# BJT

27 October 2024 11:07 AM

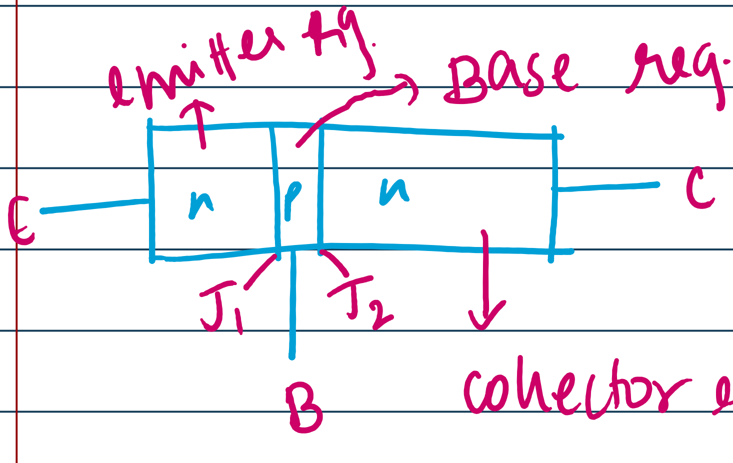
## BJT (Bipolar Junction Transistor)

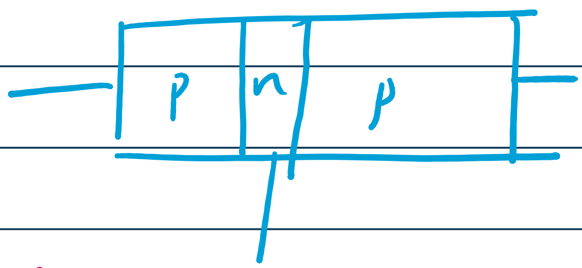
→ 3-terminal device.

→ amplification of weak signals.

→ switching operations

## Physical Structure:




$J_1$ → Emitter-Base Junction

$J_2$ → Collector-Base Junction

width : C > E > B

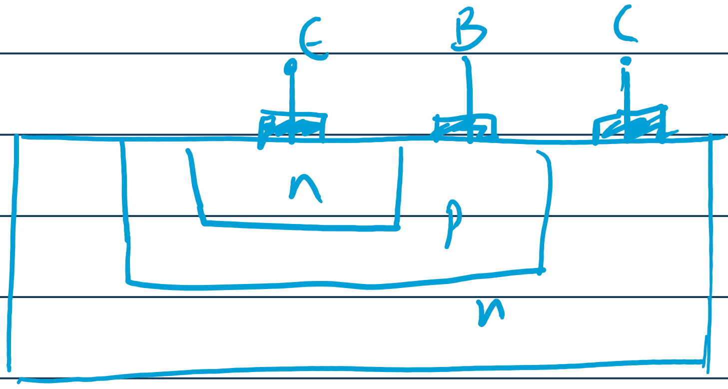
↓

more width, better heat dissipation.

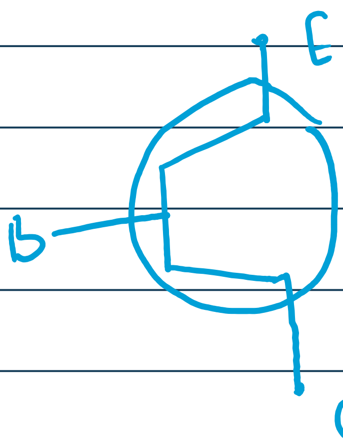
more width, better heat dissipation.

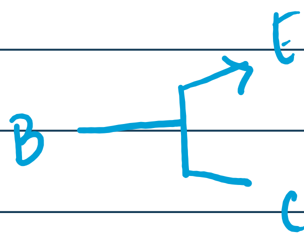
doping: E > C > B

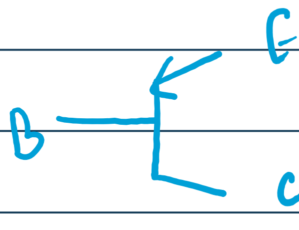
Cross-sectional view :



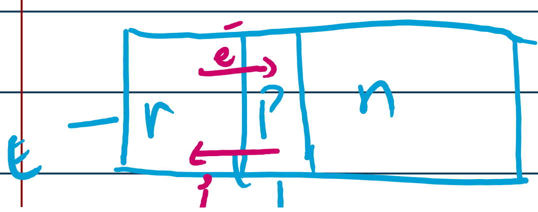

Symbol

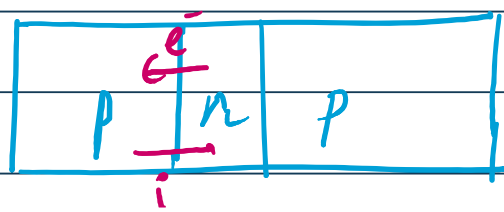


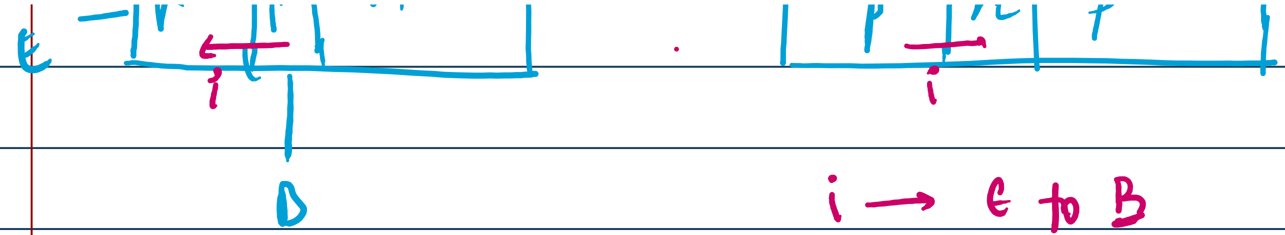




npn pnp






i → E to B

i moves from
B → E

* Generally n-p-n is used as mobility of $e^-$ > mobility of holes.

Bipolar Jun. Transistor

$\underbrace{\text{Transistor}}_{\text{Transfer + Resistor.}}$

$J_1 \rightarrow$ f.b (low R)
$J_2 \rightarrow$ r.b (high R)

Regions of op:

| | | | |
|---|---|---|---|
| FB | RB | Active | Amplifies |
| FB | FB | Saturation | "ON" |
| RB | RB | cutoff | "OFF" |
| RB | FB | inverted | |

# Working of Transistor

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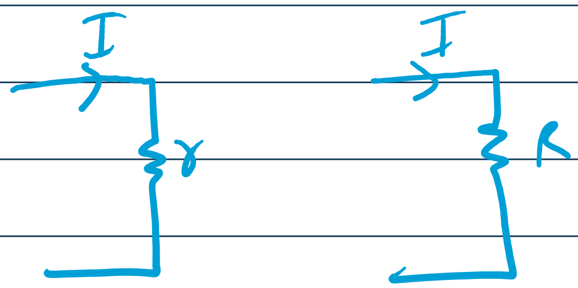
## Working of Transistor:

### Active mode:

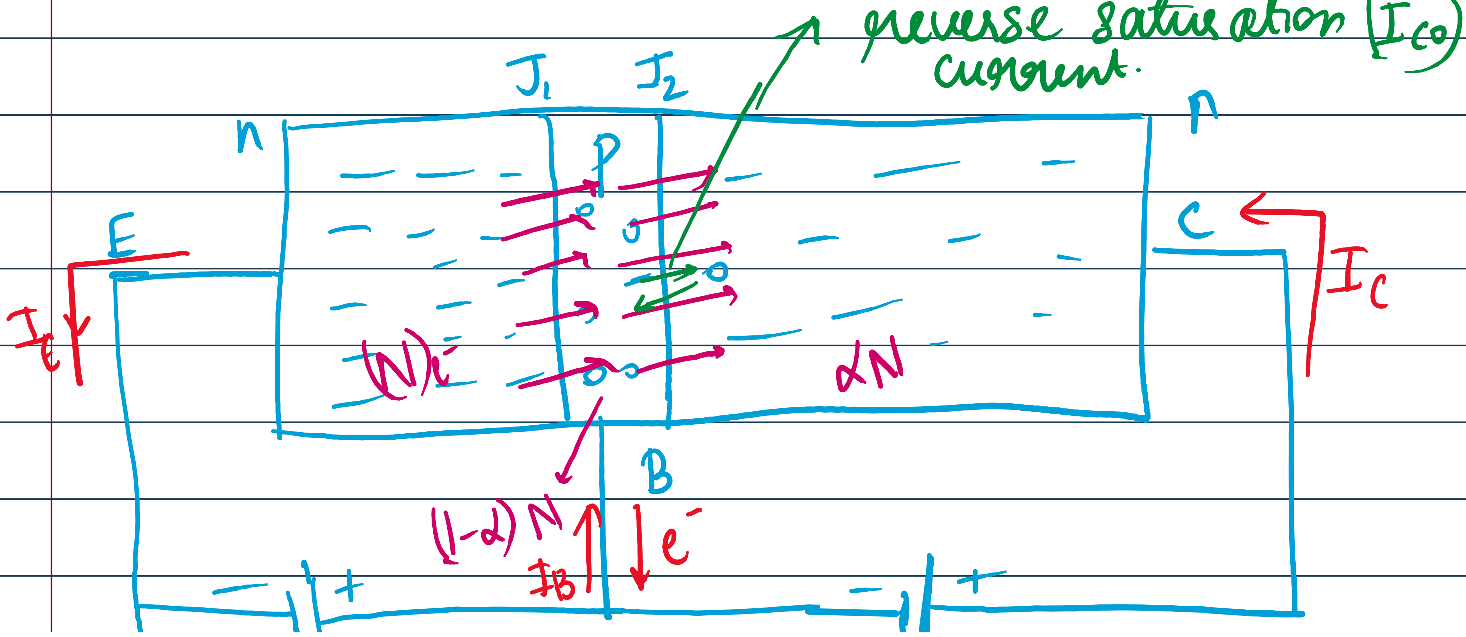
$J_1 \rightarrow$ f.b $\quad R \approx 0$

$J_2 \rightarrow$ r.b $\quad R = \infty$




output

$V_i = Ir < \underbrace{V_0 = IR}_{\text{amplified signal at output}}$




Base → very small + lightly doped } most $e^-$ from E go to collector.

$e^-$ : 2% – 5% at base

95% – 98% at collector.

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

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

# CB config

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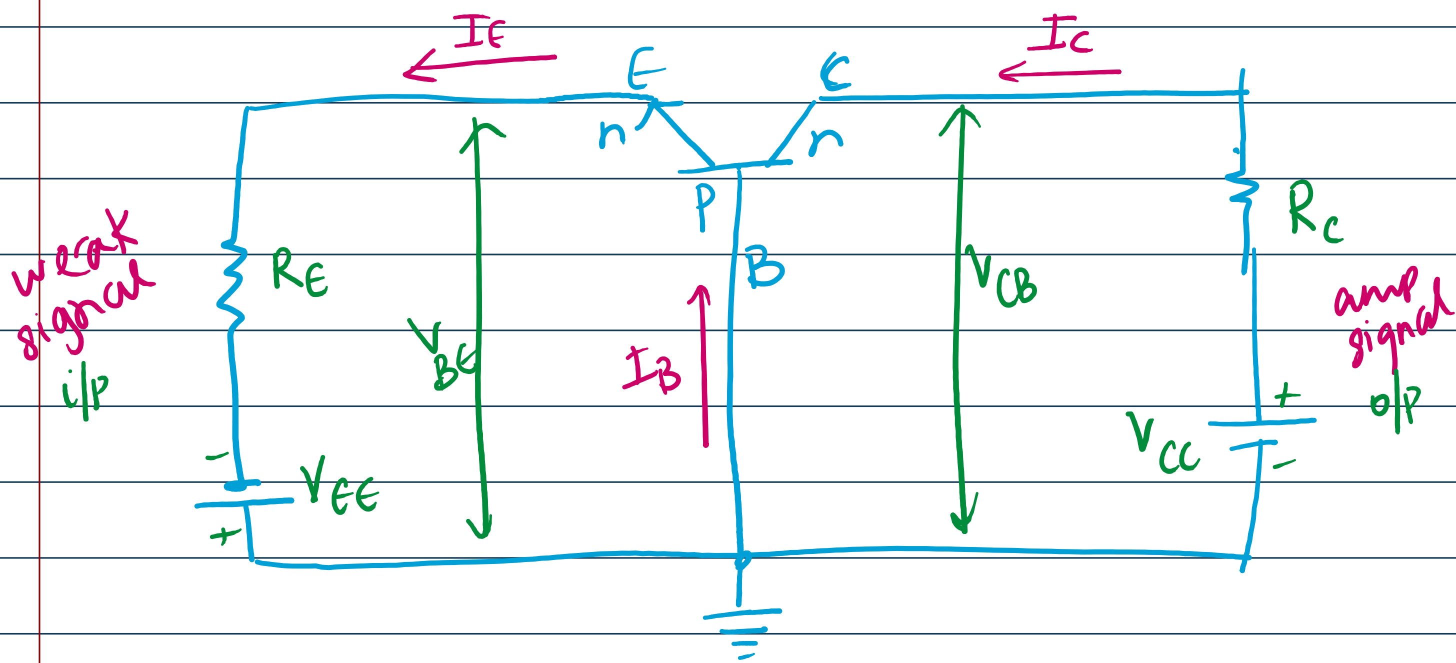
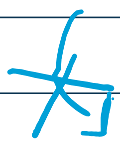
B, E and C

i) Common Base
ii) Common base
iii) Common Collector




low pot

$V_{BE} = V_{EE}$ $\qquad$ $V_{CB} = V_{CE}$



$V_{EB}$ high pot

→ i/p char. → $I_E$ vs $V_{BE}$

o/p char. $\rightarrow$ $I_C$ vs $V_{CB}$

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

leaving current = entering current

$I_C = \alpha I_E + I_{CO}$ (r.s.c)

or $I_C = \alpha I_E + I_{CBO}$ open circuit

$I_E \gg I_{CBO}$

can be neg.

$I_C = \alpha I_E$

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

common base current gain

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

$\alpha \rightarrow$ 0.95 - 0.98

$$\boxed{I_B = (1-\alpha) I_E}$$

# CB (i/p char)

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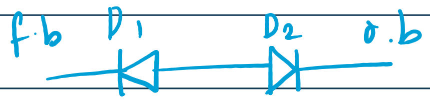
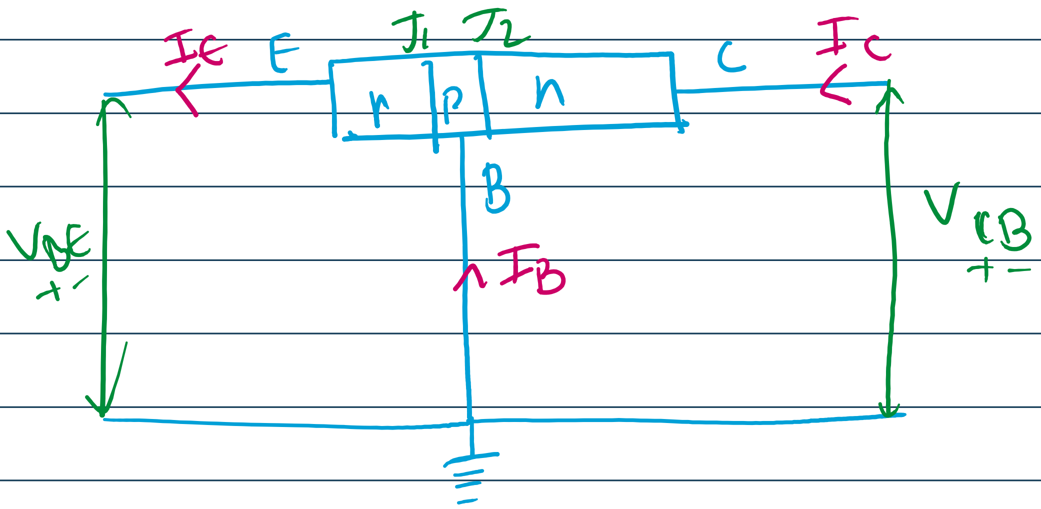
## CB Trans. (I/p char.) [Early effect]

↓

f.b. diode

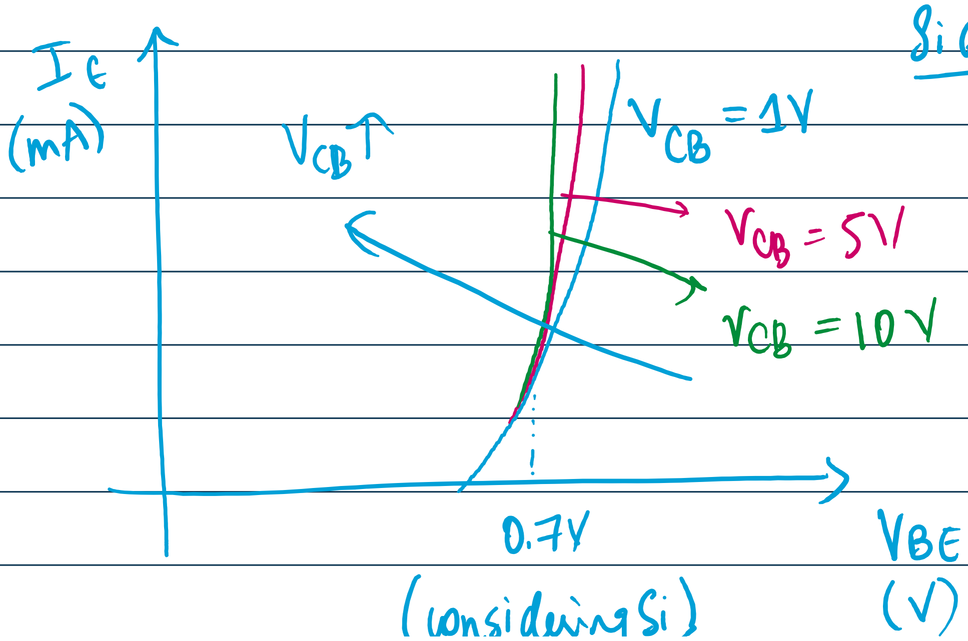



i/p $I = I_E$ o/p $I = I_C$

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

Si diode

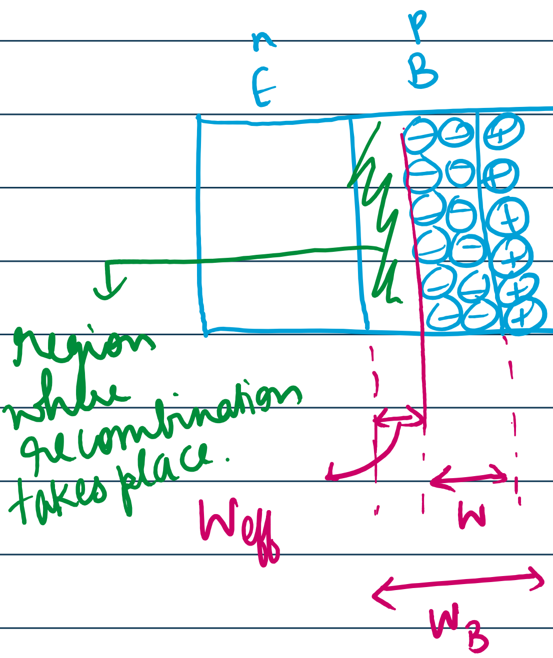


(considering Si) (V)

# Early Effect. ⟨aka Base-width modulation⟩

$V_{CB} \uparrow$

reverse bias voltage




$W_B \rightarrow$ width of base / metallurgical base width.

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

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

if $V_{CB} \uparrow \Rightarrow W \uparrow \Rightarrow W_{eff} \downarrow$

(chance of recombination ↓)

$\Rightarrow I_C \uparrow$

(conc. gradient ↑)

more $e^-$ flow towards base.

# CB (o/p char)

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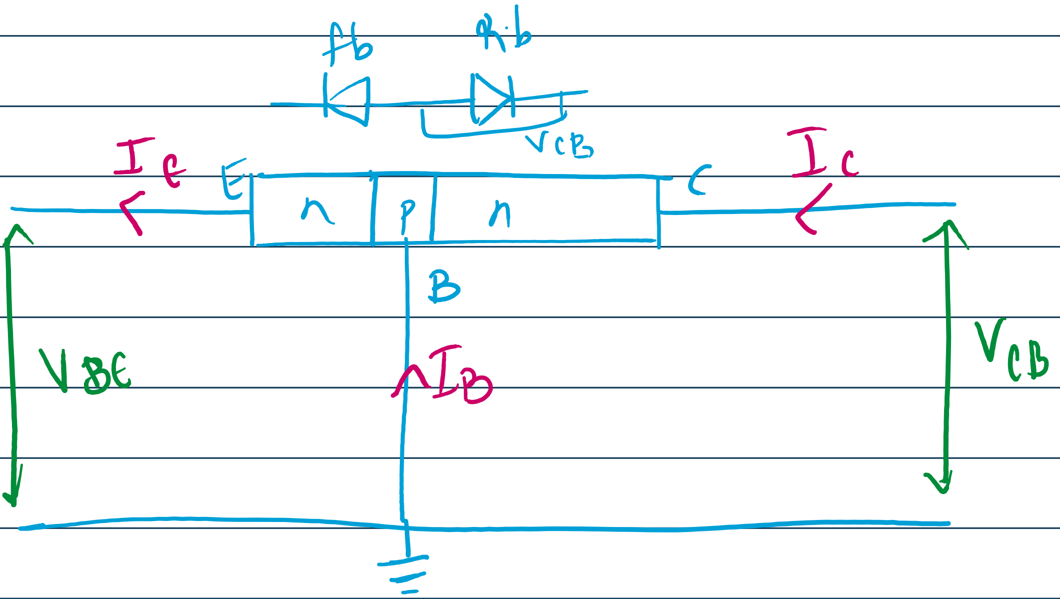
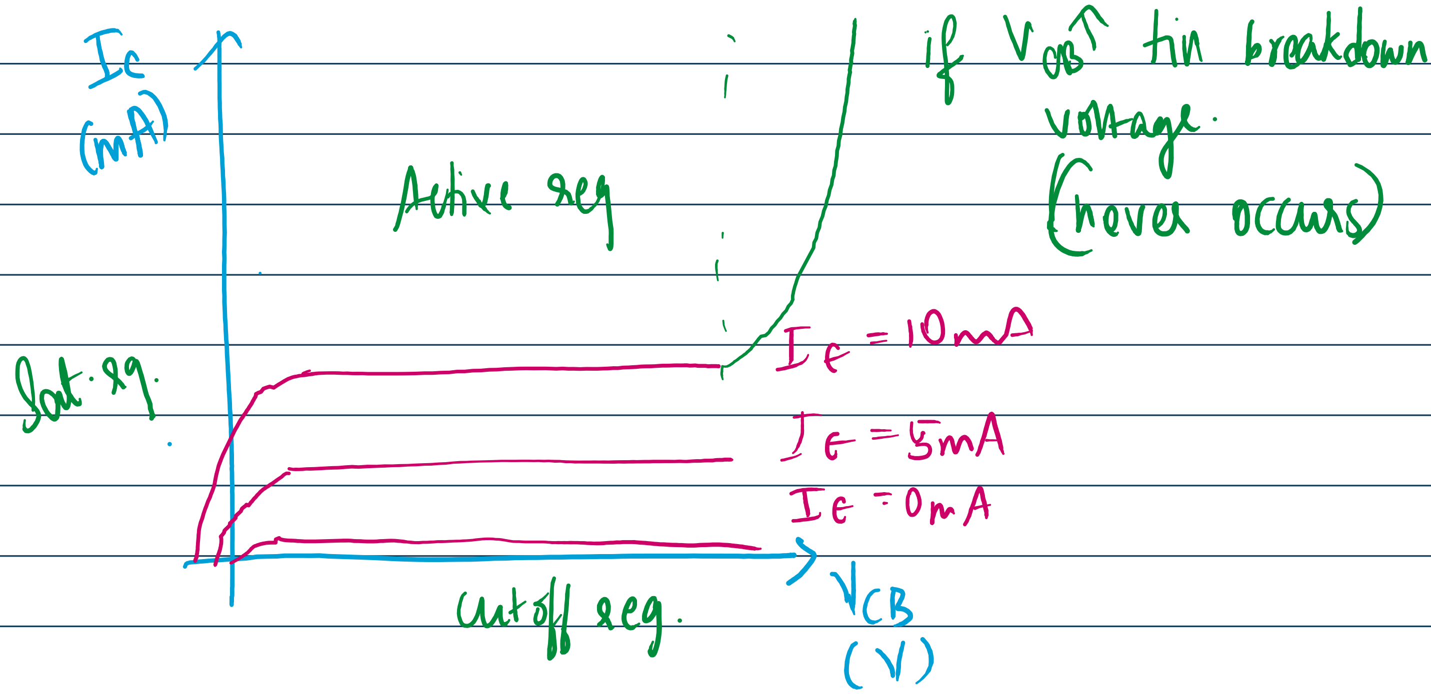
CB Trans. (o/p char) → r.b diode.




o/p I ($I_C$) vs o/p V ($V_{CB}$) for various levels of i/p I ($I_E$)



$I_C = \alpha I_E + \cancel{I_{CBO}}^{\approx 0}$ (independent of $V_{CB}$)

$I_C \approx \alpha I_E$

$\underset{\text{o/p}}{I_C} \approx \underset{\text{i/p}}{I_E}$ $(\alpha = 0.95 - 0.98)$

# Tras amp action

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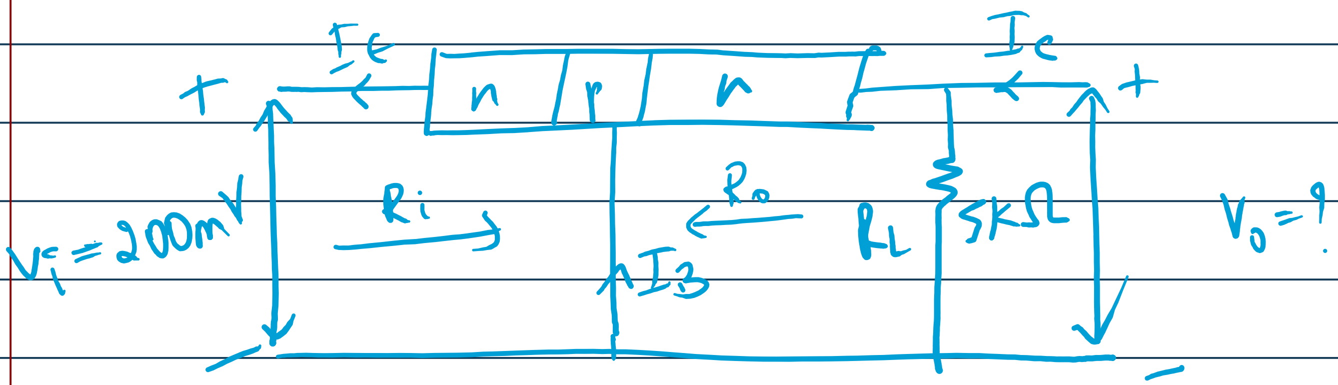
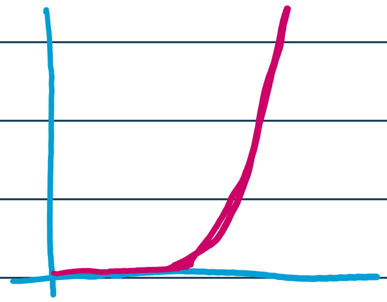
## Transistor Amplifying Action:



slope ↑ ⇒ $R_i$ ↓ $\left[ m \propto \frac{1}{R_i} \right]$

$R_i = 20\Omega$

slope ↓ ⇒ $R_o$ ↑

$R_o = 1M\Omega = 100 k\Omega$

Sol$^n$: $V_i = I_i R_i$

$V_i = I_E R_i \Rightarrow I_E = \frac{V_i}{R_i} = \frac{200mV}{20\Omega}$

$I_E = 10mA$

$I_E = 10mA$

$$I_C \approx I_E = 10mA$$

$$V_o = I_C R_L$$
$$= (10mA) \times (5 k\Omega)$$

$$V_o = 50V$$

Voltage Amp.

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

$V_o$ is amplified 50 times.

Amplication of current is always less than 1

# CE config

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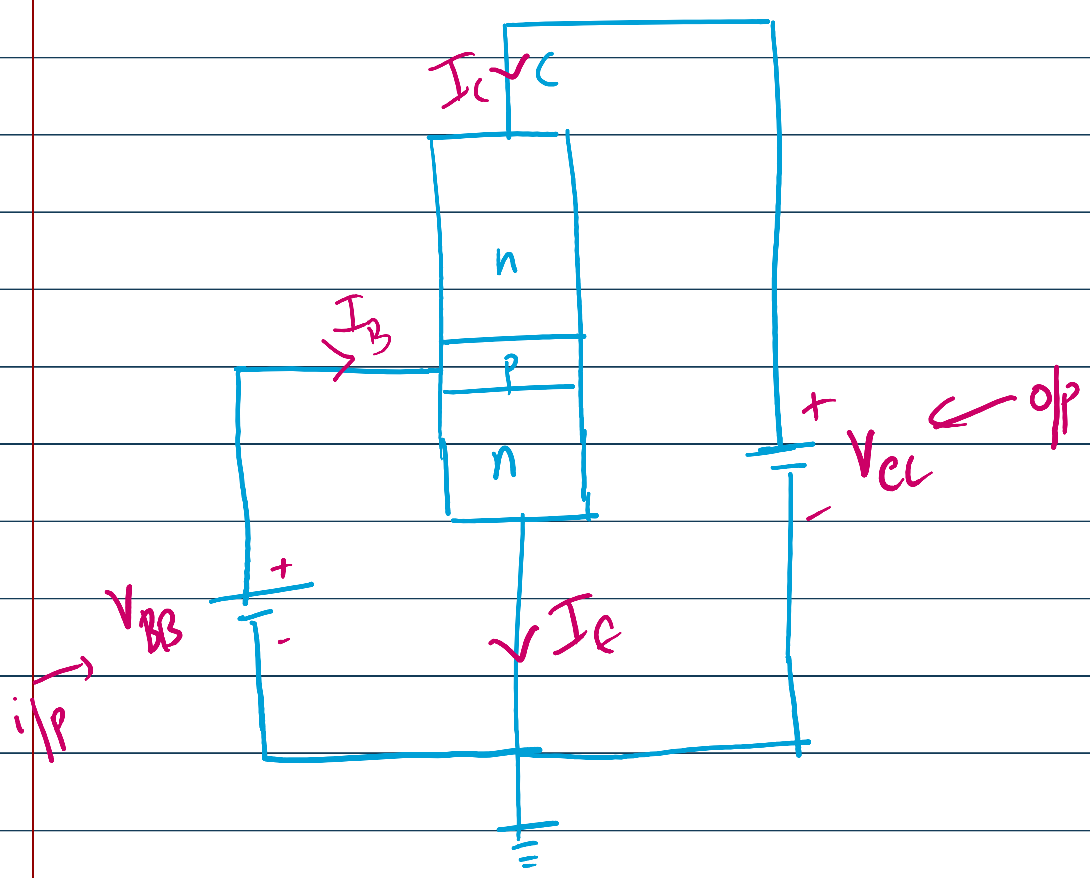
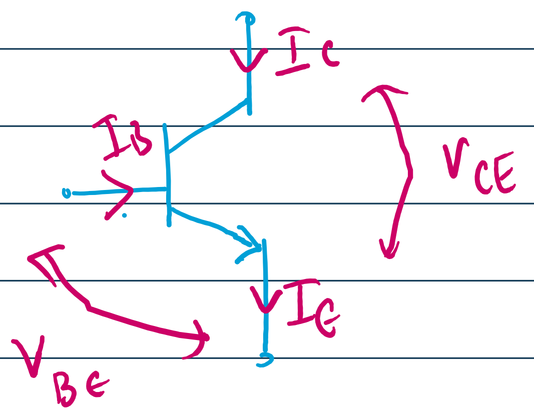
Common Emitter Config.




i/p $I \rightarrow I_B$ o/p $I \rightarrow I_E$

i/p $V \rightarrow V_{BE}$ o/p $V \rightarrow V_{CE}$

$$I_E = I_C + I_B$$

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

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

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

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

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

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

$$\left\{ \beta = \frac{\alpha}{1-\alpha} \; ; \; \beta + 1 = \frac{\alpha}{1-\alpha} + 1 = \frac{1}{1-\alpha} \right\}$$

CI: $\alpha = 0.98$ $\quad \beta = \dfrac{0.98}{1-0.98} = 49$

CII $\alpha = 0.95$ $\quad \beta = \dfrac{0.95}{1-0.95} = 19$

slight change in $\alpha$ changes $\beta$ significantly.

$$\left[\alpha < 1 \qquad 50 \leq \beta \leq 400\right]$$

$\alpha$

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

reverse saturation current in CE-config.

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

$I_{CEO} \ll \beta I_B$

$$I_C = \beta I_B$$

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

current amplification factor.

NOTE: $I_C = \alpha I_E + I_{CBO}$ CB config

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

[contribution of leakage current in the o/p current is more in case of CE config. than CB config]

$\beta = 99$, $I_C$ in CB config $\rightarrow 99 I_{CBO}$

in CE config $\longrightarrow 100\, I_{CBO}$

# CE (i/p char)

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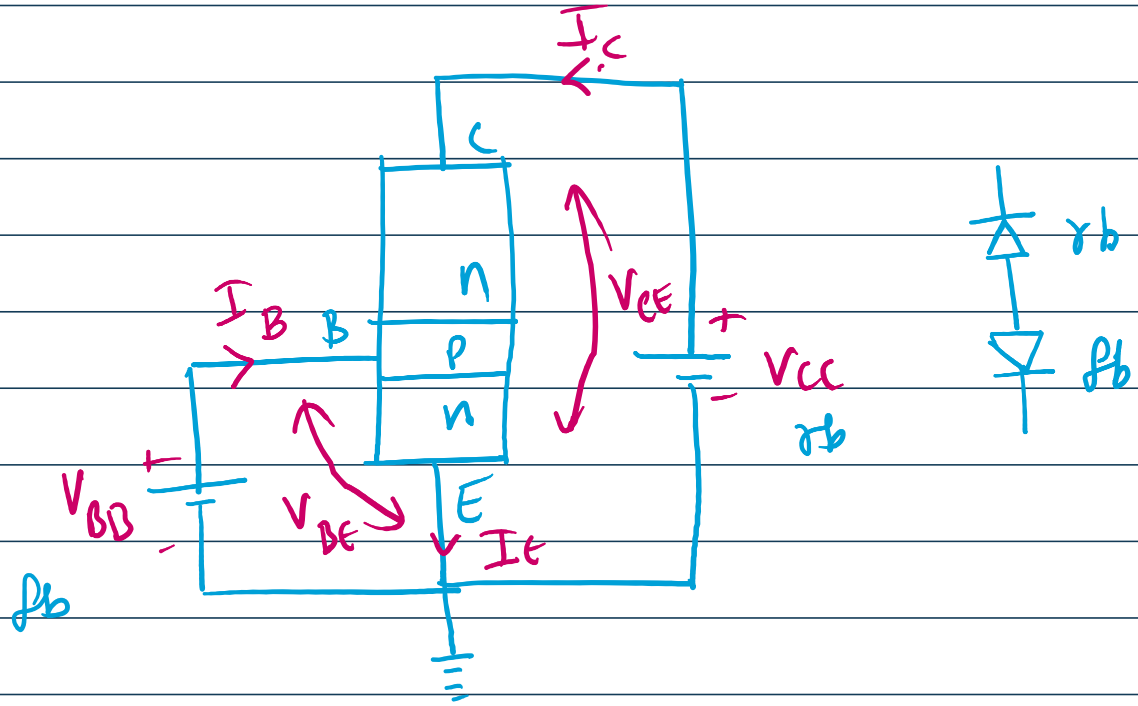
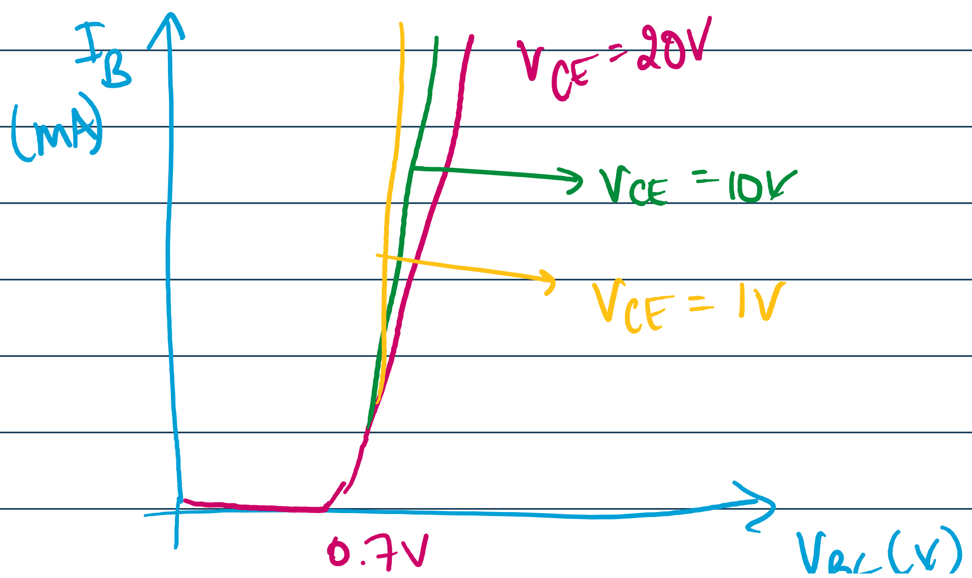
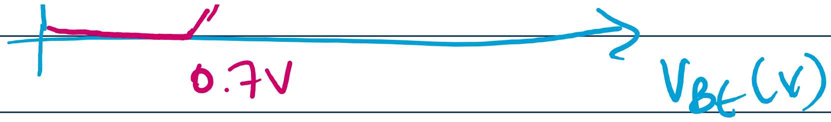
CE trans (I/p char).

$V_{BB}$ & $V_{CC}$ → Biasing pot.

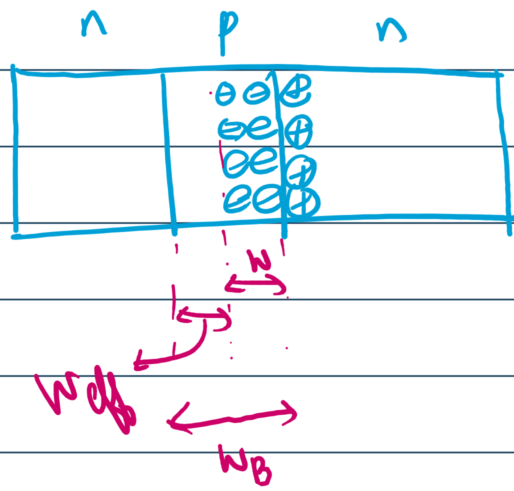



$I_B$ vs $V_{BE}$ for diff values of $V_{CE}$






when $V_{BE} > \underbrace{V_b}_{\text{barrier pot.}}$




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

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

$$V_{CB}\uparrow \Leftrightarrow V_{CE}\uparrow \Rightarrow W\uparrow \Rightarrow W_{eff}\downarrow$$

$$\Rightarrow I_B\downarrow \quad (I_E\uparrow)$$

# CB (o/p char)

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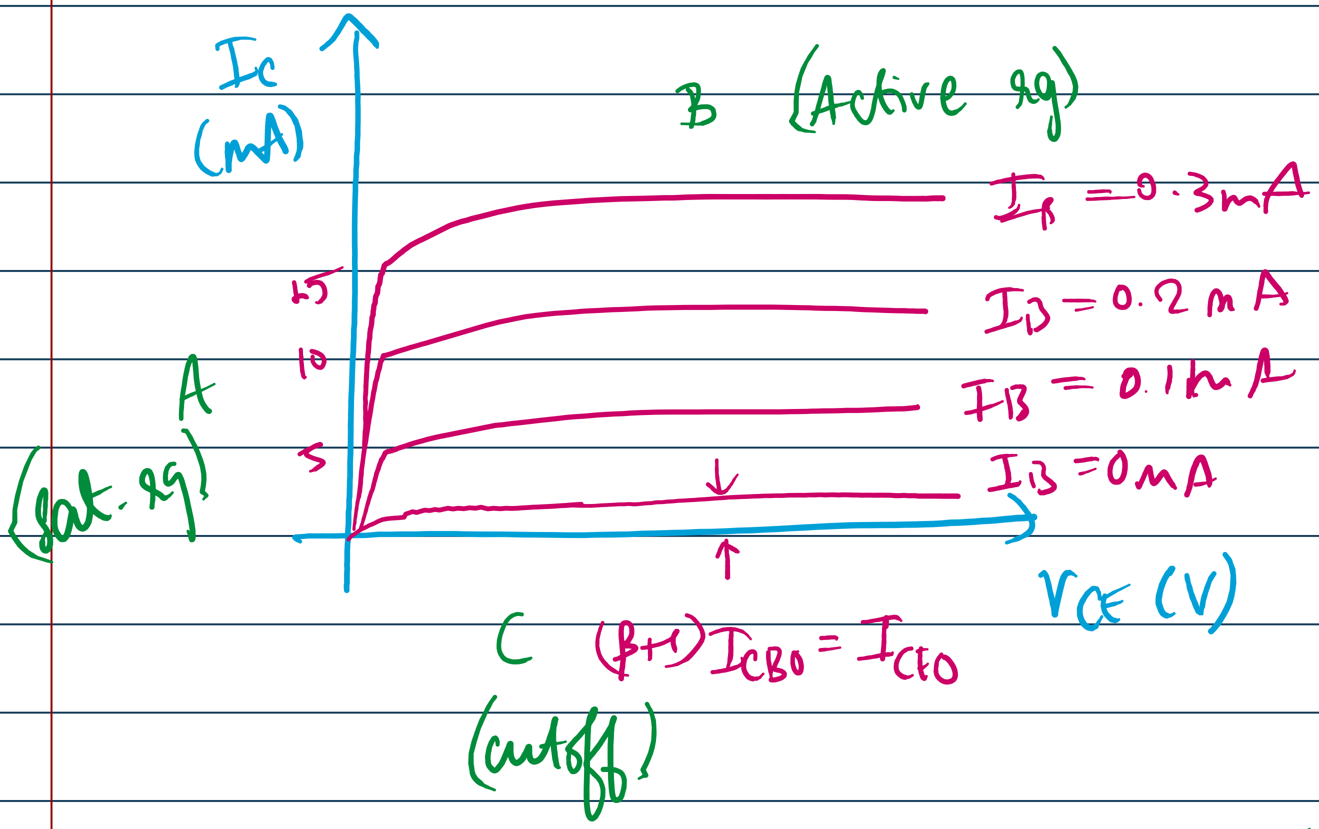
CE config (o/p - char).

$I_C$ vs $V_{CE}$ for diff levels of $I_B$.




$$I_C = \beta I_B + (\beta+1) I_{CB0}$$

$I_B = 0$, $I_C = (\beta+1) I_{CB0}$.

$I_B = 0.1\,mA \longrightarrow I_C = 5\,mA$

$I_B = 0.2\,mA \longrightarrow I_C = 10\,mA$

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

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

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

# CC config

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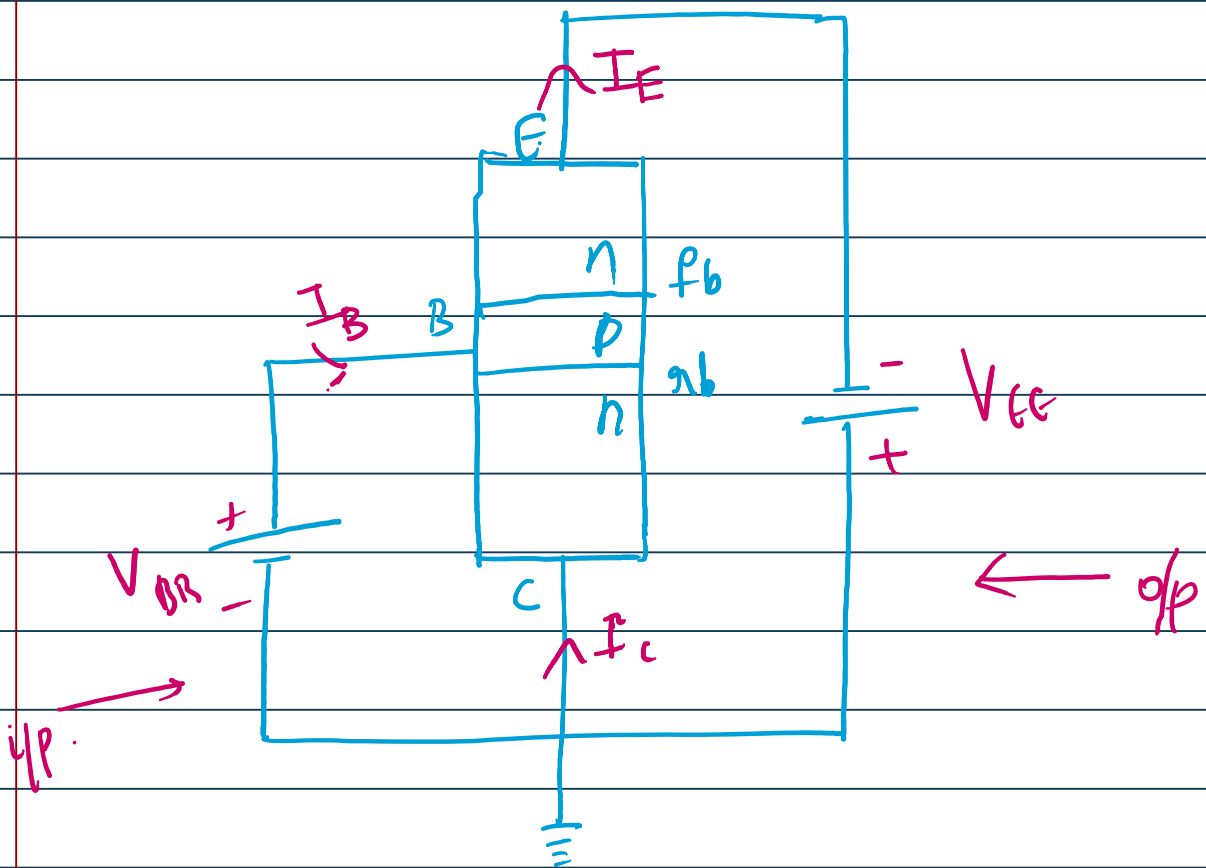
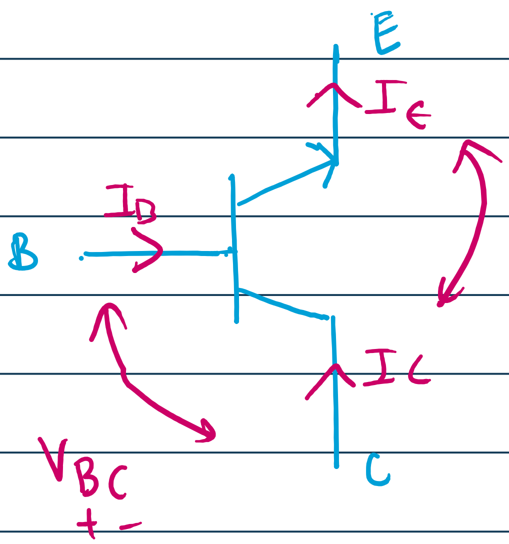
## Common Collector Config




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

imp $I_E$ vs $V_{CE}$ for various levels of $I_B$

$$I_C \left\{ \begin{array}{ll} I_C = \alpha I_E & \alpha \Rightarrow 0.95 - 0.98 \simeq 1 \\ I_C \simeq I_E & \end{array} \right\}$$

o/p char of CE $\Leftrightarrow$ o/p char of CC.

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

current amplification factor.

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

$$I_C = \alpha I_E + I_{CBO} \longrightarrow (2)$$

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

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

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

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

$$\left\{ \gamma = \frac{1}{1-\alpha}. \right\}$$

# Relation b/w 3 amp factors

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Relation b/w $\alpha, \beta, \gamma$. {Amplification factors}

(CB) $\alpha$ → $\alpha_{dc} = \frac{I_C}{I_E}$

→ $\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}\Big|_{V_{CB} = \text{const}}$

(CE) $\beta$ → $\beta_{dc} = \frac{I_C}{I_B}$

→ $\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}\Big|_{V_{CE} = \text{const}}$

(CC) $\gamma$ → $\gamma_{dc} = \frac{I_E}{I_B}$

→ $\gamma_{ac} = \Delta I_E \Big|$

$$\gamma_{ac} = \frac{\Delta I_E}{\Delta I_B} \bigg|_{V_{CE} = \text{const}}$$

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

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

$$\gamma = \beta + 1$$

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

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

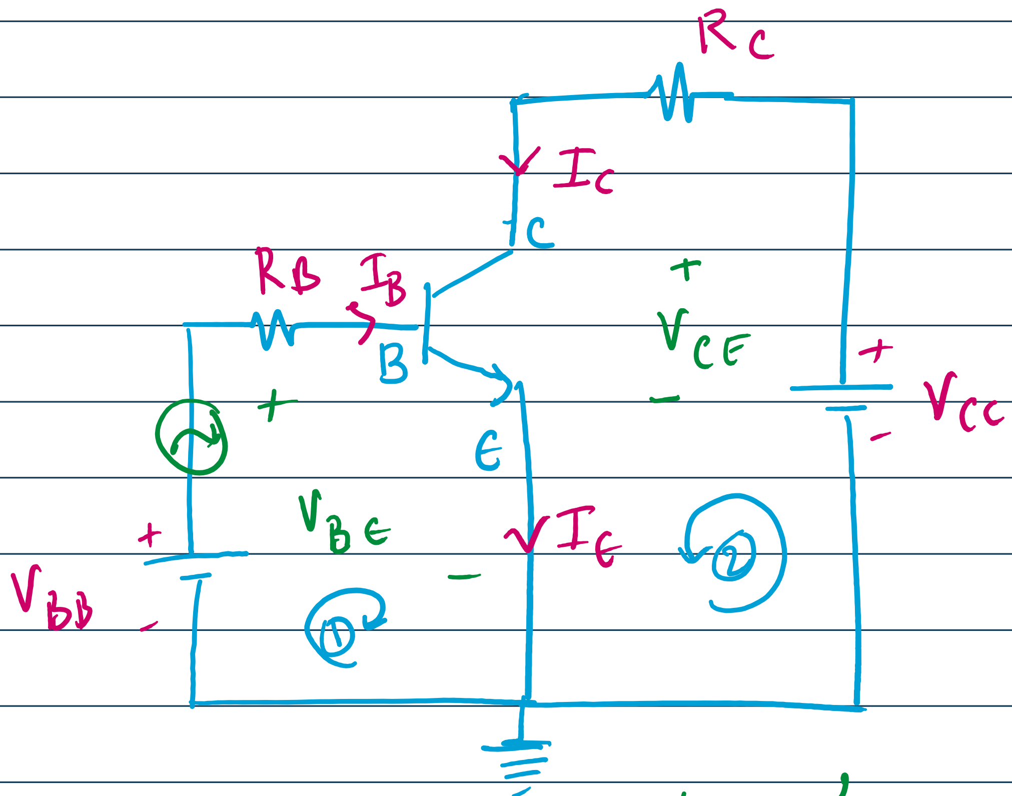
$$\gamma = \frac{1}{1-\alpha}$$

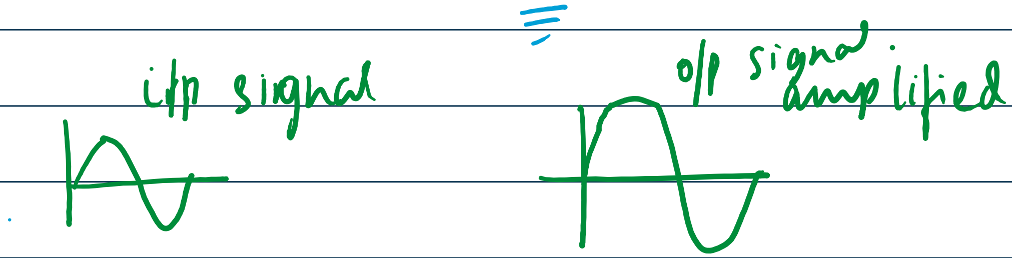
$$\boxed{\gamma = \beta + 1 = \frac{1}{1-\alpha}}$$

# DC Biasing of Transistors

→ Baising : the process in which we apply external dc voltages to select the appropriate or proper OP. (operating point).

→ $\boxed{\text{npn CE trans.}}$ → used.



i/p OP —

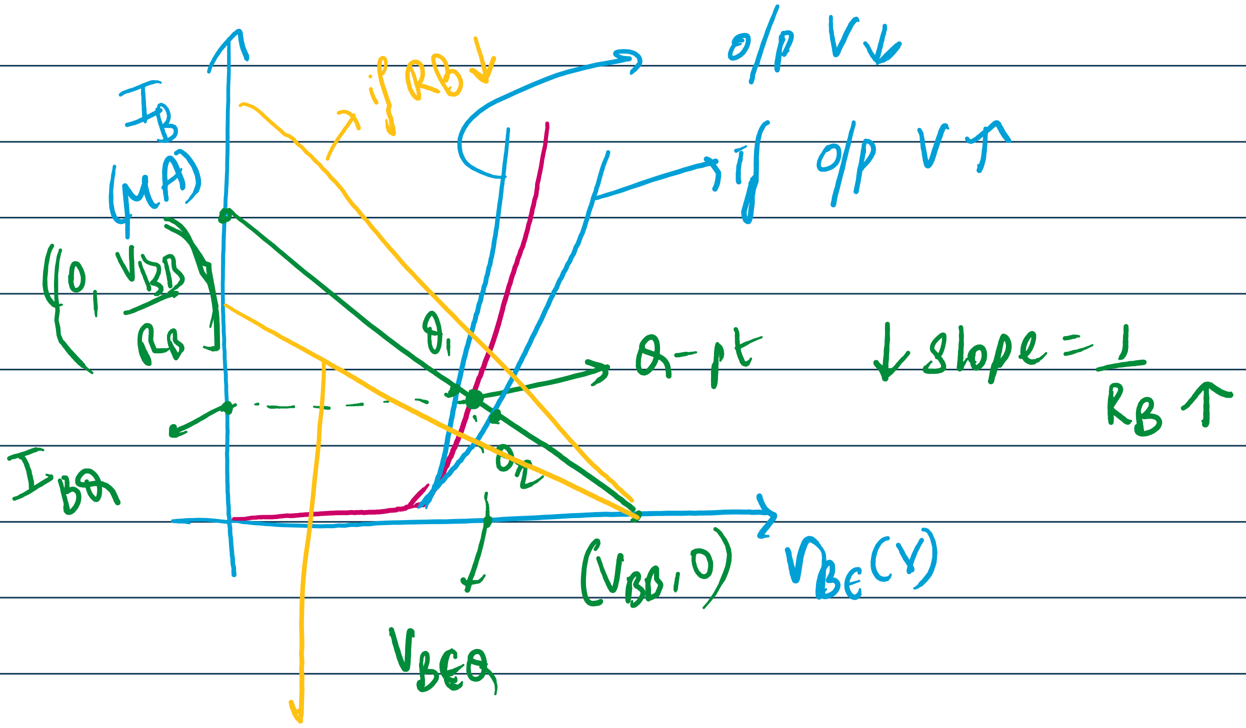
→ KVL in loop ①:

$$+V_{BB} - \overset{y}{I_B} R_B - \overset{x}{V_{BE}} = 0$$

$P_1 \equiv (0, I_C) \qquad P_2 \equiv (V_{BE}, 0)$

→ $V_{BE} = 0$ → $I_B = 0$

$I_B = \dfrac{V_{BB}}{R_B} \qquad V_{BE} = V_{BB}$




new load line (if $R_B$ ↑)

→ KVL in loop ②:

KVL in loop ②.

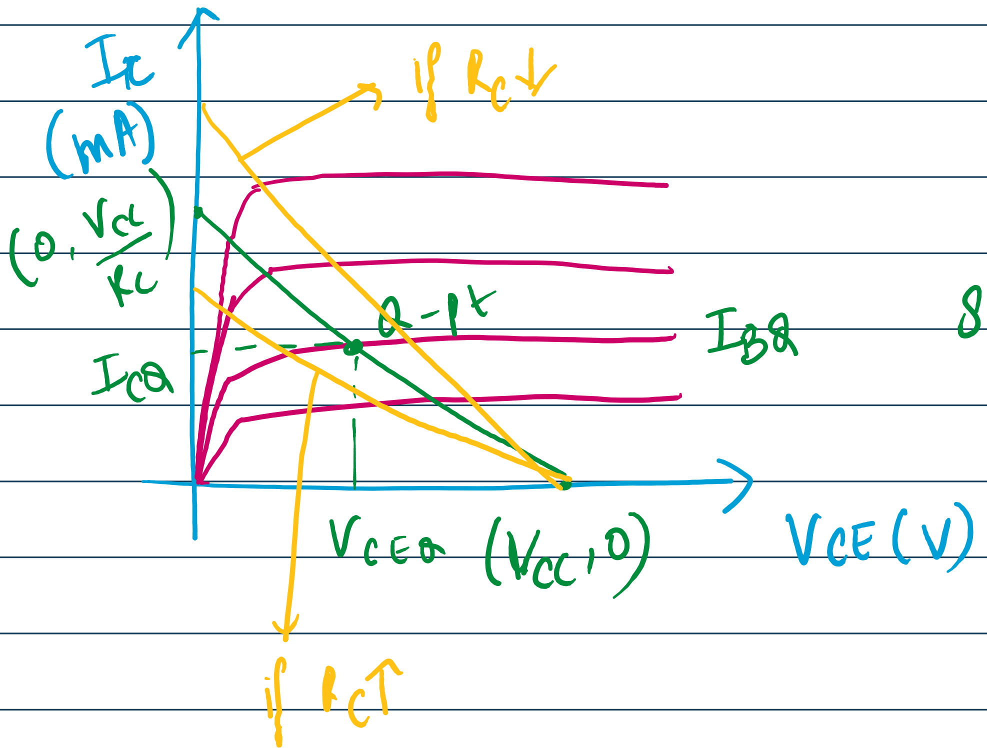
$$V_{CC} - I_C R_C - V_{CE} = 0$$

(with $y$ marked at $I_C$ and $x$ marked at $V_{CE}$)

$P_1 \equiv (0, I_C)$ $\qquad$ $P_2 \equiv (V_{CE}, 0)$

$V_{CE} = 0$ $\qquad$ $I_C = 0$

$I_C = \dfrac{V_{CC}}{R_C}$ $\qquad$ $V_{CE} = V_{CC}$.




$$\text{slope} = \frac{-1}{R_C \uparrow}$$

# Fixed Bias Config

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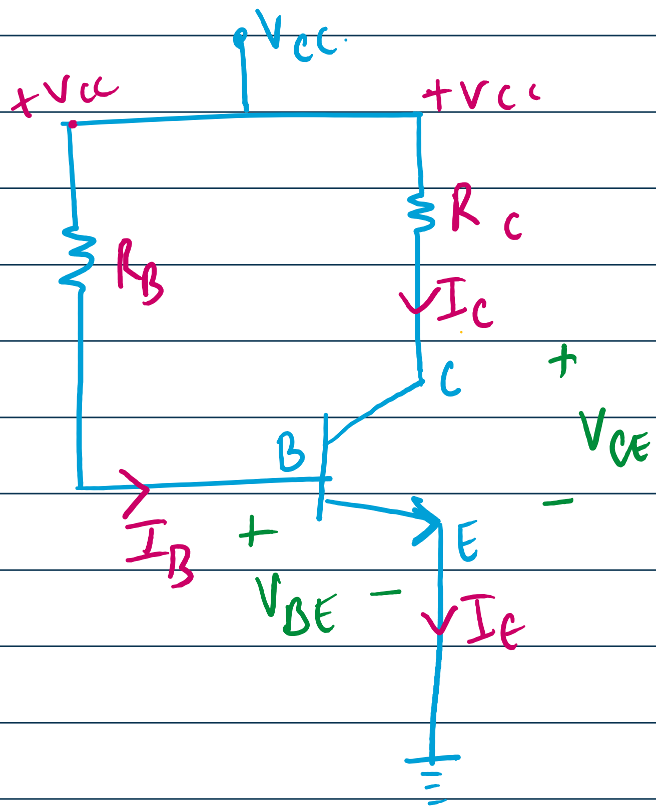
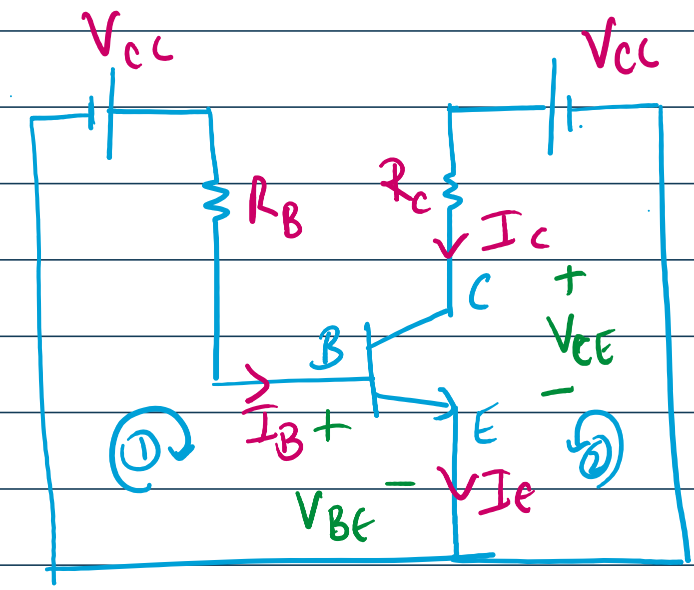
## Fixed Bias Configuration




$I_C = ?$

$V_{CE} = ?$

Soln →




→ KVL for loop ①:

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

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

$$I_C = \beta I_B$$

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

$V_{BE}$ → 0.7V (Si)
0.3V (Ge)

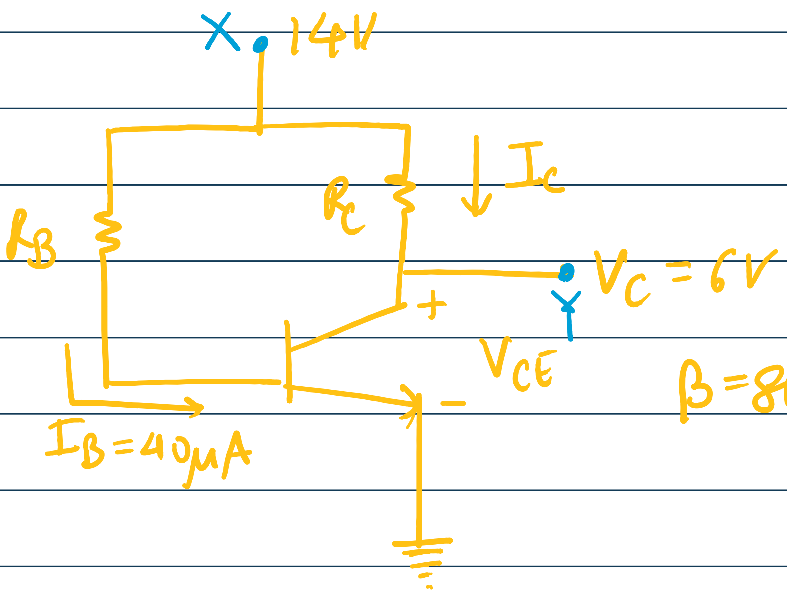
→ KVL for loop ②:

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

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

ex:

① For the fixed bias config., determine,




$\beta = 80$

find → (a) $I_C$

(b) $R_C$

(c) $R_B$

(d) $V_{CE}$

Sol$^n$:

$V_{CC} = 14V$

$I_B = 40\mu A$

$\beta = 80$

$V_C = 6V$

→ wkt, $I_C = \beta I_B$

$= 80 \times 40\mu A$

$= 3200\mu A$

$I_C = 3.2mA$ (a).

→ KVL, (from X → Y)

$14 - I_C R_C = 6$

$I_C R_C = 8$

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

$R_C = 2.5k\Omega$ (b)

→ KVL, (in i/p loop)

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

$$R_B = \frac{14 - V_{BE}}{I_B}$$

$$= \frac{(14 - 0.7)\,V}{40\,\mu A}$$

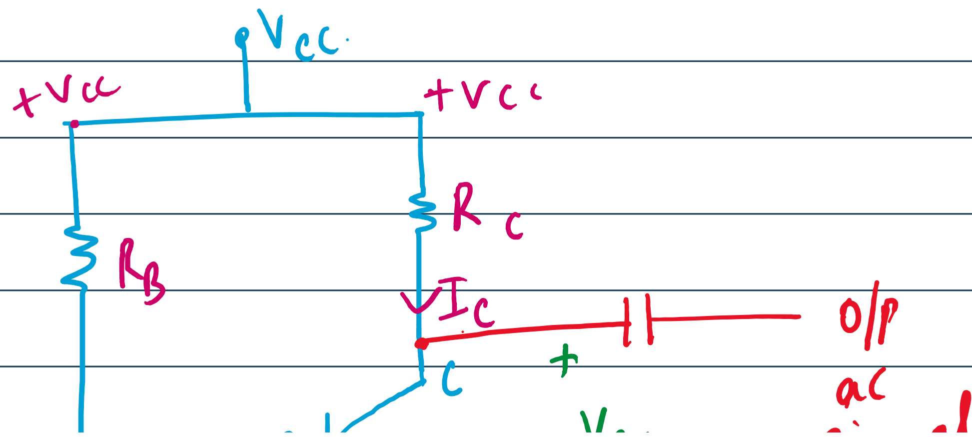
$$= \frac{13.3\,V}{40\,\mu A}$$

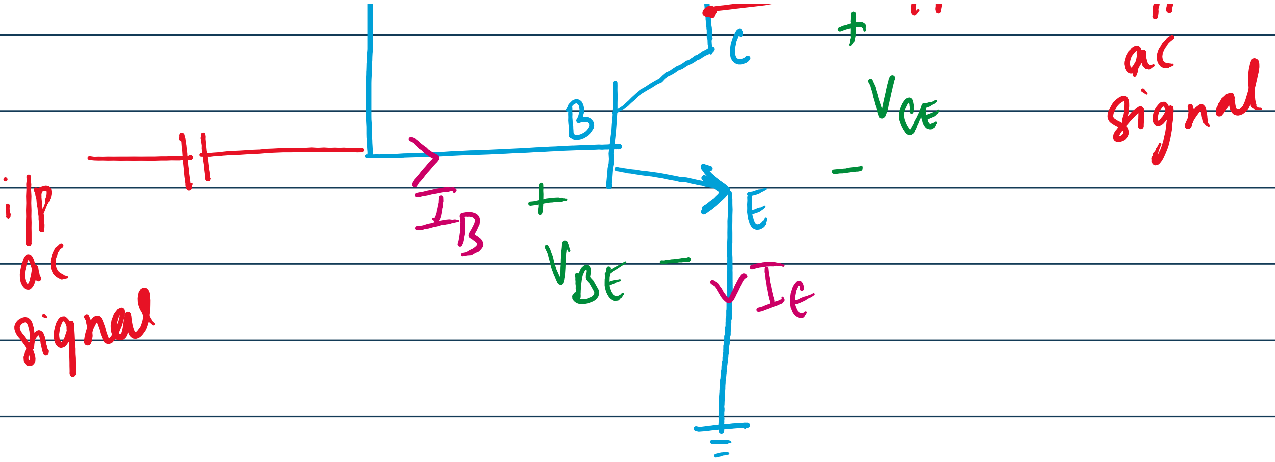
$$R_B = 332.5\,k\Omega \quad (c)$$

→ $V_{CE} = V_C - V_E$

$$= 6 - 0$$

$$V_{CE} = 6\,V \quad (d)$$






$$X_c = \frac{1}{2\pi\nu C}$$

$\nu = 0$ (in case of dc)

$$X_c = \frac{1}{0} = \infty .$$

⇒ thus, —||— part becomes an open circuit — — and is ignored in dc.

② For the fixed bias config, determine

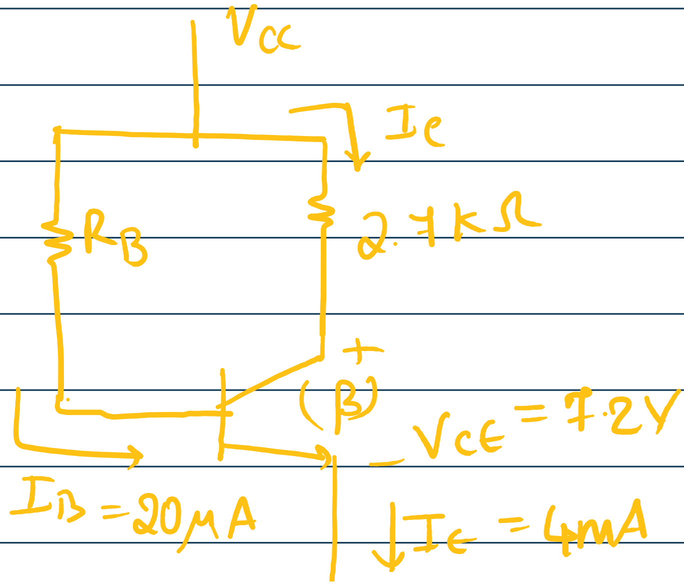
find:

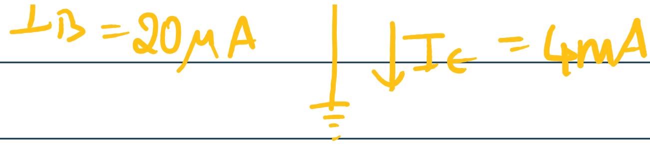
(a) $I_C$

(b) $V_{CC}$

(c) $\beta$

(d) $R_B$






Sol$^n$: We have, $R_C = 2.7K\Omega$

$V_{CE} = 7.2V$

$I_E = 4mA$

$I_B = 20\mu A$

$\rightarrow$ $I_E = I_B + I_C$

$$I_C = I_E - I_B$$
$$= 4mA - 20\mu A$$
$$= 4\times10^{-3} - 20\times10^{-6}$$
$$= 4\times10^{-3}(1 - 5\times10^{-3})$$
$$= 4\times10^{-3} \times 0.995$$
$$I_C = 3.98\ mA \quad (a)$$

$1 - 0.005$

$(0.995)$

$\rightarrow$ KVL, (in o/p loop)

$$V_{CC} - I_C R_C - V_{CE} = 0$$
$$V_{CC} - (3.98m)(2.7k) - 7.2 = 0$$
$$V_{CC} - 10.7460 - 7.2 = 0$$
$$V_{CC} = 17.946V \quad (b)$$

$$V_{CC} = 17.946\,V \quad (b)$$

$\rightarrow$ $I_C = \beta I_B$

$$\beta = \frac{I_C}{I_B} = \frac{3.98\,m}{20\,\mu}$$

$$= \frac{3980}{20}$$

$$\beta = 199 \quad (c)$$

$\rightarrow$ KVL, (in i/p loop)

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

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

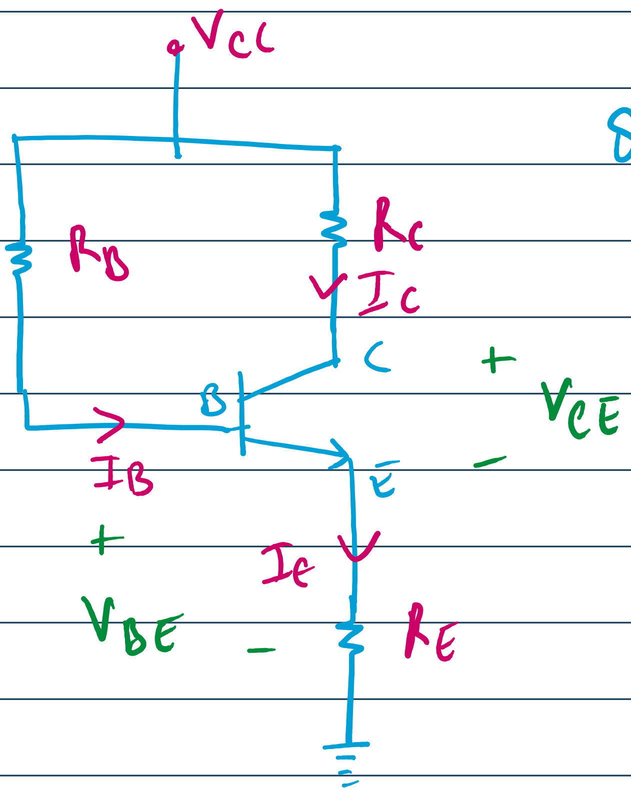
$$= \frac{17.946 - 0.7}{20\mu}$$

$$= \frac{17.246}{20} \times 10^6$$

$$\cdot R_B = 862.3\,K\Omega$$

27 October 2024 11:58 PM

# Emitter Bias Config




Q-pt ≡ $(I_{CQ}, V_{CEQ})$

→ KVL, (in i/p loop):

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

$$\left[\begin{aligned} I_E &= I_C + I_B \\ &= \beta I_B + I_B \\ I_E &= (\beta+1) I_B \end{aligned}\right]$$

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

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

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

$$I_C = \beta I_B$$

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

→ KVL, (in o/p loop)

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

$$[I_E \approx I_C]$$

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

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

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

Advantage of using $R_E$ :

i) Temp ↑ ⇒ $I_C$ ↑ $\{ I_C = \beta I_B + (\beta+1)\underline{\underline{I_{CBO}}} \}$

$\Rightarrow I_E R_E \uparrow$ $\quad\quad$ $\uparrow$ as $I_E \uparrow$

$\Rightarrow I_B \downarrow \quad \Rightarrow I_C \downarrow$

ii) $\beta$ changes, $I_C$ changes.

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

$$= \frac{\beta(V_{CC} - V_{BE})}{R_B + \beta R_E} \quad [\beta R_E \gg R_B]$$

$$= \frac{\beta(V_{CC} - V_{BE})}{\beta R_E}$$

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

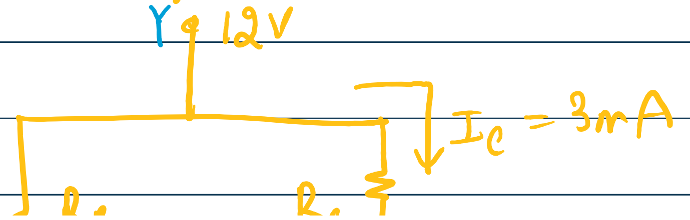
independent of $\beta$.

ex:

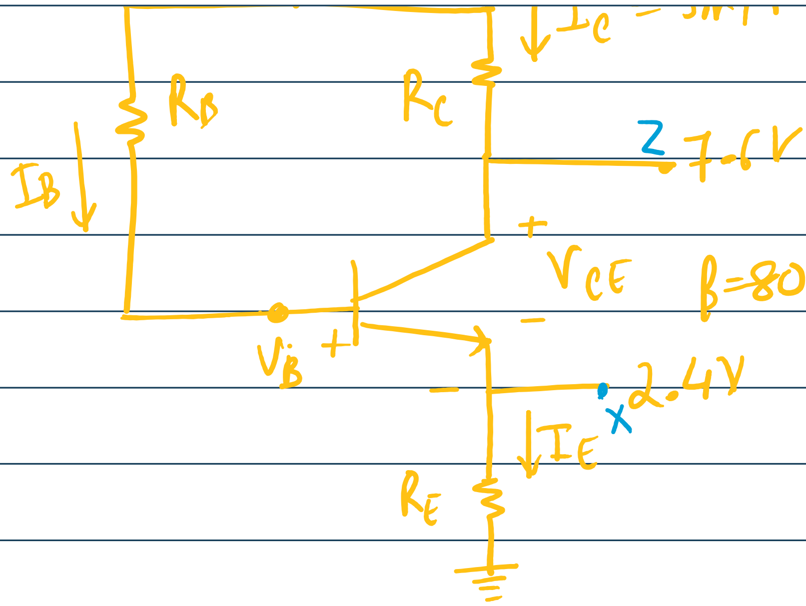
1 For emitter-bias config., determine:

(a) $R_C$

(b) $R_E$



(b) $R_E$
(c) $R_B$
(d) $V_{CE}$
(e) $V_B$




Sol^n: we have, $V_{CC} = 12V$ $\quad V_{BE} = 0.7V$
$I_C = 3mA$
$\beta = 80$
$V_C = 7.6V$
$V_E = 2.4V$

→ $V_{CE} = V_C - V_E = 7.6 - 2.4$

$V_{CE} = 5.2V$ (d)

→ $V_{BE} = V_B - V_E$

$0.7 = V_B - 2.4$

$V_B = 3.1V$ (e)

→ KVL, (in i/p loop)

$$V_{CC} - I_B R_B = V_B.$$

$$I_C = \beta I_B$$

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

$$= \frac{3m}{80}$$

$$I_B = 37.5\,\mu A$$

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

$$= \frac{12 - 3.1}{37.5\mu}$$

$$= \frac{8.9}{37.5} \times 10^6$$

$$R_b = 237.33\ k\Omega \quad (c)$$

→ KVL, (from X → ground)

$$2.4 - I_E R_E = 0.$$

$$I_E = I_C$$

$$R_E = \frac{2.4}{I_C}$$

$$= \frac{2.4}{3m}$$

$$R_E = 0.8\,k\Omega \quad (b)$$

→ KVL, (from Y to Z)

$$12 - I_C R_C = 7.6$$

$$R_C = \frac{12 - 7.6}{I_C}$$

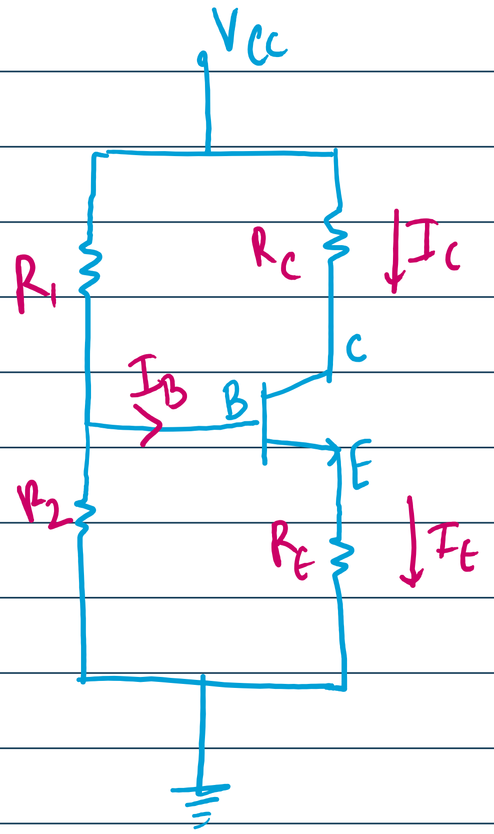
$$= \frac{4.4}{3m}$$

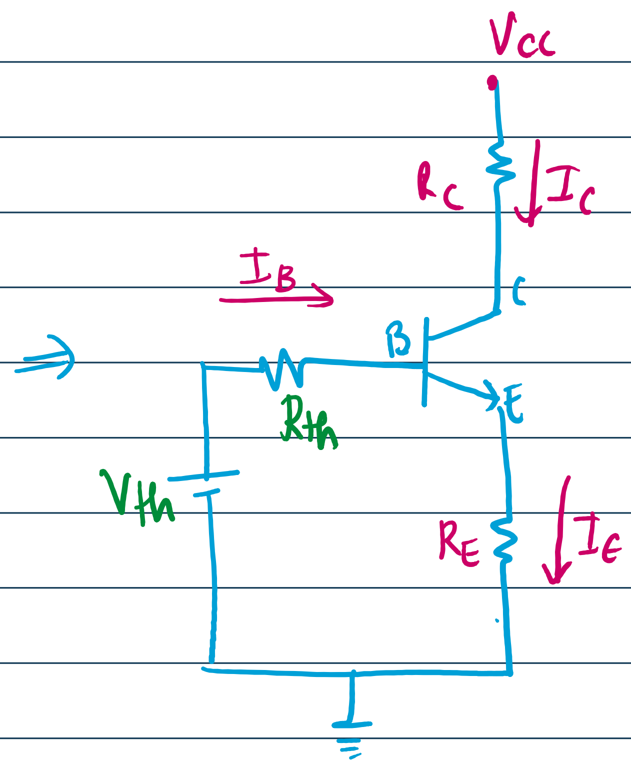
$$R_C = 1.4667\ k\Omega$$

# Voltage Divider Bias

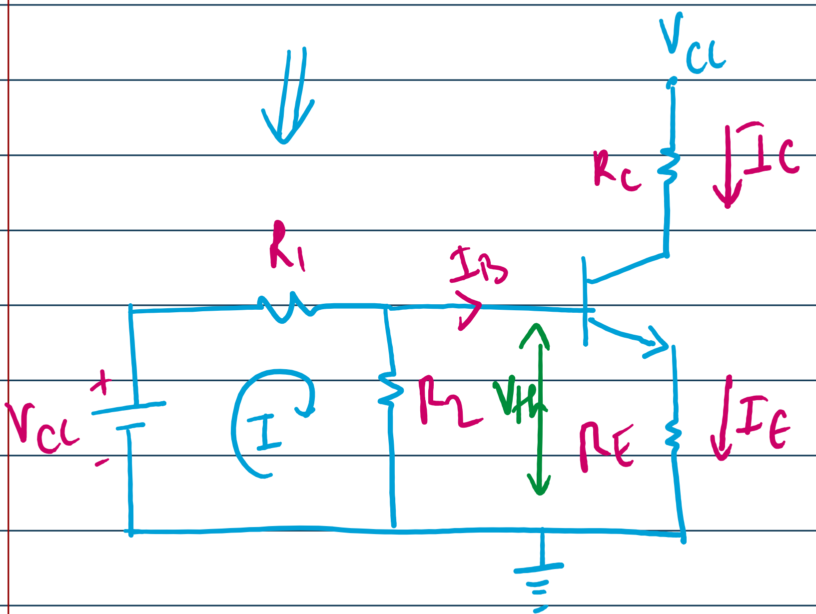
28 October 2024 01:24 AM

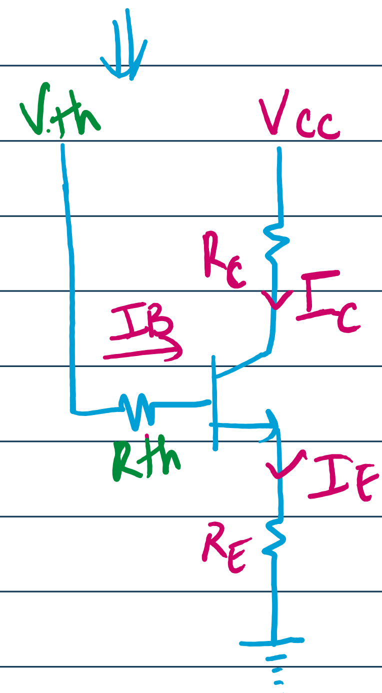
## Voltage Divider Bias

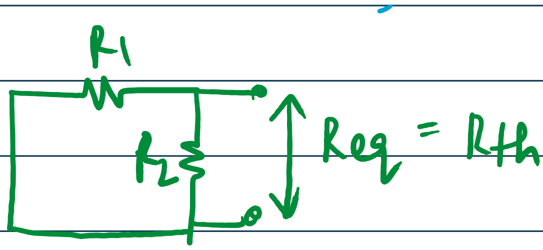


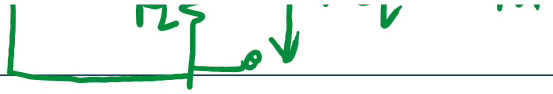




<emitter bias>





$$\boxed{R_{th} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}}$$

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

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

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

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

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

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

If $R_{th} << (\beta+1) R_E$
then $I_C$ is independent of $\beta$.

then $I_C$ is independent of $\beta$.

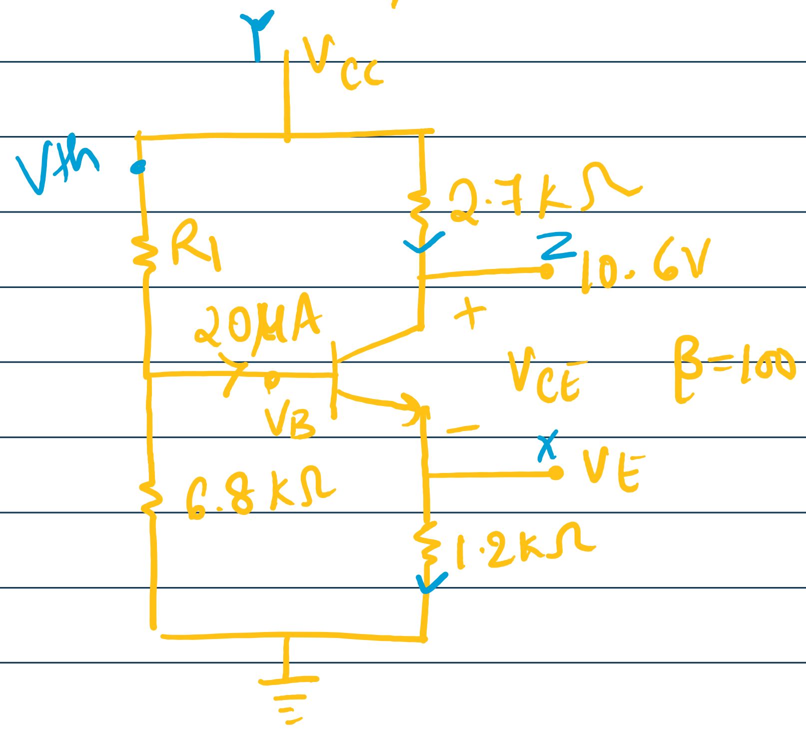
→ $V_{CC} - I_C R_C - \underline{V_{CE}} - \cancel{I_E}^{I_C} R_E = 0$

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

ex:

① For the voltag divider bias, determine–

(a) $I_C$
(b) $V_E$
(c) $V_{Ce}$
(d) $V_{CE}$
(e) $V_B$
(f) $R_1$




Soln: We have, $R_C = 2.7\Omega$
$V_C = 10.6V$
$\beta = 100$
$R_E = 1.2k\Omega$
$R_2 = 6.8k\Omega$

$R_2 = 6.8k\Omega$
$I_B = 20\mu A$

$\rightarrow$ $I_C = \beta I_B$
$= 100 \times 20\mu$
$I_C = 2mA$ (a)

$\rightarrow$ KVL, (from X to ground)

$V_E - I_E R_E = 0$

$V_E = I_E R_E$
$= (2.02m)(1.2k)$
$V_E = 2.424$ (b)

$I_E = I_C + I_B$
$= 2m + 20\mu$
$= 2\times10^{-3}(1 + 10\times10^{-3})$
$= 2\times10^{-3}\times(1.01)$
$I_E = 2.02 mA$

$\rightarrow$ $V_{CE} = V_C - V_E$
$= 10.6 - 2.424$
$V_{CE} = 8.176V$ (d)

$\rightarrow$ KVL, (from Y to Z)

$V_{CC} - I_C R_C = V_C$

$V_{CC} - (2m)(2.7K) = 10.6$
$V_{CC} = 10.6 + 5.4$

$$V_{CC} = 10.6 + 5.4$$
$$V_{CC} = 16V \quad (c)$$

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

$$0.7 = V_B - 2.424$$
$$V_B = 3.1240V \quad (e)$$

$\rightarrow$ $V_{th} \approx V_B$

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

$$3.124 = \frac{16 \times 6.8K}{R_1 + 6.8K}$$

$$R_1 + 6.8K = \frac{108.8K}{3.124}$$

$$R_1 + 6.8K = 34.8271 K$$
$$R_1 \approx 28.0271 K\Omega \quad (f)$$

# Thermal runaway

30 October 2024 05:43 PM

## Thermal runaway in Transistors

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

$I_{CBO}$ causes → flow of minority charge carriers (MCC)

$T\uparrow \Rightarrow$ conc of MCC $\uparrow \Rightarrow I_{CBO}\uparrow \Rightarrow I_C\uparrow$

$\boxed{I_C \propto \text{Temp.}}$

→ With every 10° rise in temp, $I_{CBO}$ doubles

→ flow of $I_C$ → produces heat

↓

$T\uparrow \Rightarrow I_C\uparrow$

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

$I_{CBO} \uparrow$ ↗

→ Because of the cummulative process, in few seconds collector current will become large enough to burn the transistor

→ Definition of thermal runaway :

The self destruction of unstabilized transistor.

→ mitigation of thermal runaway.

→ introduction of Negative feedback.

$I_C \uparrow \Rightarrow I_B \downarrow \Rightarrow I_C \downarrow)$

(presence of $I_E$)

→ Heat sinks → dissipation of heat

# Bias stabilization

30 October 2024 06:15 PM

## Bias Stabilization and Stability factors.

→ **Stabilization:**

Q-pt ($V_{CB}, I_C$)

The process of making OP (Q-pt) independent of temperature changes and variations in transistor parameters.

→ **Causes of unstabilization:**

Q-pt will shift → $\underbrace{I\uparrow\downarrow}$

w/ change in $\underline{\underline{\beta}}$

when transistors change, β changes

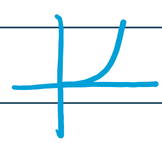
ii) change in T → $T\uparrow \Rightarrow I_{CBO}\uparrow \Rightarrow I_C\uparrow$

[$10^\circ C\uparrow$, $I_{CBO}$ doubles.]

[$1^\circ C\uparrow$, $V_{BE}\downarrow$ by 2.5mV]

i/p I    i/p V

$I_B \to V_{BE}$



→ Stability factor:

The rate of change of collector current ($I_C$) w.r.t the leakage current ($I_{CBO}$) at constant i/p V ($V_{BE}$) and amp. factor ($\beta$)

$$S = \frac{\partial I_C}{\partial I_{CBO}} \Big| \text{ at const } V_{BE} \,\&\, \beta.$$

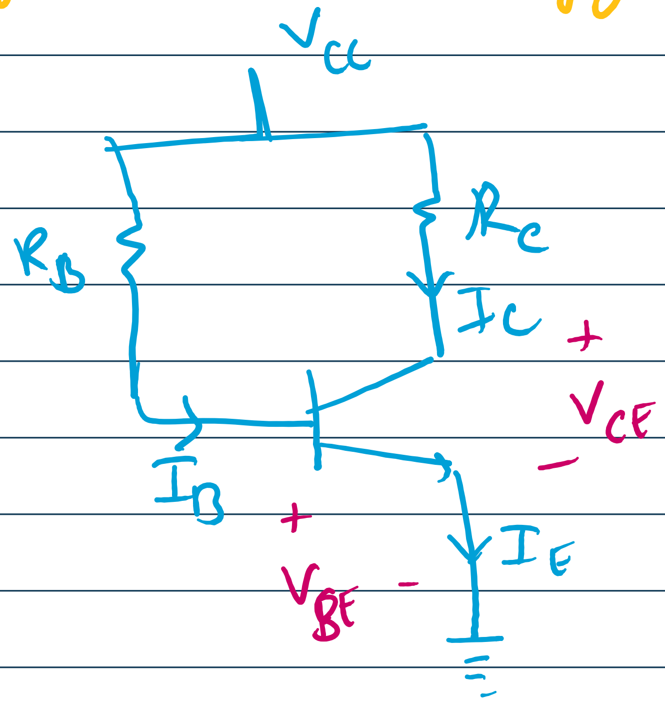
$$S' = \frac{\partial I_C}{\partial V_{BE}} \Big| \text{ at const } I_{CBO} \,\&\, \beta$$

$$S'' = \frac{dI_C}{\partial \beta} \Big| \text{ at const } I_{CBO} \,\&\, V_{BE}$$

Stability factor (FBC)

30 October 2024 06:26 PM

# Stability Factor for Fixed Bias config.




Step 1: KVL in i/p loop.

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

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

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

$$I_C = \beta \frac{(V_{CC} - V_{BE})}{R_B} + (\beta+1) I_{CBO} \rightarrow (2)$$

diff (2) w.r.t $I_C$.

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

Step 3 :

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

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

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

→ General exp of S.F.

diff ① w.r.t $I_B$

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

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

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

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

$$S = \frac{dI_C}{dI_{CBO}} \Bigg| V_{BE} \ \& \ \beta$$

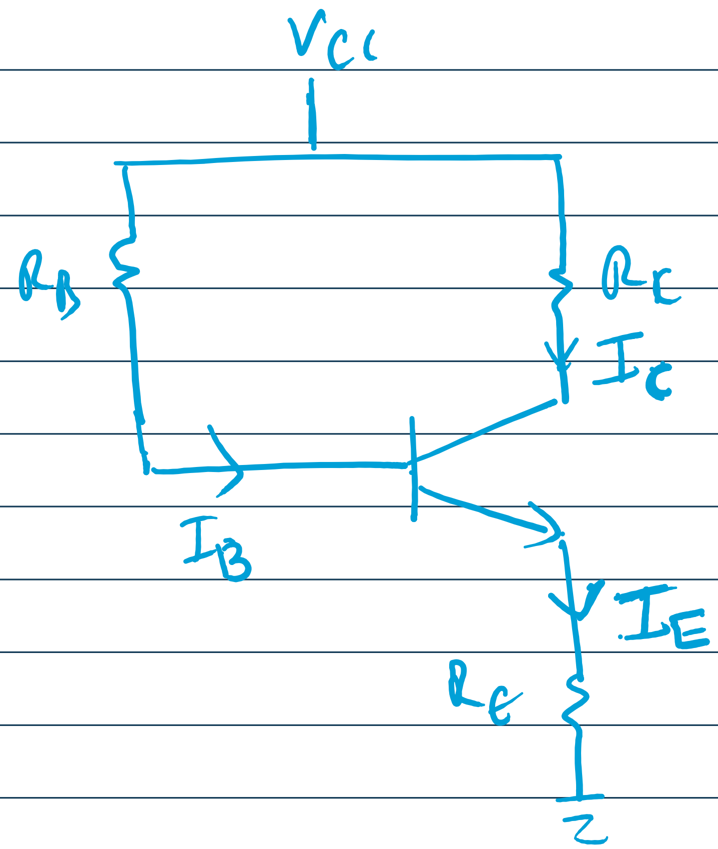
$$S' = \frac{dI_C}{dV_{BE}} \Bigg| I_{CBO} \ \& \ \beta$$

$$S'' = \frac{dI_C}{d\beta} \Bigg| I_{CBO} \ \& \ V_{BE}$$

Stability factor (EBC)

30 October 2024 06:43 PM

# Stability factor for Emitter Bias config.




## S1.

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

$$I_E = I_C + I_B$$

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

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

$$I_B = \underline{V_{CC} - V_{BE} - I_C R_E} \rightarrow (1)$$

$R_B + R_E$

S-2: $I_C = \beta I_B + (\beta+1) I_{CBO}$

$$I_C = \beta \frac{(V_{CC} - V_{BE} - I_C R_E)}{R_B + R_E} + (\beta+1) I_{CBO} \longrightarrow (2)$$

diff (2) w.r.t. $I_C$.

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

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

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

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

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

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

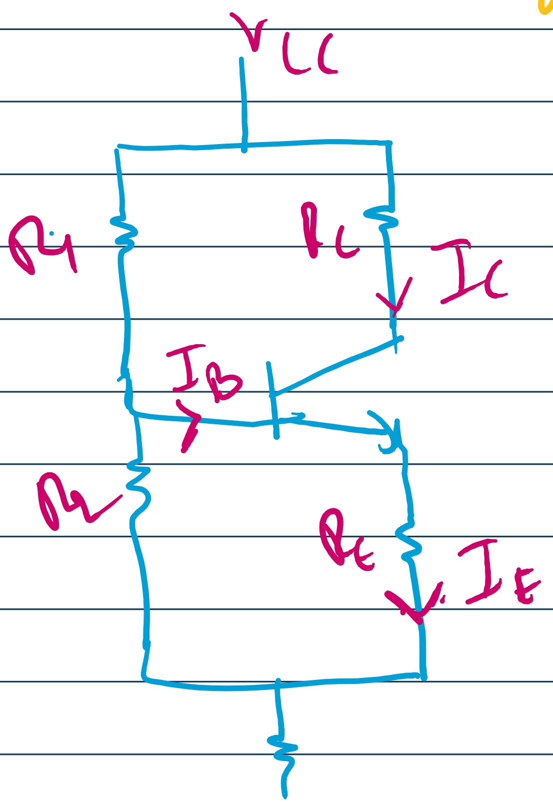
$$\boxed{S = \frac{(\beta+1)(R_B+R_E)}{R_B+(\beta+1)R_E}}$$

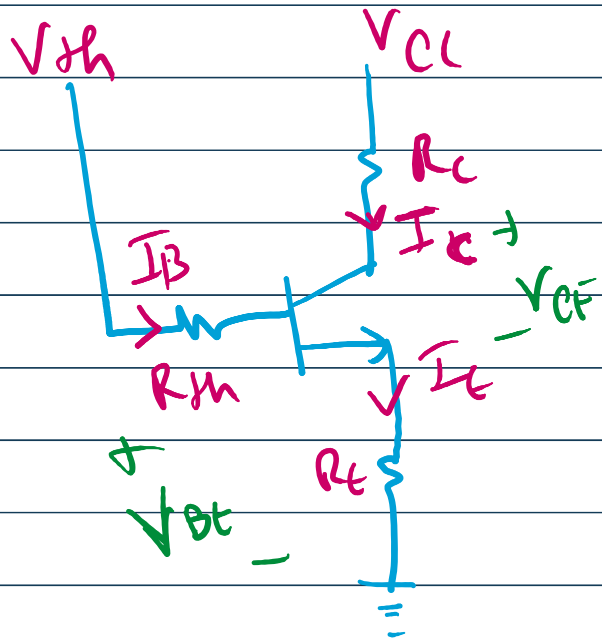
$$\boxed{S = \frac{\beta+1}{1-\beta\left(\frac{dI_B}{dI_C}\right)}}$$ ⟨Gen. expression⟩

SF (VDB)

30 October 2024 07:00 PM

## S-F for Voltage divider Bias.




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

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

S1. KVL in i/p → $I_B = ?$

S2: $I_C = \beta I_B + (\beta+1) I_{CBO}$

S3: diff w.r.t $I_C$ keeping $\beta$ & $V_{BE}$ const

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

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

changed term from CE.

$$S' = \frac{-\beta}{R_{th}+(\beta+1)R_E}$$

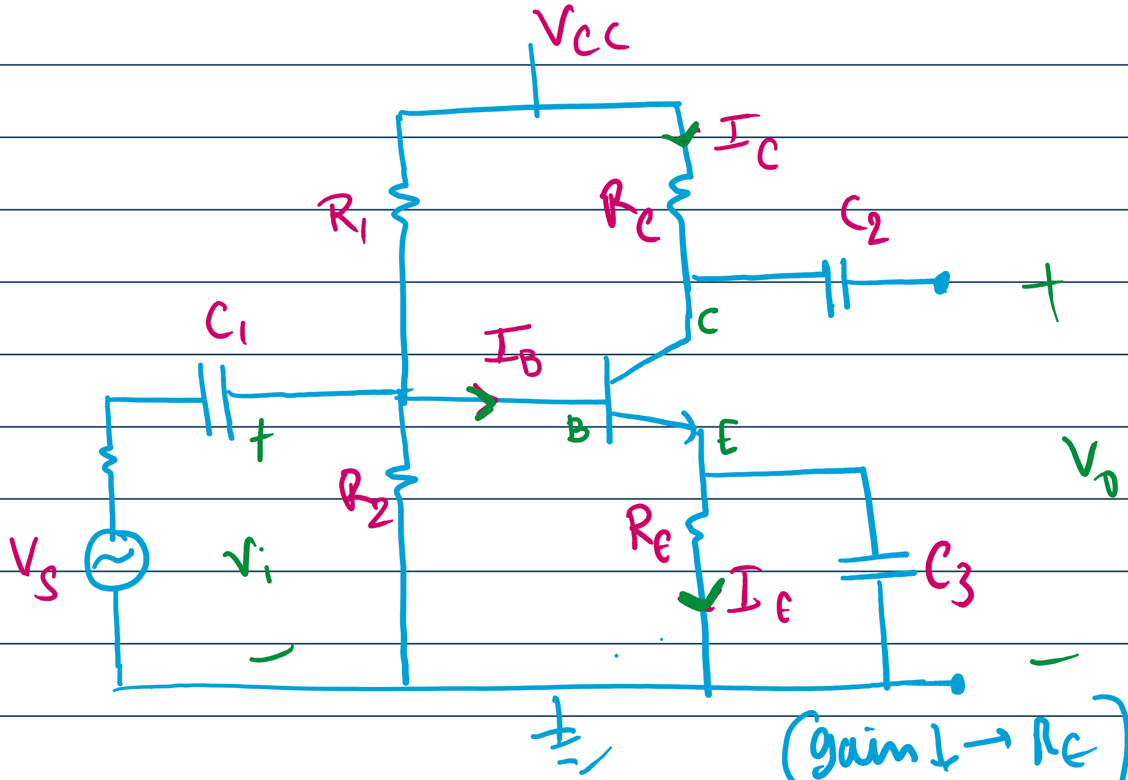
$$S' = \frac{-\beta}{R_B+(\beta+1)R_E}$$

$S(V_{BE})$

Small signal analysis of bjt

30 October 2024 07:07 PM

# Small signal Analysis of BJT :




(gain ↓ → $R_E$)

$C_1$ & $C_2$ → coupling capacitors

$C_3$ → bypass capacitors

$$X_C = \frac{1}{2\pi f C}$$

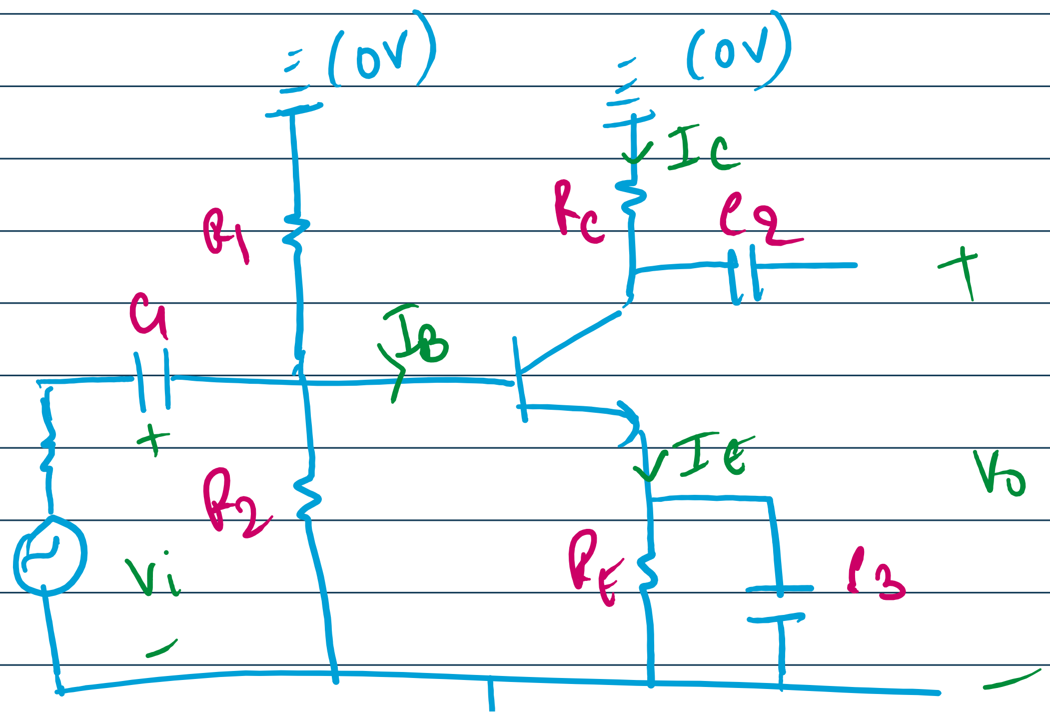
dc signal $\Rightarrow$ $f=0$ $\Rightarrow$ $X_C = \infty$.
open circuit

ac signal $\Rightarrow$ $f \neq 0$, $C\uparrow\uparrow$ $\Rightarrow$ $X_C \approx 0$.

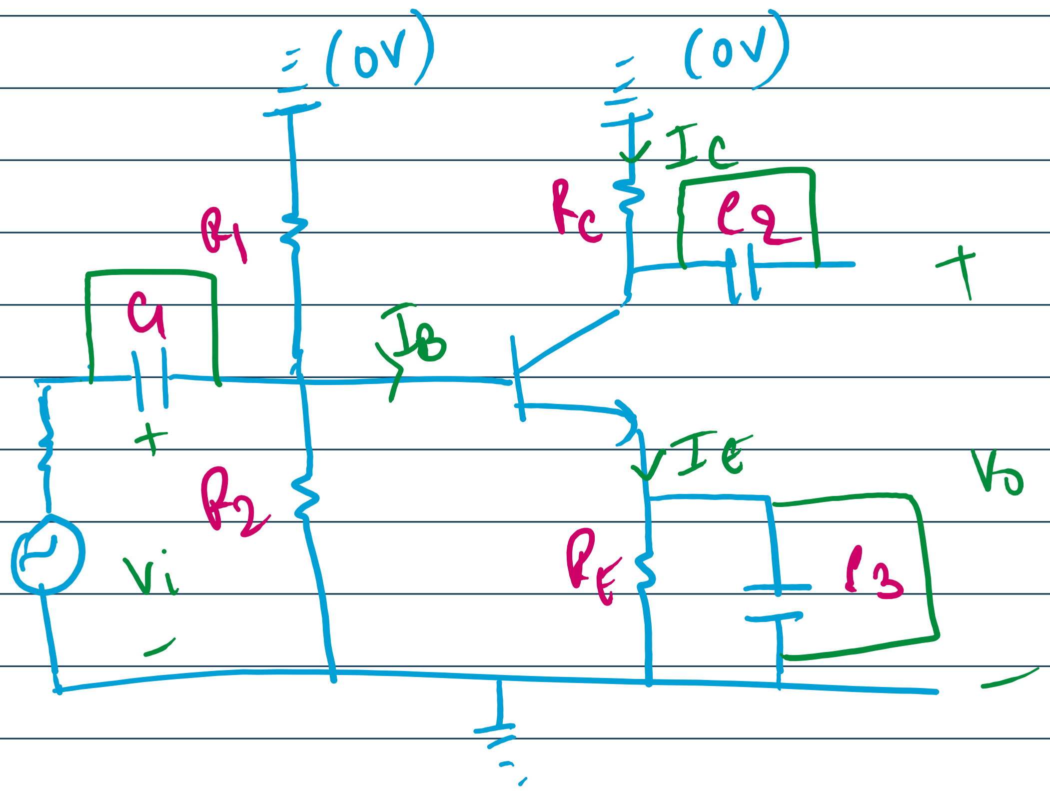
AC response:

AC Equivalent circuit of BJT Amplifier

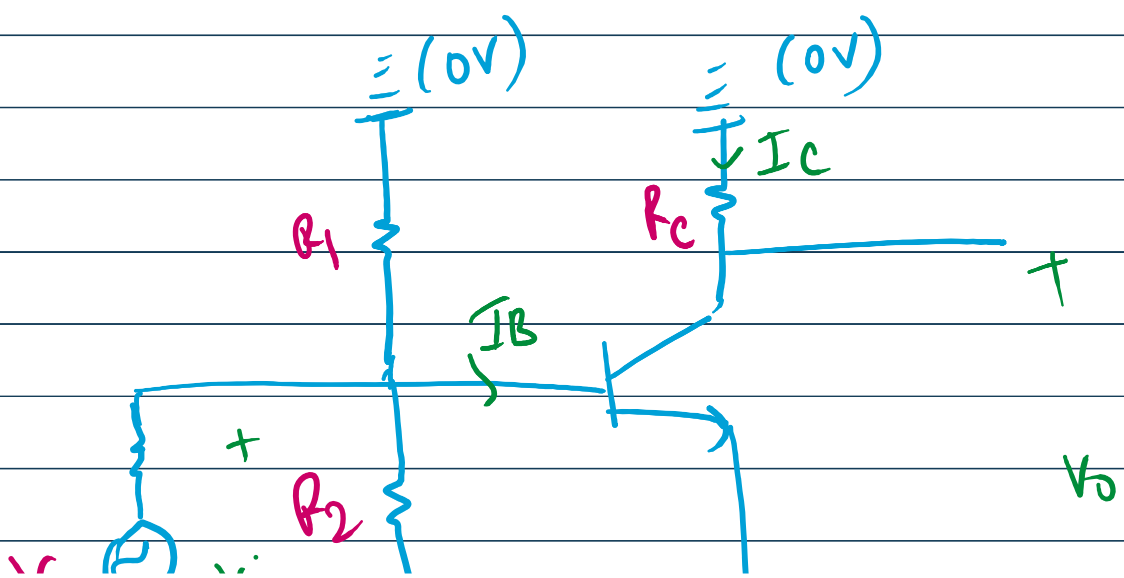
S1: Short circuit all the dc sources.



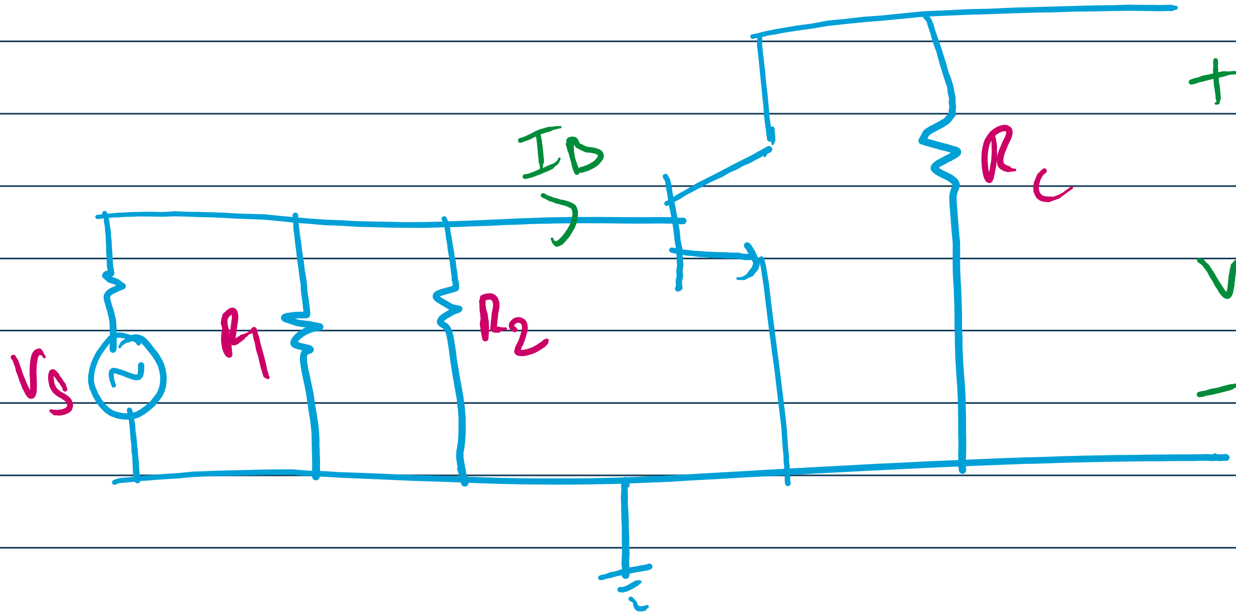
S2: Short all capacitors.



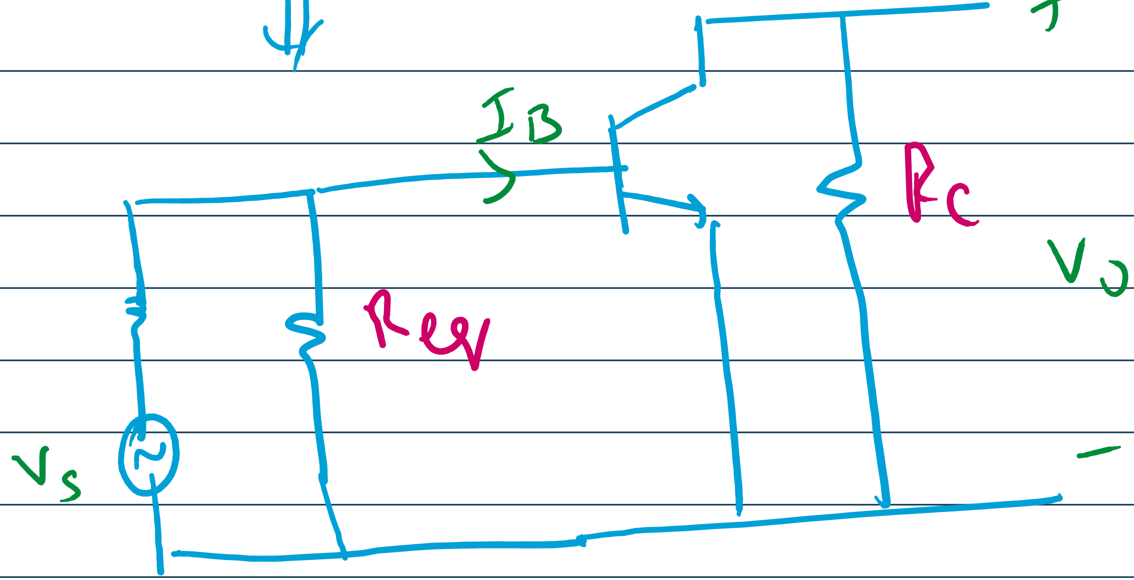

S3: Redraw the network removing all the elements which are short circuited in S1 & S2




$\Downarrow$




$\Downarrow$




$R_{eq} = R_1 \| R_2$

→ what is an eq model?

An equivalent model is combination of circuit elements properly chosen to best represent the actual behaviour of device under specific operating point

# Re Transistor model.

(T-model)

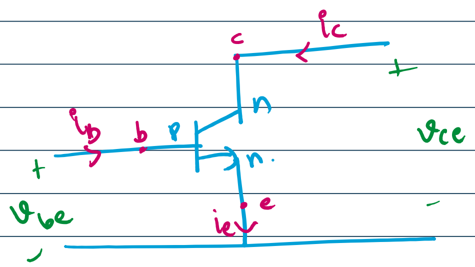
→ Low freq.

h-parameter, re-model.

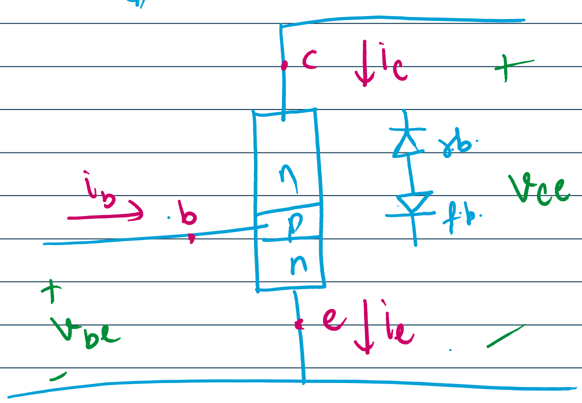
High freq.

hybrid model, Y-parameter.

→ CE - trans.




⇓

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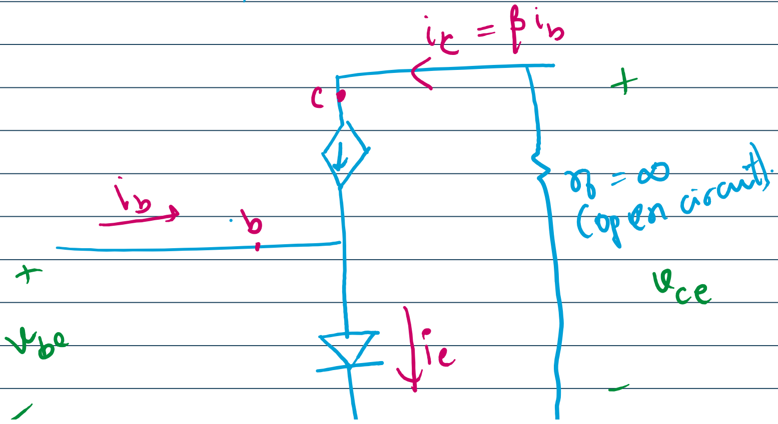
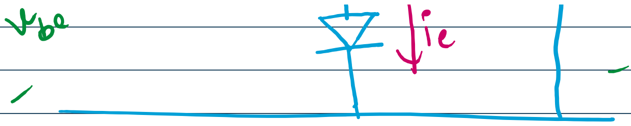
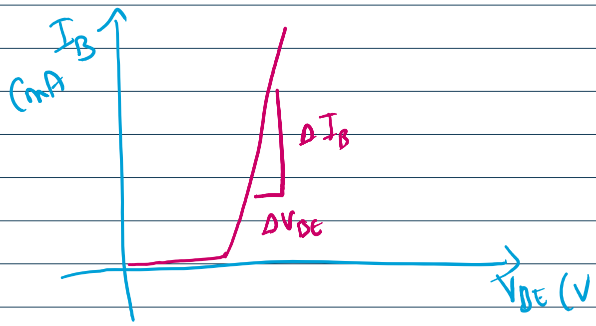
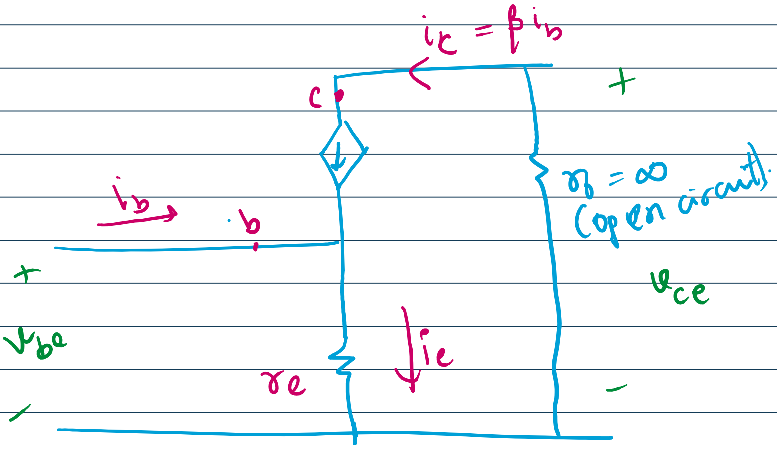


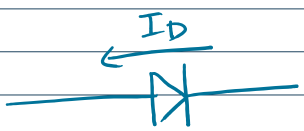



$$r_o = \frac{1}{\text{slope} \approx 0} \Rightarrow r_o \approx \infty$$




$$r_d = \frac{\Delta V_{BE}}{\Delta I_B} \qquad r_d \rightarrow r_e.$$




r.s.c = $I_S$

$$I_D = I_S \left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

$$\frac{dI_D}{dV_D} = I_S \frac{d}{dV_D}\left(e^{\frac{V_D}{nV_T}} - 1\right)$$

$\eta = 1$

when $I_D \uparrow$.

$T = 300K$.

$$\frac{1}{r_d} = \frac{I_S e^{\frac{V_D}{V_T}}}{V_T}$$

$$\frac{1}{r_d} = \frac{I_S e^{V/V_T}}{V_T}$$

$$\frac{1}{r_d} = \frac{I_D + I_S}{V_T}$$

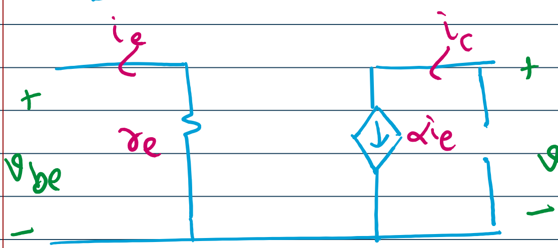
$$\frac{1}{r_d} = \frac{I_D}{V_T}$$

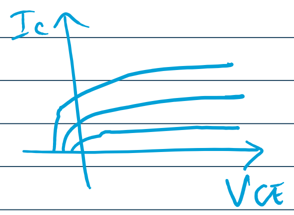
$$r_d = \frac{V_T}{V_D}.$$

$$r_d = \frac{26\,mV}{I_D}$$

$$\boxed{r_e = \frac{26\,mV}{I_E}}$$

**CB:**



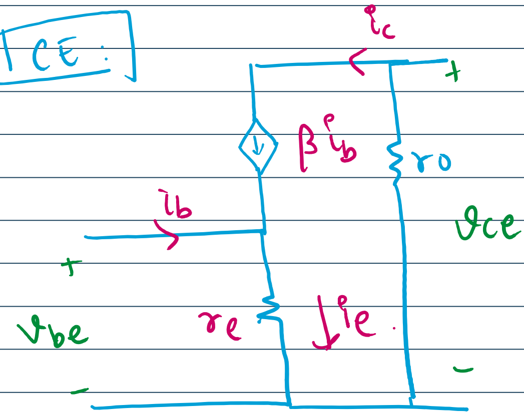



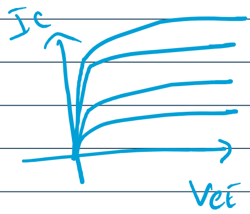

slope ≈ 0.

$r_o = \infty$.

can neglect.

**CE:**




slope ≠ 0

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

$\beta$ is large.

can / cannot ← $r_o \neq \infty$.
neglect.   but v. large.

$i_e = i_b + i_c$.

$= i_b + \beta i_b$

$i_e = i_b + i_c$

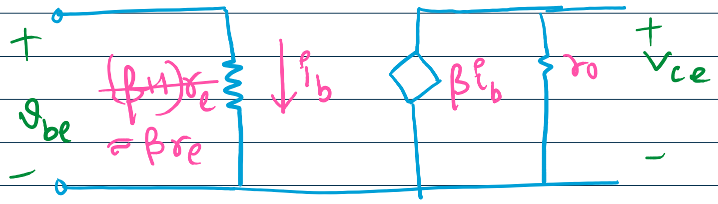
$\quad = i_b + \beta i_b$

$i_e = (1+\beta) i_b$

can/cannot neglect ← $r_o \neq \infty$ but v. large.

→ drop across $r_e = r_e \cdot i_e$

$= \underbrace{r_e(\beta+1)}\,\underbrace{i_b}$

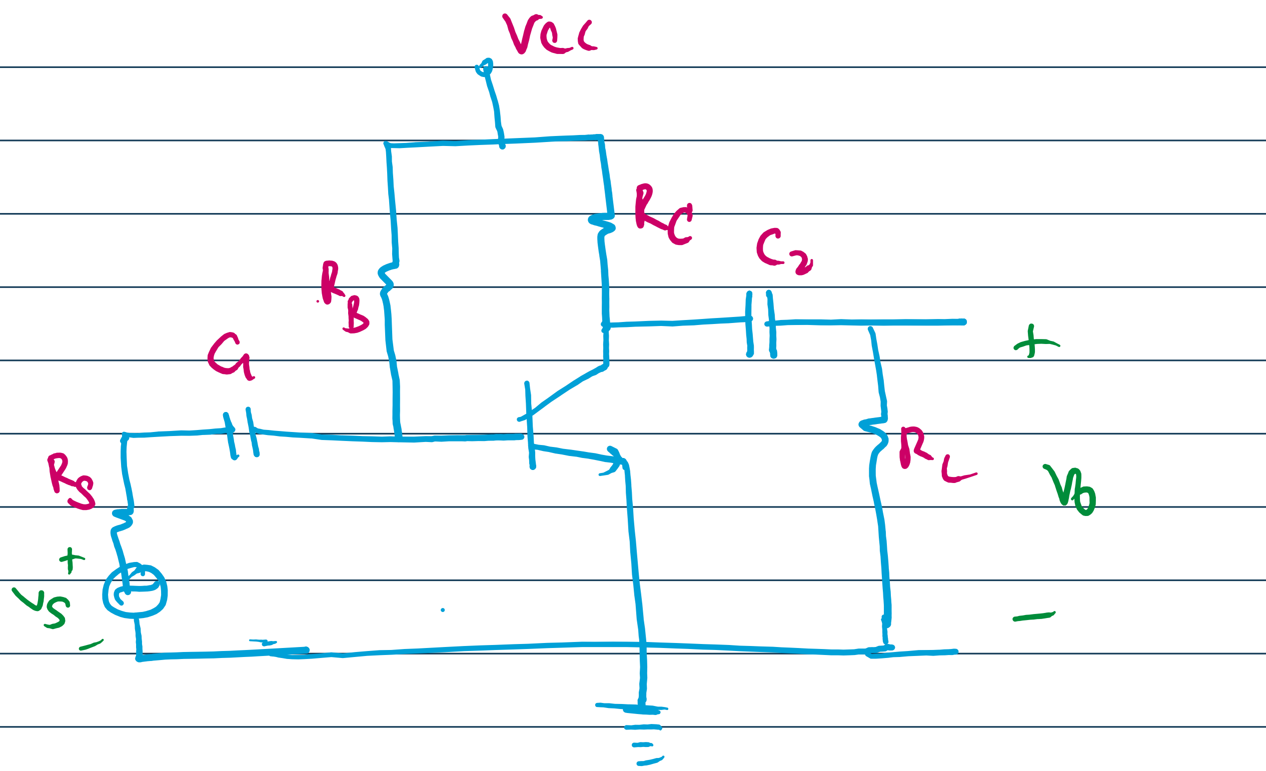


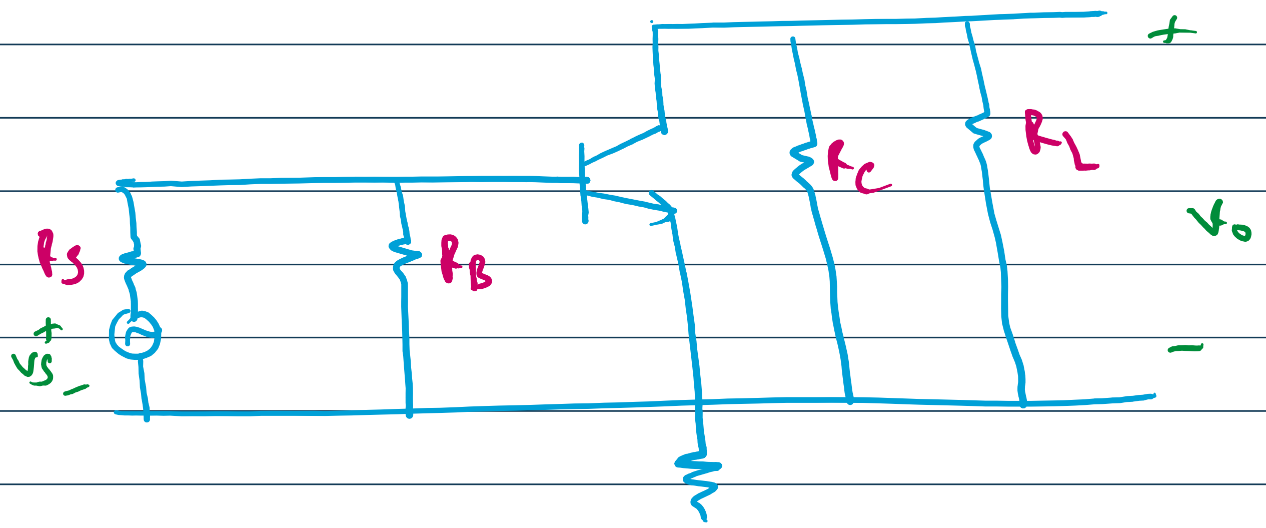

$\beta+1 \approx \beta$

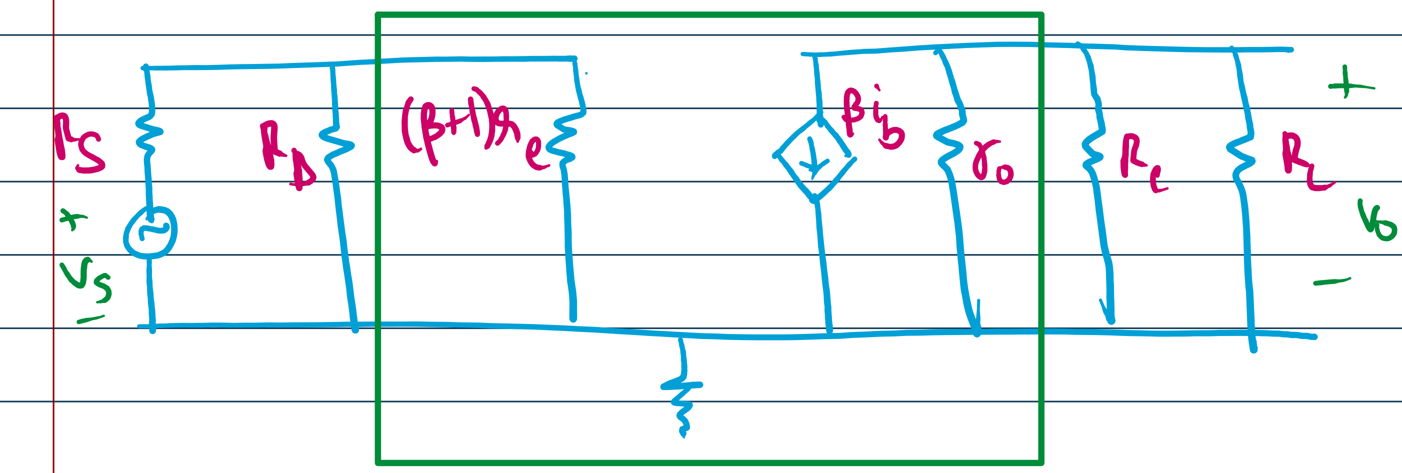
# Re model (FBC)

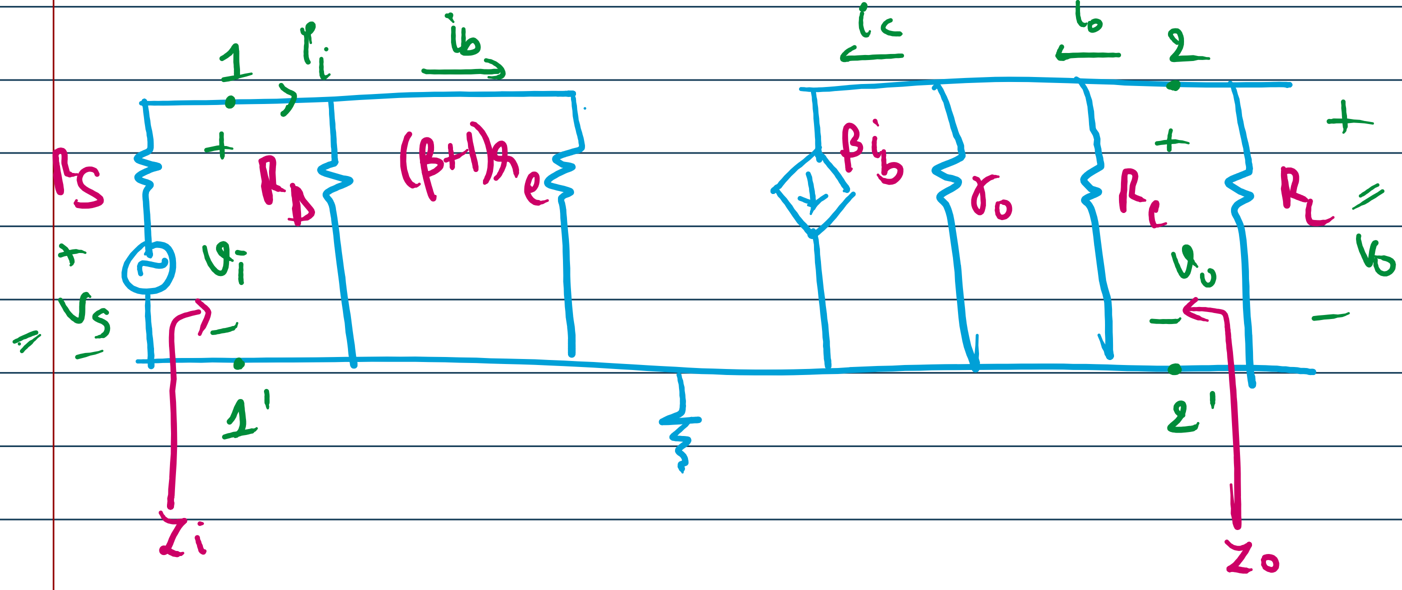
31 October 2024 10:45 AM

## Re Model ( Fixed Bias config)






→ input impedance.

$$Z_i = \frac{V_i}{I_i}$$

$$\boxed{Z_i = R_B \parallel (\beta+1)r_e.}$$

$$Z_i = \frac{R_B \, (\beta+1) r_e}{R_B + (\beta+1) r_e}$$

$\boxed{\text{Alter}}$ : $Z_i = \dfrac{(\beta+1) r_e \cdot i_b}{i_i}$ ← $v_i$

current divider rule →

$$Z_i = \frac{(\beta+1) r_e}{\cancel{i_i}} \cdot \frac{\cancel{i_i} R_B}{R_B + (\beta+1) r_e}$$

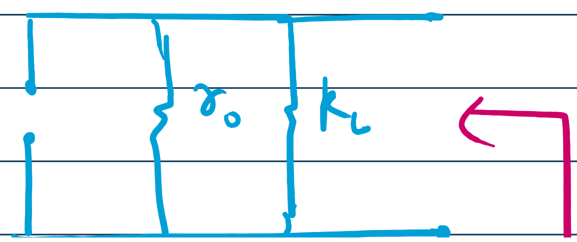
$$Z_i = \frac{(\beta+1) r_e R_B}{R_B + (\beta+1) r_e}$$

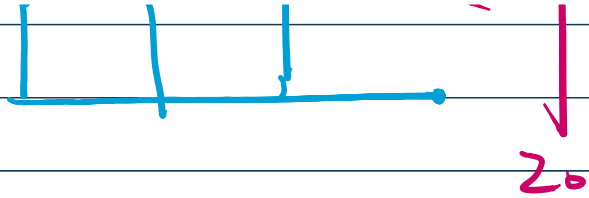
→ output impedance.

$$Z_o = \frac{v_o}{i_o}$$

$V_s = 0V \Rightarrow v_i = 0V \Rightarrow i_b = 0A \Rightarrow i_c = 0A$

$R_L = \infty \, \Omega$





$$\boxed{Z_o = r_o \parallel R_C}$$

$$Z_o = \frac{r_o \cdot R_C}{r_o + R_C}.$$

→ $\beta + 1 \approx \beta$

$(\beta+1) r_e \approx \beta r_e$

$R_B \gg 10 \underbrace{(\beta+1) r_e}_{\text{neg}}.$

$$Z_i = \frac{R_B (\beta+1) r_e}{R_B}$$

$$\boxed{\begin{array}{c} Z_i = (\beta+1) r_e. \\ \text{when } R_B \gg 10(\beta+1) r_e. \end{array}}$$

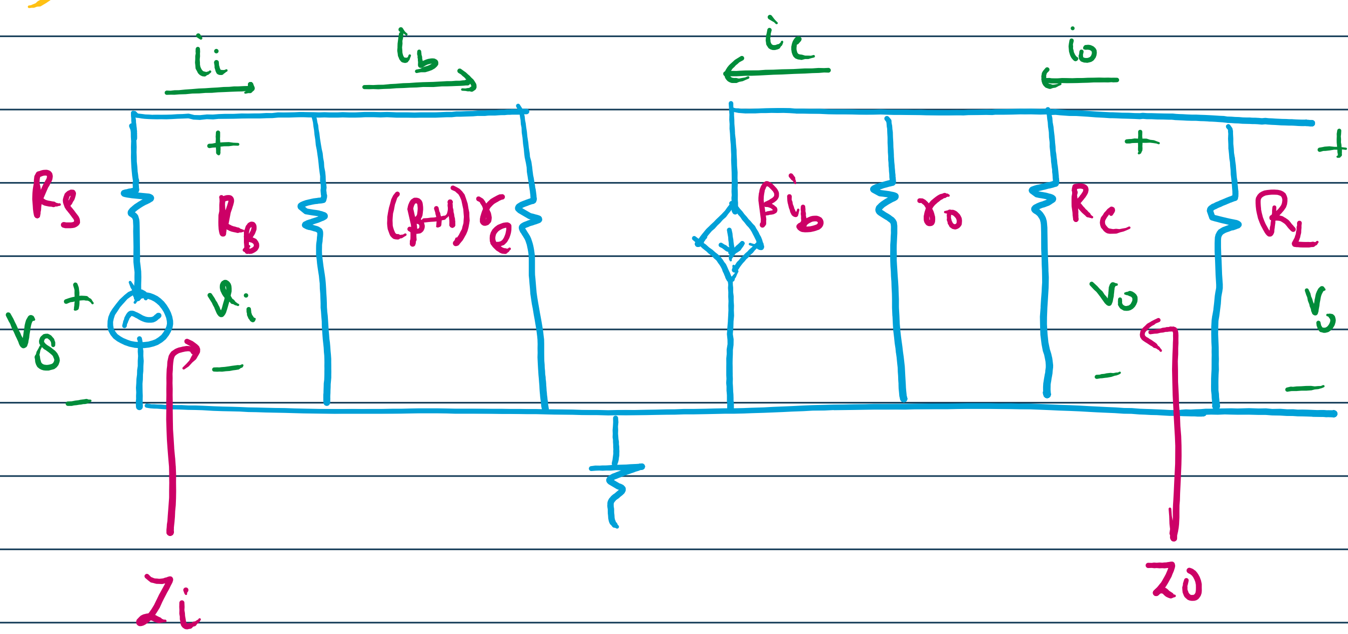
→ $r_o \gg 10 R_C$

$Z_o = \frac{r_o \cdot R_C}{\quad}$

$r_o$

$$\boxed{\begin{array}{l} Z_o = R_C. \\ \text{when } r_o \geqslant 10R_C \end{array}}$$

$\Rightarrow$




$Z_i = R_B \,||\, (\beta+1) r_e$

if $R_B \geqslant 10(\beta+1)r_e$

$Z_i = (\beta+1) r_e$

$Z_o = r_o \,||\, R_C$

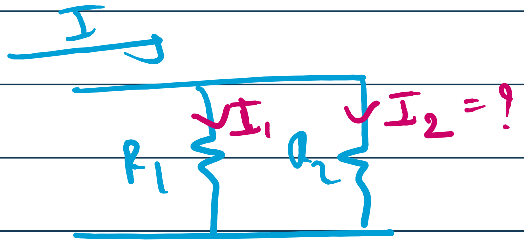
if $r_o \geqslant 10 R_C$

$Z_o = R_C$

## $\Rightarrow$ Current Gain:

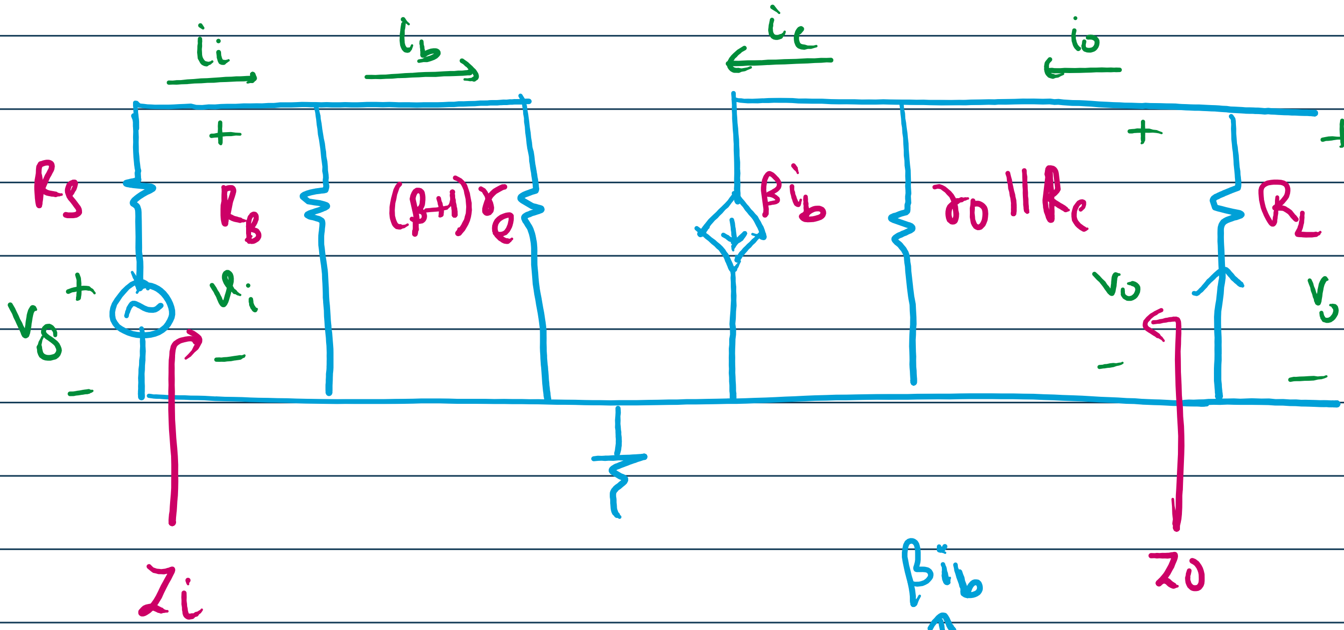
$$A_i = \frac{i_o}{i_i}$$

→ Current divider rule: (CDR)




$$I_2 = \frac{I R_1}{R_1 + R_2}$$

$$I_1 = \frac{I R_2}{R_1 + R_2}$$




$\beta i_b$
↑
using CDR,

$$i_o = \frac{i_c (r_o \parallel R_c)}{r_o \parallel R_c + R_L}$$

$$A_i = \frac{i_o}{i_i} = \frac{\beta i_b (r_o \parallel R_c)}{r_o \parallel R_c + R_L}$$

$$\overline{\qquad\qquad\qquad}$$
$$i_i$$

$$i_b = \frac{i_i R_B}{R_B + (\beta+1) r_e}.$$

$$A_i = \frac{\beta\left(\frac{\cancel{i_i} R_B}{R_B + (\beta+1) r_e}\right)\left(\frac{r_o \parallel R_C}{r_o \parallel R_C + R_L}\right)}{\cancel{i_i}}$$

$$\boxed{A_i = \beta\left(\frac{R_B}{R_B + (\beta+1) r_e}\right)\left(\frac{r_o \parallel R_C}{r_o \parallel R_C + R_L}\right)}$$

Case 1: $r_o \geq 10 R_C$

$$r_o \parallel R_C = R_C$$

$$A_i = \beta\left(\frac{R_B}{R_B + (\beta+1) r_e}\right)\left(\frac{R_C}{R_C + R_L}\right)$$

Case 2: $R_B$ & $R_C = \infty$

$$r_o < R_C \Rightarrow r_o \parallel R_C = r_o$$

$$A_i = \beta \left(\frac{R_B}{R_B}\right)\left(\frac{r_o}{r_o + R_L}\right)$$

$$A_i = \beta \left(\frac{r_o}{r_o + R_L}\right)$$

→ overall current Gain: ($A_{is}$

$$A_{is} = \frac{i_o}{i_s} = A_i \left(\frac{R_s}{R_s + Z_i}\right)$$

→ Voltage Gain: ($A_v$)

$$A_v = \frac{V_o}{V_i}$$

$$V_o = -i_o R_L \qquad \left[-i_o R_L - V_o = 0\right]$$

$$V_o = -\beta i_b \left(\frac{r_o \,||\, R_C}{r_o \,||\, R_C + R_L}\right) R_L$$

$$V_i = i_b (\beta + 1) r_e .$$

$$\rightarrow A_v = \frac{-\beta\,(r_o \,||\, R_C \,||\, R_L)}{(\beta+1)\, r_e}$$

(i) $\beta + 1 \approx \beta$

$$\rightarrow A_v = -\frac{(r_o \,||\, R_C \,||\, R_L)}{r_e}.$$

ii) $r_o \geq 10 R_C$.
$\downarrow$ neg.

$$\rightarrow \boxed{A_v = \frac{-R_C \,||\, R_L}{r_e}}$$

iii) $R_L = \infty \gg R_C$

$$\rightarrow \boxed{A_v = \frac{-R_C}{r_e}.}$$

Overall Voltage Gain ($A_{vs}$).

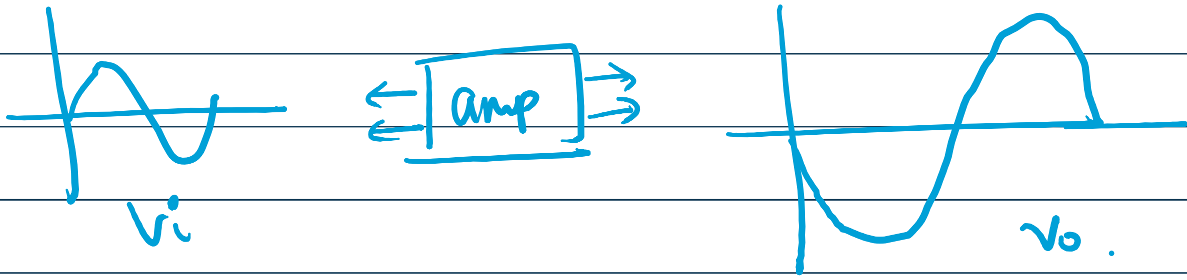
$$A_{vs} = \frac{V_o}{V_s}$$

$$A_{vs} = \frac{v_o}{v_s}$$

$$A_{vs} = A_v\left(\frac{Z_i}{Z_i + R_s}\right)$$

Note: $-ve$ sign in the above formula represents $180^\circ$ phase shift b/w the o/p V & i/p V

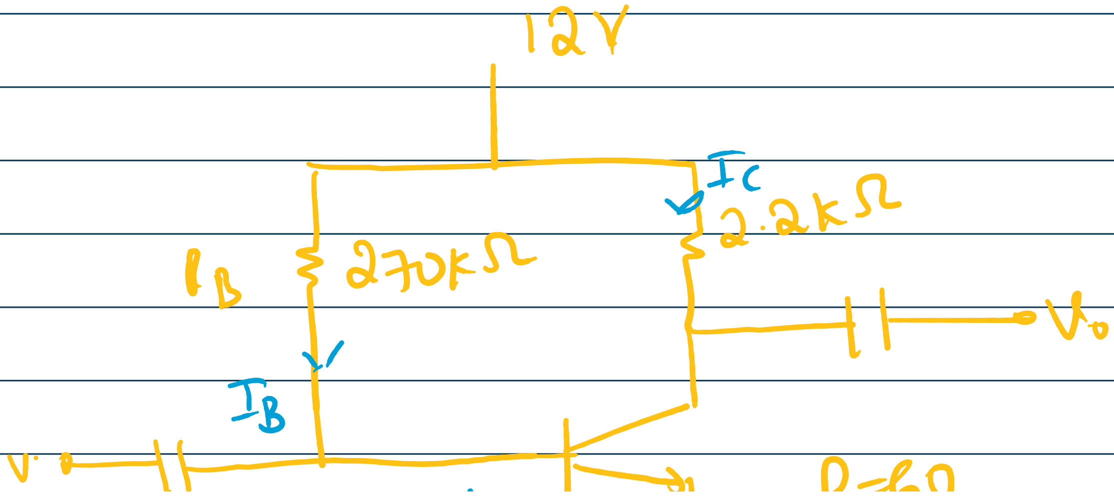
eg

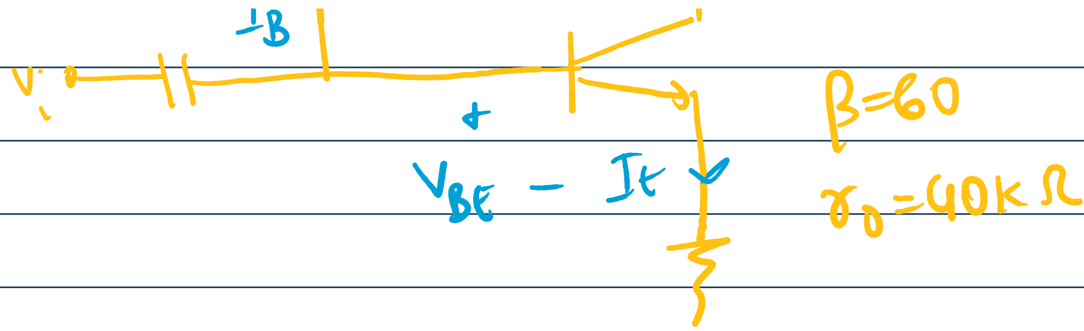



$$\boxed{r_e = \frac{26\,mV}{I_E}}$$

ex:

①






For the network shown:

(i) Determine i/p & o/p impedances

(ii) Determine voltage gain.

(iii) Determine current gain

Sol^n:

$R_B = 270\,k\Omega$

$R_C = 2.2\,k\Omega$

$\beta = 60$

$r_o = 40\,k\Omega$

→ $r_e = \dfrac{26\,mV}{I_E}$

→ KVL in i/p loop.

$12 - I_B R_B - V_{BE} = 0$

$12 - I_B(270\,k) - 0.7 = 0$

$$12 - I_B(270k) - 0.7 = 0$$

$$I_B = 0.0419\ mA$$

$$I_B = 41.9\ \mu A$$

$$I_E = I_B + I_C$$

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

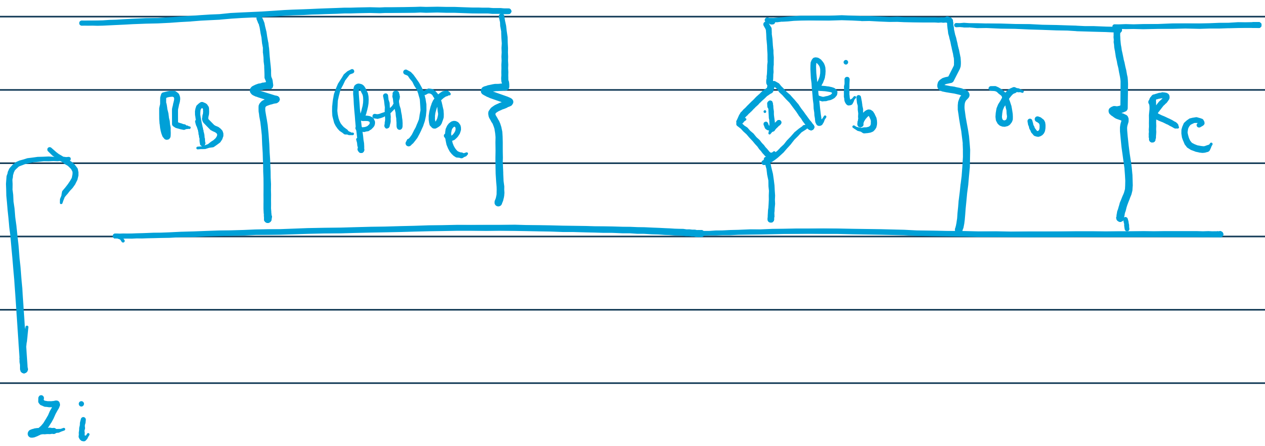
$$= 61 \times 41.9\mu$$

$$I_E = 2.55\ mA$$

$\rightarrow$ $$r_e = \frac{26\ mV}{2.55\ mA}$$

$$r_e = 10.18\ \Omega$$

$\rightarrow$ find ac equi circuit




$$Z_i = R_B \parallel (\beta+1)\ r_e$$

$$= \frac{R_B \; (\beta+1) r_e}{R_B + (\beta+1) r_e}$$

$$= \frac{(270k)\;(61)\;(10.18)}{270k + (61)(10.18)}$$

$$= 0.6195\,k\Omega$$

$$Z_i = 619.5\,\Omega$$

(OR) [ if $R_B \geq 10(\beta+1) r_e$
↳ can be neg ]

$$Z_i = (\beta+1) r_e$$

$$= 61 \times 10.18$$

$$= 0.621\,k\Omega$$

$$\underline{\underline{Z_i = 621\,\Omega}}$$

$$Z_o = r_o \parallel R_C$$

$$= \frac{r_o R_C}{r_o + R_C}$$

$$= \frac{(40k)\,(27k)}{}$$

$$= \frac{(40\,k)(2.2\,k)}{40\,k + 2.2\,k}$$

$$Z_o = 2.085\ k\Omega$$

$\boxed{\text{or}}$ $10R_C = 22\ k\Omega < r_o$

$$\Rightarrow \quad Z_o = R_C = 2.2\ k\Omega$$

$$A_v = \frac{v_o}{v_i} = \frac{-R_C}{r_e}.$$

$$A_v = \underline{\underline{-216.1}}$$

$$A_i = \frac{i_o}{i_i}$$

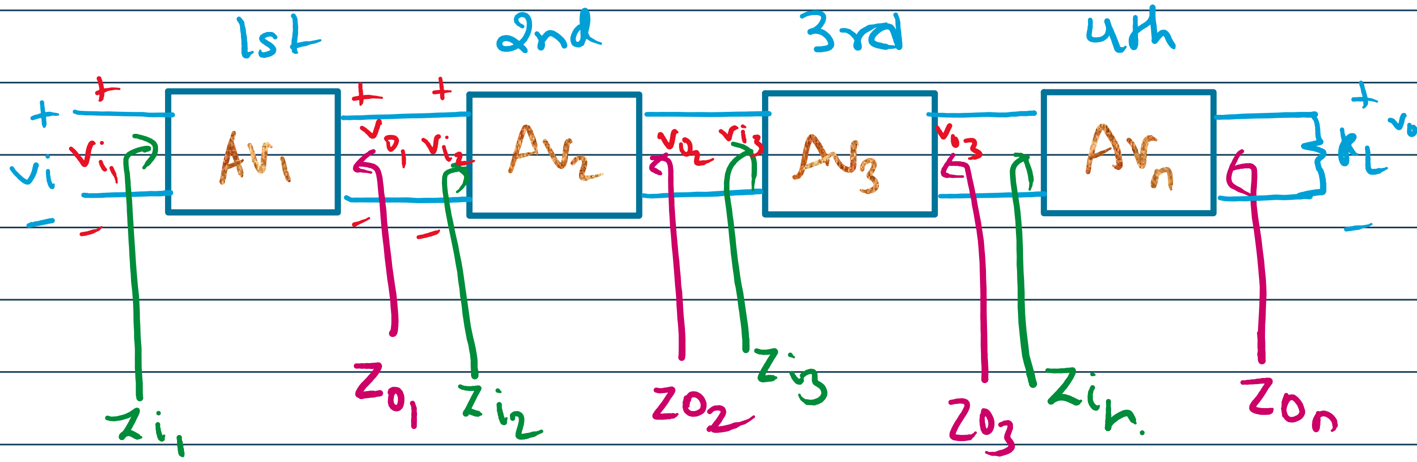
# Cascaded systems

31 October 2024 12:28 PM

Cascaded systems.

↓

arranging obj in series/seq




$v_{i_1} = v_i$ $\quad V_{o_1} = V_{i_2}$ $\quad V_{o_2} = V_{i_3}$.