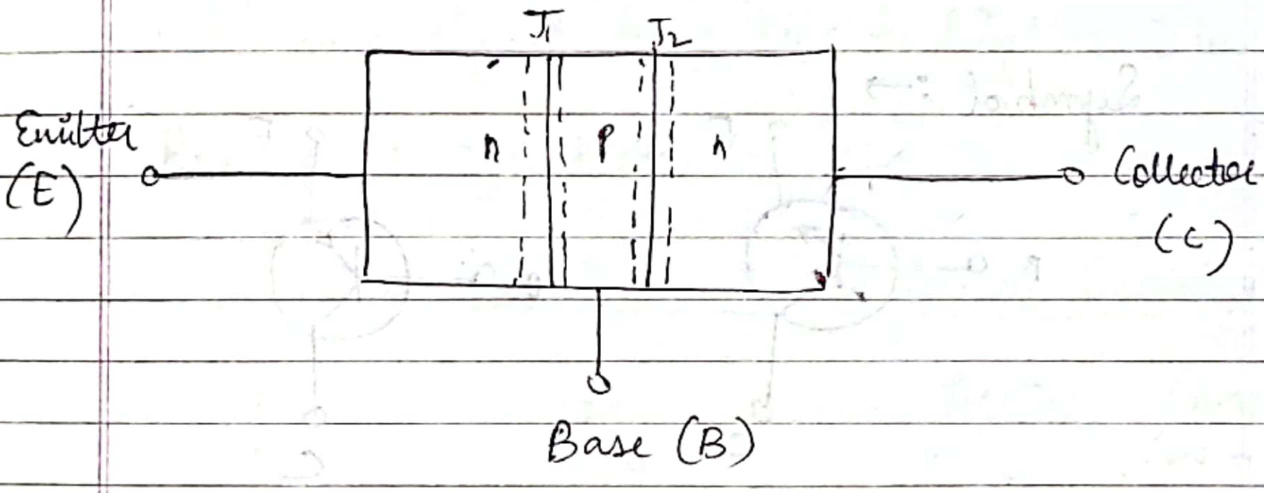
TRANSISTOR

→ Three layer semiconductor device, either with two n and one p material, or two p type and one n-type material.

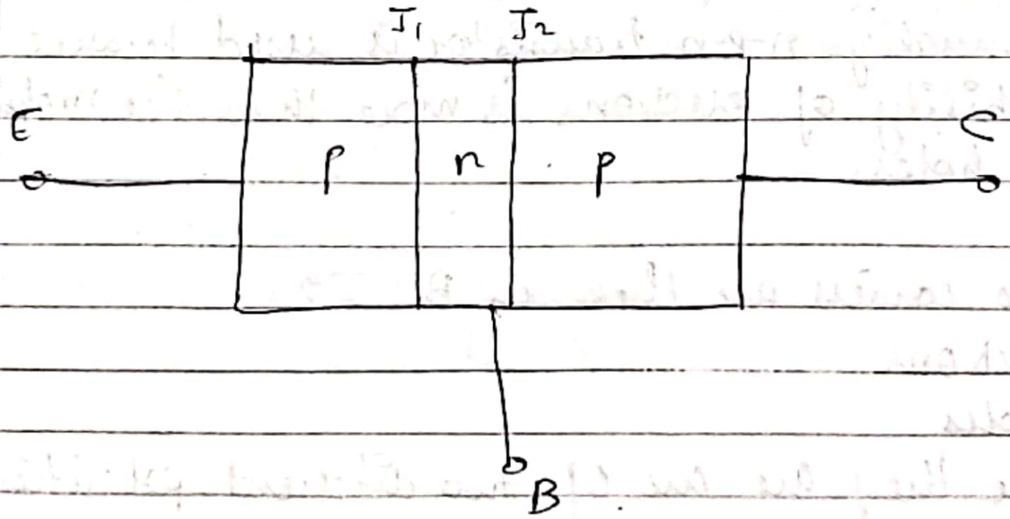
→ Former is npn, latter is pnp

→ There are 3 terminals, one taken from each semiconductor

→ Middle layer is thin as compared to the other two.

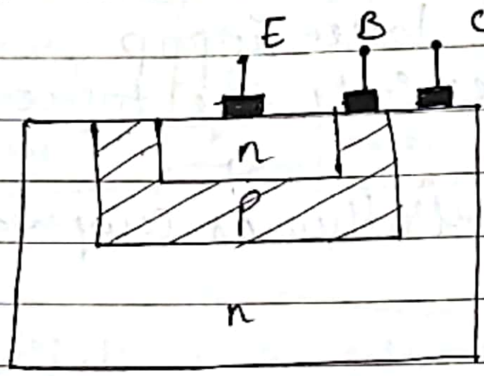


J_1 → Emitter-Base junction
J_2 → Base-Collector junction

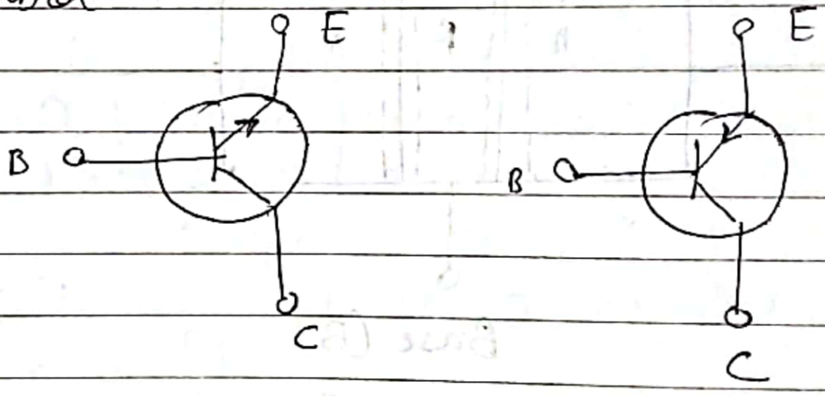


Width : C > E > B
Doping : E > C > B

Cross Section View :→



Symbol :→



→ Transistor can be considered as two diodes connected back to back.
→ Generally n-p-n transistor is used because the mobility of electrons is more than the mobility of holes.

Two carriers are there in BJT:
→ electrons
→ holes
Since they are are of two different polarities

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transistors are called Bipolar.
Also;
TRANSISTOR = TRANSFER + RESISTOR

If J_1 is → Forward Bias
→ It offers low resistance
J_2 is → Reverse Bias
→ It offers high resistance

Weak signal is introduced at low resistance & output is taken at high resistance. Thus BJT transfers signal from low to high resistance

Regions of operation:

J_1	J_2	Region of Operation
F.B	R.B	Active (Amplifier)
F.B	F.B	Saturation (ON → closed switch)
R.B	R.B	Cut-off (OFF → open circuit)
R.B	F.B	Inverted (rarely used) ↓ J_1, J_2 reverse their roles.

Active mode:
Ideal Condition →
- J_1 → FB Resistance = 0
- J_2 → R.B $R = \infty$

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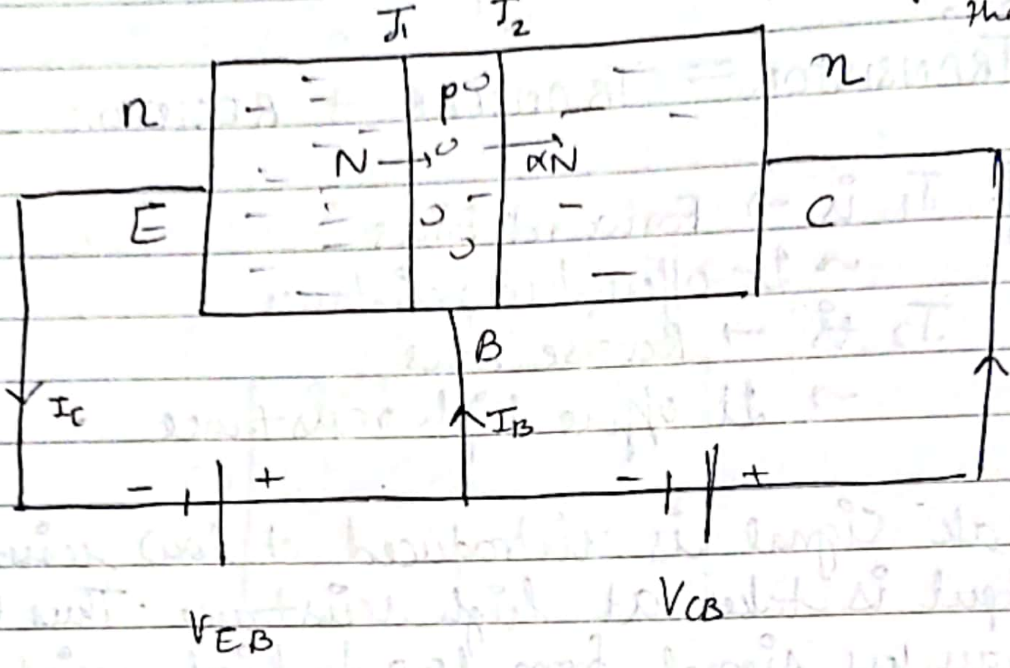
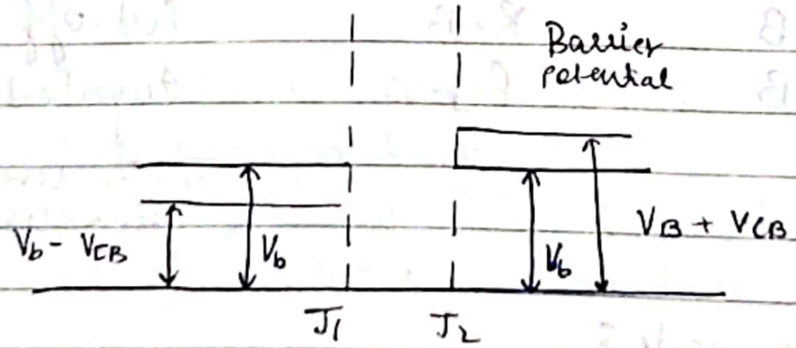
(N = no. of electrons entering base
αN = No. of electrons moving to the collector)



$J_1 \longrightarrow$ F.B $\qquad$ $J_2 \longrightarrow$ R.B

Initially before biasing, the barrier potential of junction J_1, J_2 was V_b.
After biasing: as J_1 is in F-B, its barrier potential ~~se~~ decreases while that of J_2 increase.



Because of the reduced barrier potential of J_1, e^- at emitter side will move to the base and recombine with holes in base.

Base → very small, lightly doped

Since base is very small and lightly doped there is very little recombination here. So more e^- will cross junction J_2 and they have high velocity, high kinetic energy. Only 2-5% e^- recombine in the base and 95-98% move to the collector.

Also since J_2 is reverse biased, there must be reverse saturation current. In collector minority charge carriers is holes, on p side electrons. So holes move towards base and e^- in base to collector. This reverse saturation current is also known as leakage current when J_2 is R.B.

I_{CO} = leakage current
(We measure this current when emitter terminal is open circuited)

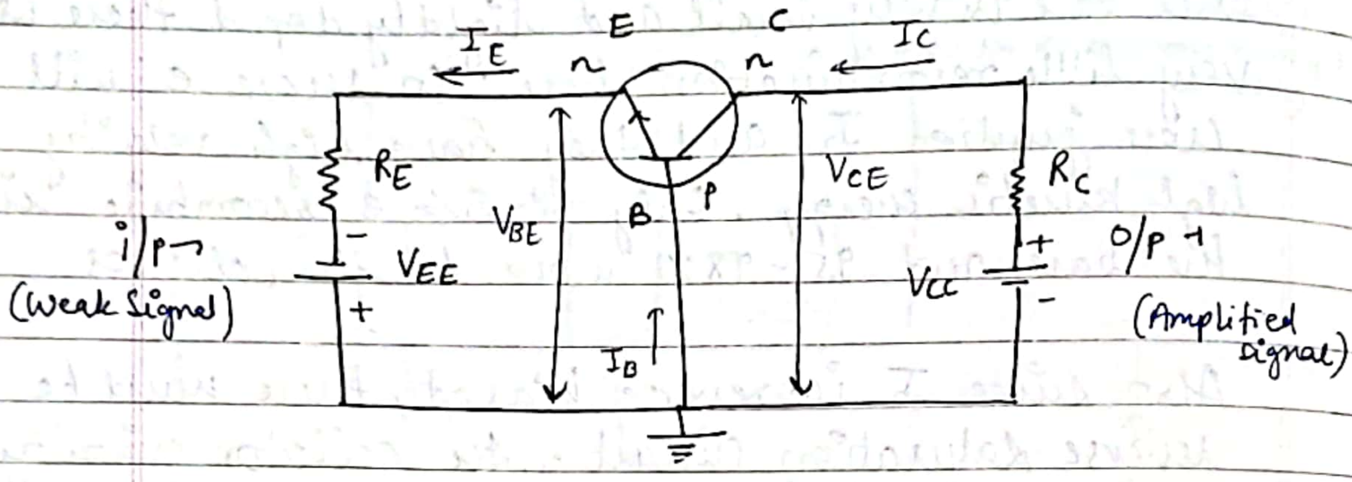
$$I_C = \alpha I_E + I_{CO}$$

By KCL:
$$I_E = I_B + I_C$$

Configurations:

i) Common Base
ii) Common Emitter
iii) Common Collector

i) Common Base:
Base is common in CB config. and it is grounded.



→ There is amplification of weak signal in active mode

$J_1 \rightarrow$ F.B

$J_2 \rightarrow$ R.B

i/p characteristics : I_E Vs V_{BE}

o/p characteristics : I_C Vs V_{CB}

- If we neglect $R_E \rightarrow V_{EE} = V_{BE}$
- If we neglect $R_C \rightarrow V_{CE} = V_{CC}$

$V_{BE} \rightarrow$ Emitter at lower potential

↑ Base at higher potential

V_{EB} ✗

By KCL :

$$I_E = I_B + I_C \quad \text{—— (1)}$$

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

$$I_E >> I_{CBO}$$

$$\therefore I_C = \alpha I_E \quad \text{—— (2)}$$

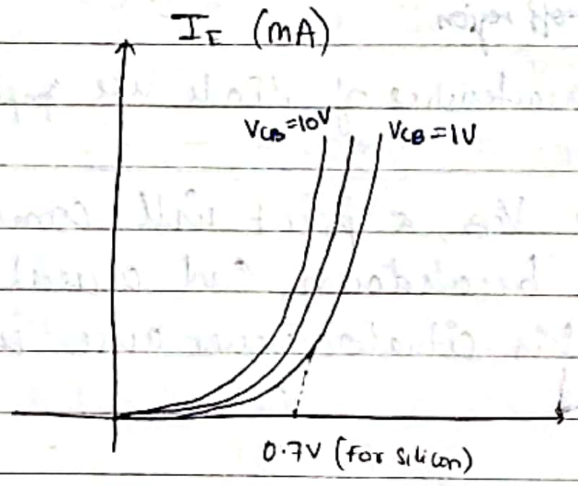
$$\boxed{\alpha = \frac{I_C}{I_E}}$$

$\alpha \Rightarrow$ Common base current gain / Amplification factor
Range of $\alpha \Rightarrow 0.95$ to 0.95

From ①, ②
$$I_B = (1-\alpha) I_E$$

Input Characteristics:

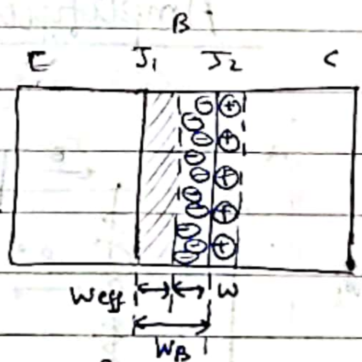
i/p current $\Rightarrow I_E$ i/p voltage $\Rightarrow V_{BE}$
o/p current $\Rightarrow I_C$ o/p voltage $\Rightarrow V_{CB}$



V_{BE} (V)

$V_{CB}\uparrow \Rightarrow I_E\uparrow$

Early Effect:



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

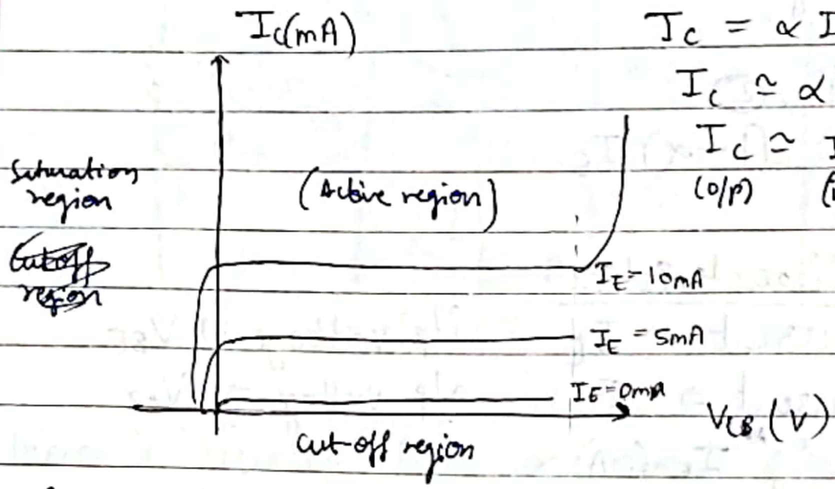
On increasing V_{CB}, reverse bias will increase so penetration of depletion layer in base will increase & hence W will increase.

$$W\uparrow \Rightarrow W_{eff}\downarrow$$

W_{eff} → Region where recombination takes place.
Chance of recombination reduces, $I_E\uparrow$

So $\boxed{V_{CB}\uparrow \Rightarrow I_E\uparrow}$

Output Characteristics:



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

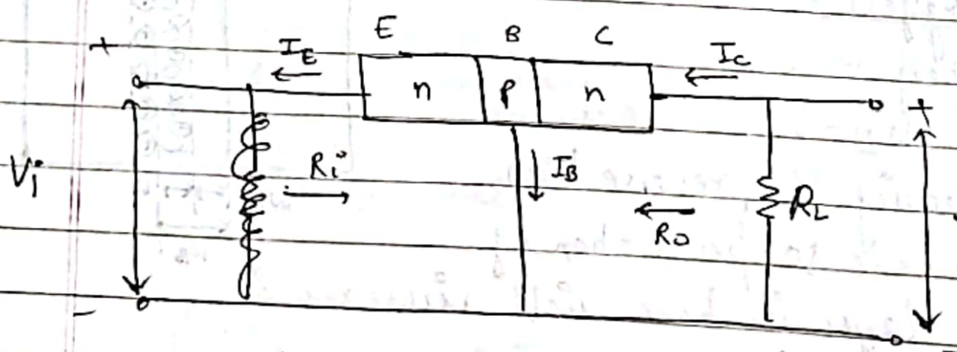
$$I_C \simeq \alpha I_E$$

$$\underset{(o/p)}{I_C} \simeq \underset{(i/p)}{I_E} \quad (\alpha = 0.95 \text{ to } 0.98)$$

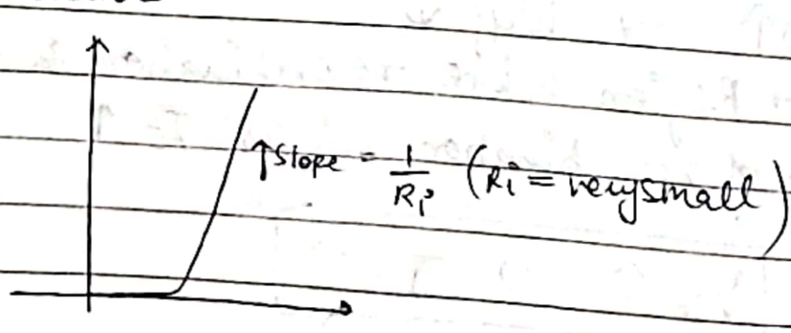
(reverse bias characteristics of diode like graph)

→ If we increase V_{CB}, a point will come where there will be breakdown and current will increase rapidly. But this situation never arises in transistor

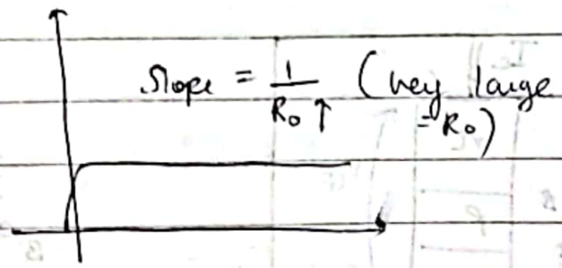
Amplifying Action:



I/P Charac ⇒



O/P Charact :-)



Taking $V_i = 200mV$, $R_L = 5k\Omega$, $R_i = 20\Omega$, $R_o = 100k\Omega$, $V_o = ?$

$$V_i = I_E R_i \Rightarrow I_E = \frac{V_i}{R_i}$$

$$I_E = \frac{200mV}{20\Omega} = 10mA$$

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

$$I_C \simeq \alpha I_E$$

$$I_C \simeq I_E$$

$$I_C = 10mA$$

$$V_o = I_C R_L$$

$$= 10mA \times 5k\Omega$$

$$\boxed{V_o = 50V}$$

$$V_i = 200mV \xrightarrow[\text{Amplification}]{} V_o = 50V$$

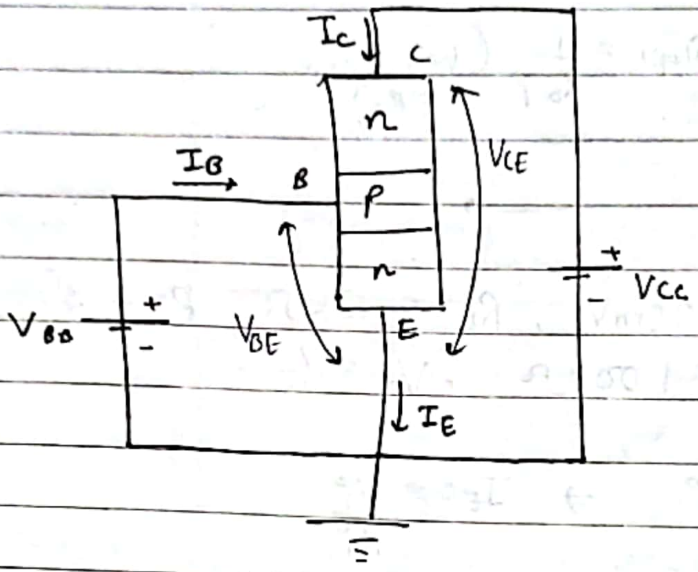
$$\boxed{A_V = \frac{V_o}{V_i}} \qquad A_V = \frac{50V}{200mV} = 50$$

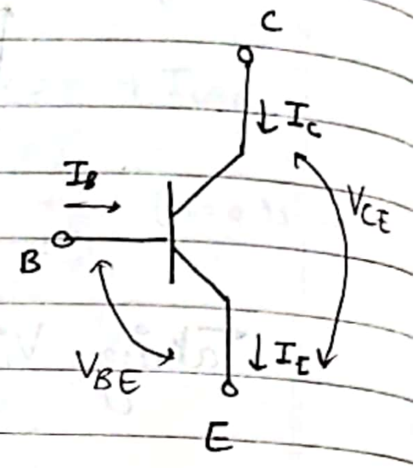
→ Input voltage is amplified 50 times

→ Range of A_V : 50 – 300

→ Range α : 0.95 – 0.99

Common Emitter: (Mostly used)





i/p current → I_B o/p current → I_C

i/p vol → V_{BE} o/p voltage → V_{CE}

KCL:

$$I_E = I_C + I_B \quad \text{——} (1)$$

$$I_C = \alpha I_E + I_{CBO} \quad \text{——} (2)$$

{ These 2 relations are true for any transistor connection }

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

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

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

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

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

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

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

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

$$\left\{\begin{array}{l} \Rightarrow \alpha < 1 \\ \Rightarrow \beta \text{ range} \Rightarrow 50 \text{ to } 400 \end{array}\right\}$$

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

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

$$I_{CEO} << \beta I_B$$

$$I_C = \beta I_B$$

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

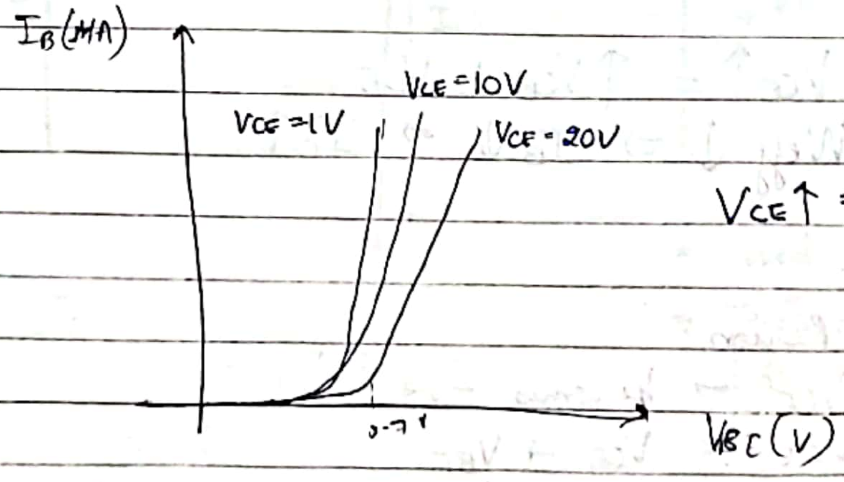
$\beta \rightarrow$ Current amplification factor

$\Rightarrow$ CE Configuration works as current amplifier

$\Rightarrow$ Leakage current (I_{CBO}) has more contribution in CE config and less contribution in CB Config.

$\Rightarrow$ Used as CURRENT BUFFER

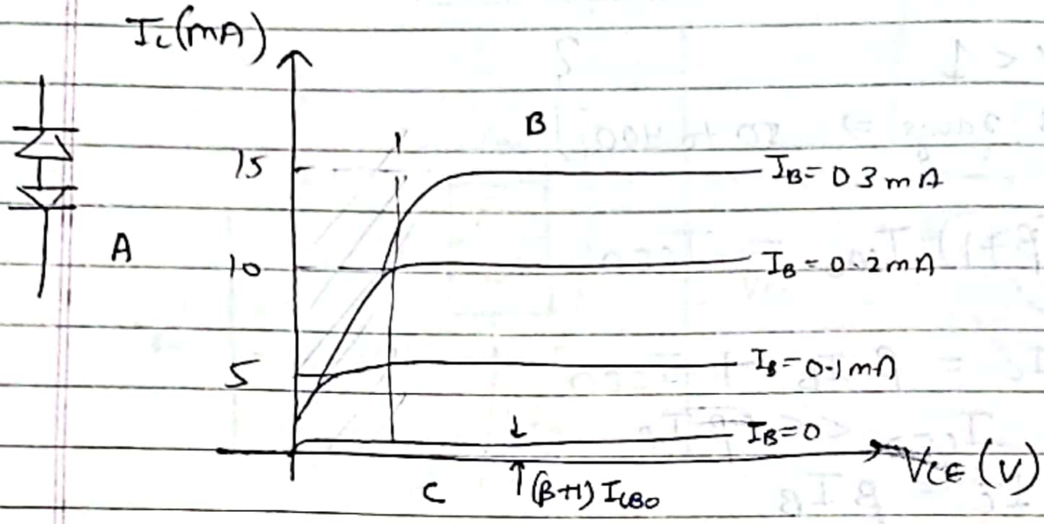
Input Characteristics :-



$V_{CE} \uparrow \Rightarrow I_B \downarrow$

Early effect : $V_{CE} \uparrow \Rightarrow V_{CB} \uparrow \Rightarrow W_{eff} \downarrow \Rightarrow W \uparrow \Rightarrow I_B \downarrow$

Output Characteristics



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

(when $I_B = 0$)

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

$I_B = 0.1\text{mA} \longrightarrow I_C = 5\text{mA}$

$I_B = 0.2\text{mA} \longrightarrow I_C = 10\text{mA}$

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{10-5}{0.2-0.1} = 50$$

$V_{CE}\uparrow = \uparrow V_{CB} + V_{BE}$

$W_{eff}\downarrow \Rightarrow I_B\downarrow \Rightarrow I_C\uparrow$

A Region:

$V_{CE} \rightarrow$ becomes $-$ve

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

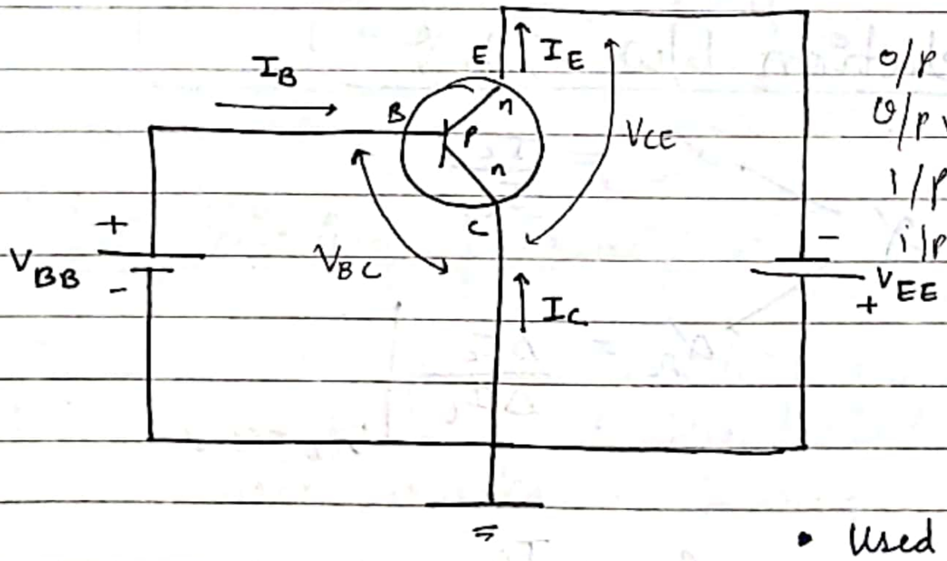
$V_{CB} = -V_{CE} - V_{BE}$

V_{CB} is now (−ve) which means V_{CB} is now in forward bias and direction of I_c will change. A is saturation region. Some of the shaded region is also a part of this because $V_{CE} > 0$ but it is very small so V_{CB} is still (-ve).

Region B :
It is active region because there is amplification of input signal.

Region C :
$I_B < 0 \Rightarrow$ So the direction Base current changes. Both diodes are reverse biased. This happens in cut-off region.

Common Collector :



o/p current = I_E
O/p voltage = V_{CE}
I/p current = I_B
I/p voltage = V_{BC}

- Used as voltage Buffer
- This configuration has highest input impedence

$$I_C = \alpha I_E$$
$$\alpha = 0.95 \text{ to } 0.98$$
$$I_C \simeq I_E$$

$$V_{CE} = V_B + V_{BC}$$

o/p characteristics of CE = o/p of CC as $(I_C \simeq I_E)$

γ = current amplification

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

$I_E = I_C + I_B$

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

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

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

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

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

Relation b/w α, β, γ

$\alpha \rightarrow \alpha_{DC} = \frac{I_C}{I_E}$

$\alpha \rightarrow \alpha_{AC} = \frac{\Delta I_C}{\Delta I_E}\Big|_{V_{CB} = const}$

$\beta \rightarrow \beta_{DC} = \frac{I_C}{I_B}$

$\beta \rightarrow \beta_{AC} = \frac{\Delta I_C}{\Delta I_B}\Big|_{V_{CE} = const}$

$$V_{DC} = \frac{I_E}{I_B}$$

V

$$V_{AC} = \frac{\Delta I_E}{\Delta I_B}\Bigg|_{V_{CE} = \text{const}}$$

$$I_E = I_C + I_B$$

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

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

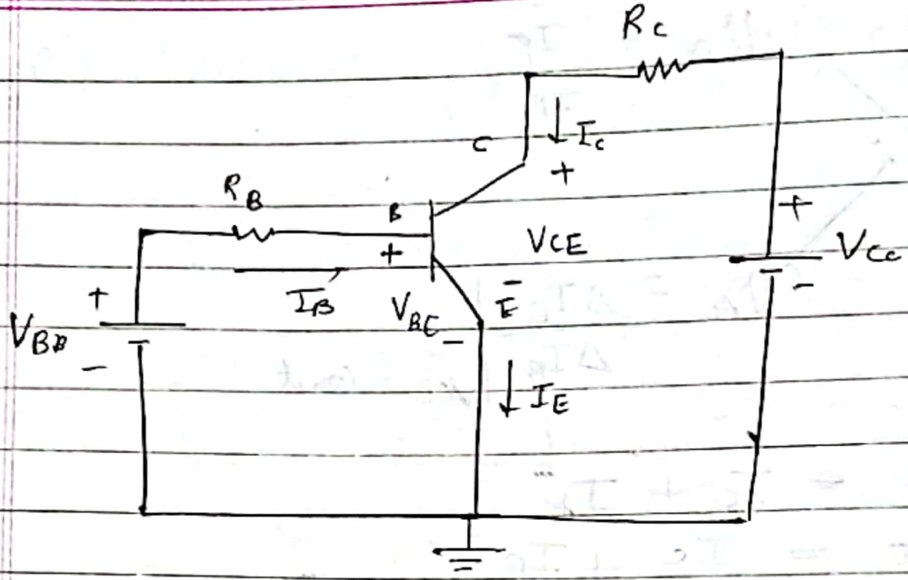
$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

$$\boxed{V = \frac{1}{1-\alpha}} \qquad \boxed{V = \beta + 1}$$

DC Biasing of Transistors

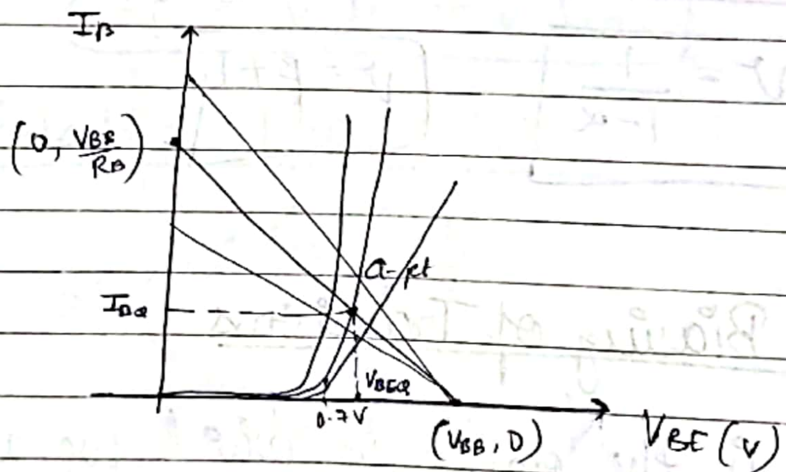
Biasing is the process in which we apply external DC Voltages to establish the desired operation point. These networks are biasing networks.

- Active Region
- Saturation Region
- ~~both~~ cut-off region
  (npn (CE))



→ If we apply an input signal, we want the output signal without any distortion. We do not want any portion of output waveform to be clipped this is <u>faithful amplification</u> of input signal.

i/p operating pt →



KVL:

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

when $V_{BE} = 0$, $I_B = V_{BB}/R_B$

$I_B = 0$, $V_{BE} = V_{BB}$

Slope $= -1/R_B$

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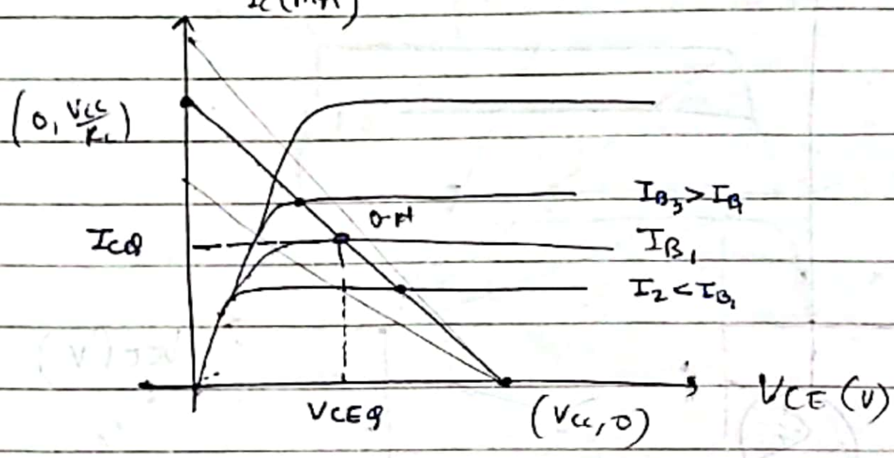
o/p operating pt :-



KVL :

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

When $V_{CE} = 0$ $\quad I_C = V_{CC}/R_C$

$I_C = 0$ $\quad V_{CE} = V_{CC}$

Slope $= -1/R_C$

⇒ Setting of operating point is basic thing for amplification of weak signal. ~~becaus~~

⇒ Operating pt. should be in the middle of load line, if not have distortionless output signal.

⇒ When operating point is near the cut-off region the positive part of waveform is clipped.

⇒ When operating point is near the saturation region the negative portion of the waveform is clipped. or swing (strength) is reduced.

⇒ This is why operating pt. should be selected in the middle of active region for max. swing & min distortion otherwise it results in UNFAITHFUL AMPLIFICATION.

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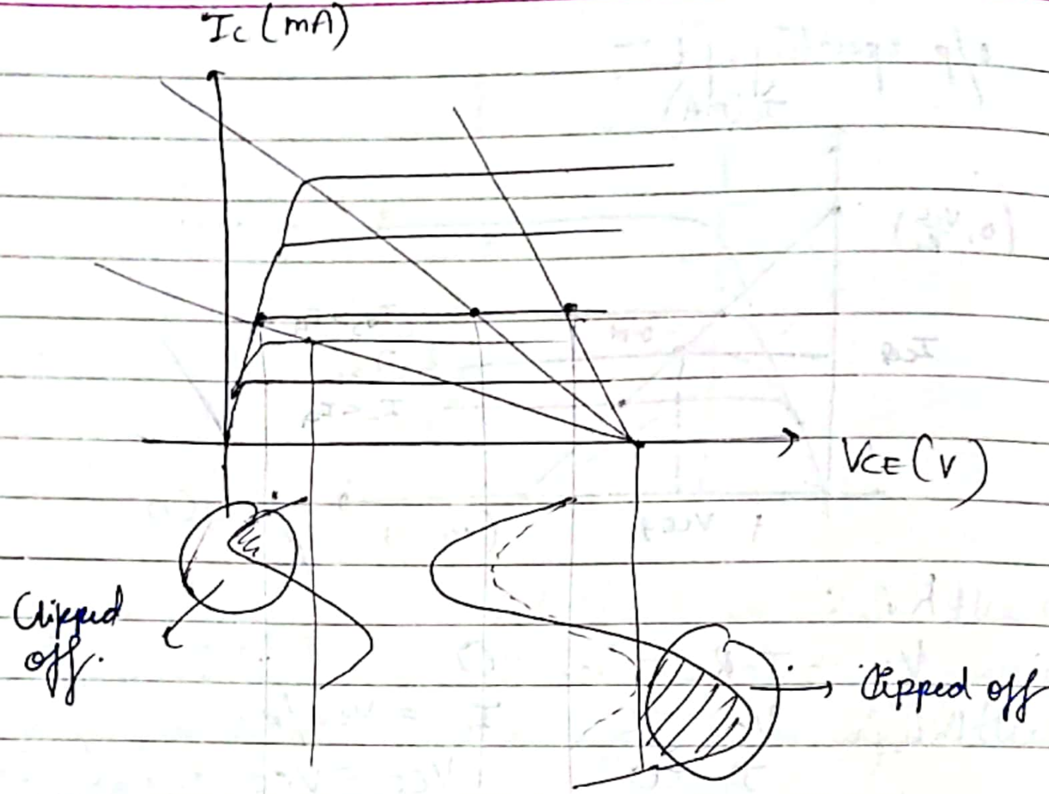


→ Once Q-point is fixed, it should not change with collector current.

I_C may change

→ Change in β

(No two ~~sam~~ transistors have same β)

$$I_C = \beta I_B$$

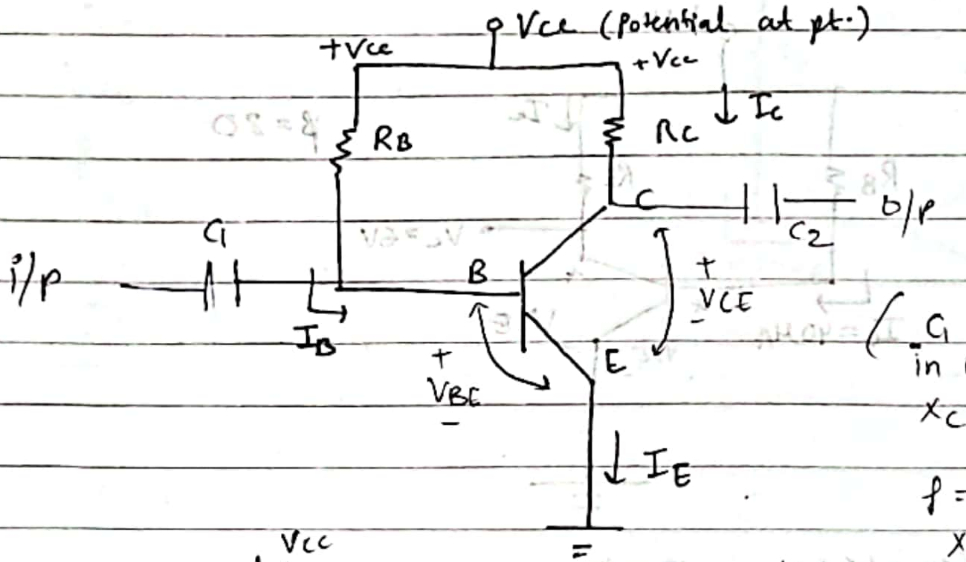
→ Change in T

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

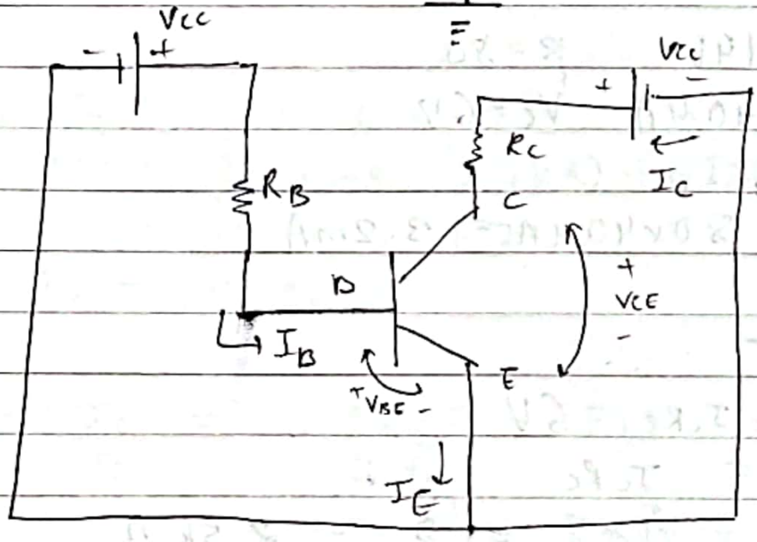
T changes, sat current changes due to effect on minority charge carriers

$$T\uparrow \Rightarrow I_{CBO}\uparrow \Rightarrow I_C\uparrow$$

Fixed-Bias Config (Base bias Config)



(C_1 & C_2 are ignored in DC analysis because
$$X_C = \frac{1}{2\pi f C}$$
$f = 0$ in DC
$X_C = \infty$, so it would make the capacitor open circuit)



(i/p) KVL:

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

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

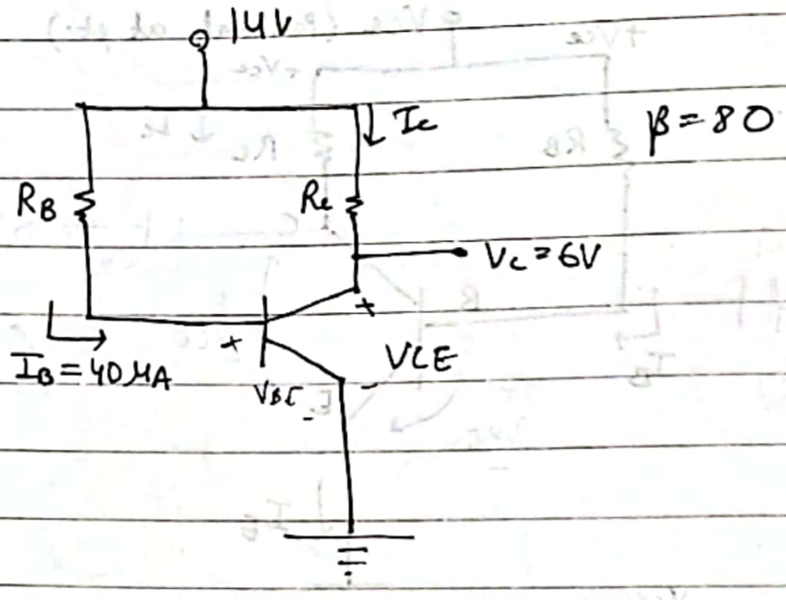
$$I_C = \beta I_B = \beta \frac{(V_{CC} - V_{BE})}{R_B}$$

(o/p) KVL:

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

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

Q. Find i) I_c ii) R_c iii) R_B iv) V_{CE}



$V_{CC} = 14V$ $\quad \beta = 80$

$I_B = 40\mu A$ $\quad V_c = 6V$

i) $I_c = \beta I_B$

$= 80 \times 40\mu A = 3.2mA$

ii) $14V - I_c R_c = 6V$

$8 = I_c R_c$

$R_c = \frac{8}{I_c} = \frac{8}{3.2mA} = 2.5k\Omega$

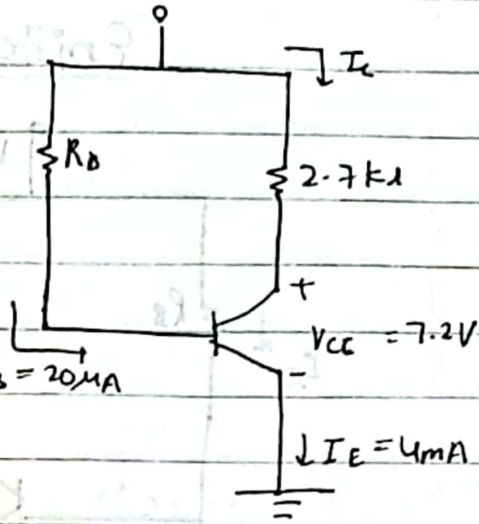
iii) $14 - I_B R_B - V_{BE} = 0$

$R_B = \frac{14 - V_{BE}}{I_B} = \frac{13.3\ V}{40\mu A}$

$= 332.5k\Omega$

iv) $V_{CE} = V_c - V_E = 6 - 0 = 6V$

Q. Determine
a) I_c
b) V_{cc}
c) β
d) R_B



i) $I_E = I_c + I_B$

$I_c = I_E - I_B$

$= 4mA - 20\mu A$

$I_c = 3.98 mA$

ii) $V_{cc} - I_c(2.7k\Omega) - 7.2V = 0$

$V_{cc} = (3.98\ mA)(2.7k\Omega) + 7.2V$

$= 10.746\ V + 7.2V$

$V_{cc} = 17.946V$

iii) $\beta = \frac{I_c}{I_B} = \frac{3.98mA}{20\mu A} = 199$

iv) KVL:

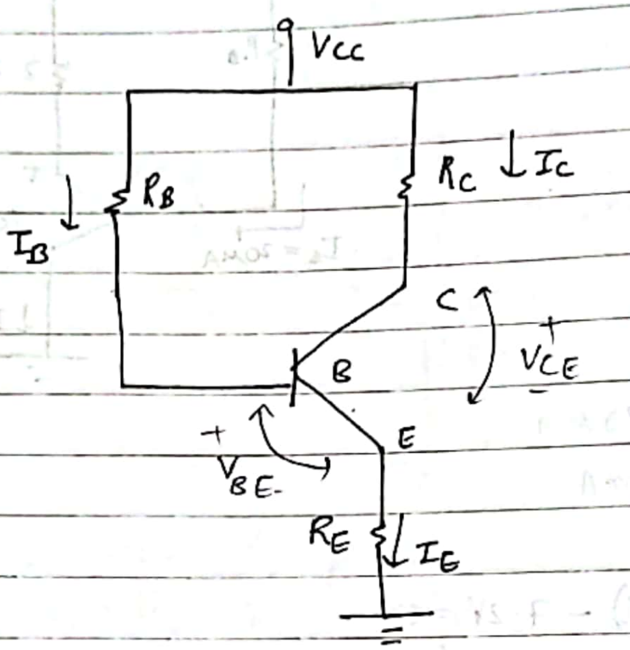
$V_{cc} - I_B R_B - V_{BE} = 0$

$17.946V - 20\mu A \times R_B - 0.7V = 0$

$R_B = \frac{17.946V - 0.7V}{20\mu A}$

$R_B = 862.3k\Omega$

Emitter Bias Config



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

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

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

$$I_C = \beta I_B$$

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

O/p loop:

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

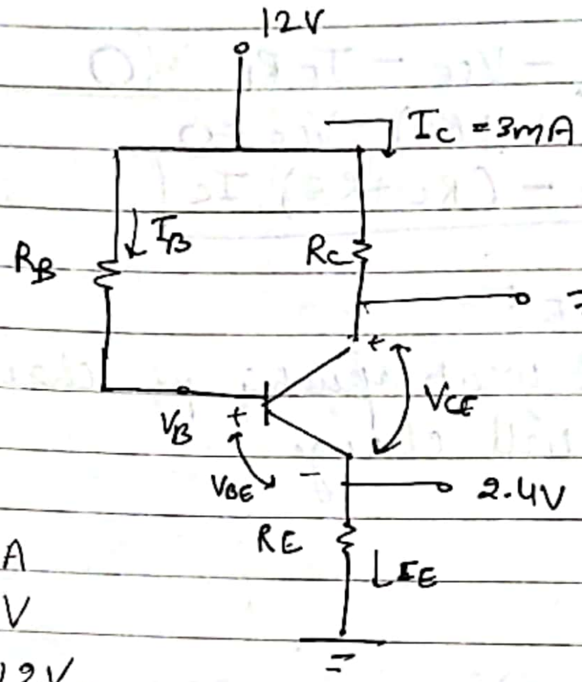
$$V_{CC} - I_C(R_C + R_E) - V_{CE} = 0$$

$$\boxed{V_{CE} = V_{CC} - (R_C + R_E) I_C}$$

Why to use RE:

We do not want operating pt change. If we take I_C, Q-pt will change.

Q. Find: R_C, R_E, R_B, V_{CE}, V_B



$\beta = 80$

$I_C = 3mA$

$V_C = 7.6V$

$V_{CC} = 12V$

$\beta = 80 \quad V_E = 2.4V$

$\Rightarrow \quad V_{BE} = 0.7V \; (Si)$

$$V_B - V_E = 0.7$$
$$V_B = 2.4 + 0.7$$
$$V_B = 3.1V$$

$\Rightarrow$
$$V_{CE} = V_C - V_E$$
$$= 7.6 - 2.4$$
$$V_{CE} = 5.2V$$

$\rightarrow$
$$12 - I_B R_B = 3.1$$
$$I_B = I_C/\beta = \frac{3mA}{80} = 37.5\mu A$$
$$R_B = \frac{12 - 3.1}{37.5 \times 10^{-6}} = 237.4 k\Omega$$

$\Rightarrow$ $2.4 - I_E R_E = 0$

$I_E \approx I_C$

$\frac{2.4V}{3mA} = R_E$

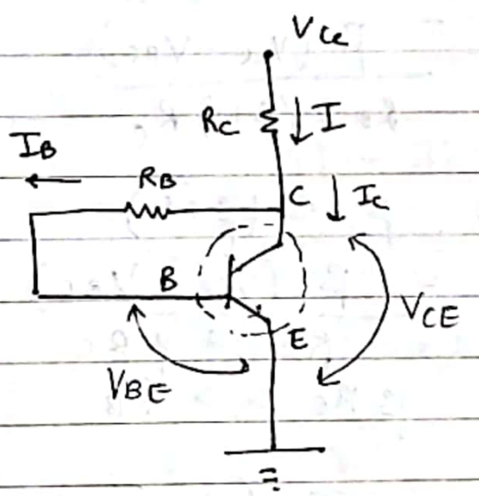
$R_E = 0.8\,k\Omega$

$\Rightarrow$ $12 - I_C R_C = 7.6$

$\frac{12 - 7.6}{3m} = R_C$

$R_C = 1.47\,k\Omega$

Collector feedback Biasing



$I = I_C + I_B$

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

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

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

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

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

KVL ~~to~~ o/p:

$$V_{CC} - IR_C - V_{CE} = 0$$

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

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

Advantages:

→ It stabilises the Q-point

1) Against the variation of Temperature (T)
2) Against the variation of biasing voltage Vcc
3) Again the variation of β

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

Now $\beta \simeq (\beta+1)$

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

also $\beta R_C >> R_B$

$$I_C = \frac{\cancel{\beta} (V_{CC} - V_{BE})}{\cancel{\beta} R_C}$$

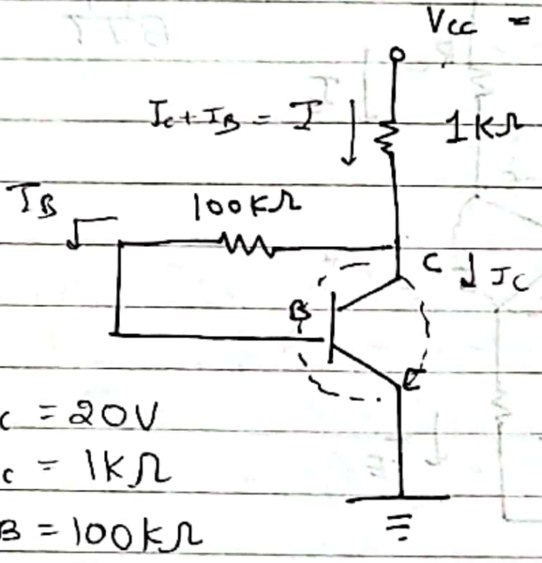
(so its independent of β)

Disadvantages:

For iii) advantage $\beta R_C >> R_B$. Many times we don't know value of β so, we have to make $R_C \uparrow\uparrow$ or $R_B \downarrow\downarrow$. If $R_C \uparrow\uparrow$, Vcc should be also $\uparrow\uparrow$, which means cost

Increases & precautions also increase. ~~R~~ Also Reverse Bias of Collect - Base junction ↓↓.

Q. Determine the Operating point:



$\beta = 100$

$V_{CC} = 20V$
$R_C = 1k\Omega$
$R_B = 100k\Omega$

$Q_{pt} = (I_C, V_{CE})$

$$V_{CC} - (I_C + I_B)(1k\Omega) - I_B(100k\Omega) - 0.7V = 0$$

$$I_C = \beta I_B$$

$$I_B = \frac{V_{CC} - 0.7}{(\beta+1)(1k\Omega) + 100k\Omega}$$

$$I_B = \frac{20 - 0.7}{(100)(1k\Omega) + 100k\Omega} = \frac{19.3\,V}{201k\Omega}$$

$$I_B = 0.096mA$$

$$I_B = \cancel{96mA}\ 96\mu A$$

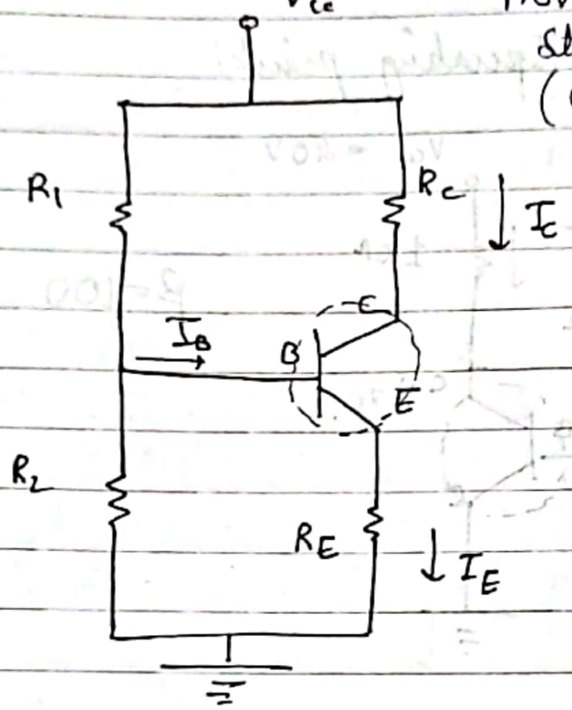
$$I_C = \beta I_B = 9.6mA$$

Now, $20V - (I_C + I_B)(1k\Omega) - V_{CE} = 0$

$$V_{CE} = 10.304V$$

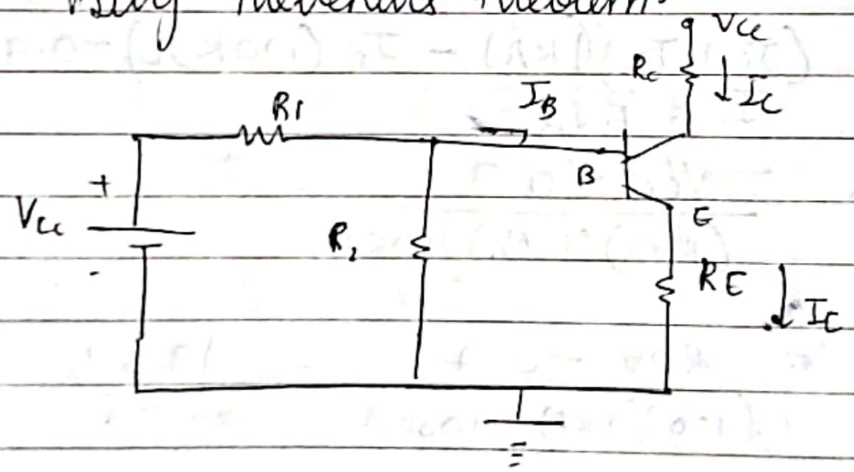
$$Q_{pt} = (9.6mA, 10.304V)$$

VOLTAGE DIVIDER BIAS

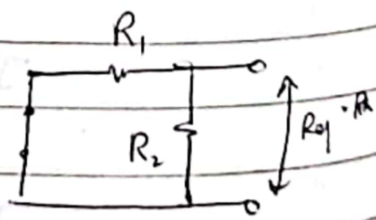


- Provides the best stabilisation of Q-point (Operating point) for BJT

Using thevenin's theorem:-



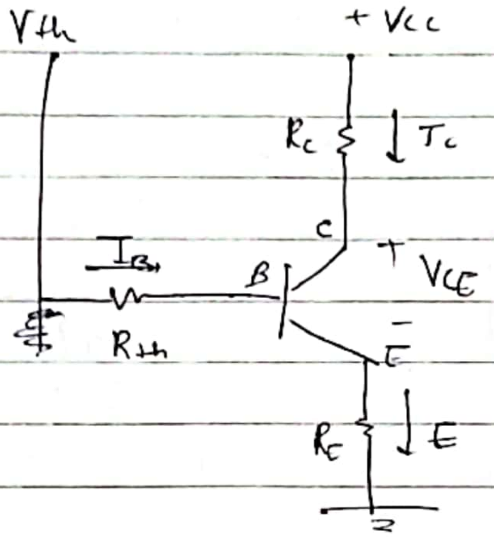
$$R_{th} = (R_1 \| R_2) = \frac{R_1 R_2}{R_1 + R_2}$$



$$I = \frac{V_{cc}}{R_1 + R_2}$$

~~V_{th}~~

$$V_{th} = IR_2 = \frac{R_2 V_{cc}}{R_1 + R_2}$$



$$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$$

$$V_{th} - I_B R_{th} - V_{BE} - (\beta+1) I_B R_E = 0$$

$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (\beta+1) R_E}$$

$$I_C = \beta I_B = \frac{\beta (V_{th} - V_{BE})}{R_{th} + (\beta+1) R_E}$$

$$R_{th} << (\beta+1) R_C$$

Now,

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

$$I_E \simeq I_C$$

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

$$\Rightarrow V_{CE} = V_{CC} - I_C (R_C + R_E)$$

ADVATANGES :

- Mostly Used Bias Config.
  $R_{th} << (\beta+1) R_E$ and since $R_{th} = R_1 || R_2$ it is already small