{R_B + R_C}$$

$$\frac{I_C}{\beta} + \frac{I_C R_C}{R_B + R_C} = \frac{V_{CC} - V_{BE}}{R_B + R_C}$$

$$I_C \left[\frac{1}{\beta} + \frac{R_C}{R_B + R_C}\right] = \frac{V_{CC} - V_{BE}}{R_B + R_C}$$

$$I_C \left[\frac{R_B + R_C + \beta R_C}{\beta \cancel{(R_B + R_C)}}\right] = \frac{V_{CC} - V_{BE}}{\cancel{(R_B + R_C)}}$$

$$I_C(R_B+R_C+\beta R_C) = (V_{CC}-V_{BE})\beta$$

$$+ R_C(1+\beta)I_C = (V_{CC}-V_{BE})\beta$$

$$I_C\left[R_B+(1+\beta)R_C\right] = (V_{CC}-V_{BE})\beta$$

$$I_C = \frac{(V_{CC}-V_{BE})\beta}{R_B+(1+\beta)R_C}.$$

$$\boxed{\frac{\partial I_C}{\partial V_{BE}} = \frac{-\beta}{R_B+(1+\beta)R_C}}$$

Relation b/w S and S' :-

$$S = \frac{(1+\beta)}{1+\beta\left(\frac{R_C}{R_C+R_B}\right)} \quad \text{and} \quad S' = \frac{-\beta}{R_B+(1+\beta)R_C}$$

$$S = \frac{(1+\beta)\cdot(R_C+R_B)}{R_C+R_B+\beta R_C} = \frac{(1+\beta)(R_C+R_B)}{R_B+(1+\beta)R_C}$$

$$\frac{S}{(1+\beta)(R_C+R_B)} = \frac{1}{R_B+(1+\beta)R_C}$$

(multiply with $-\beta$ on both sides)

$$\frac{-S\cdot\beta}{(1+\beta)(R_C+R_B)} = \underbrace{\frac{-\beta}{R_B+(1+\beta)R_C}}_{S'}$$

$$\boxed{S' = \frac{-S\cdot\beta}{(1+\beta)(R_C+R_B)}} \;//$$

If 'S' is small, S' is still smaller, If we provide stability against I_{CO} Variations, we get stability against V_{BE} Conditions also.

Stability factor (S'') :—

$$S'' = \frac{\partial I_C}{\partial \beta} \Big|\ I_{CO}, V_{BE}\ \text{Const.}$$

KVL at Base circuitary.

$$V_{CC} - (I_C + I_B)R_C - I_B R_B - V_{BE} = 0$$

$$V_{CC} - V_{BE} = (\beta I_B + I_B) R_C + I_B R_B$$

$$= I_B\left[(1+\beta)R_C + R_B\right]$$

$$I_B = \frac{V_{CC} - V_{BE}}{(1+\beta)R_C + R_B}$$

$$\therefore\ I_C = \frac{\beta(V_{CC} - V_{BE})}{(1+\beta)R_C + R_B} \quad —— \quad ⓐ$$

$$\frac{\partial I_C}{\partial \beta} = \frac{\left[(1+\beta)R_C + R_B\right]\left[V_{CC} - V_{BE}\right] - \beta\left[V_{CC} - V_{BE}\right]R_C}{\left[(1+\beta)R_C + R_B\right]^2}$$

$$\left[\because\ \frac{d}{dt}\left(\frac{u}{v}\right) = \frac{v\frac{du}{dt} - u\frac{dv}{dt}}{v^2}\right.$$

$$\frac{\partial I_C}{\partial \beta} = \frac{(V_{CC} - V_{BE})\left[(1+\cancel{\beta})R_C + R_B - \cancel{\beta R_C}\right]}{\left((1+\beta)R_C + R_B\right)^2}$$

$$= \frac{\left[V_{CC} - V_{BE}\right]\left[R_B + R_C\right]}{\left[(1+\beta)R_C + R_B\right]^2}$$

$$= \frac{(V_{CC} - V_{BE})(R_B + R_C)}{\left[(1+\beta)R_C + R_B\right]\left[(1+\beta)R_C + R_B\right]}$$

$$\boxed{S'' = \frac{\partial I_C}{\partial \beta} = \frac{I_C\,(R_B + R_C)}{\beta\left[(1+\beta)R_C + R_B\right]}}\ //$$

$\frac{I_C}{\beta}$ from ⓐ

Relation b/w S and S'' :-

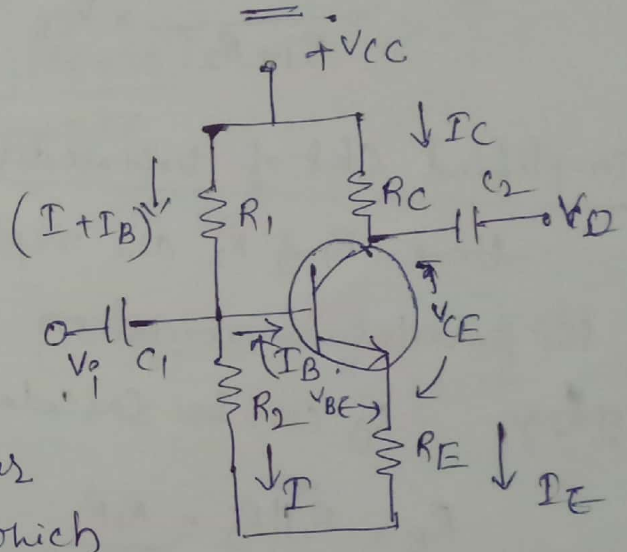
$$S'' = \frac{I_C(R_B+R_C)}{\beta[(1+\beta)R_C+R_B]} \rightarrow \frac{S}{1+\beta}, \quad S' = \frac{-S\cdot\beta}{(1+\beta)(R_C+R_B)}$$

$$\boxed{S'' = \frac{I_C}{\beta} \times \frac{S}{1+\beta}}, \quad S = \frac{(1+\beta)}{1+\beta\left(\frac{R_C}{R_C+R_B}\right)}$$

$$S = \frac{(R_C+R_B)(1+\beta)}{\cancel{\beta}(1+\beta)R_C+R_B}$$

If 'S' is small, S'' is also very small. Thus if we provide stability against I_{CO} variation, we get stability β variations also.

③ Voltage divider Bias :-



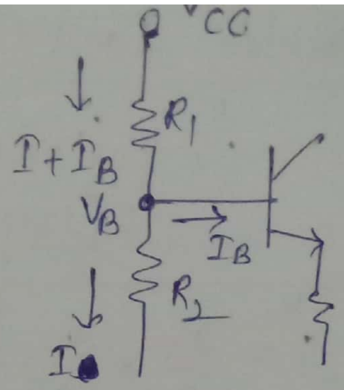
→ Here biasing is provided by three resistors R_1, R_2, R_E. The resistors R_1, R_2 acts as potential divider resistors giving a fixed voltage to point B which is base.

→ If collector current increases due to change in temperature or change in β, The I_E increases and voltage drop across R_E increases that reduces voltage drop b/w Base and Emitter V_{BE}. Due to reduction in V_{BE} collector current I_C reduces.

→ Therefore we can say that negative feedback exists in the emitter bias ckt. This reduction in collector current I_C compensates for original change in I_C.

Base circuit :-

Let Consider base circuit



Voltage across R_2 is the base Voltage V_B. Applying Voltage divider theorem

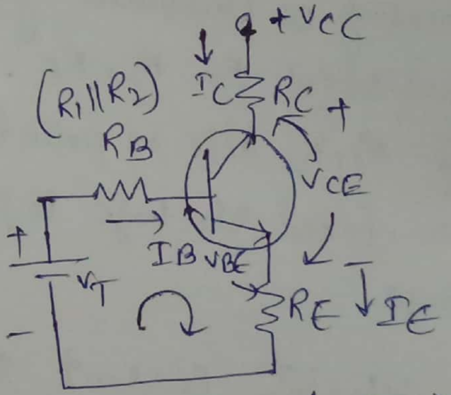
$$V_B = \frac{R_2 \cdot I}{R_1(I+I_B) + R_2 \cdot I} \times V_{CC} \qquad (\because I > I_B)$$

$$V_B = \frac{R_2}{R_1+R_2} \times V_{CC}$$

Simplified ckt of Voltage divider ckt :

Here : R_1 & R_2 are replaced by R_B and V_T, where R_B is the parallel combination of R_1 & R_2 and V_T is the Thevenin's Voltage. R_B can be calculated as

$$R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1+R_2}$$



Thevenin's Equivalent ckt For Voltage divider bias

Applying KVL at base ckt

$$V_T - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_T = I_B R_B + V_{BE} + I_E R_E$$

$$V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E \qquad (\because I_E = I_B + I_C)$$

$$V_T = I_B (R_B + R_E) + V_{BE} + I_C R_E .$$

Apply '∂' on both sides.

$$V_T = \partial I_B (R_B + R_E) + V_{BE} + \partial I_C R_E .$$

~~diff with ∂I_E'~~ diff with '∂I_C'

$$0 = \frac{\partial I_B}{\partial I_C}(R_B + R_E) + 0 + R_E \Rightarrow \boxed{\frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_B + R_E}}$$

∴ Stability factor (S) = $\frac{(1+\beta)}{1-\beta\left(\frac{\partial I_B}{\partial I_C}\right)}$

$$\boxed{S = \frac{(1+\beta)}{1+\beta\left(\frac{R_E}{R_E+R_B}\right)}}$$

Applying KVL to Collector ckt :-

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$I_C = \frac{V_{CC} - V_{CE} - I_E R_E}{R_C}$$

$$\therefore S = \frac{(1+\beta)}{1+\beta\left(\frac{R_E}{R_E+R_B}\right)} \Rightarrow \frac{(1+\beta)(R_E+R_B)}{R_E+R_B+\beta R_E}$$

÷ with R_E

$$S = \frac{(1+\beta)(1+R_B/R_E)\cdot\cancel{R_E}}{\cancel{R_E}(1+\beta)+(R_B/R_E)}$$

($\because R_B/R_E$ is verysmall) <<1
we can neglect

$$\boxed{S = \frac{(1+\beta)}{(1+\beta)} = 1}$$

To become S – small.

R_B – reasonablysmall.

R_E = not very large.

∴ If Ratio R_B/R_E is fixed, S increases with β. Therefore Stability decreases with increases β.

Not :- stability factor 's' for Voltage divider bias (or) self bias is less Compared to other biasing circuits studied. So this ckt is most Commonmly prefered.

Stability factor (S') :-

$$S' = \frac{\partial I_C}{\partial V_{BE}} \Big|_{I_{CO}, \beta \text{ Const}}$$

i.e Varying of I_C wi
when I_{CO}, β c

$\therefore$ weknow that $I_C = (1+\beta) I_{CO} + \beta I_B$. — ①

and $V_T = I_B R_B + V_{BE} + (I_B + I_C) R_E$.

$$V_{BE} = V_T - (R_B + R_E) I_B - R_E I_C \quad — ②$$

By Eqn ① $\quad I_B = \dfrac{I_C - (1+\beta) I_{CO}}{\beta} \quad — ③$.

Sub ③ in ②

$$V_{BE} = V_T - (R_B + R_E) \cdot \left[\frac{I_C - (1+\beta) I_{CO}}{\beta} \right] - R_E I_C$$

$$V_{BE} = V_T - \frac{(R_E + R_B) I_C}{\beta} + \frac{(R_B + R_E)(1+\beta) I_{CO}}{\beta} - R_E \cdot I_C$$

$$V_{BE} = V_T - \left[\frac{(1+\beta) R_E + R_B}{\beta} \right] I_C + \frac{(R_B + R_E)(1+\beta) I_{CO}}{\beta .} \quad — ④$$

Diff ④ with V_{BE} where I_{CO}, & β .

$$1 = 0 - \left[\frac{(1+\beta) R_E + R_B}{\beta} \right] \frac{\partial I_C}{\partial V_{BE}} + 0$$

$$\frac{\partial I_C}{\partial V_{BE}} = \frac{-\beta}{R_B + (1+\beta) R_E}$$

$$\boxed{S' = \frac{-\beta}{R_B + (1+\beta) R_E .}}$$

Relation b/w S and S'

$$S = \frac{(1+\beta)(1+R_B/R_E)}{(1+\beta)+R_B/R_E}$$

multiplying both numerator & denominator by R_E we get

$$S = \frac{(1+\beta)(R_E+R_B)}{R_E(1+\beta)+R_B}$$

$$\therefore \frac{S}{(1+\beta)(R_E+R_B)} = \frac{1}{R_B+(1+\beta)R_E} \quad — ①$$

$$\therefore S' = \frac{-\beta}{R_B+(1+\beta)R_E} \Rightarrow -② \quad \text{sub ① in ②}$$

$$\boxed{S' = \frac{-S\cdot\beta}{(1+\beta)(R_E+R_B)}}$$

we can see lower value of 'S' " lower is the value of S''. as we reduce the value of 'S' towards unity, we minimize the change of I_C with respect to both, V_{BE} and I_{CO}.

Stability factor (S''):-

$$S'' = \frac{\partial I_C}{\partial \beta}\bigg|_{I_{CO},\, V_{BE}\ \text{Const.}}$$

It is the variation of I_C with β when I_{CO} and V_{BE} are considered const. we recall.

$$V_{BE} = V_T - \frac{(R_B+(1+\beta)R_E)}{\beta} \times I_C + \left[\frac{(R_E+R_B)(1+\beta)}{\beta}\right] I_{CO}$$

$$V_{BE} = V_T - \frac{[R_B+(1+\beta)R_E]}{\beta} I_C + V'$$

where $V' = \left[\frac{(R_B+R_E)(1+\beta)}{\beta}\right] I_{CO} = (R_B+R_E)I_{CO}$ $\quad (\because \beta >>$

$$\therefore \quad I_C = \frac{(-V_{BE}+V'+V_T)\beta}{R_B+R_E(1+\beta)}$$

Diff I_C ac (u/v) where V' independent of β, we get

$$\frac{\partial I_C}{\partial \beta} = \frac{[R_B+R_E(1+\beta)][-V_{BE}+V'+V_T] - \beta[V_T+V'-V_{BE}]R_E}{[R_B+R_E(1+\beta)]^2}$$

Multiply & numerator & Denominator by $(1+\beta)$ we get

$$= \frac{(1+\beta)(R_B+R_E)(V_T+V'-V_{BE})}{(1+\beta)[R_B+R_E(1+\beta)][R_B+R_E(1+\beta)]}$$

$$\because \quad S = \frac{(1+\beta)(R_E+R_B)}{R_B+(1+\beta)R_E}$$

$$\frac{\partial I_C}{\partial \beta} = \frac{S\cdot(V_T+V'-V_{BE})}{(1+\beta)(R_B+R_E(1+\beta))}$$

$\div \beta.$

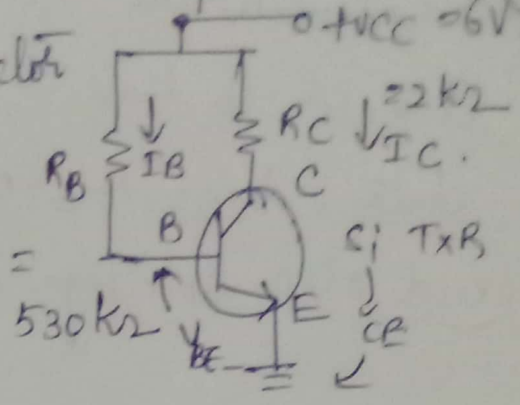
$$\frac{\partial I_C}{\partial \beta} = \frac{\beta(V_T+V'-V_{BE})\cdot S}{\beta(1+\beta)(R_B+R_E(1+\beta))} \Rightarrow \frac{I_C\cdot S}{\beta(1+\beta)}$$

$$\because \quad I_C = \frac{\beta(V_T+V'-V_{BE})}{R_B+R_E(1+\beta)}$$

$$\boxed{S'' = \frac{\partial I_C}{\partial \beta} = \frac{I_C\cdot S}{\beta(1+\beta)}}$$

if $S\downarrow$, S'' also $\downarrow$.

① Figure shows fixed bias ckt. Determine with $\beta = 100$
i) operating point (ii) the stability factor



Given:- $R_B = 530k\Omega$, $\beta = 100$.
$R_C = 2k\Omega$
$V_{CC} = 6V$. ; For Si TxR
$V_{BE} = 0.7V$.

Cal:- (V_{CEQ}, I_{CQ}).

Base ckt

$V_{CC} - I_B R_B - V_{BE} = 0 \Rightarrow 6 - I_B \cdot (530k\Omega) - 0.7 = 0$

$I_B = \frac{6-0.7}{530}\times10^{-3} = \frac{5.3}{530}\,mA \Rightarrow \frac{\cancel{5.3}}{\cancel{5300}_{100}}\times10^{-3} = 10^{-5} = 10\mu A$

$I_B = 10\mu A$

$I_C = \beta I_B \Rightarrow 100\times10\times10^{-6} = 1mA$

Collector ckt $V_{CC} - I_C R_C - V_{CE} = 0$

$6 - 1\times\cancel{10^{-3}}\times 2\times\cancel{10^{3}} - V_{CE} = 0$

$V_{CE} = 6-2 = 4V$.

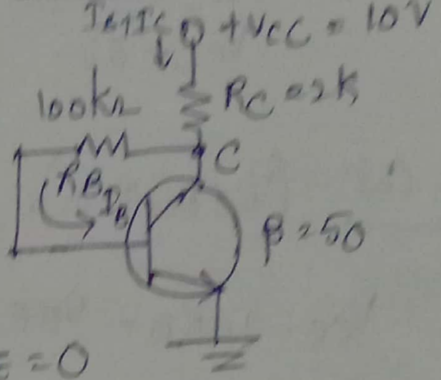
Operating point $(V_{CEQ}, I_{CQ}) = (4V, 1mA)$

Stability factor $(S) = 1+\beta = 101.$ // (For fixed bias)

⑦

Note:- The small value of stability factor indicates good bias stability, whereas large value of stability factor indicates poor bias stability. Ideal value of stability factor is zero. Since β is large quantity, this is a very poor bias stable ckt.

② Calculate the quiescent current and voltage of collector to base bias arrangement using the following data. $V_{CC} = 10V$, $R_B = 100k\Omega$, $R_C = 2k\Omega$, $\beta = 50$, (and also specify a value of R_B so that $V_{CE} = 7V$)



$I_{CQ}, V_{CEQ} = ?$

By applying KVL to base ckt

$$V_{CC} - (I_B + I_C)R_C - I_B R_B - V_{BE} = 0$$

$$V_{CC} - (I_B + \beta I_B)R_C - I_B R_B - V_{BE} = 0$$

$$V_{CC} - I_B(R_B + (1+\beta)R_C) - V_{BE} = 0$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta)R_C} = \frac{10 - 0.7}{100k + (1+50)\,2\times10^3}$$

$$I_B = 46\mu A$$

$$\because I_C = \beta \cdot I_B$$

$$I_C = 50\times(10^{-6}\times 46)$$

$$I_C = 2.3mA \,//$$

∴ By applying KVL to collector ckt

$$V_{CC} - (I_B + I_C)R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - (I_B + I_C)\cdot R_C$$

$$V_{CE} = 10 - (46\mu A + 2.3mA)(2\times10^3)$$

$$V_{CE} = 5.308V.$$

$$(V_{CEQ}, I_{CQ}) = (5.308V, 2.3mA)$$

(b) Given $V_{CE} = 7V$. ; $R_B = ?$

Soln.

$$V_{CC} - (I_C + I_B)R_E - V_{CE} = 0$$

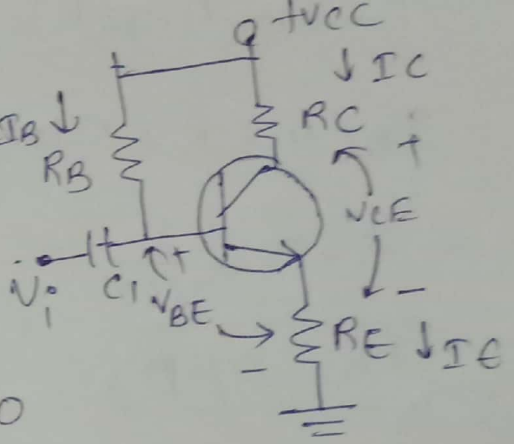
$$(I_C + I_B)R_E = V_{CC} - V_{CE}$$

$$(\beta I_B + I_B)R_E = V_{CC} - V_{CE}$$

$$I_B = \frac{V_{CC} - V_{CE}}{(1+\beta)R_E} = \frac{10-7}{(1+50)\times 2\times 10^3}$$

$$I_B = \frac{3}{51\times 2\times 10^3} = 29.41\mu A.$$

⊛ Emitter stabilized bias :-



By Applying KVL to Base ckt

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - I_B \cdot R_B - V_{BE} - (I_B + I_C)R_E = 0$$

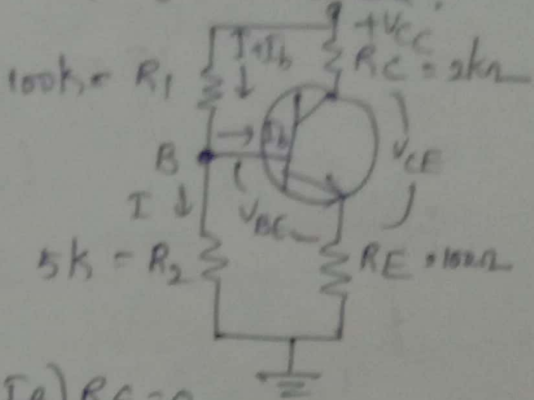
$$V_{CC} - V_{BE} - I_C \cdot R_E = I_B(R_B + R_E)$$

$$I_B = \frac{V_{CC} - V_{BE} - I_C R_E}{R_B + R_E}$$

$$\frac{\partial I_B}{\partial I_C} = \frac{-R_E}{R_B + R_E} \quad , \quad S = \frac{(1+\beta)}{1 + \beta \cdot \left(\frac{\partial I_B}{\partial I_C}\right)}$$

$$\therefore S = \frac{(1+\beta)}{1 + \beta\left(\frac{R_E}{R_B + R_E}\right)} \;//$$

③ For a ckt shown in fig. $V_{CC}=20V$, $R_C=2k\Omega$, $\beta=50$. V_{BE} sat $=0.2V$, $R_1=100k\Omega$, $R_2=5k\Omega$, $R_E=100\Omega$ Cal. I_B, V_{CE}, I_C.



∴ By Applying KVL at base ckt

$V_T - I_B \cdot R_B - V_{BE} - I_E \cdot R_E = 0$

$V_T - I_B(R_1 \| R_2) - V_{BE} - (I_B + \beta I_B)R_E = 0$

$1 - I_B(4.76k) - 0.2 - I_B(1+50)(100) = 0$

$I_B(4.76k + 5{,}100) = 1 - 0.2$

$I_B = \frac{0.8}{9860} = 0.0000811$

$\boxed{I_B = 81\mu A}$

$I_C = \beta \times I_B = 50 \times 81\mu$

$= 4050\mu A$

$\boxed{I_C = 4.050 mA}$

$R_1 \| R_2 = \frac{100 \times 5 \times 10^{-6}}{(105)k}$

$= \frac{500k}{105}$

$R_B = 4.76k\Omega$

$V_T = \frac{V_{CC} \times R_2}{R_1 + R_2}$

$V_T = \frac{20 \times 5k}{(105)k}$

$V_T = \frac{100}{105}$

$V_T \simeq 1V$.

$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$

$20 - 4.050mA - V_{CE} - (81\mu A + 4.050mA) = 0$

$V_{CE} = 20 - 4.050mA - (0.081mA + 4.050mA)$

$= 20 - 4.050mA - 4.131mA$

$V_{CE} = 20 - 0.008181$

$\boxed{V_{CE} = 19.991V}$