B.J.T [Bipolar Junction Transistor]

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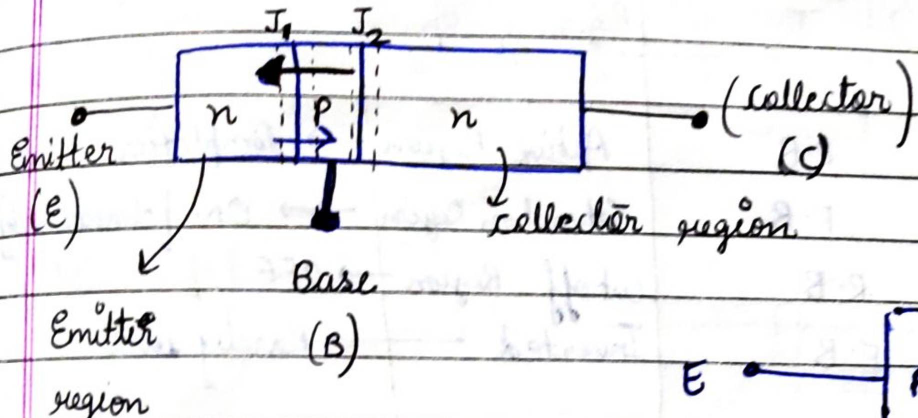
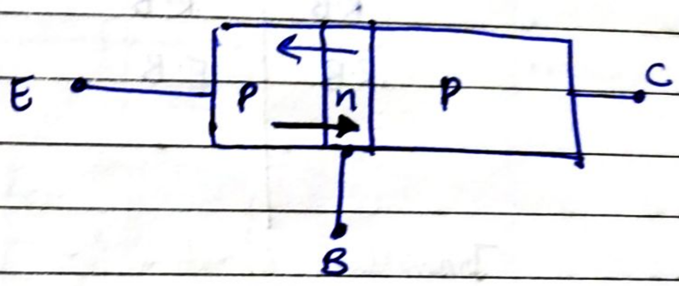
Physical Structure :-





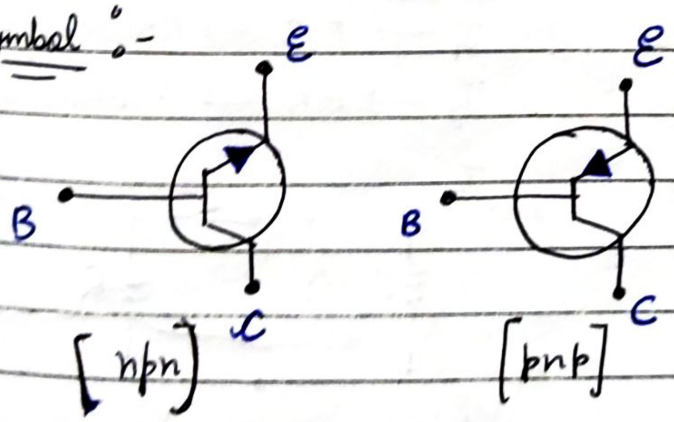
$J_1 \longrightarrow$ emitter-base

$J_2 \longrightarrow$ collector-base

☆ Width :- $C > E > B$

☆ Doping :- $E > C > B$

Symbol :-



• Bipolar Junction Transistor :-

① $e^{\ominus}$
② holes

Transistor ⇒ Transfer + Resistor

$J_1 \rightarrow$ Forward biased

$J_2 \rightarrow$ Reverse biased

Regions of Operation :-

J_1	J_2	Region of Operation
F·B	R·B	Active Region → Amplifier
F·B	F·B	Saturation Region → ON [closed switch]
R·B	R·B	cut off Region → OFF [open switch]
R·B	F·B	Inverted → Rarely used

Transistor Operation :-

B J T

B → [Bipolar] [e, holes]

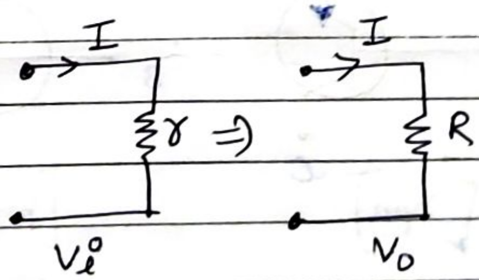
J → [Junction]

T → Transistor ⇒ Transferred Resistor

Active Mode :-

$J_1 \rightarrow F \cdot B \rightarrow$ Resistance ≠ 0

$J_2 \rightarrow R \cdot B \rightarrow$ Resistance ≠ ∞



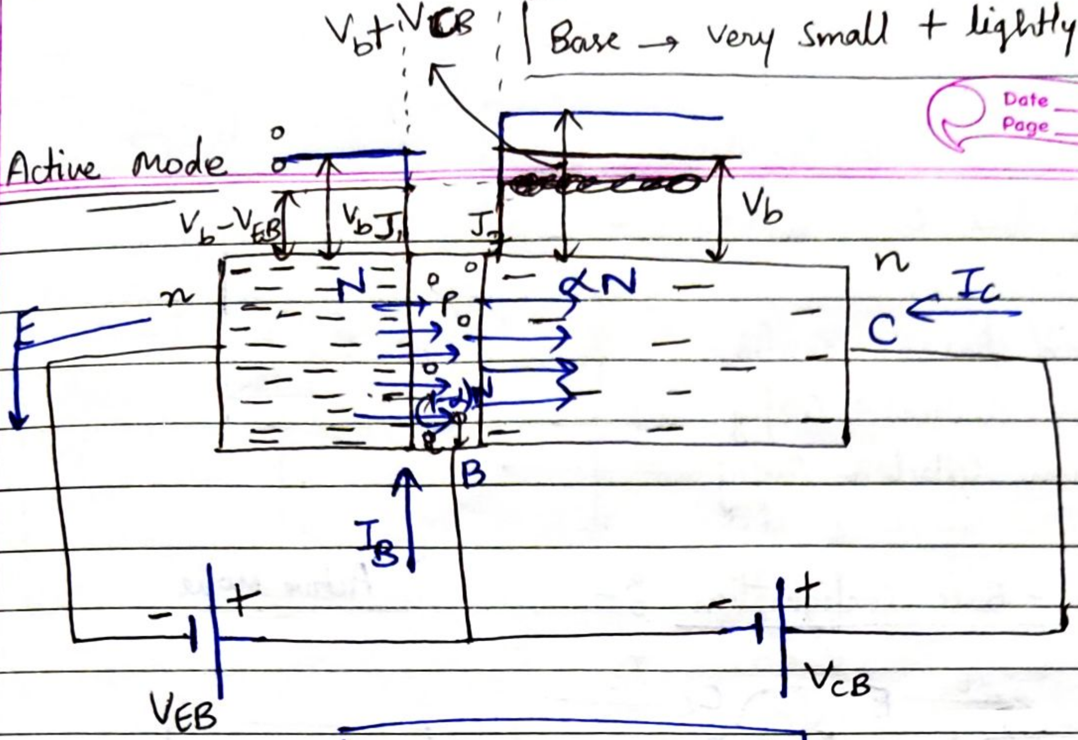
$V_i = I \times r$ $\qquad$ $V_0 = I \times R$

$[R > r]$

$\boxed{V_i < V_0}$ [Amplification]

Base → very small + lightly doped

Active Mode :-



I_{CO} → Reverse sat-current or Leakage current

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

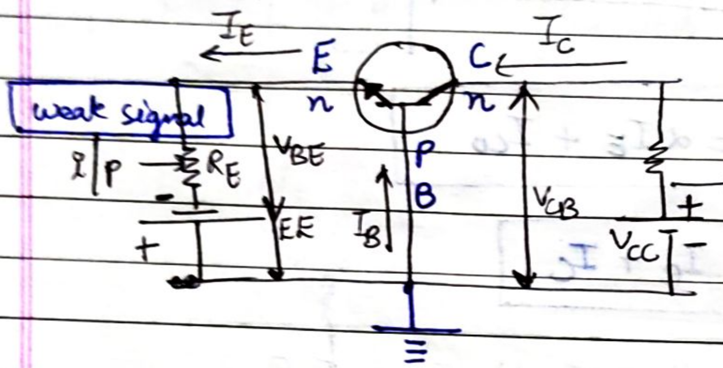
KCL :- $\boxed{I_E = I_B + I_C}$

Active Mode :- Emitter Base Junction (J_1) is F.B
Collector Base Junction (J_2) is R.B

- B, E and C

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

→ Common - Base Configuration :- Active Mode



$J_1 \to$ F.B

$J_2 \to$ R.B

i/p characteristic :-

I_E Vs V_{BE}

$J_1 \to$ EB Diode

$J_2 \to$ BC Diode

o/p characteristic :-

I_C Vs V_{CB}

Active Mode

KCL :- $\boxed{I_E = I_B + I_C} \to (1)$

$I_C = \alpha I_E + I_{CO}$ → Reverse saturation current

or

$\boxed{I_C = \alpha I_E + I_{CBO}}$ → Reverse saturation current when emitter terminal is open

$I_E >> I_{CBO}$

$\boxed{I_B = (1-\alpha) I_E}$ $I_C = \alpha I_E$ $\boxed{\alpha = \frac{I_C}{I_E}}$ I_C → o/p, I_E → i/p

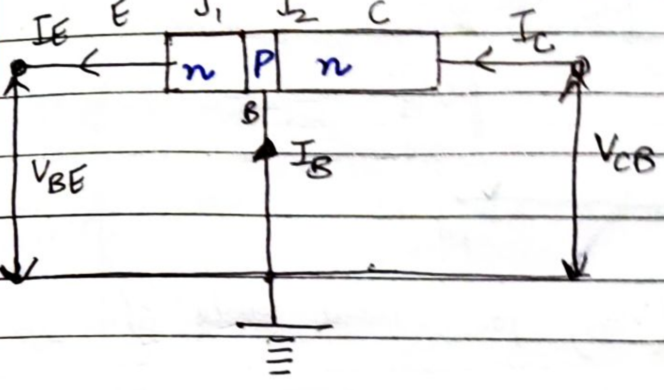
gain $= \frac{o/p}{i/p}$

Common base current gain / amp. factor

$\alpha = 0.95 - 0.98 \to 95\% - 98\%$

Common Base Transistor [Input Characteristics]

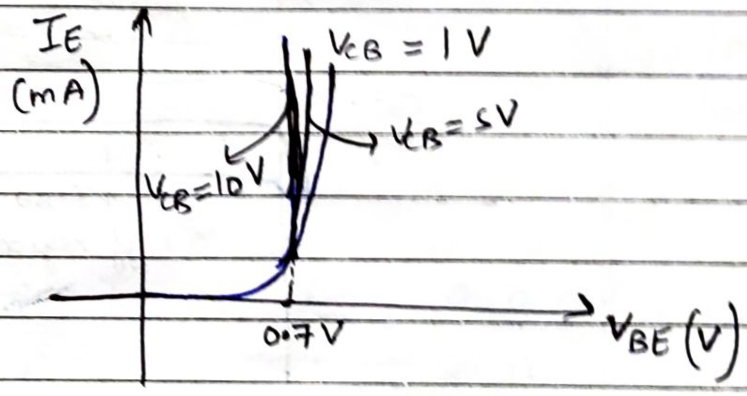
F.B Diode   Early Effect



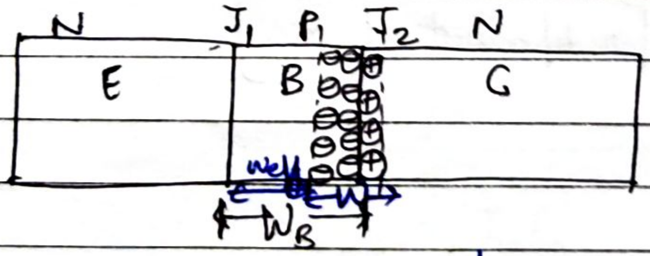
i/p I vs i/p V for different o/p V.

$i/p\ I = I_E$
$i/p\ V = V_{BE}$
$o/p\ V = V_{CB}$
$o/p\ I = I_C$

$\boxed{V_{CB}\uparrow \rightarrow I_E\uparrow}$



Early Effect :- [Base width Modulation]



$J_1 \Rightarrow F.B$ $J_2 \Rightarrow R.B$
$V_{CB}\uparrow \rightarrow R.B\uparrow$

$W_B \Rightarrow$ width of the Base / Metallurgical base width

Doping :-
E > C > B

$V_{CB}\uparrow$ R.B $\uparrow$ W $\uparrow$
R.B increase $\Rightarrow$ Depletion layer will increase
$W_{eff} = W_B - W\uparrow$
$W_{eff} \Rightarrow \downarrow$

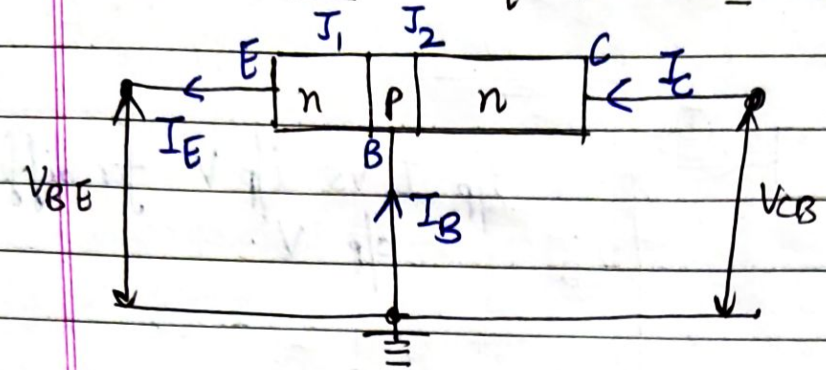
☆ $\boxed{R.B\uparrow\downarrow \Rightarrow W.B\uparrow\downarrow}$

① $W_{eff} \Rightarrow \downarrow$
Less Recombination $\Rightarrow \alpha\uparrow$
$I_C = \alpha I_E + I_{CBO}$
$\boxed{\alpha\uparrow\ I_C\uparrow}$

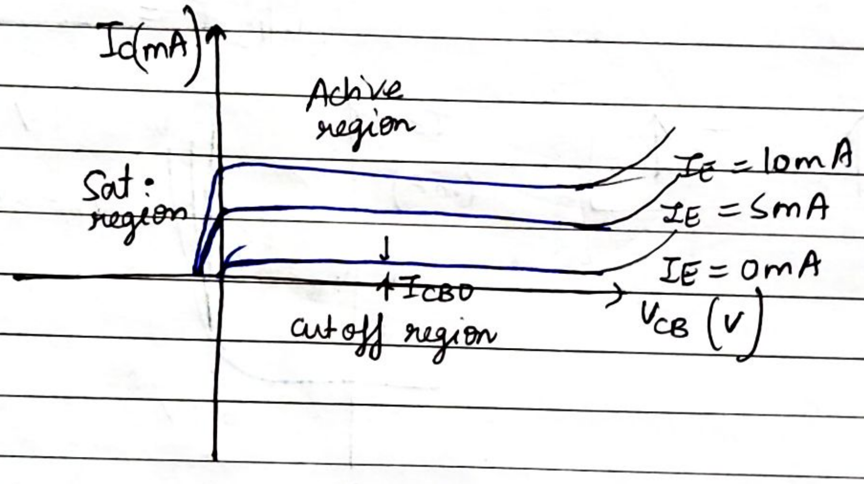
② conc. gradient $\uparrow$
$\boxed{I_E\uparrow}$

Reverse Biased Diode

Common Base Transistor [Output Characteristics]



O/p I (I_C) Vs O/p V (V_{CB}) for various levels of i/p I (I_E).



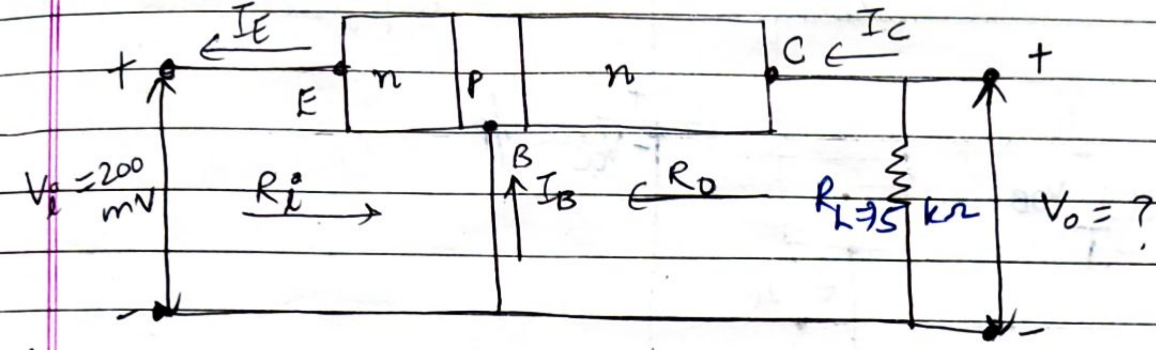
$I_c = \alpha I_E + I_{CBO}$ [independent of V_{CB}]

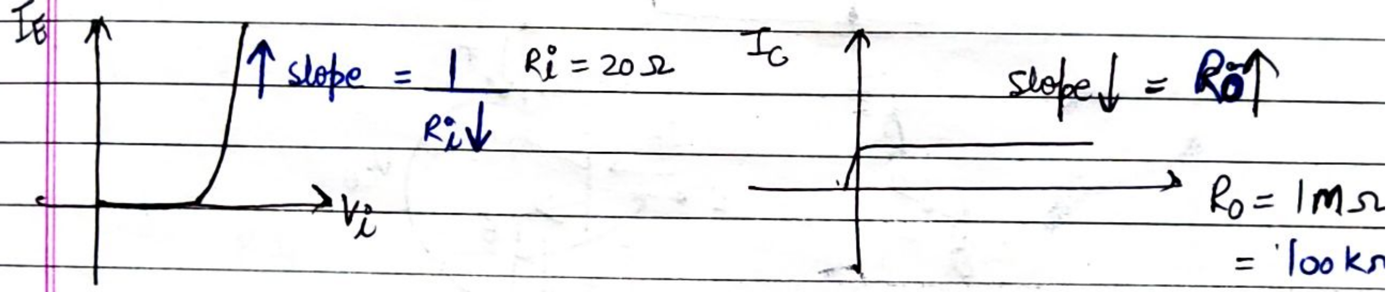
$I_c \approx \alpha I_E$

$\boxed{I_c \approx I_E}$ ($\alpha = 0.95 - 0.98$)

o/p i/p

Transistor Amplifying Action :-





$$V_i = I_E R_i$$

$$V_i = I_E R_i \Rightarrow I_E = \frac{V_i}{R_i} = \frac{200\text{ mV}}{20\,\Omega} \Rightarrow 10\text{mA}$$

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

$$I_C \approx \alpha I_E$$

$$I_C \approx I_E \qquad \boxed{I_C = 10\text{ mA}}$$

$$V_0 = I_C R_L$$

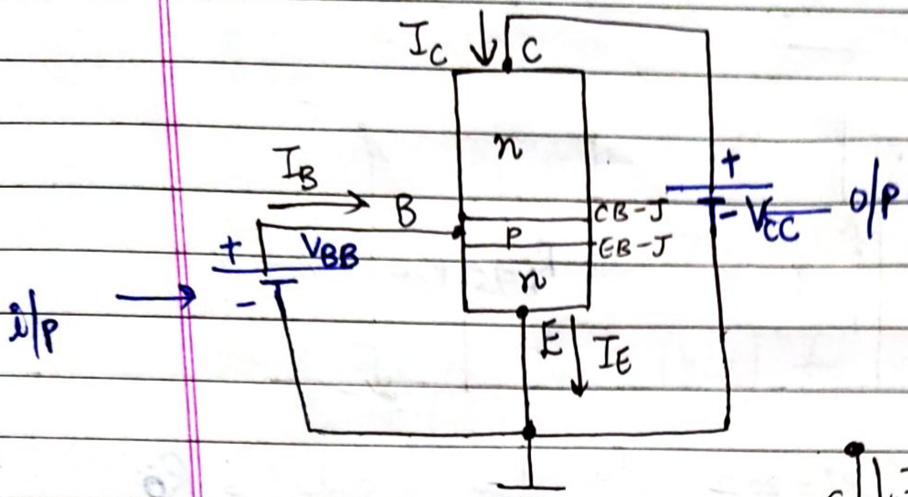
$$= 10\text{mA} \times 5\text{k}\Omega$$

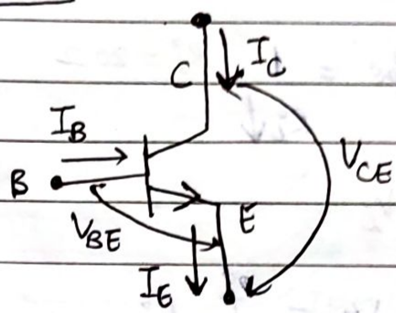
$$\boxed{V_0 \Rightarrow 50V}$$

Voltage Amplification :- $A_V = \frac{V_0}{V_i} = \frac{50V}{200mV} \Rightarrow 50$

Common-Emitter Configuration of Transistor :-

Amplifier ∃ Active Mode





i/p current → I_B

i/p voltage → V_{BE}

o/p current → I_C

o/p voltage → V_{CE}

$$I_E = I_C + I_B \longrightarrow (i)$$

$$I_C = \alpha I_E + I_{CBO} \longrightarrow (ii)$$

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

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

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

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

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

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

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

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Case ① :-

$\alpha = 0.98$ $\rightarrow \alpha < 1$

$\beta = \frac{0.98}{1-0.98} \Rightarrow 49$ $\rightarrow 50 \leq \beta \leq 400$

Case ⑪ :

$\alpha = 0.95$

$\beta = \frac{0.95}{1-0.95} \Rightarrow \frac{0.95}{0.05} \Rightarrow 19$

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

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

$I_{CEO} << \beta I_B$

$I_C = \beta I_B$

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

Current Amplification factor

$I_B = 1mA$

$\beta = 100$

$I_C = \beta I_B$

$I_C = 100\ mA$

* • Common Emitter config. works as Current Amplifier.

Note :- $[I_C = \alpha I_E + I_{CBO}]$ Common Base

$[I_C = \beta I_B + (\beta+1) I_{CBO}]$ Common emitter

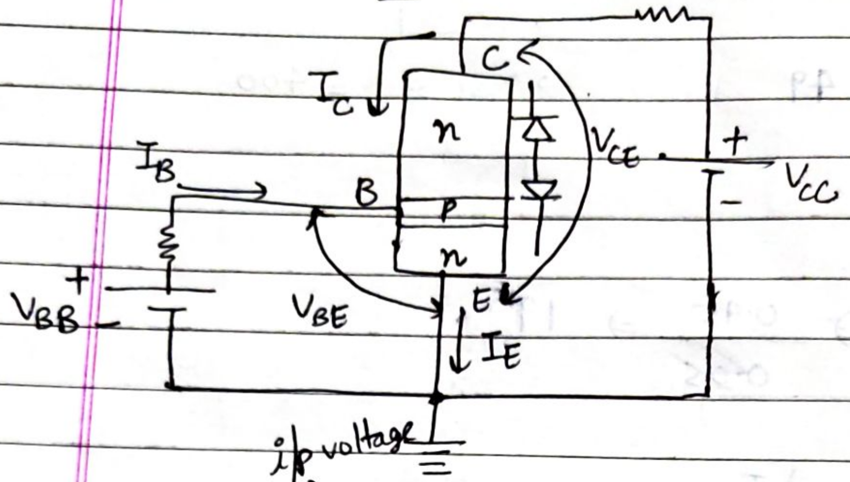
Let $\beta = 99$

$(\beta+1) \Rightarrow 100$

• Contribution of leakage current to the output current is more in case of Common emitter config. and contribution of leakage current to the output current is less in case of common base configuration

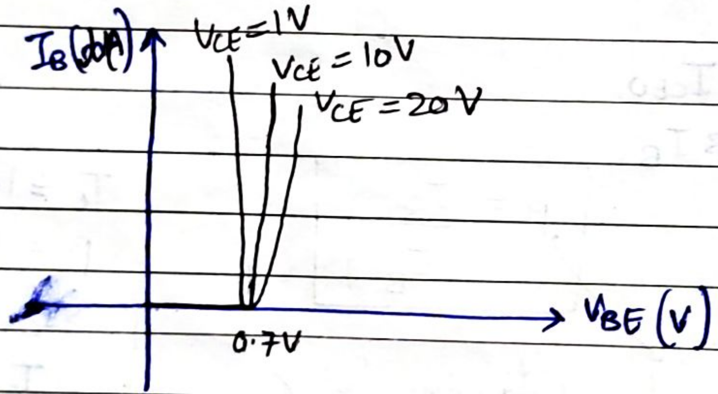
Forward Biased Diode

Common Emitter Transistor [Input characteristic]



→ I_B vs V_{BE} for diff. values of V_{CE} (o/p voltage)

i/p current



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

$V_{CE} \uparrow \Rightarrow V_{CB} \uparrow \Rightarrow I_B \downarrow$ (Less Recombination)

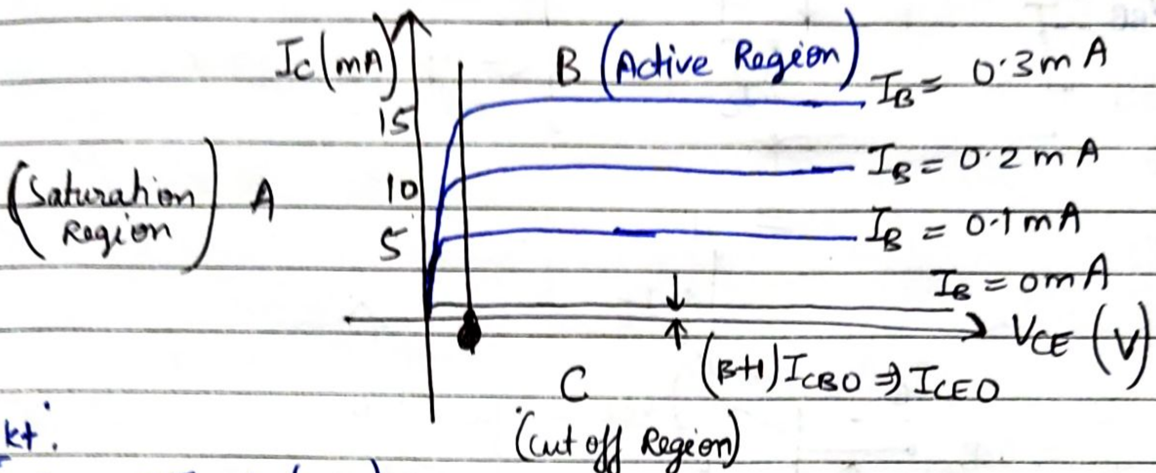
(By Early effect)

$$\boxed{\begin{array}{l} V_{CE} \downarrow \Rightarrow I_B \uparrow \\ V_{CE} \uparrow \Rightarrow I_B \downarrow \end{array}}$$

Common Emitter Transistor [output characteristic]

I_c Vs V_{CE} for different levels of I_B

(output current) (output voltage) (Input current)



w.k.t:

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

$$I_B = 0$$

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

$$\beta = \frac{\Delta I_c}{\Delta I_B} \Rightarrow \frac{10-5}{0.2-0.1}$$

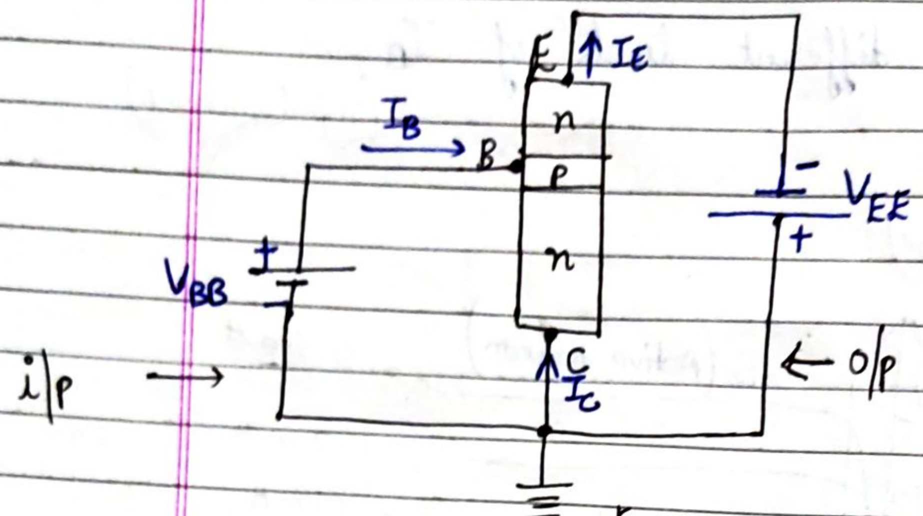
$$\beta \Rightarrow 50$$

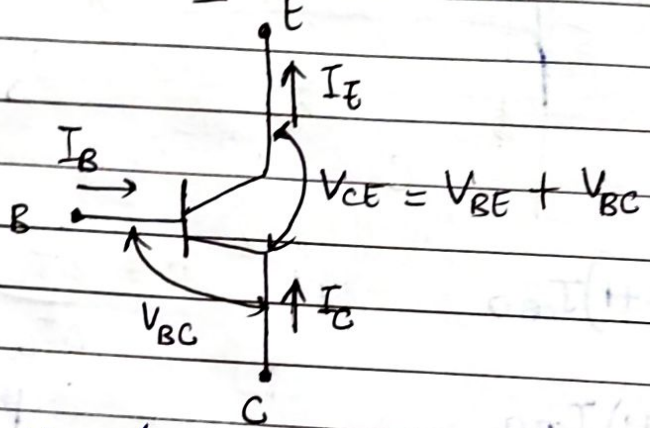
A ⟶ Saturation Region

B ⟶ Active Region

C ⟶ Cut off Region

Common-Collector Configuration of Transistor





I_C

I_E Vs V_{CE} for various levels of I_B

$I_C = \alpha I_E$

$\alpha = 0.95 - 0.98 \approx 1$

$\boxed{I_C \approx I_E}$

IMP: o/p char. of CE ⇒ o/p char. of C.C

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

Current Amplification factor

$I_E = I_C + I_B \longrightarrow (I)$

$I_C = \alpha I_E + I_{CBO} \longrightarrow (II)$

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

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

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

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

RELATION B/W α, β and γ :-

$$\alpha \rightarrow \alpha_{dc} \Rightarrow \frac{I_C}{I_E}$$

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

$$\beta \rightarrow \beta_{dc} \Rightarrow \frac{I_C}{I_B}$$

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

$$\gamma \rightarrow \gamma_{dc} \Rightarrow \frac{I_E}{I_B}$$

$$\gamma \rightarrow \gamma_{ac} \Rightarrow \frac{\Delta I_E}{\Delta I_B}\Big|_{V_{CE} = const.}$$

$$I_E = I_B + I_C$$

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

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

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

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

$$\gamma = \frac{\alpha + 1 - \alpha}{1-\alpha} \Rightarrow \frac{1}{1-\alpha}$$

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

1.00
0.99
0.01

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

$$\beta \Rightarrow \frac{0.99}{1-0.99}$$

$$\beta = \frac{0.99}{0.01}$$

$$\alpha \Rightarrow \frac{I_C}{I_E}$$

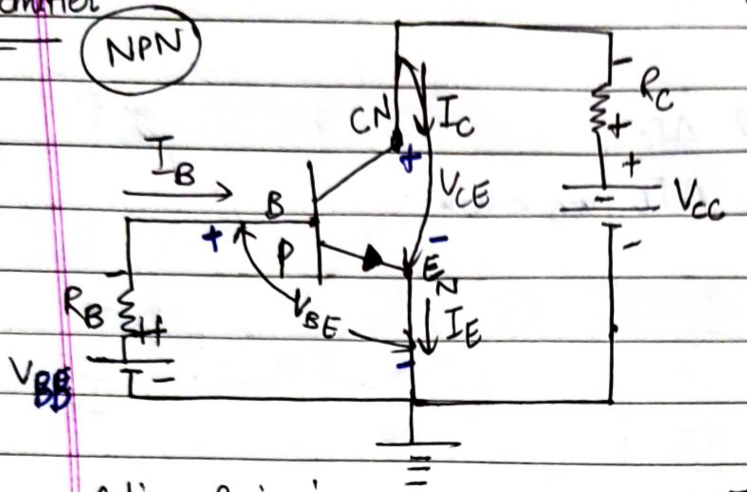
$$\beta = \frac{I_C}{I_B}$$

$$0.99 = \frac{I_C}{I_E}$$

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

DC Biasing, Load Line & Operating point / Q-Point of Transistors :-

Common Emitter



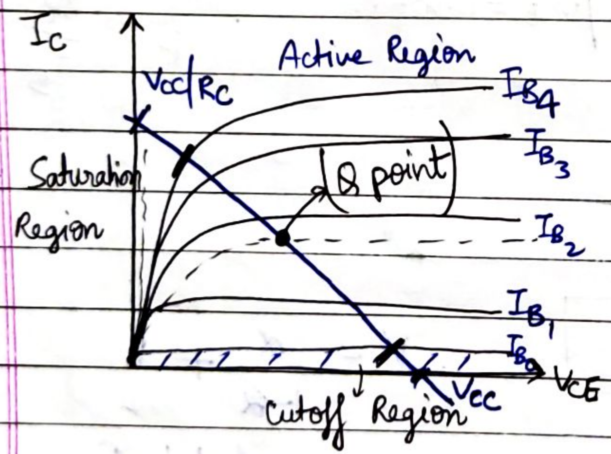
☆ **Q point :-** [Quiescent Point]
when no ac signal applied on the base junction, cond^n called as Q-point.

Active Region :

EB ⟶ F.B
CB ⟶ R.B

$$I_E = I_B + I_C$$

Output Characteristics :



i/p section :

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

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \quad V_{BE} \to 0.7V\ (si)$$

$$\boxed{I_B \approx \frac{V_{BB}}{R_B}}$$

O/p section :

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

Eq^n of st. line

$$y = mx + c$$

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

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

$$y = c + mx$$

On y-axis :

$$V_{CE} = 0$$

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

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

$$\boxed{c = \frac{V_{CC}}{R_C}}$$

$$\boxed{m = -\frac{1}{R_C}}$$

On x-axis :

$$I_C = 0$$

$$\boxed{V_{CC} = V_{CE}}$$

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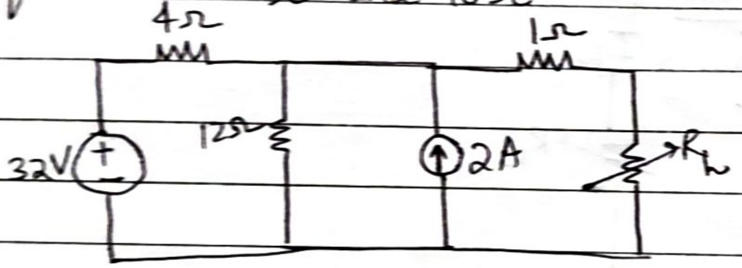
Thevenin's Theorem :- "A linear and bidirectional two-terminal network can be replaced by an equivalent network consisting of a voltage source V_{Th} connected in series with R_{Th}".

- Thevenin Resistance — R_{Th}
- Thevenin Voltage — V_{th}

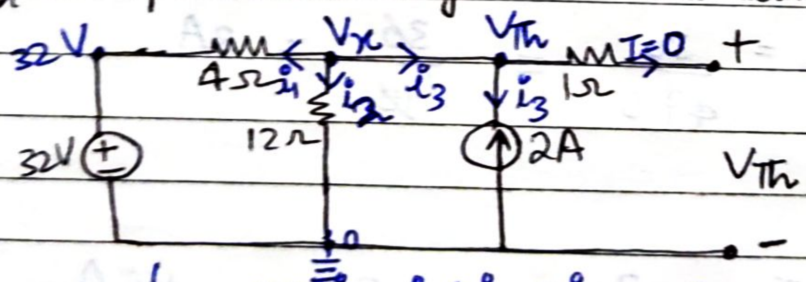
- R_{Th} — All the voltage source are short circuited and current source are open circuited.

- V_{Th} — Open circuit voltage across the terminal.

Q. Find current flowing through the load resistance when it is equal to 6Ω and 16Ω.



Sol: 1. V_{Th} :- Open circuit voltage across the terminal.



from KCL :- $i_1 + i_2 + i_3 = 0$

$$\frac{V_x - 32}{4} + \frac{V_x - 0}{12} + (-2) = 0$$

$$3V_x - 96 + V_x = 24$$

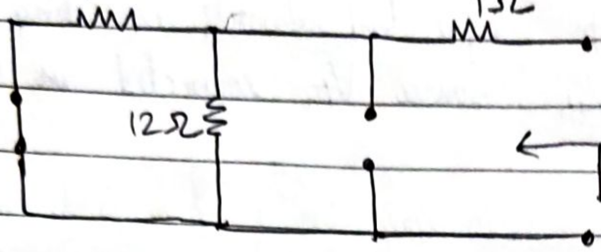
$$4V_x = \cancel{120}\ 30$$

$$\boxed{V_x = 30\ V}$$

W.k.t :- $V_{Th} = V_x$

$$\boxed{V_{Th} = 30V}$$

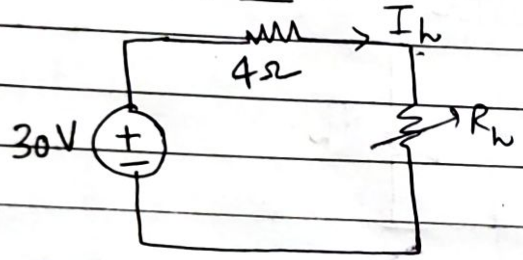
2. R_{Th} :- All the voltage source are short circuited and current source are open circuited.



$$R_{Th} = 4 \parallel 12 + 1$$

$$R_{Th} = \frac{4 \times 12}{4+12} + 1 \Rightarrow 4\Omega$$

Thevenin's Eq. circuit :-



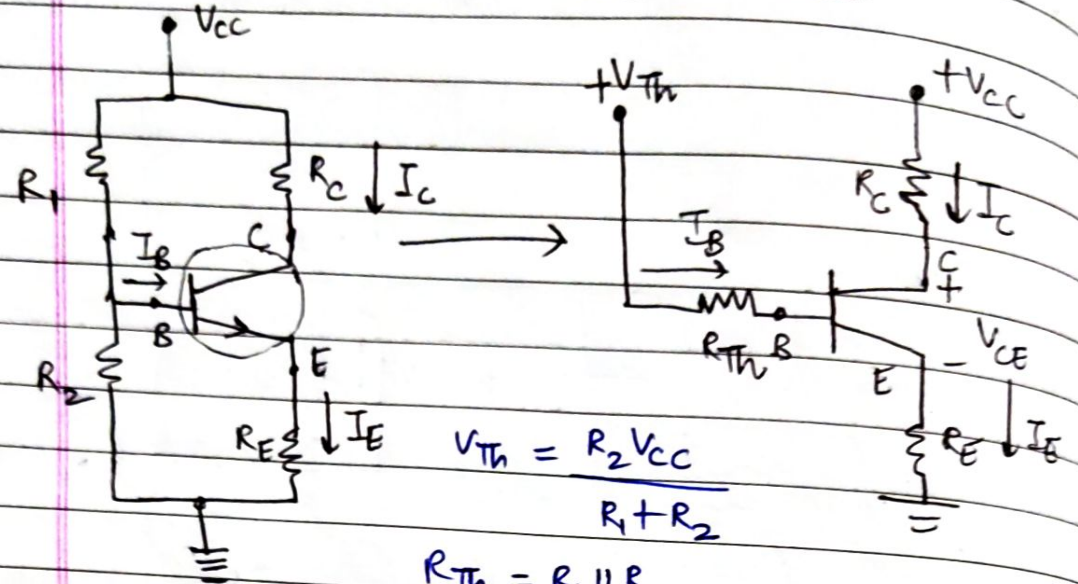
i) $R_L = 6\Omega$

$$I_L = \frac{30}{4+6} = \frac{\cancel{30}}{\cancel{10}} = 3A$$

ii) $R_L = 16\Omega$

$$I_L = \frac{30}{4+16} \Rightarrow \frac{3\cancel{0}}{2\cancel{0}} \Rightarrow 1.5A$$

Stability factor for Voltage Divider Biasing :



$$V_{Th} = \frac{R_2 V_{CC}}{R_1 + R_2}$$

$$R_{Th} = R_1 \parallel R_2$$

$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2}$$

Step① $I_B = ?$

Step② $I_C = \beta I_B + (\beta+1) I_{CBO}$

Step③ Diff. wrt to I_C keeping β & V_{BE} const.

→ Stability factor does not depend on V_{CC}. So replacing V_{CC} with V_{Th} will have no effect.

$$S = \frac{(\beta+1)(\overset{\to R_{Th}}{R_B} + R_E)}{\underset{\downarrow R_{Th}}{R_B} + (\beta+1) R_E}$$

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

S.F for V.D.B

$$s' = \frac{-\beta}{R_B + (\beta+1)R_E}$$

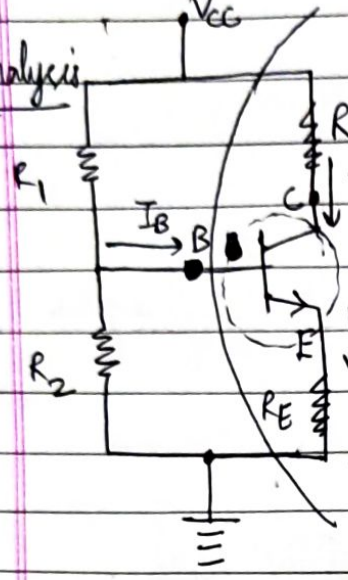
R_{Th}

$$\boxed{s' = \frac{-\beta}{R_{Th} + (\beta+1)R_E}}$$

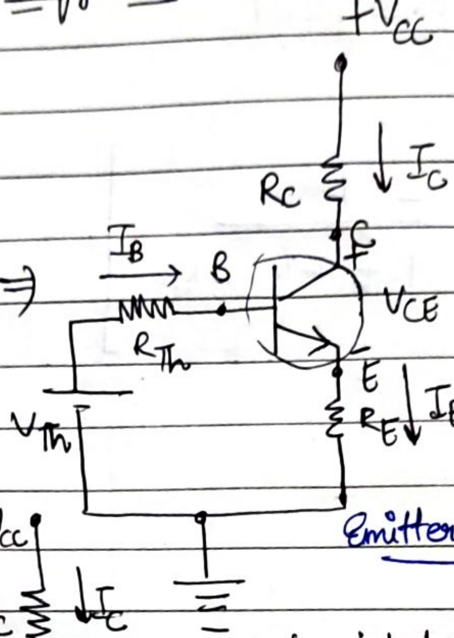
V.D.B

Voltage-Divider Bias Configuration :-

Accurate Analysis

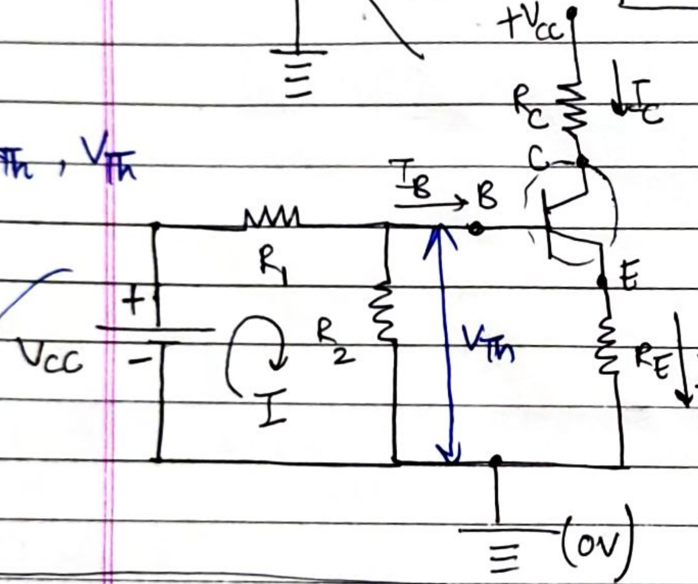


$\Rightarrow$



Emitter-Bias

R_{Th}, V_{Th}



Eq^n for input :-

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

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

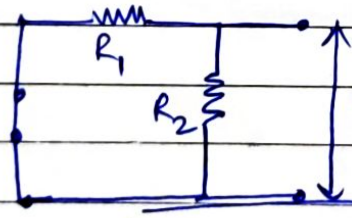
$$\boxed{I_B = \frac{V_{Th} - V_{BE}}{R_{Th} + (\beta+1) R_E}}$$

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

If $\boxed{R_{Th} << (\beta+1) R_E}$

then I_C is independent of β.

• R_{Th} :-



$R_{eq} = R_{Th}$

$$\boxed{R_{Th} = \frac{R_1 R_2}{R_1 + R_2}}$$

• V_{Th} :-

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

$$V_{Th} = I R_2 = \frac{R_2 V_{CC}}{R_1 + R_2}$$

Eq^n for output ;

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

$$I_E \approx I_C$$

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

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

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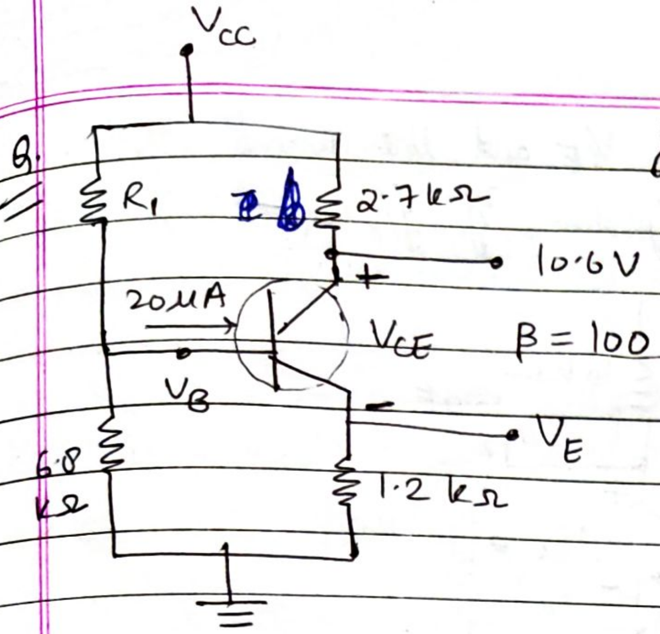
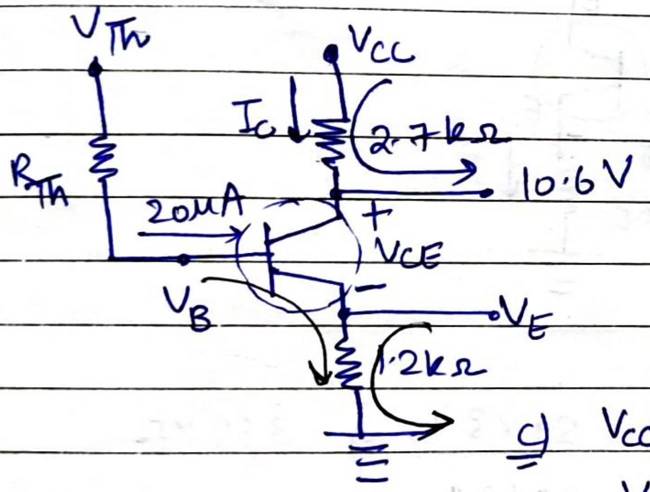
Q. 

find:
(a) I_C
(b) V_E
(c) V_{CC}
(d) V_{CE}
(e) V_B
(f) R_1

Sol: Given: $I_B = 20\mu A$, $V_C = 10.6V$, $R_2 = 6.8k\Omega$

$\beta = 100$, $R_E = 1.2k\Omega$, $R_C = 2.7k\Omega$



a) $\beta = \dfrac{I_C}{I_B}$

$100 \times 20\mu A = I_C$

$100 \times 20 \times 10^{-6} = I_C$

$\boxed{I_C = 2mA}$

c) $V_{CC} - I_C R_C = 10.6V$

$V_{CC} = (2)(2.7) + 10.6V$

$V_{CC} \doteq 16V$

b) $I_E = I_B + I_C$

$I_E \approx I_C$

$I_E = 2mA$

$I_E = 2mA + 20\mu A$

$I_E = 2mA + 0.02mA = 2.02mA$

diff. $\Rightarrow 0.02mA$

$\boxed{R_1 = 28k\Omega}$

(f) $V_{Th} = V_B$

$V_{Th} = \dfrac{V_{CC} R_2}{R_1 + R_2}$

$3.124 \Rightarrow \dfrac{16 \times 6.8}{R_1 + 6.8k\Omega}$

$V_E - I_E R_E = 0$

$V_E = (2.02mA)(1.2k\Omega) \Rightarrow 2.424V$

(d) $V_{CE} = V_C - V_E$

$= 10.6V - 2.424V$

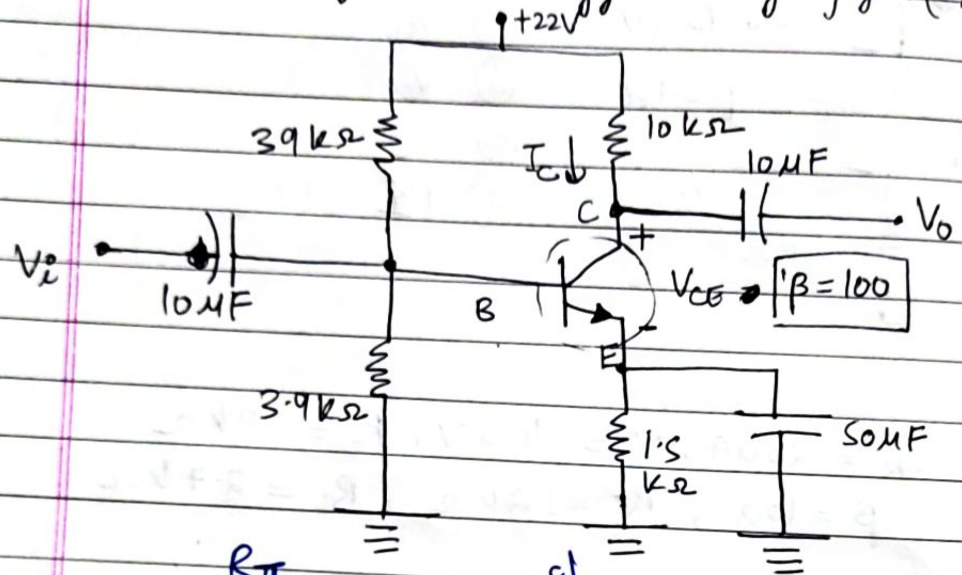
$V_{CE} = 8.176V$

(e) $V_{BE} = V_B - V_E$

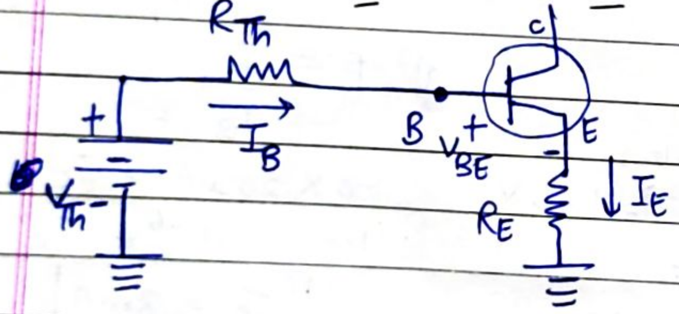
$0.7V = V_B - 2.424V$

$\boxed{V_B = 3.124V}$

Q. Determine the dc bias voltage V_{CE} and the current I_C for the voltage divider configuration of figure (4.35)



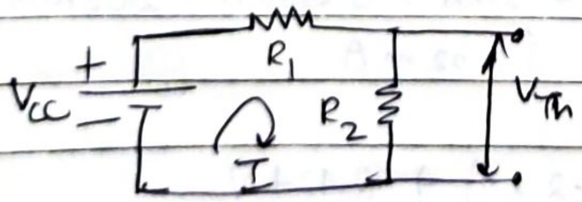
Sol:



$$R_{Th} = R_1 \parallel R_2$$

$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2} = \frac{39 \times 3.9}{39 + 3.9} \Rightarrow 3.55\ k\Omega$$

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



$$V_{Th} = \frac{3.9 \times 22}{39 + 3.9}$$

$$\boxed{V_{Th} = 2V}$$

$$V_{Th} - I_B \times R_{Th} - V_{BE} - I_E R_E = 0$$

$$2 - I_B \times 3.55 - 0.7 - (\beta + 1) 1.5 = 0$$

$$2 - I_B \times 3.55 - 0.7 - (101) 1.5 = 0$$

$$\boxed{I_B = 8.38\ \mu A}$$

$I_E = I_B + I_C$

$\boxed{I_E \approx I_C}$

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

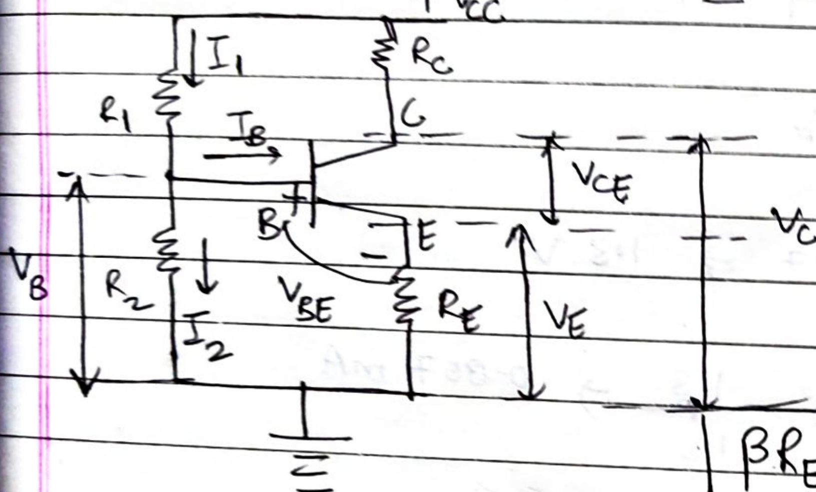
$I_C = 100 \times 8.38 \Rightarrow 0.84\ mA$

$V_{CC} - I_C R_C - V_{CE} - I_E \times 1.5 = 0$

$22 - 0.84 \times 10 - V_{CE} - 0.84 \times 1.5 = 0$

$\boxed{V_{CE} = 12.34V}$

Approximate Analysis of Voltage-Divider Biasing :-



$V_{CC} = I_C R_C + V_{CE} + I_E R_E$

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

as $I_C \approx I_E$

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

$\boxed{\beta R_E \geq 10 R_2}$

★ Approximate Analysis :

$\boxed{I_B \approx 0}$

$I_1 = I_2 + I_B$

$\boxed{I_1 \approx I_2}$

$I_E = \cancel{I_B}^{0} + I_C$

$\boxed{I_E \approx I_C}$

$V_{BE} = V_B - V_E$

$V_{BE} = V_B - I_E R_E$

$V_{BE} = V_B - I_C R_E$

$\boxed{I_C = \frac{V_B - V_{BE}}{R_E}}$

$V_{CC} = I_1 R_1 + I_2 R_2$

$V_{CC} = I_1(R_1 + R_2)$ or $I_2(R_1 + R_2)$

$\boxed{I_1 = I_2 = \frac{V_{CC}}{R_1 + R_2}}$

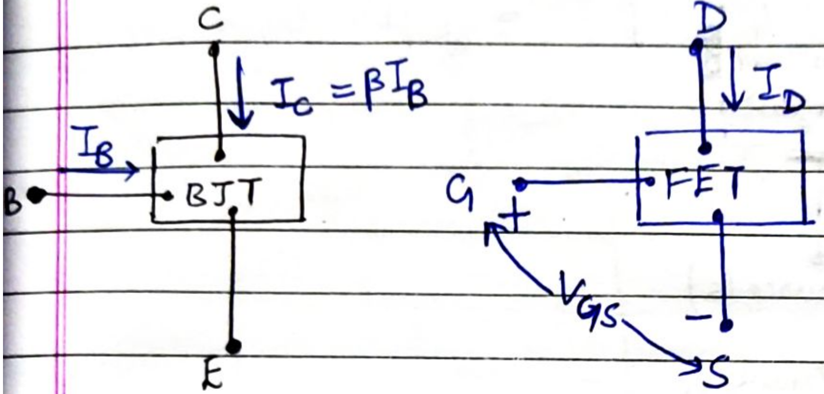
$V_B = R_2 I_2$

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

Field-Effect Transistors (FETs) :-

FETS & BJTs :- → FETs are smaller than BJTs

→ BJT → 3 terminal ← FET • Application of FET ≈ App. of BJT



D → Drain
G → Gate
S → Source

BJT	FET
→ BJT is current controlled device	→ I_D depends on V_{GS}.
	→ FET is voltage controlled device
→ $I_C = f(I_B)$	→ $I_D = f(V_{GS})$
→ BJT → Bipolar ($e^{\ominus}$ & holes both)	→ FET → Unipolar ($e^{\ominus}$ or holes)
	→ n-channel ($e^{\ominus}$) & p-channel (holes)
→ npn & pnp	
→ BJT is used for amplication & switching	→ FET is used for amplication & switching

FET
- JFET
  - n-channel
  - p-channel
- MOSFET
  - D-MOSFET
    - n-c
    - p-c
  - E-MOSFET
    - n-c
    - p-c

→ "Field-Effect"

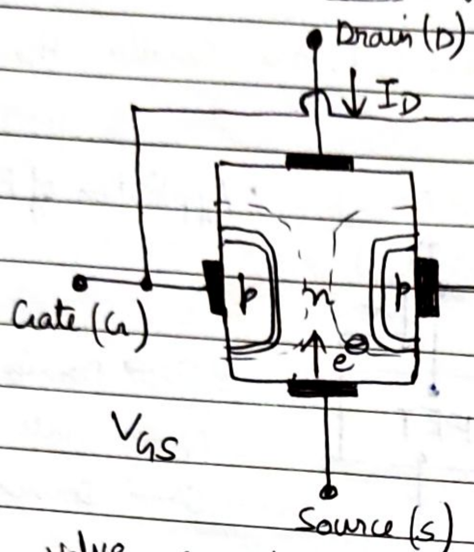
E.F developed by the charges present

→ This E.F controls the conduction path of o/p

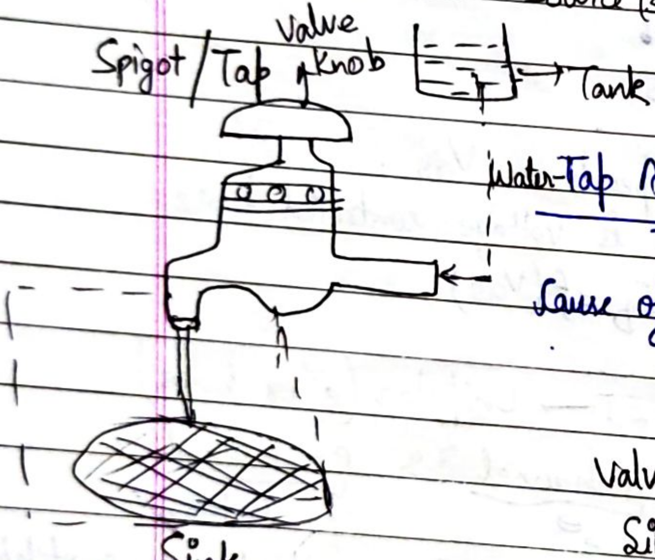
→ FET_s has high input impedance & more temp. stable.

n-channel   p-channel

Construction and Working of JFET :-



2 pn junction
⇓
2 - Depletion layer



Water-Tap Analogy :-

water → $e^{\ominus}$

Cause of water flow → Applied voltage b/w Drain & source

Valve knob → Gate

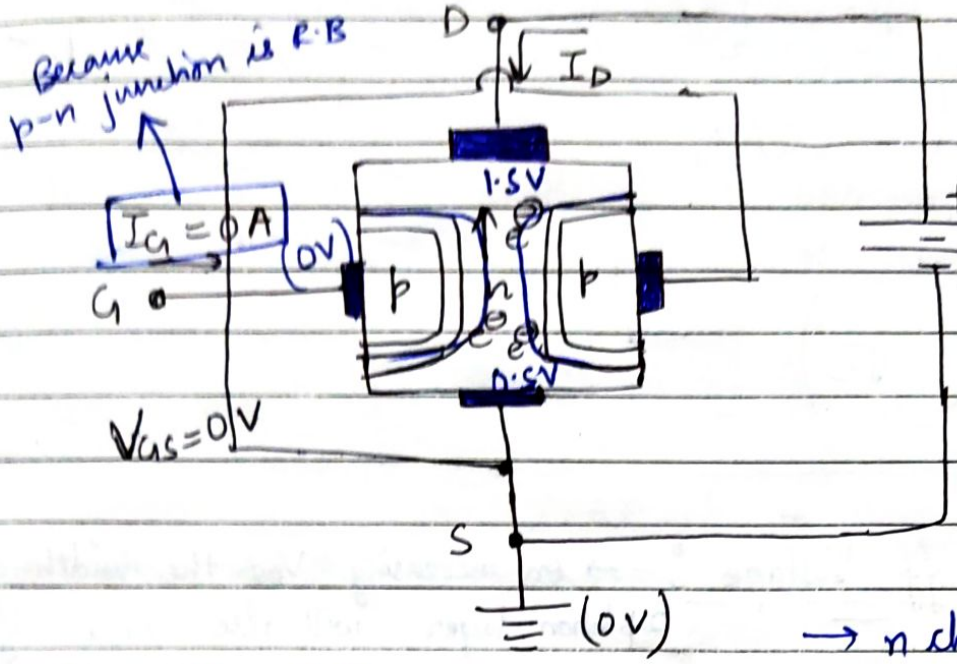
Sink → Drain

Tap → Source

Working of JFET ($V_{GS} = 0V$ & $V_{DS} > 0V$)

Case ① : $V_{GS} = 0V$
Case ② : $V_{GS} < 0V$
} $V_{DS} > 0V$

Case ① $V_{GS} = 0V$, $V_{DS} > 0V$



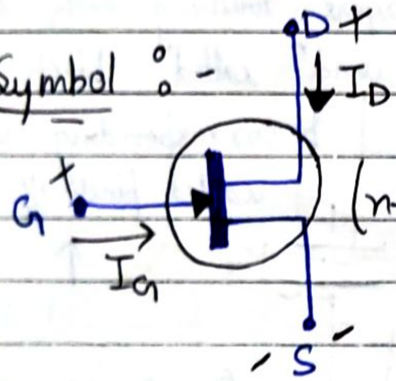
→ n channel width decreases as we move up.

→ Depletion Region increases as we move up.

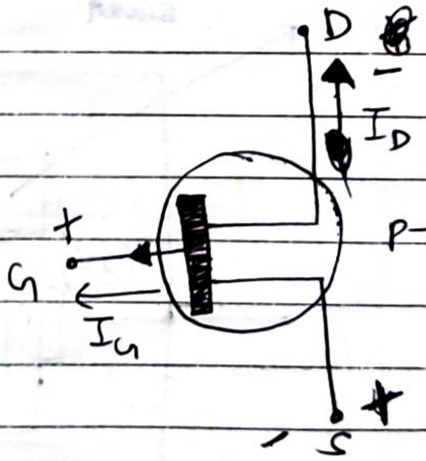
→ n channel providing the resistance to the current flow.

$V_{DS} = V_{DD} > 0$

→ Symbol :-



V_{DS} (n-channel JFET)



V_{DS} p-channel JFET

Rough Work :-

$$\boxed{r_d = \frac{r_0}{\left(1 - \frac{V_{GS}}{V_P}\right)^2}}$$

$$2r_0 = \frac{r_0}{\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

$$r_d = \frac{r_0}{\left(1 - \frac{1}{2}\right)^2}$$

$$\boxed{r_d = 4r_0}$$

$$\left(1 - \frac{V_{GS}}{V_P}\right)^2 = \frac{1}{2}$$

$$1 - \frac{V_{GS}}{V_P} = \frac{1}{\sqrt{2}}$$

$$I_d \Rightarrow \left(1 - \frac{2}{-8}\right)^2 \Rightarrow \left(1 - \frac{-1}{4}\right)^2 \Rightarrow \left(1 + \frac{1}{4}\right)^2 \Rightarrow \left(\frac{5}{4}\right)^2 \Rightarrow \frac{25}{16} \Rightarrow 1.5$$

$$I_D = I_{DS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

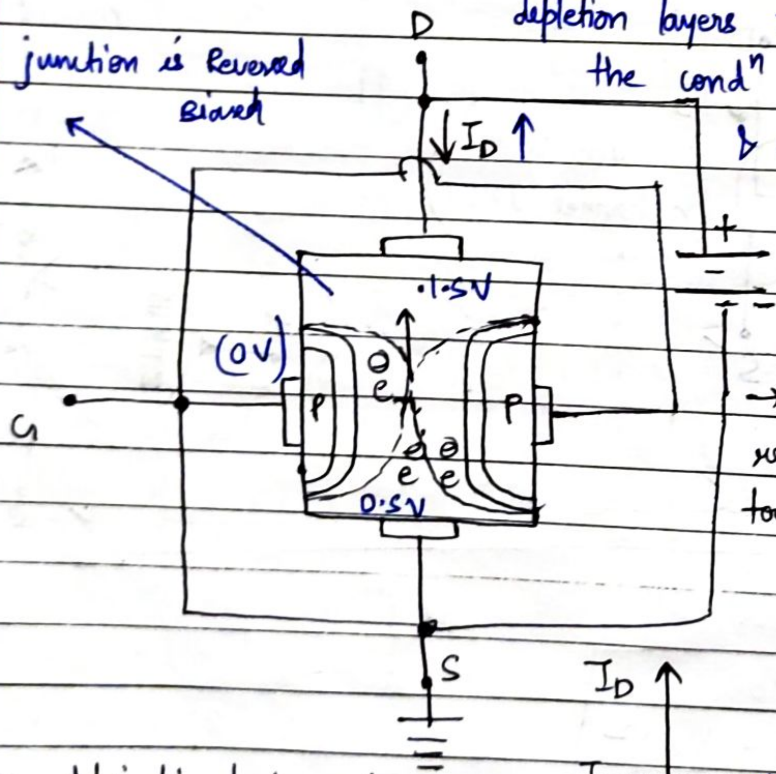
$$\frac{1}{2} = \left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$\frac{1}{\sqrt{2}} = 1 - \frac{V_{GS}}{V_P}$$

$$V_{GSS} = V_P\left(1 - \frac{1}{\sqrt{2}}\right)$$

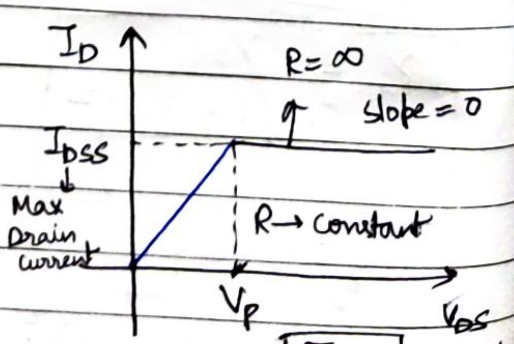
→ Pinch-off Voltage (V_P) :- → On increasing V_{DS} the width of depletion layer will also increase if V_{DS} increases to the level when two depletion layers touching each other the condⁿ called pinch-off & corresponding voltage called pinch-off voltage

p-n junction is Reversed Biased



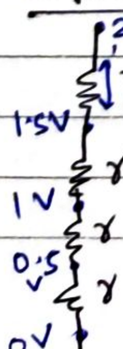
$V_{DD} = V_{DS}$ ↑

→ Two Depletion region will never touch each other.



$\boxed{I_{DSS}}$ → defined for $\boxed{V_{GS} = 0V}$ & $\boxed{V_{DS} > |V_P|}$

→ for explaination purpose only



$R_{eq} = 4r$

let $V_{DD} = 2V$

$2V \rightarrow 4r$ or $r = 0.5V$

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JFET as a current source :-

→ Effect on Depletion Region
→ Effect on I_D

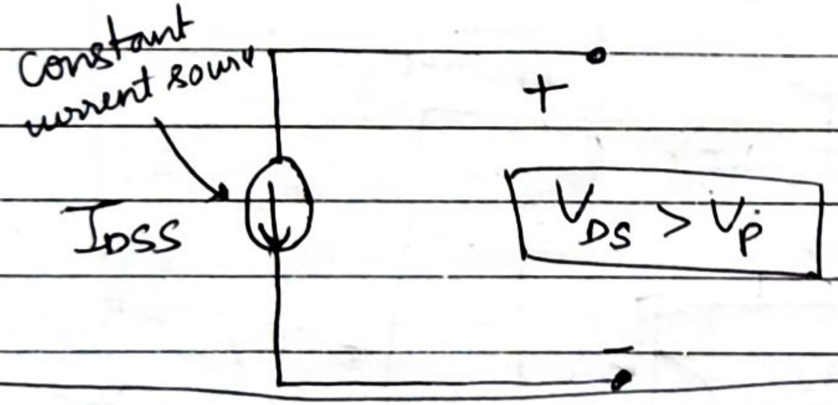
} when $\boxed{V_{DS} > V_P}$

→ When $V_{DS} > V_P$, the width of D.R increases along the length of the n-channel.

→ $\underbrace{\boxed{I_D = I_{DSS}} \text{ when } \boxed{V_{DS} > V_P} \ \& \ \boxed{V_{DS} < V_{DS\,max}}}_{\text{JFET act as a constant current source.}}$

$V_{DS\,max}$ → Breakdown condn

→ ~~when~~



Working of JFET [Negative Voltage at GATE]

Case (I) $\boxed{V_{GS} = 0V}$ $V_{DS} > |V_P|$ then $\boxed{I_D = I_{DSS}}$

and $V_{DS} = V_{DD} > 0V$

Max. Drain current

Case (II) $\boxed{V_{GS} < 0V}$

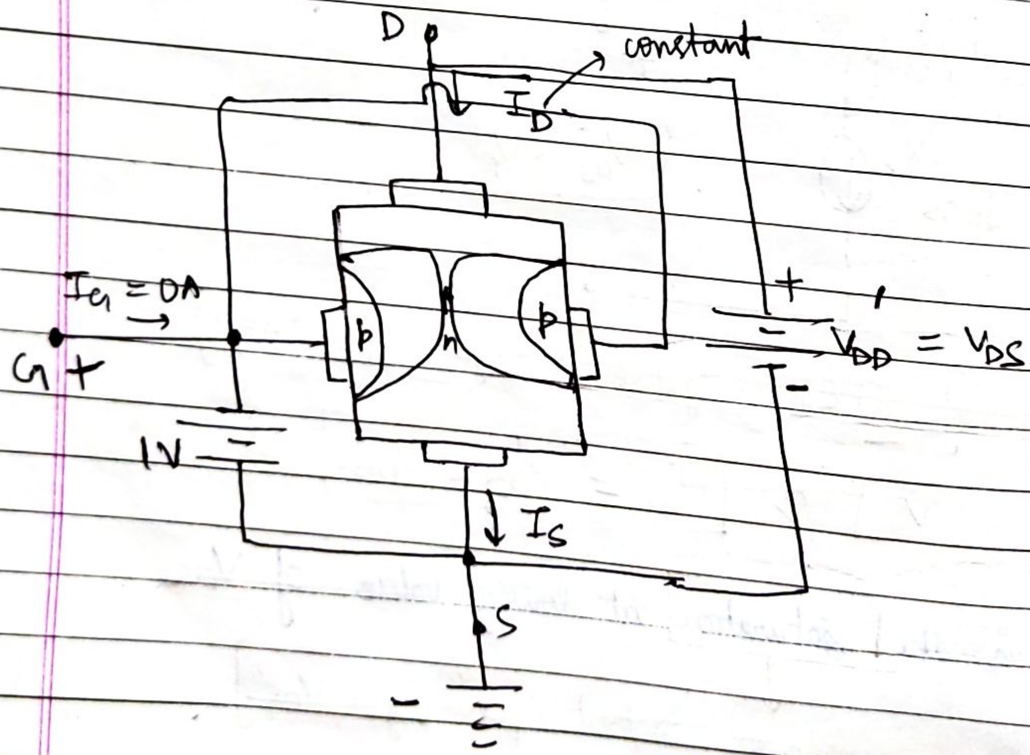
& $V_{DS} = V_{DD}' < V_{DD}$

→ obtain the $\boxed{\text{saturation}}$ at lower value of V_{DS}

I_{DSS} X

$I_D \rightarrow$ constant with change in V_{DS}

$I_D \neq I_{DSS}$ $V_{DS} \downarrow$ V_{GS} more -ve



n-channel

Output or Drain Characteristic of n-channel JFET :-

CE Transistor:

I_C Vs V_{CE}

$\underbrace{I_C}_{\text{o/p current}}$ output voltage

for different I_B (i/p current)

(controlling current)

JFET :-

I_D Vs V_{DS}

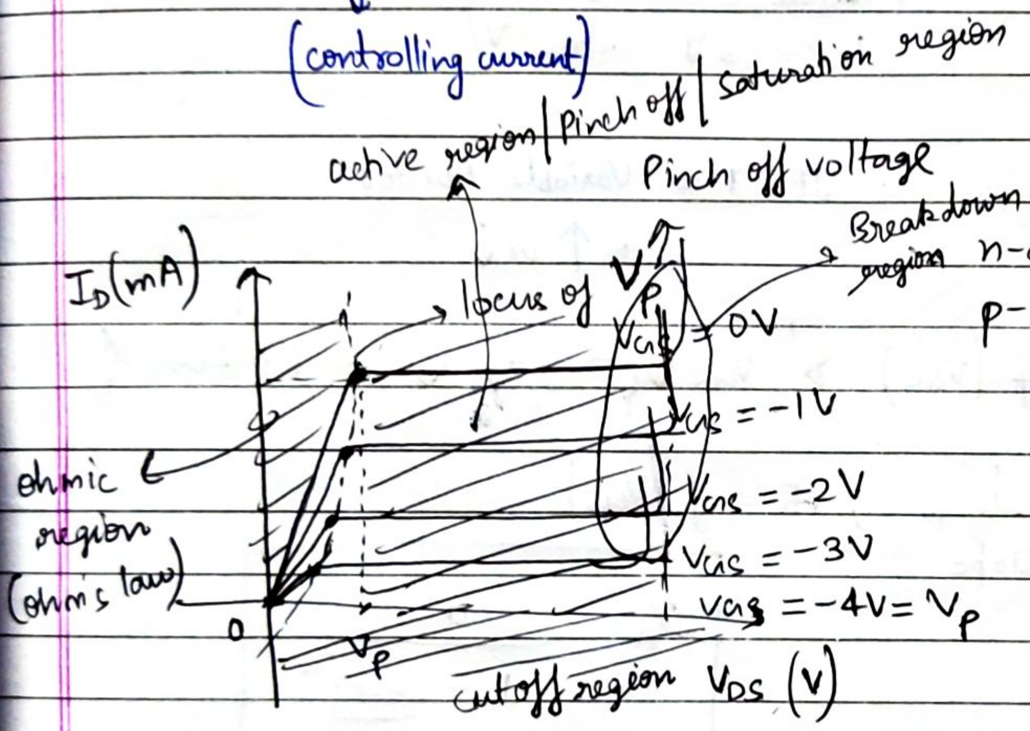
$\underbrace{I_D}_{\text{output current}}$ $\underbrace{V_{DS}}_{\text{o/p voltage}}$

for different levels of V_{GS} (i/p voltage)

(controlling voltage)

n-channel → $V_{GS} < 0V$

p-channel → $V_{GS} > 0V$



Case ① $I_{DSS} = 8$ mA

$V_P = -4V$

$\boxed{V_{GS} = 0\,V \quad V_{DS} > |V_P|}$

Case ② $V_{GS} = -1\,V$

Case ③ $V_{GS} = -2\,V$

Case ④ $V_{GS} = -3\,V$

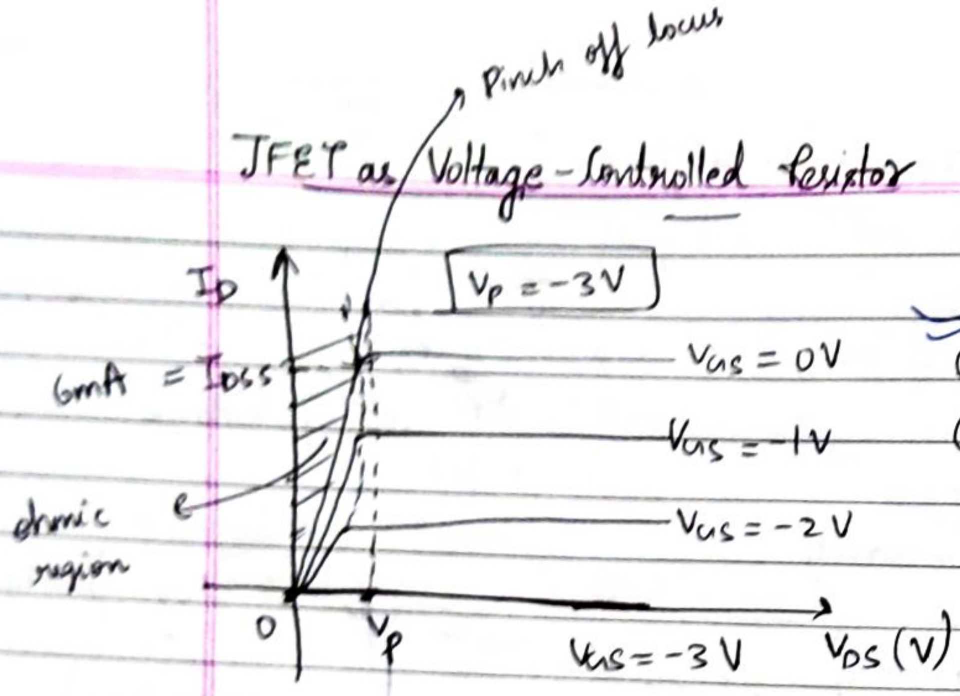
Case ⑤ $V_{GS} = -4\,V$

n-channel → -ve
p-channel → +ve

} R.B ↑ = D.L ↑

Pinch off-voltage obtained early

JFET as Voltage-Controlled Resistor :-



1. ~~ohmic~~ ⇒ Voltage contr
2. Sat.
3. cut-off
4. Breakdown

JFET ⇒ Variable Resistor
R ↑ or ↓

→ Slope $= f(V_{GS})$ & $V_{GS} \downarrow$ ⇒ Slope ↓ ⇒ (R) Resistance ↑

$$R = \frac{1}{\text{Slope}} \Rightarrow R = f(V_{GS})$$

$$\boxed{r_d = \frac{r_0}{\left(1 - \frac{V_{GS}}{V_p}\right)^2}}$$

★ $\left\{ \begin{array}{l} V_{GS} <<< 0V \\ R \text{ of JFET} \uparrow \end{array} \right\}$

Ex:- $r_0 = 10\,k\Omega$ → when $V_{GS} = 0V$
$V_p = -6V$
$V_{GS} = -3V$

$$r_d = \frac{10}{\left(1 - \frac{(-3)}{(-6)}\right)^2} \Rightarrow 40\,k\Omega$$

$\left(1 - \frac{\cancel{2}}{\cancel{4}}\right)^2 \Rightarrow 2^{4}\,\frac{1}{\cancel{4}}$

$\Rightarrow \left(1 - \frac{1}{2}\right)^2$

$2mA \left(1 - \frac{\cancel{2}}{\cancel{4}}\right)^2$ $\quad I_D \Rightarrow I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2 \Rightarrow 2\left(1 - \frac{1}{2}\right)^2$

$2mA\left(1 - \frac{1}{2}\right)^2$ $\quad I_D \Rightarrow 2\left(1 - \frac{\cancel{2}}{\cancel{4}}\right)^2$

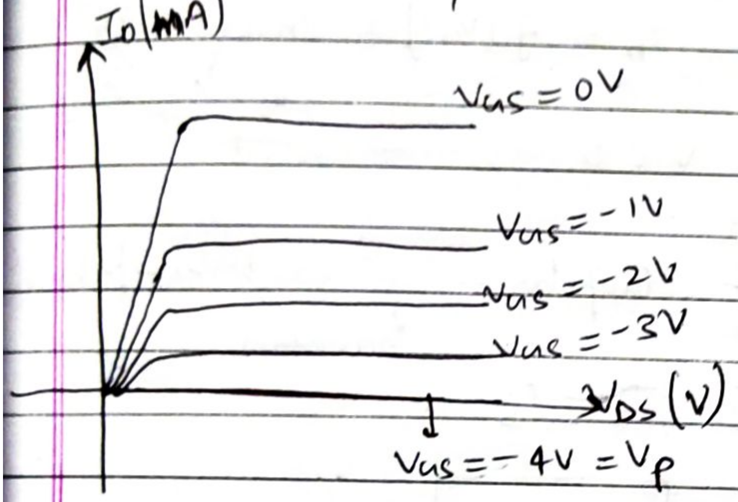
$2mA \times \frac{1}{4}$ $\quad \Rightarrow \cancel{2} \times \frac{1}{\cancel{4}}$

Transfer characteristics of JFET :-

Q. what is Transfer characteristic ?

Ans I_D Vs V_{GS} plot (o/p I → i/p V)

Keeping V_{DS} → constant (o/p V)



BJT :-

$I_C = f(I_B)$

$\boxed{I_C = \beta I_B}$

linear eq^n — β constant — I_B controlled variable

JFET :-

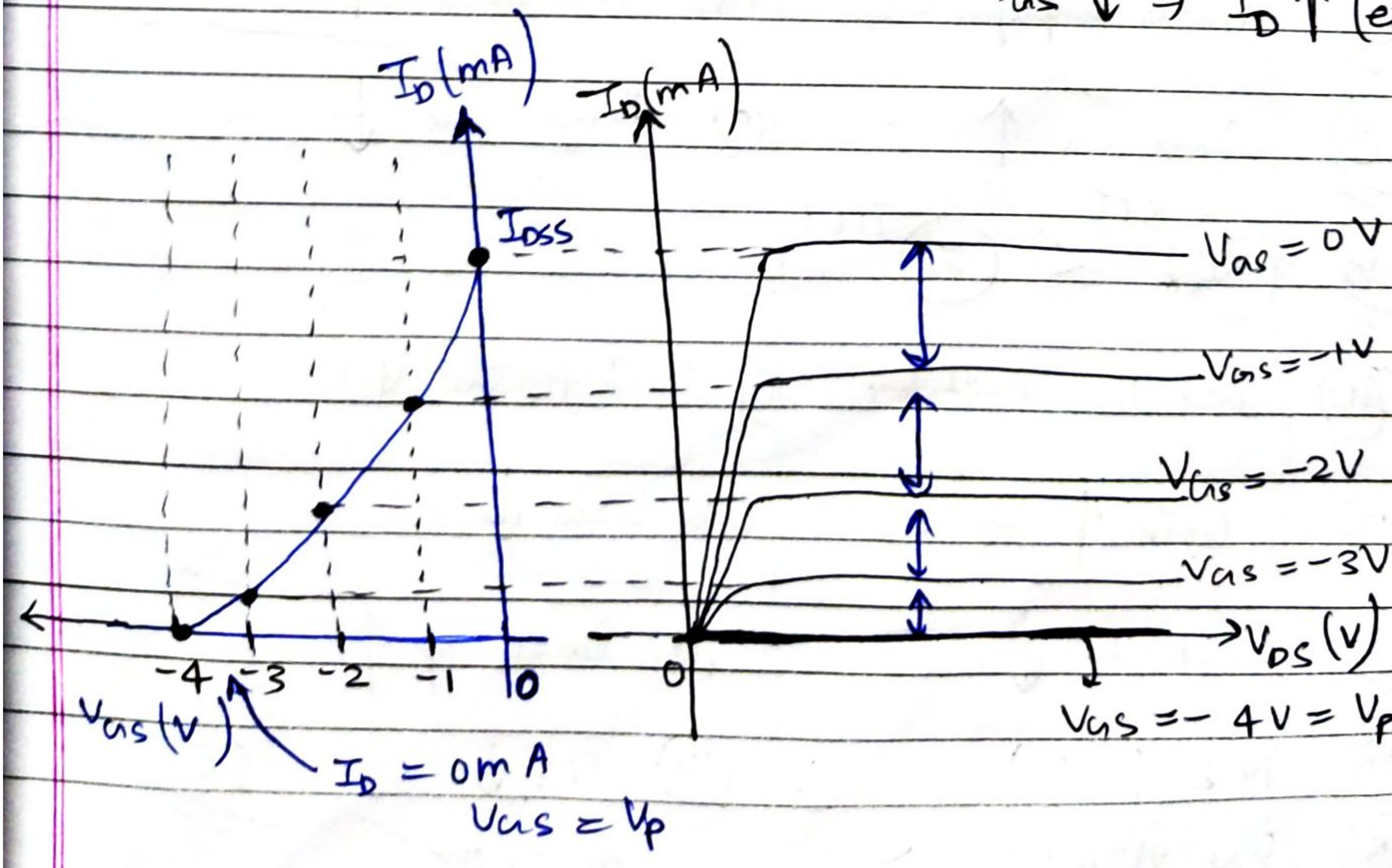
$I_D = f(V_{GS})$

$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

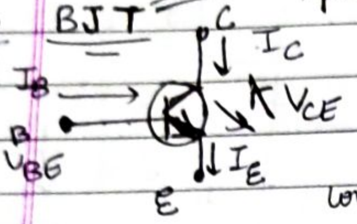
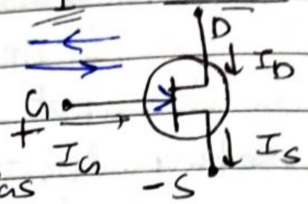
I_{DSS} constant, V_P constant

non-linear eq^n

$V_{GS} \downarrow \Rightarrow I_D \uparrow$ (exp.)



BJT Vs JFET

1. BJT → npn, pnp	1. JFET → n-channel, p-channel
	
2. $I_C = f(I_B) = \beta I_B$	2. $I_D = f(V_{GS}) = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$ (constant)
3. C.C.D	3. V.C.D
4. Bipolar	4. Unipolar → e^- (n-channel) or holes → p-channel
5. $I_C \approx I_E$	5. $I_D = I_S$
6. $V_{BE} = 0.7V$ (Si Trans)	6. $\boxed{I_G = 0A}$
7. Good fanout	7. Bad fanout
8. Linear amplifier	8. Non-linear amp.
9. Power cons. ↑	9. Power cons. ↓

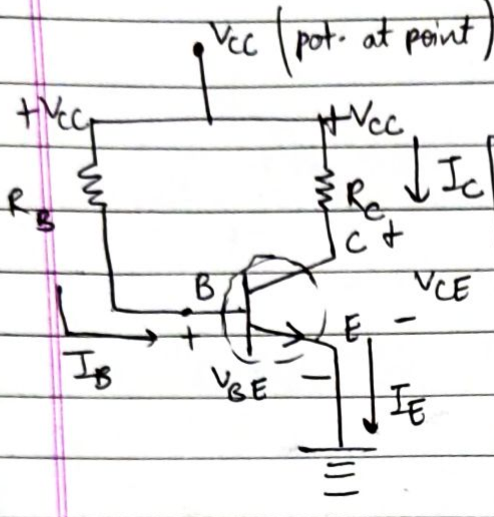
10. $Z_i^{BJT} < Z_i^{JFET}$

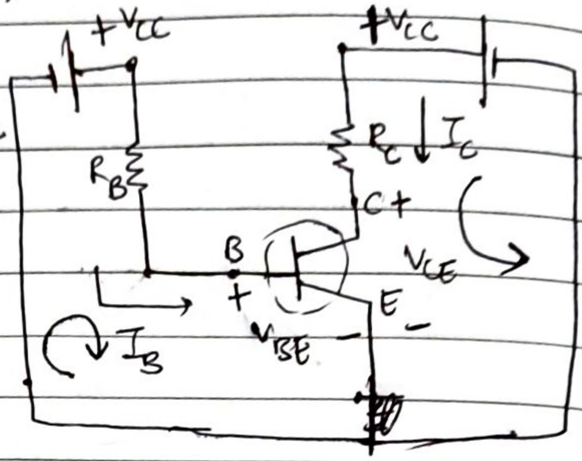
11. Bad thermal stab.	11. Good thermal stab.
12. Gain ↑	12. Gain ↓
13. Sensitivity ↓	13. Sensitivity ↑
14. N.L ↑	14. N.L ↓

15. Size of BJT > Size of JFET → I.C

(Base-Bias)

Fixed Bias Configuration :





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

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

0.3 V → Ge

0.7 V → Si

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

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

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

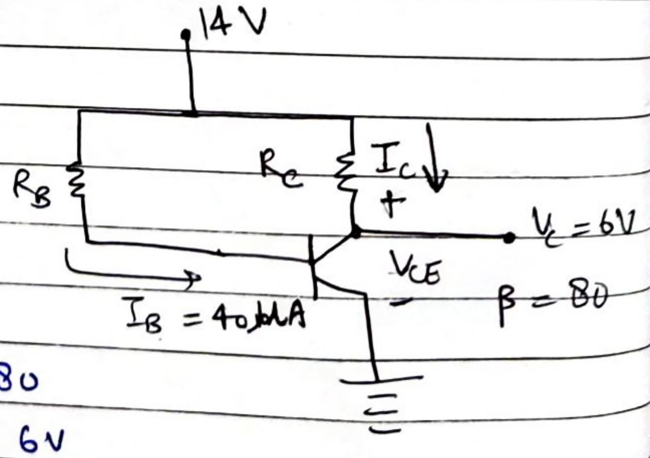
Q. for fixed biased config, determine

a) I_C

b) R_C

c) R_B

d) V_{CE}



Sol.

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

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

a) $I_C = \beta I_B = 80 \times 40 \Rightarrow 3.2\ mA$

b) $14V - I_C R_C = 6V$

$$R_C = \frac{8}{I_C} = \frac{8}{3.2mA} \Rightarrow R_C$$

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(c) $14V - I_B R_B - V_{BE} = 0$

$\frac{14V - 0.7}{40} \Rightarrow \frac{3.3\,V}{40} \Rightarrow 332.5\ k\Omega \Rightarrow R_B$

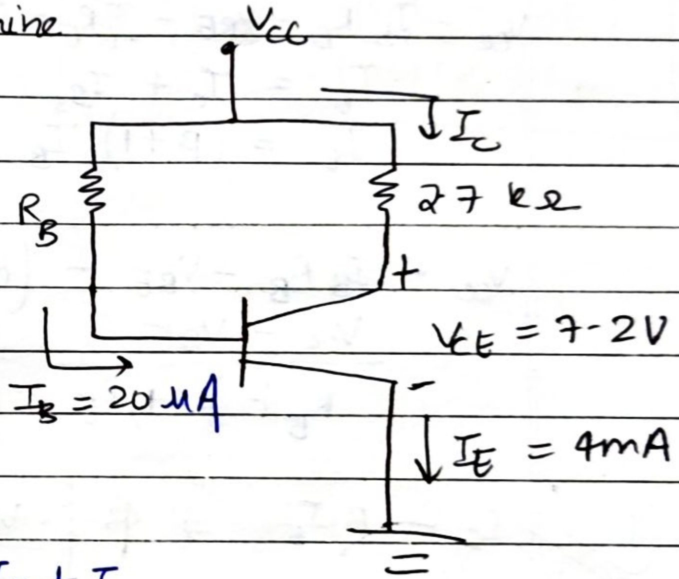
(d) $V_{CE} = V_C - V_E$

$= 6V - 0\,V$

$V_{CE} \Rightarrow 6V$

Q. for the fixed-bias config., determine

(a) I_C (b) V_{CC} (c) β (d) R_B



Sol. $R_C = 2.7\ k\Omega$

$I_B = 20\,\mu A$

$V_{CE} = 7.2V$

$I_E = 4\,mA$

$I_C = \beta I_B$

$I_C \approx I_E$

(a) $I_E = I_B + I_C$

$4 = 20 + I_C$

$I_C = 4mA - 20\,\mu A$

$I_C = 4\,mA - 0.02\,mA \Rightarrow 3.98\,mA$

(b) $V_{CC} - I_C \times 2.7 - 7.2V = 0$

$V_{CC} = 7.2V + 3.98 \times 2.7 \Rightarrow 17.946\ V$

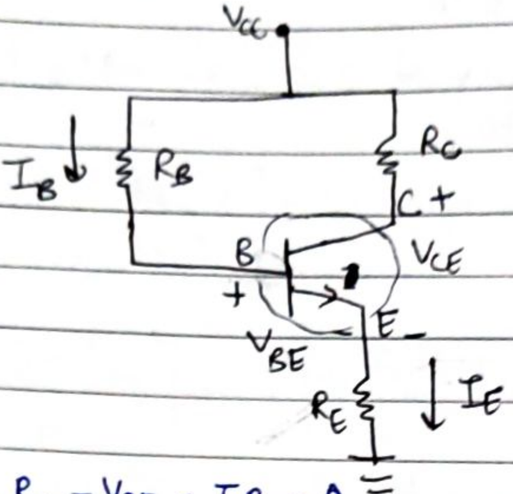
(c) $\beta = \frac{I_C}{I_B} = \frac{3.98\,mA}{20\,\mu A} \Rightarrow 199$

(d) $V_{CC} - I_B R_B - V_{BE} = 0$

$\frac{17.946 - 0.7V}{20\,\mu A} \Rightarrow 862.3\ k\Omega$ Ans

[Introduce R_E in fixed biased to improve stability of operating point]

Emitter-Bias Configuration :- Q point $= (I_{CQ}, V_{CEQ})$



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

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

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

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

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

Advantages of using R_E :-

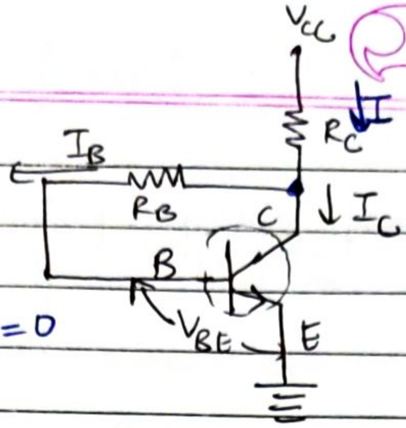
$I_C \Rightarrow$ Q pt. $\quad \begin{bmatrix} \beta+1 = \beta \\ \beta R_E >> R_B \end{bmatrix}$ $\quad I_C = \frac{\cancel{\beta}(V_{CC} - V_{BE})}{\cancel{\beta} R_E}$ → indep. of β

i) $T \uparrow = I_C \uparrow$ $\quad \{I_C = \beta I_B + (\beta+1) I_{CBO}\}$ $\quad$ ii) $I_C = \beta I_B$

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

$$\Rightarrow \underbrace{I_E R_E}_{\text{Drop}} \uparrow \Rightarrow I_B \downarrow \Rightarrow I_C \downarrow$$

Collector feedback biasing :-



$I = I_C + I_B$

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

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

$I_C = \beta I_B$

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

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

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

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

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

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

Advantages :- ① Stabilizies the Q-pt → i) against variation of T

ii) " " " V_{CC}

iii) " " " β

$$I_C = \frac{\beta (V_{CC} - V_{BE})}{\underbrace{(\beta+1)}_{\beta} R_C + R_B} \Rightarrow \frac{\beta (V_{CC} - V_{BE})}{\beta R_C + R_B} \Rightarrow \frac{\cancel{\beta} (V_{CC} - V_{BE})}{\cancel{\beta} R_C}$$

If $(\beta R_C >> R_B)$

Disadvantages :- for $\boxed{\beta R_C >> R_B}$

$R_C \uparrow\uparrow$ $V_{CC} \uparrow\uparrow$ cost $\uparrow$

$R_B \downarrow\downarrow$ R.B of C-B $\downarrow$

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Bias Stabilization & Stability factors :-

Q-pt $\equiv \left(\underset{x}{V_{CEQ}}, \underset{y}{I_{CQ}}\right)$

Stabilization :- The process of making operating point independent of temperature changes & variations in transistor parameters is known as stabilization.

→ Causes of unstabilization :- → Q-point will shift → $I_C \uparrow\downarrow$

i) changes in β

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

ii) Change in T :-

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

$(10^\circ \uparrow T) \longrightarrow$ Double I_{CBO}

→ V_{BE} (decreased by 2.5 mV/°C ↑ T)

$I_B \rightarrow V_{BE}$

i/p i   i/p V

Stability factor : The rate of change of collector current (I_C) with respect to the leakage current $[I_{CBO}]$ at constant input voltage (V_{BE}) & amplification factor (β) is called stability factor.

$$\boxed{S = \left.\frac{dI_C}{dI_{CBO}}\right|_{\text{at const. } V_{BE}\ \&\ \beta}}$$

$S\downarrow \rightarrow$ More stable the system

Ex :- $T_1 \rightarrow S_1 = 8$

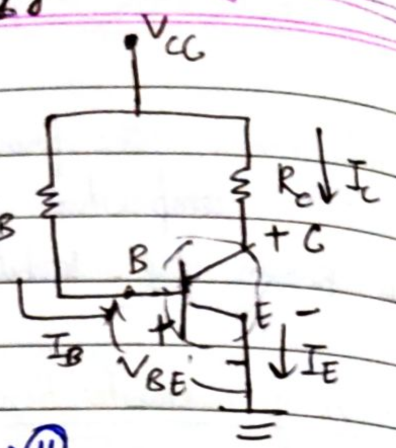
$T_2 \rightarrow S_2 = 5$

Stability $[T_2 > T_1]$

$$S' = \left.\frac{dI_C}{dV_{BE}}\right|_{\text{at const. } I_{CBO}\ \&\ \beta}$$

$$S'' = \left.\frac{dI_C}{d\beta}\right|_{\text{at const. } I_{CBO}\ \&\ V_{BE}}$$

Stability factor for fixed-Bias Config.



Step ① K.V.L in I/p loop :-

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

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

Step ② $I_C = \beta I_B + (\beta+1) I_{CBO} \longrightarrow$ ①

$$I_C = \beta\left(\frac{V_{CC}-V_{BE}}{R_B}\right) + (\beta+1) I_{CBO} \longrightarrow ⑪$$

Step ③ Diff. eq ⑪ wrt to I_C (at const. V_{BE} & β)

$$S = \left.\frac{dI_C}{dI_{CBO}}\right|_{\text{at const. } V_{BE} \,\&\, \beta}$$

V_{BE} & $\beta \rightarrow$ const.

V_{CC} & $R_B \rightarrow$ const.

$$\frac{dI_C}{dI_C} = \frac{\beta}{R_B}\frac{d}{dI_C}(V_{CC} - V_{BE}) + (\beta+1)\frac{d}{dI_C} I_{CBO}$$

$$1 = \frac{\beta}{R_B}(0 - 0) + (\beta+1)\frac{1}{S}$$

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

General exp. of S.F :-

Diff. ① wrt to I_C (at const. V_{BE} & β)

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

$$1 = \beta\frac{dI_B}{dI_C} + (\beta+1)\times\frac{1}{S}$$

General exp. of S.F for any biasing.

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

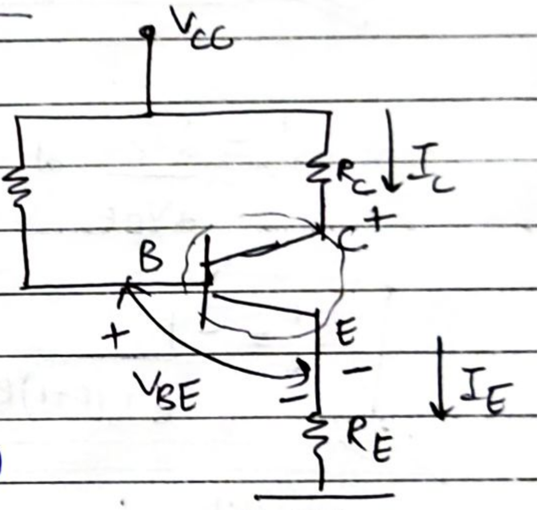
$$S = \frac{\beta+1}{1-0} \Rightarrow \beta+1$$

Diff eq (II) wrt to I_c keeping I_{CBO} & β as const.

$$1 = \frac{\beta}{R_B}\left(\cancel{\frac{dV_{CC}}{dI_c}}^{\,0} - \frac{dV_{BE}}{dI_c}\right) + (\beta+1)\cancel{\frac{dI_{CBO}}{dI_c}}^{\,0}$$

$$1 = \frac{\beta}{R_B}\left(0 - \frac{1}{S'}\right) \Rightarrow \boxed{S' \Rightarrow -\frac{\beta}{R_B}}$$

Stability factor for Emitter-Bias Config :-



Step (1) K.V.L in i/p loop

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

$$I_E = I_B + I_C$$

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

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

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

$$\frac{dI_B}{dI_C} = \frac{1}{R_B+R_E}\left(\cancel{V_{CC}}^{\,0} - \cancel{V_{BE}}^{\,0} - I_C R_E\right)$$

$$\frac{dI_B}{dI_C} \Rightarrow \frac{-R_E}{R_B+R_E}$$

Step (2) $I_c = \beta I_B + (\beta+1) I_{CBO}$

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

Step (3) Diff. eq (II) wrt to I_c (at const. V_{BE} & β)

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

$$1 = \frac{\beta}{R_B+R_E}\left[0 - 0 - R_E \cdot 1\right] + (\beta+1)\frac{1}{S}$$

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

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

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

General form for any biasing

$$\boxed{S = \frac{\beta+1}{1-\beta\left(\frac{dI_B}{dI_C}\right)}}$$

or

E.B.C → $$\boxed{S = \frac{(\beta+1)(R_B+R_E)}{R_B+(\beta+1)R_E}}$$

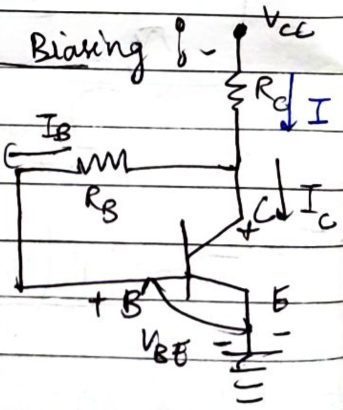
$$S = \frac{\beta+1}{1-\beta\left(\frac{-R_E}{R_B+R_E}\right)}$$

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

→ $S' = \frac{dI_C}{dV_{BE}}$ at const β & I_{CBO}

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

★ Stability factor for collector feedback Biasing :-



$I = I_C + I_B$

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

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

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

② $I_C = \beta I_B + (\beta+1) I_{CBO}$ RE

$$I_C = \beta\left(\frac{V_{CC}-V_{BE}-I_C R_C}{R_B+R_C}\right) + (\beta+1) I_{CBO} \rightarrow ⑪$$

RE

③ $\frac{dI_C}{dI_C}$ keeping β & V_{BE} → const.

$$\boxed{S = \frac{(\beta+1)(R_B+R_C)}{R_B+(\beta+1)R_C}}$$ → C.F.B

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$$s' = \frac{dI_C}{dV_{BE}} \Bigg| \; I_{CBO} \text{ \& } \beta \text{ are const.}$$

$$\frac{dI_C}{dI_C} = \frac{\beta}{R_B+R_C}\frac{d}{dI_C}\left(V_{CC} - V_{BE} - I_C R_C\right) + 0$$

$$1 = \frac{\beta}{R_B+R_C}\left[0 - \frac{dV_{BE}}{dI_C} - R_C\right]$$

$$1 = \frac{\beta}{R_B+R_C}\left[-\frac{1}{s'} - R_C\right]$$

C.F.B $\rightarrow$ $$\boxed{s' = -\frac{\beta}{R_B+(\beta+1)R_C}}$$

compare

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

E.B.C