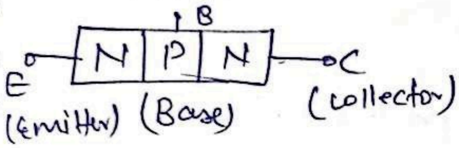
Bipolar Junction Transistor (BJT)

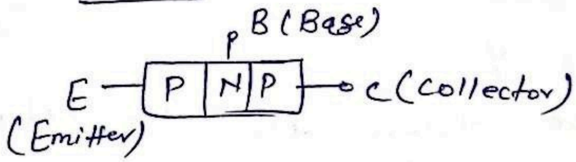
BJT is a three terminal Device which is mainly used as an Amplifier but also used as switch

Types

↳ NPN



PNP



Construction of BJT :-

Emitter (E) :- Highly Doped
Size → Moderate

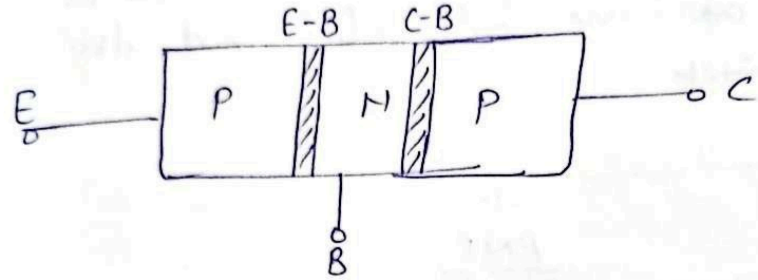
Collector (C) :- Doping → Moderate
Size → Large

Base (B) = Doping → Lightly doped
Size → thin

* Doping
E > C > B

* Size
C > E > B

Working of BJT

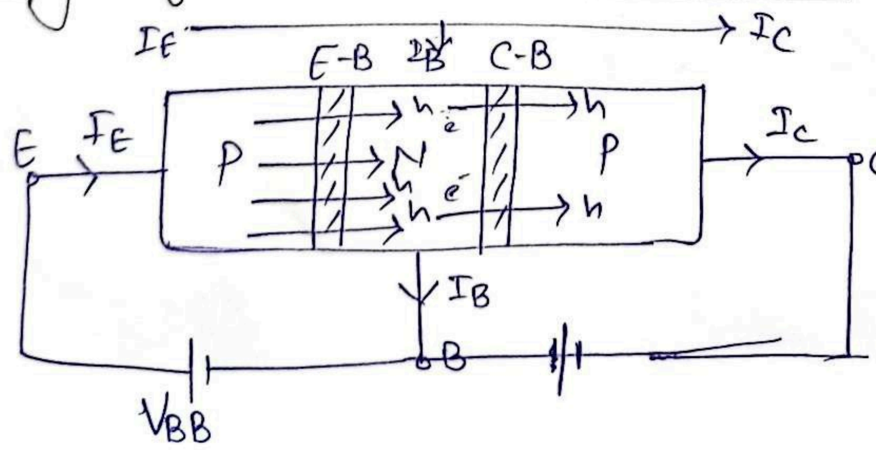


Modes of operation

Since there are 2 Junctions in BJT. Therefore we have to connect 2 Batteries one at each terminal and according to the connection of Bateries across the Junction the BJT will operates in total 4 modes, as follows:-

Mode	E-B Junction	C-B Junction	Application
Active	Forward	Reverse	Amplifier
Saturation	Forward	Forward	ON switch
cut off	Reverse	Reverse	OFF switch
Inverse-Active	Reverse	forward	PreAmplification

Working of BJT as an Amplifier



(1) E-B Junction should be Forward Biased.

E-B → depletion layer gets reduced

- The holes will move from emmiter to Base and the no. of holes moving from emmiter will constitute the emmiter current (I_E)
- As the holes enters the base they will recombine with the e^-'s but since base is lightly doped, there-fore very few holes will recombine in the Base and the no. of holes recombining in the base will constitue the Base current (I_B).
- The remaining holes in the Base will act as minority charge carriers and since these minority charge carriers have to move to the collector, therefore the collector Base Junction should always be reverse Bias and Hence the no. of holes will move from base to collector and constitute the collector current (I_C).

$$\boxed{I_E = I_B + I_C}$$

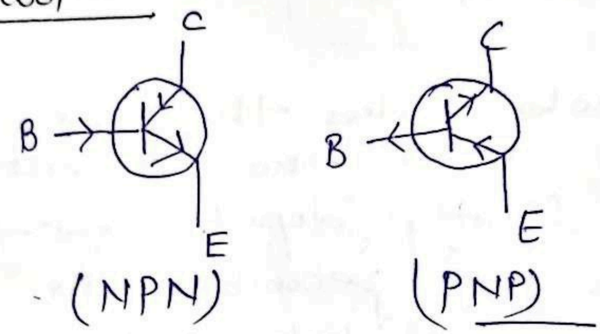
$$I_C = I_E - I_B$$

Majority Minority

That's why Bipolar called.

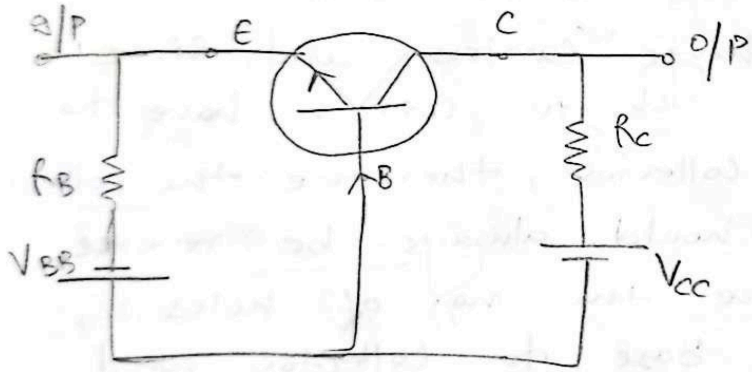
For Amplification Action since the signal is transfering from low resistance (E·B·) to High Resistance (C·B·) there-fore it is named as transistor· (Transfer + Resistor)

Transistor Symbol

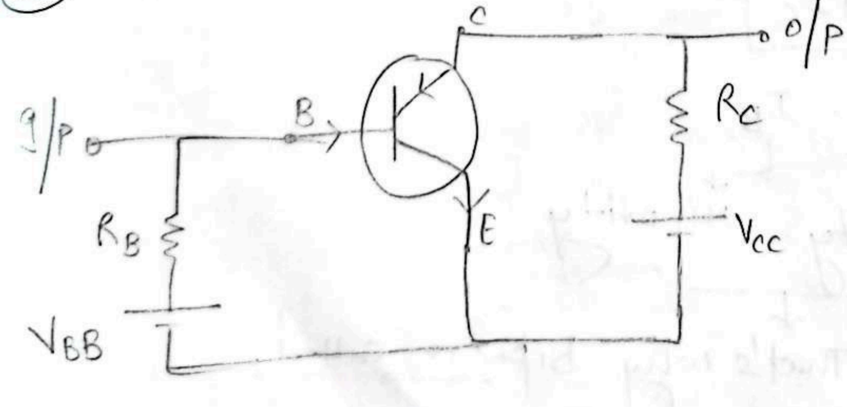


Transistor Configuration :-

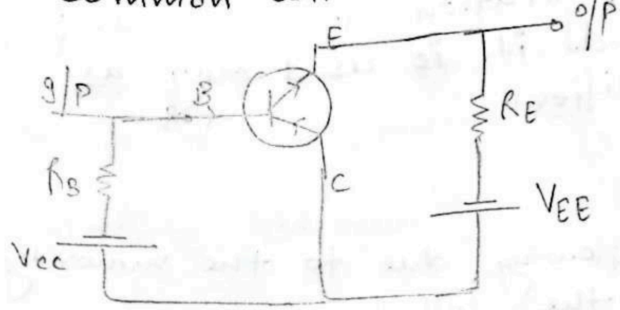
① common Base



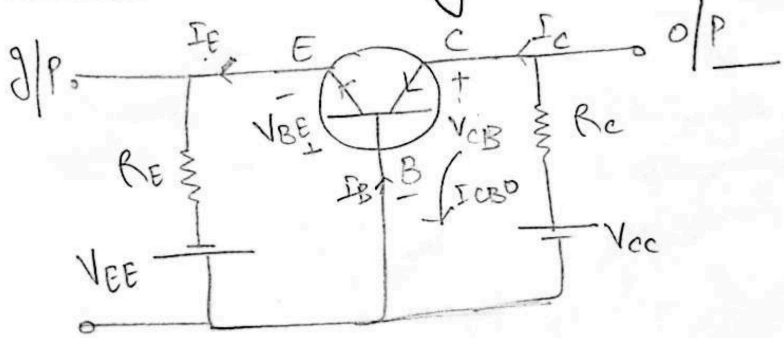
② common Emmiter



③ Common collector



Common base configuration



I_{CBO}
↳ collector to Base with emitter terminal open.

I/P current :- I_E

I/P Voltage = V_{BE} $\{V_{EB} = -V_{BE}\}$

O/P current = I_C

O/P Voltage = V_{CB}

current gain :- $\frac{\text{O/P current}}{\text{I/P current}}$

$$\boxed{\frac{I_C}{I_E} = \alpha}$$ → Amplification factor or current gain for common Base config^n.

$$\boxed{\alpha \leq 1}$$

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

Injected current

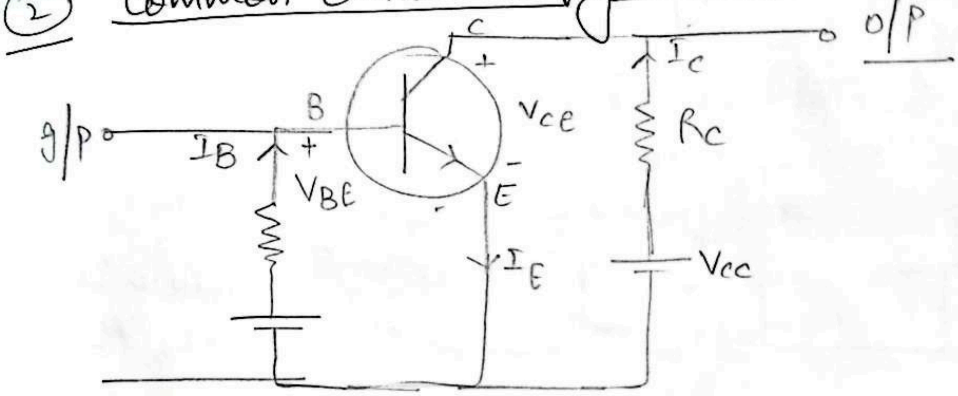
Reverse saturation current / leakage current

Since (α) is less than or equal to (1) therefore common base configuration does not amplify the current and it is used only as a voltage Amplifier.

* I_{CBO}

It is the current flowing due to the minority charge carriers of the collector.

② Common Emitter configuration



Input current = I_B

Input Voltage = V_{BE}

output Voltage = V_{CE}

Output current = I_C

$$\text{current gain} = \frac{\text{O/P current}}{\text{I/P current}} = \frac{I_C}{I_B} = \beta$$

β = It is the amplification factor or current gain for the common emitter configuration.

$$\boxed{\beta >> 1}$$

→ since I_C is very much greater than I_B therefore (β) will be very high and hence common Emitter circuit is used as a power Amplifier.

Relation between α and β

$$I_E = I_B + I_C$$

Divide whole eq^n with I_C

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

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

$$\boxed{\alpha = \frac{\beta}{1+\beta}} \quad \text{or} \quad \boxed{\beta = \frac{\alpha}{1-\alpha}}$$

Equation for I_C :-

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

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

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

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

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

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

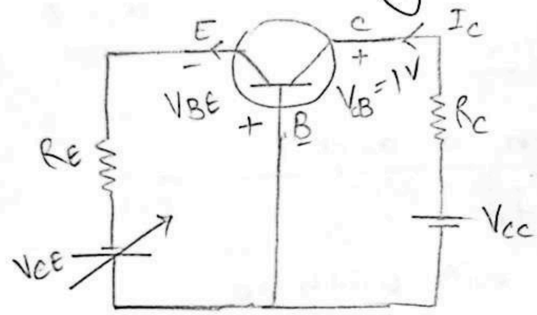
↓

leakage current more → Disadvantage

$$[I_C = \beta I_B + I_{CEO}]$$

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

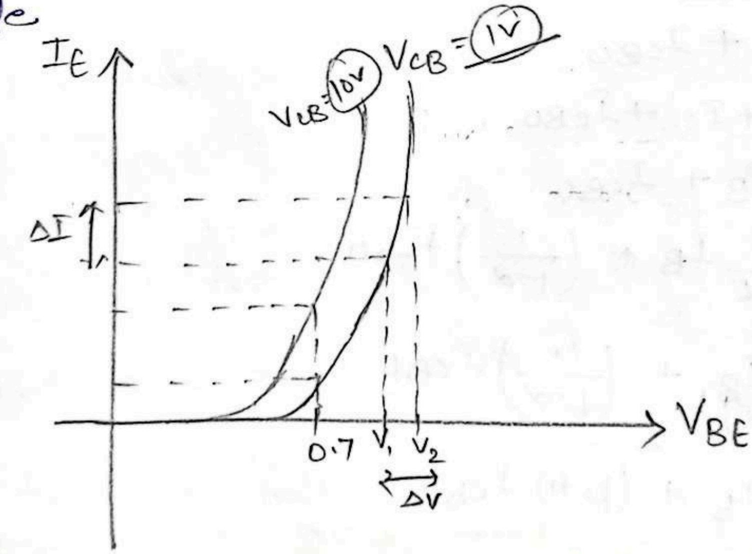
Input and output voltage characterstics (Imp) of common Base configuration.



Input characterstics

Input current v/s Input Voltage keeping output voltage constant I_E v/s V_{BE} keeping V_{CB} constant

* since Emitter Base Junction is Forward Biased therefore the Input Characterstics of the circuit will be similar to the forward Biased diode



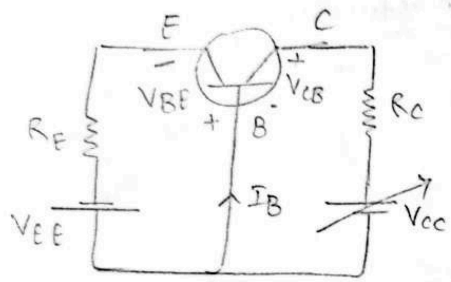
→ on Increasing the output voltage (V_{CB}) the input current (I_E) will increase

$$R_{in} = \frac{\Delta V}{\Delta I}$$

R_{in} is very low ($\Delta V << \Delta I$)

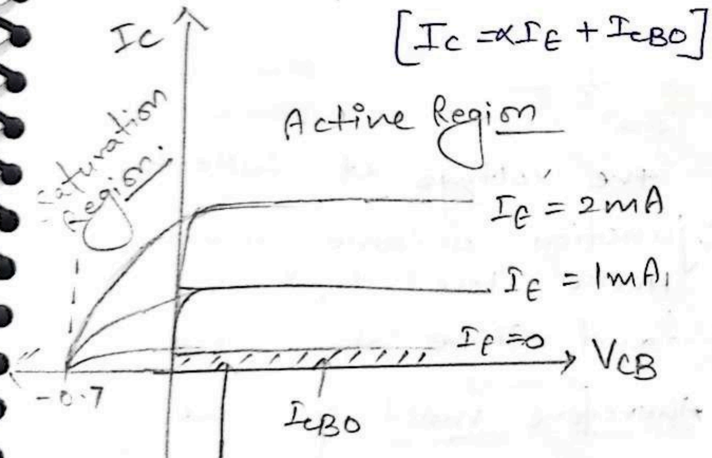
Output characterstics :- o/p current v/s o/p voltage keeping i/p current as constant

I_c v/s V_{CB} keeping I_E const.



→ Since the collector Base junction is Reverse Biased therefore, the output characteretics will be similar to the Reverse Bias diode and hence the diode current will remain const with respect to the output voltage

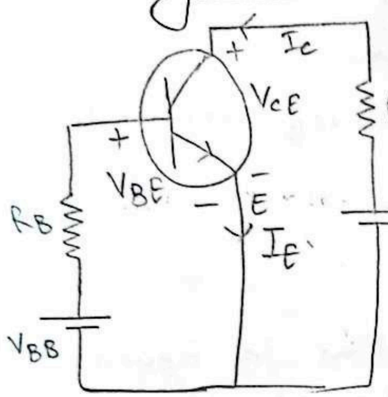
$$[I_C = \alpha I_E + I_{CBO}]$$



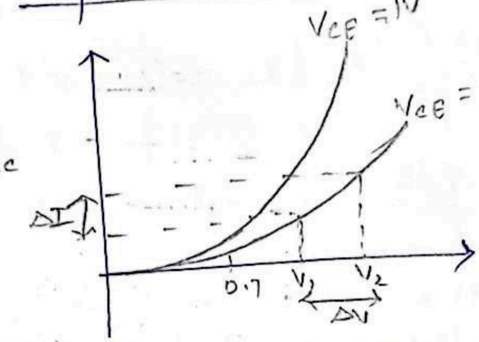
$$R_{out} = \frac{\Delta V_{CB}}{\Delta I_C}$$

R_{out} → very high

Input and output characterestics of common emitter configuration.



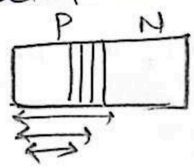
Input characterestics



$R_{In} = \frac{\Delta V_{BE}}{\Delta I_B}$

I_B v/s V_{BE} keeping V_{CE} constant

Early effect or Base width Modulation

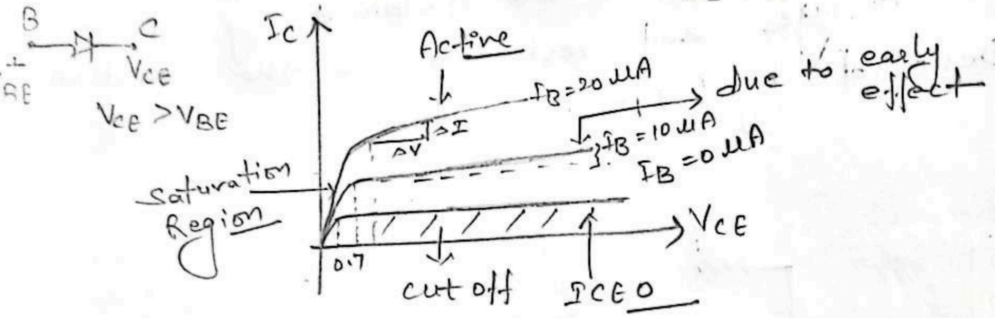


on increasing the the voltage at collector the collector base junction become more reverse bias and Hence the depletion layer gets increased and since the base is lightly doped therefore most of the depletion layer will enter in the base region due to which the effective width of the base get decreased and the base current also reduced. on increasing the output voltage, the base current gets decreased.

Output characteristics

I_C V/s V_{CE} keeping I_B constant

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



$$R_{out} = \frac{\Delta V_{CE}}{\Delta I_C}$$

R_{out} is high

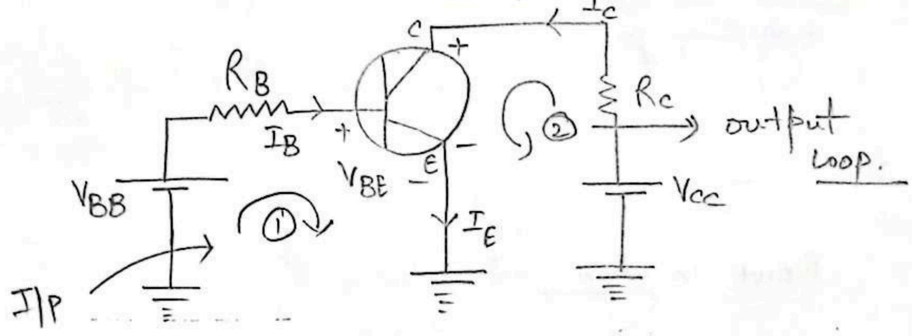
Why do we prefer common emitter over common base.

i) Common Emitter Amplifies the voltage as well as the current while common base Amplifies the voltage.

ii) Since the difference b/w input and output resistance of common emitter is comparitively lower in common Emitter circuit as compare to the common base therefore signal transfer will be higher in common emitter over the common base.

Operating point

Operating point is defined as the output Values of the circuit obtained by Applying DC Voltages and resistance to the transistor. Denoted by (Q) ⟶ Quiscent ⟶ still.



① Apply KVL in Input loop

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

Generally $V_{BE_Q} = 0.7V$

$$\boxed{I_B = I_{BQ} = \frac{V_{BB} - 0.7}{R_B}} \quad \text{—— ①}$$

② $\boxed{I_C = I_{CQ} = \beta I_{BQ}}$ —— ②

③ Apply KVL in O/P Loop

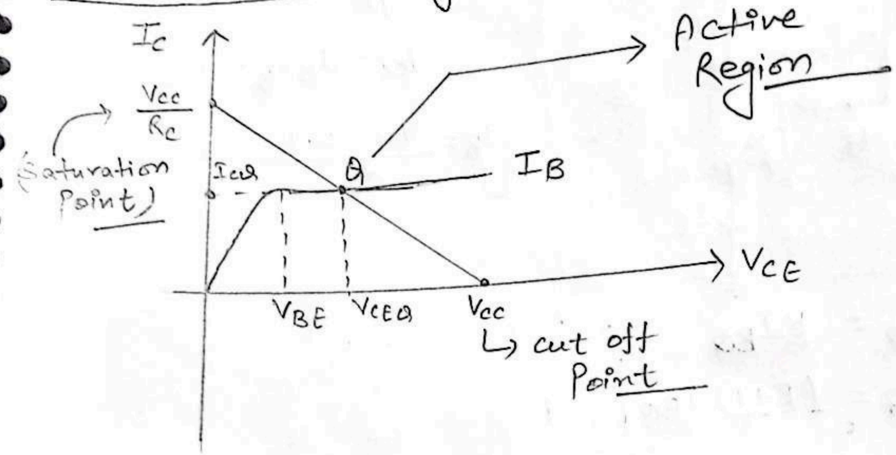
$$V_{CC} - I_C R_C - V_{CE} = 0$$

Put value of I_C from eq ②

$$\boxed{V_{CE_Q} = V_{CC} - I_{CQ} R_C} \rightarrow \text{(DC Load Line)}$$

$$I_{EQ} = I_{BQ} + I_{CQ}$$
$$= (\beta + 1) I_{BQ}$$

DC Load Line Analysis

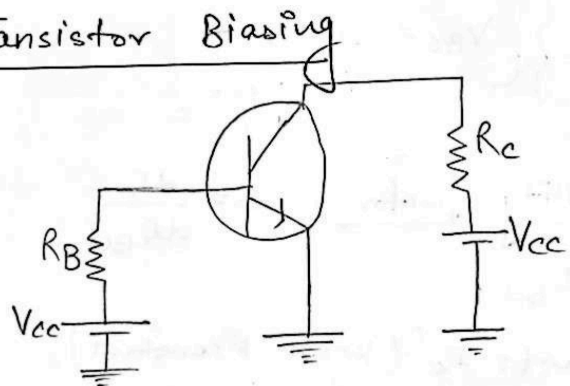


$$y = mx + c$$

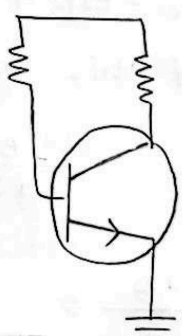
$$I_C = \frac{-V_{CE}}{R_C} + \frac{V_{CC}}{R_C} \quad \text{(From DC load Line eq}^n\text{)}$$

$$m = \frac{-1}{R_C} \longrightarrow \text{load}$$

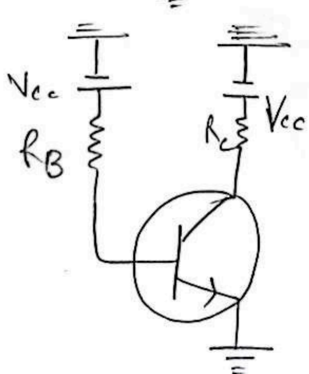
Transistor Biasing

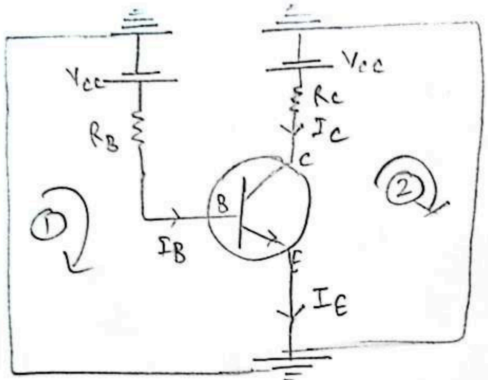


(OR)



(OR)





① I/P loop (KVL)

$$V_{cc} - I_B R_B - \cancel{V_{BE}} \xrightarrow{} 0.7 = 0$$

$$\left[I_B = \frac{V_{cc} - 0.7}{R_B} = I_{BQ} \right]$$

② $$\begin{bmatrix} I_{CQ} = \beta I_{BQ} \\ I_{EQ} = (\beta+1) I_{BQ} \end{bmatrix}$$

③ o/p loop (KVL)

$$V_{cc} - I_c R_c - V_{CE} = 0$$

$$\left[V_{CEQ} = V_{cc} - I_{CQ} R_c \right]$$

$$V_{BE} = V_B - \cancel{V_E} \rightarrow 0$$

$$V_{CE} = V_C - \cancel{V_E} \rightarrow 0$$

$$\left\{ \left[\begin{aligned} V_{BC} &= V_B - V_C \\ &= V_{BE} - V_{CE} \end{aligned} \right] \right.$$

Formula for stability factor :- $S = \dfrac{dI_C}{dI_{CBO}}$

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

Diff. this eqn wrt. I_c (keep β constant)

$$1 = \beta \frac{dI_B}{dI_c} + (\beta+1) \frac{dI_{CBO}}{dI_c}$$

$$\frac{dI_{CBO}}{dI_c} = \frac{1 - \beta \frac{dI_B}{dI_c}}{\beta + 1}$$

$$S = \frac{dI_C}{dI_{CBO}} = \frac{\beta+1}{1-\beta\frac{dI_B}{dI_C}}$$

For Fixed Bias ckt :-

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

Differentiate w.r.t. I_C

$$0 - \frac{dI_B}{dI_C} \times R_B - 0 = 0$$

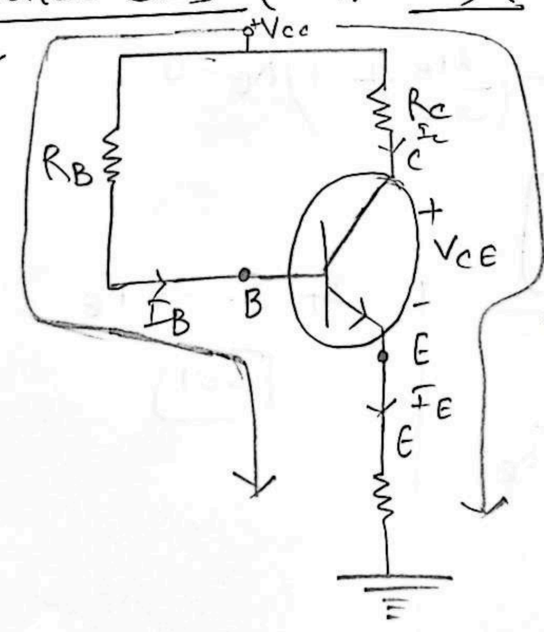
$$\frac{dI_B}{dI_C} = 0$$

So,

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

Since β is very high therefore the stability factor of fixed bias ckt is also very high and hence this ckt is not a stable ckt

Emitter Bias (Self Bias) :- (Imp)



① I/p Loop (KVL)

$$V_{CC} - I_B R_B - \overset{0.7}{V_{BE}} - I_E R_E = 0$$

Put $I_E = (\beta+1) I_B$

$$V_{CC} - I_B R_B - 0.7 - (\beta+1) I_B R_E = 0$$

$$\left[I_{BQ} = \frac{V_{CC} - 0.7}{R_B + (\beta+1) R_E} \right]$$

(2)
$$\left[\begin{array}{l} I_{CQ} = \beta I_{BQ} \\ I_{EQ} = (\beta+1) I_{BQ} \end{array}\right]$$

$$\boxed{I_C \simeq I_E}$$

(3) O/P loop (KVL)

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

$$\left[V_{CEQ} = V_{CC} - I_{CQ} R_C - I_{EQ} R_E\right]$$

$$V_E - \cancel{I_E R} \cdot I_E R_E = 0$$

$$\boxed{V_E = I_E R_E}$$

$$V_B = V_{BE} + V_E$$

$$V_C = V_{CE} + V_E$$

stability factor

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

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

Diff. wrt. I_C

$$0 - \frac{dI_B}{I_C} R_B - 0 - \left(\frac{dI_B}{dI_C} + 1\right) R_E = 0$$

$$\left[\frac{dI_B}{dI_C} = \frac{-R_E}{R_B + R_E}\right]$$

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

$$S < \beta + 1$$

If $R_B << R_E$

$$\boxed{S \simeq 1}$$