Emitter: Supplies majority charge carrier i.e e^- or holes

Base: Transfer majority charge carriers from emitter to collector

Collector: Moderately doped. Large amount of heat is liberated & so provided with large area to dissipate heat

Date __/__/____

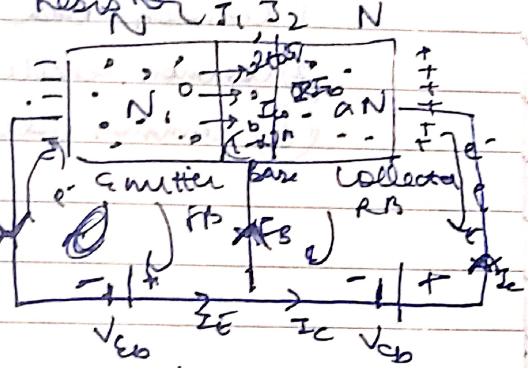
BJT = Bipolar Junction Transistor

In NPN - maxm current electrons

In PNP - maxm current holes

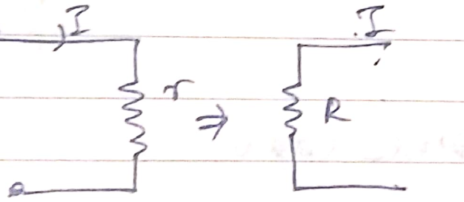
J_1	J_2	
Emitter Base Junction	Collector Base Junction	Region
FB	RB	Active (Amplification)
FB	FB	Saturation (ON-Switch)
RB	RB	Cut-Off (Off-Switch)
RB	FB	OFF Switch (Inverted)

Transistor ⇒ Transfer of Resistor



J_1 = FB] Low Resis

J_2 = RB] High Ress



$N - \alpha N = (1-\alpha)N$

95%   5%

$V_i = Ir$ $V_o = IR$

$\boxed{V_i < V_o}$

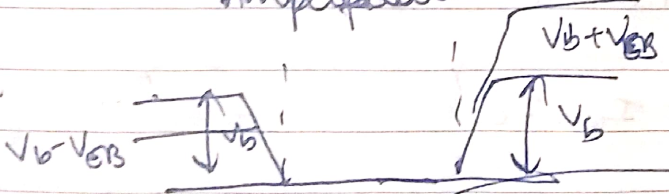
Amplification

$\boxed{A = \frac{V_o}{V_i}}$

$\boxed{I_E = I_B + I_C}$

by KCL

V_b = No bias condition



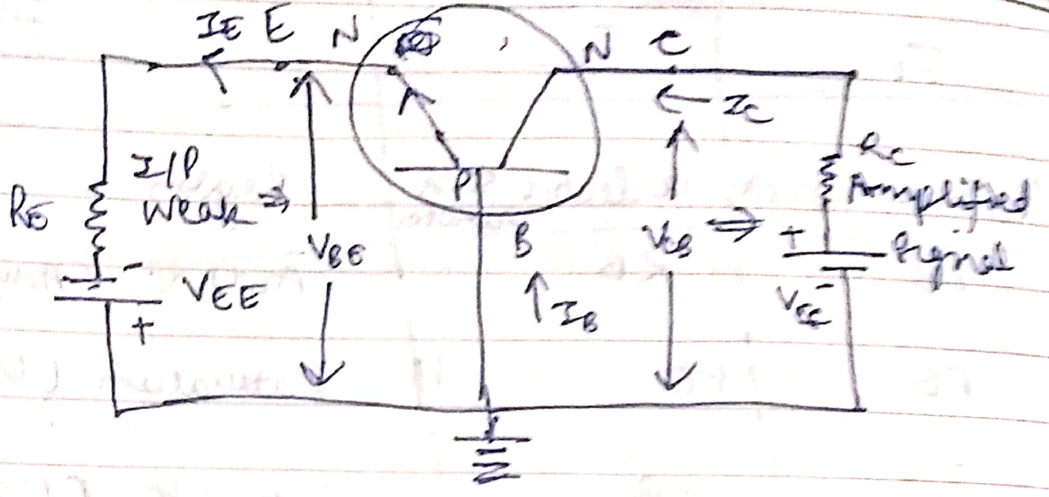
$\boxed{I_C = \alpha I_E + I_{Co}}$ → leakage or current Reverse Saturation current

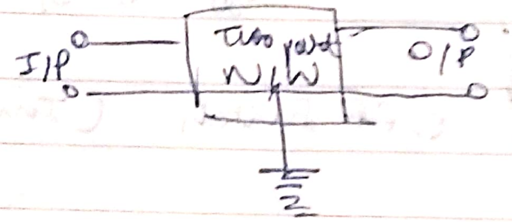
Emitter

$\boxed{I_E = I_B + I_C}$

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

Common base configuration

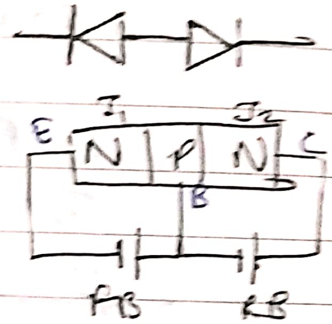




Active Region

$J_1 = FB$

$J_2 = RB$



1. Common Base conf
2. Common Emitter conf
3. common collector conf

~~Diode char~~

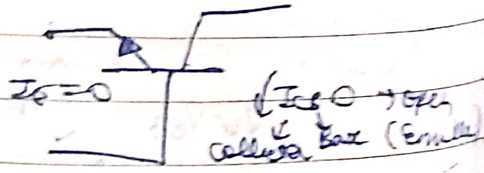
Transistor

B/w I/P volt & I/P curr ← I/P char

B/w O/P curr & O/P voltage ← O/P char

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

$\boxed{I_C = \alpha I_E + I_{C0}}$



$I_C = \alpha I_E + I_{CBO}$ (current produced when emitter terminal is left opened)

$I_C = \alpha I_E$

$\alpha = 0.95$ to 0.98

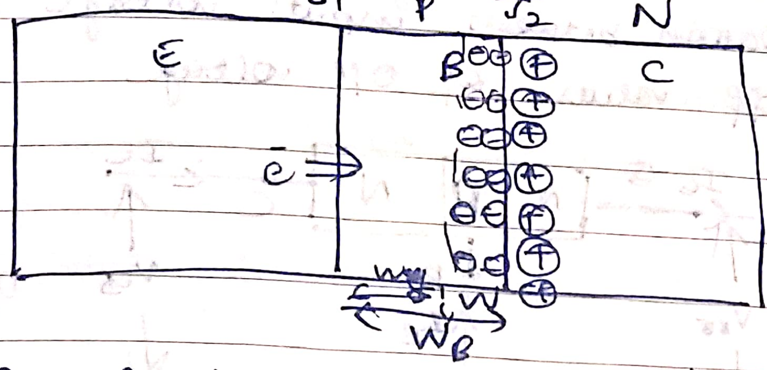
$\boxed{\alpha = \dfrac{I_C}{I_E}}$

α = current amplification factor of common base config

Date ___ / ___ / ______

Early Effect or Base Width Modulation

N J1 P J2 N



$J_1 = FB$

$J_2 = RB$

$V_{CB} \rightarrow \uparrow$

$RB \rightarrow \uparrow$

Doping : E > C > B

Base is lightly doped as the depletion layer formed will deeply penetrate in base region

W_B = Width of Base / Mettalurgical base width

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

$V_{CB} \uparrow$ $RB \uparrow$ $W \uparrow$

Reverse Bias increase $\Rightarrow$ Depletion layer increase ($W\uparrow$)

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

$$W_{eff} = \downarrow$$

① $W_{eff} \Rightarrow \downarrow$

Less Recombination

α = increase

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

$\alpha \uparrow$

$\boxed{I_C \uparrow}$

$RB \uparrow\downarrow \Rightarrow W_B \uparrow\downarrow$

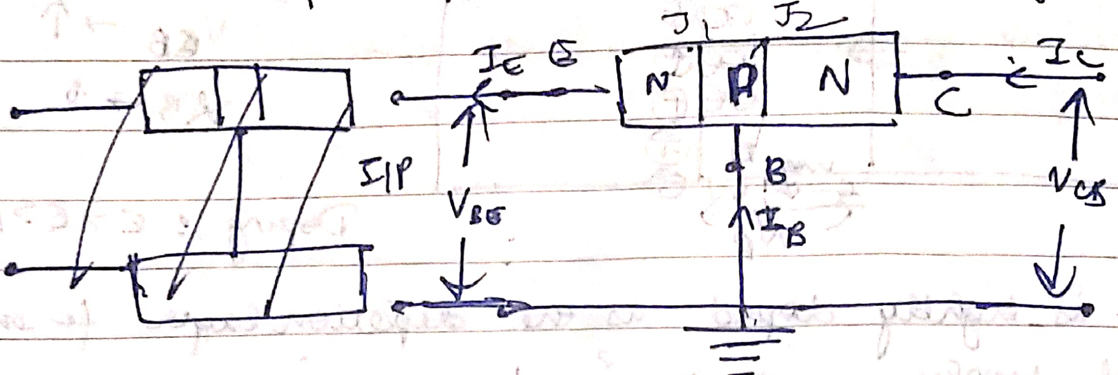
Base Modulation

② conc. gradient will increase

$\boxed{I_E \uparrow}$

Common Base Input Characteristics

It is graphical relation between input voltage & I/P current for diff values of O/P voltage



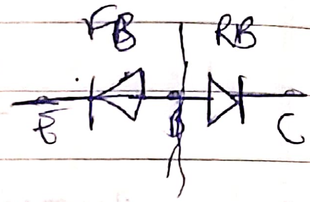
① I/P char ② O/P Char

↓

curve

I/P vs I/P curr

O/P voltage = constant



I/P voltage = V_{BE}

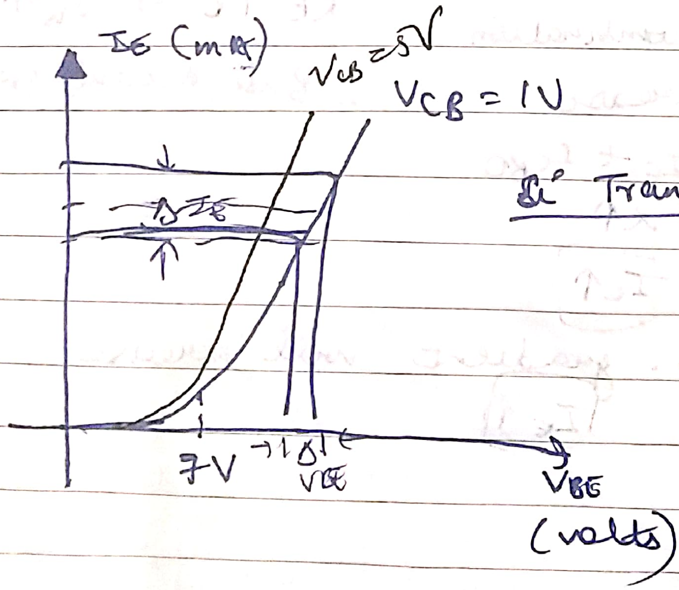
I/P current = I_E

O/P voltage = V_{CB}

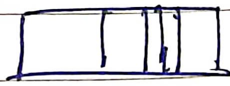
O/P current = I_C

I/P $\{V_{BE} \;\; I_E\}$

O/P $\{V_{CB} \;\; I_C\}$



Si Trans



$V_{CB} \uparrow$

$W_{eff} \downarrow$

$I_E \uparrow$

$$\boxed{\text{slope} = \frac{1}{r_i}}$$

$\uparrow \rightarrow r_i \downarrow$

$$r_i = \frac{\Delta V_{BE}}{\Delta I_E}\Big|_{V_{CB} = \text{const}}$$

$$\boxed{r_i = 20\,\Omega \text{ to } 100\,\Omega}$$

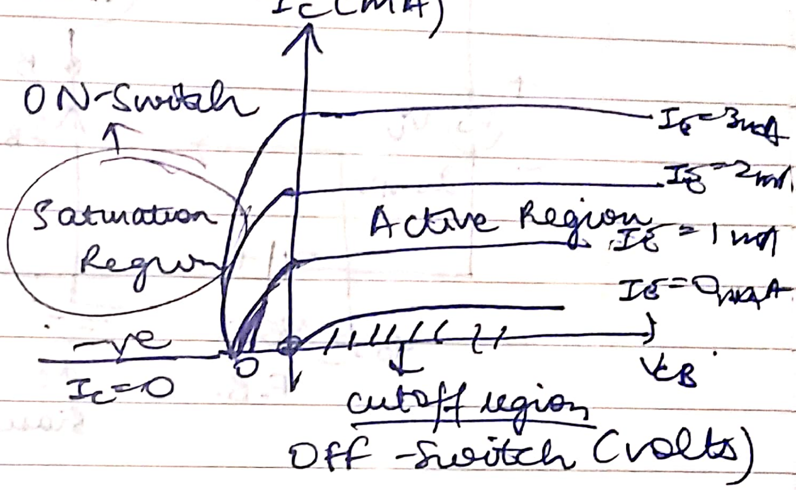
Date ___ / ___ / ______

Dynamic I/P resistance $(R_i) = \dfrac{\text{Change in I/P voltage}}{\text{change in I/P current}} \Big|_{\text{O/P voltage = constant}}$

Common Base Output Characteristics

BJT → current controlled device

V_{CB} v/s I_C (I_E = const



I_E = Fix

V_{EB} → vary

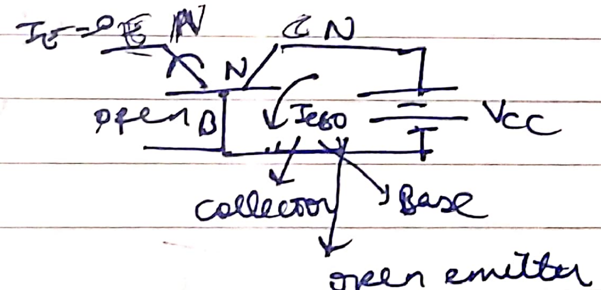
I_C → Note

$I_E = 0$ mA

$I_C = \alpha \underbrace{I_E}_{0} + I_{CBO}$

$= 0 + I_{CBO}$

$\boxed{I_C = I_{CBO}}$ μA



$I_E >> I_{CBO}$

$\alpha < 1$

$\boxed{I_C \simeq I_E}$

$\boxed{V_{CB} = 0}$ → Border line → Active Region & Saturation Region

$I_C = 0$ → Active Region & cut-off region

O/P dynamic Resistance

$r_o = \dfrac{\Delta V_{CB}}{\Delta i_C} \Big|_{I_E = \text{constant}}$

slope ↓ ∝ $\frac{1}{R_o}$ ↑

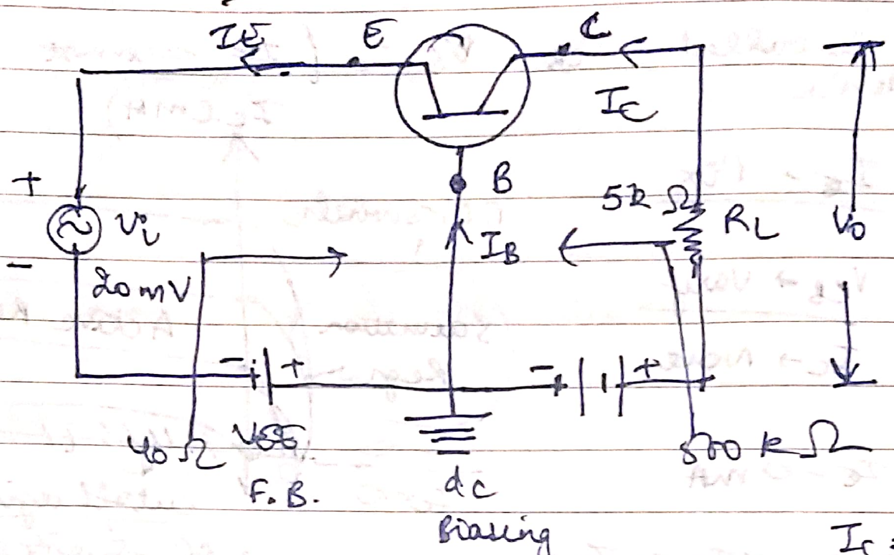
$\boxed{r_o \simeq 1 M\Omega}$ very high Resistance

Date ___ / ___ / ___

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

low freq current gain of CB conf

Transistor Amplifying Action



$I_C = \alpha I_E + \underbrace{I_{CBO}}_{\mu A}$

$I_E >> I_{CBO}$

$I_C \simeq I_E$

$v_i = 20 mV$

$v_i = I r_i$

$v_i = I_E r_i$

$I_E = \frac{v_i}{r_i} = \frac{20 mV}{40 \Omega} = \boxed{0.5 mA}$

$\alpha < 1$

0.95 50 0.98

$I_E = 0.5 mA$

$I_C = 0.5 mA$

$V_0 = I_C \times R_L$

$= 0.5 mA \times 5 k\Omega$

$= (0.5 \times 10^{-3})(5 \times 10^3)$

$V_0 = \boxed{2.5 V}$

$v_i = 20 mV$

A_v = voltage Amplification factor

$= \frac{O/P \text{ voltage}}{I/P \text{ voltage}} = \frac{2.5 V}{20 mV} = 125$

$v_o = A_v \times v_i$

$= 125 \times 20\ mV$

$= 125 \times 20\ mV$

① Voltage Amplification factor

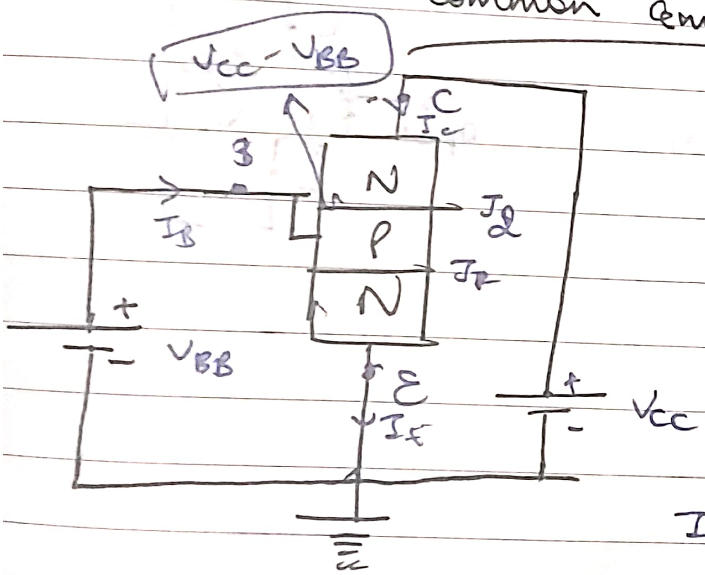
$$\boxed{A_v \Rightarrow 50 \text{ to } 300}$$

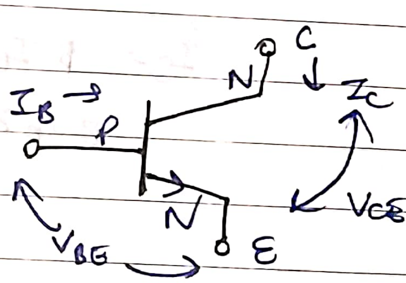
② Current Amplification factor

$$\alpha \Rightarrow < 1$$

0.95 to 0.98

Common Emitter Configuration





$I_E = I_B + I_C$ —— ①

$I_C = \alpha I_E + I_{CBO}$ —— ②

I/P current = I_B

I/P voltage = V_{BE}

O/P current = I_C

O/P voltage = V_{CE}

$I_C = f(I_B)$

Put value of I_E from eqn ① in eqn ②

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

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

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

Divide both sides by $(1-\alpha)$

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

$$I_E = I_B + I_C$$

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

$$I_E = I_B + I_C$$

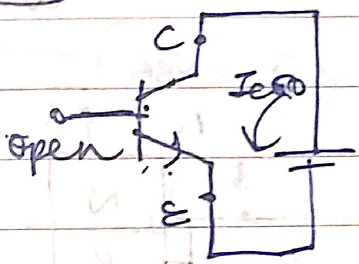
$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

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

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

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

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



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

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

Neglect

$$I_C = \beta I_B$$

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

current gain of CE configuration $\boxed{= \beta = 50 \text{ to } 400}$

" " " CB configuration $= \alpha < 1$

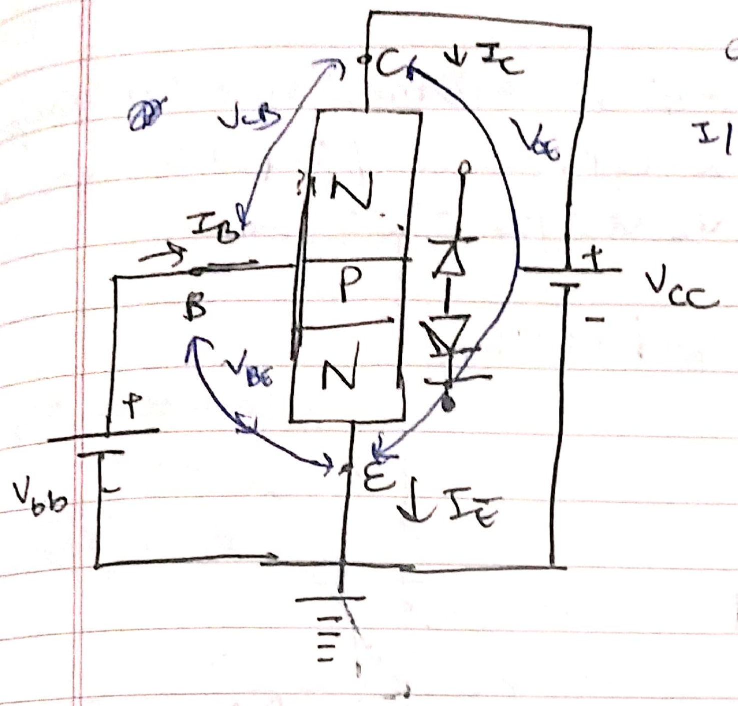
Common emitter → Current Amplifier

$I_B = 5mA$

$\beta = 200$

$\boxed{I_C = 1000\ mA}$

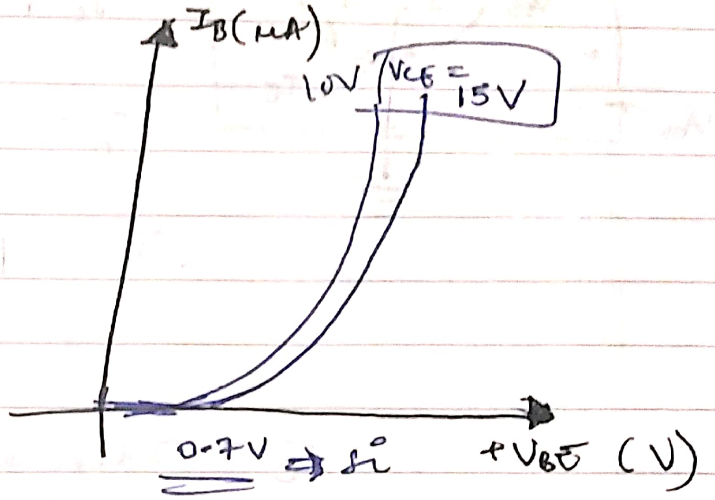
CE Input Characteristics



curve beth

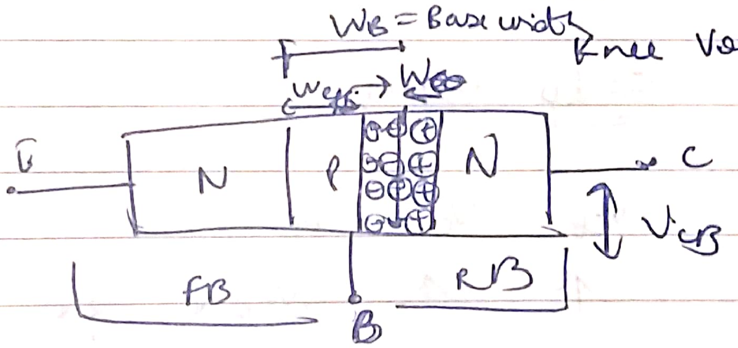
I/P & I/P curr/O/P voltage constant

V_{BE} vs I_B / V_{CE}



V_{BE} vs I_B / V_{CE}

Knee Voltage



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

$I_B\downarrow$

$W_B = W + W_{eff}$

$V_{CB}\downarrow$ $W\downarrow$ $W_{eff}\uparrow$ $I_B\uparrow$

Base width modulation $\Longleftrightarrow$ $\boxed{W_{eff} = W_B - W}$

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

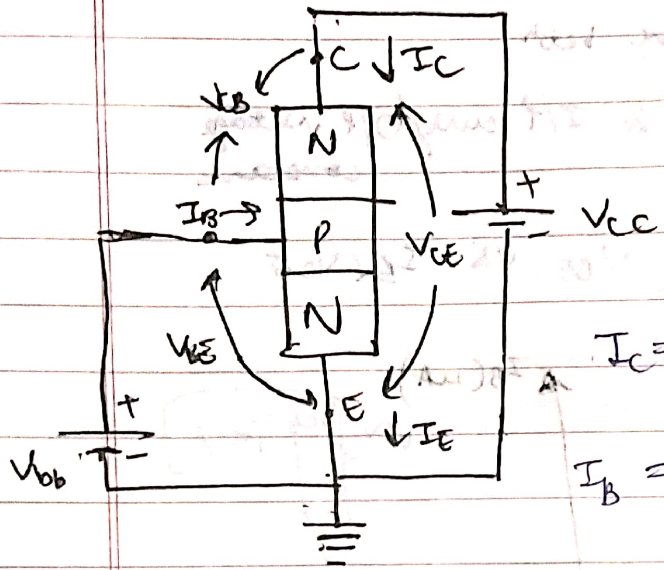
$V_{CE}\downarrow$ $V_{CB}\downarrow$ $I_B\uparrow$

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

$$\Delta r_i = \frac{\Delta V_{BE}}{\Delta I_B} \Big/ V_{CE} = \text{constant}$$

Date ___/___/______

CE Output Characteristics



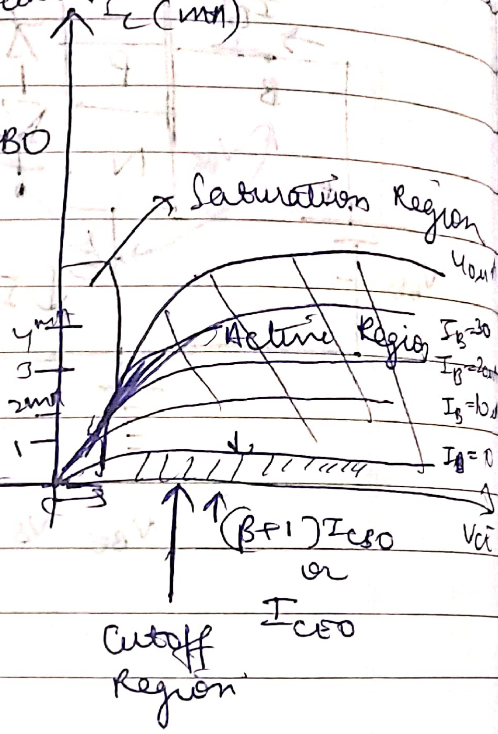
Graphical relation b/w O/P voltage & O/P current / Input current const.

V_{CE} Vs $I_C / I_B = \text{const}$

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

$I_B = 0$

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



$I_C \Rightarrow$ Independent of V_{CE}

Early Effect

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

$\uparrow \quad \uparrow \quad W_{eff} \downarrow \; I_B \downarrow \; I_C \uparrow$

Dynamic O/P resistance

$$\boxed{r_O = \frac{\Delta V_{CE}}{\Delta I_C} \Big/ I_B = \text{constant}}$$

Relation b/w α, β, γ

$\alpha \rightarrow$ Amplification factor of CB configuration

$\alpha_{dc} = \frac{I_C}{I_E}$ $\qquad$ $\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E} \Big/ V_{CB} = \text{const}$

Date ___ / ___ / ___

→ $\beta \rightarrow$ Current Amplification factor of CE configuration

$\beta_{dc} = \frac{I_C}{I_B}$

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

→ $\gamma \rightarrow$ amplification factor of CC conf

$\gamma_{dc} = \frac{I_E}{I_B}$

$\gamma_{ac} = \frac{\Delta I_E}{\Delta I_B} \Big/ V_{EC} = \text{const}$

$I_E = I_C + I_B$

divide both sides by I_B

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

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

We know that

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

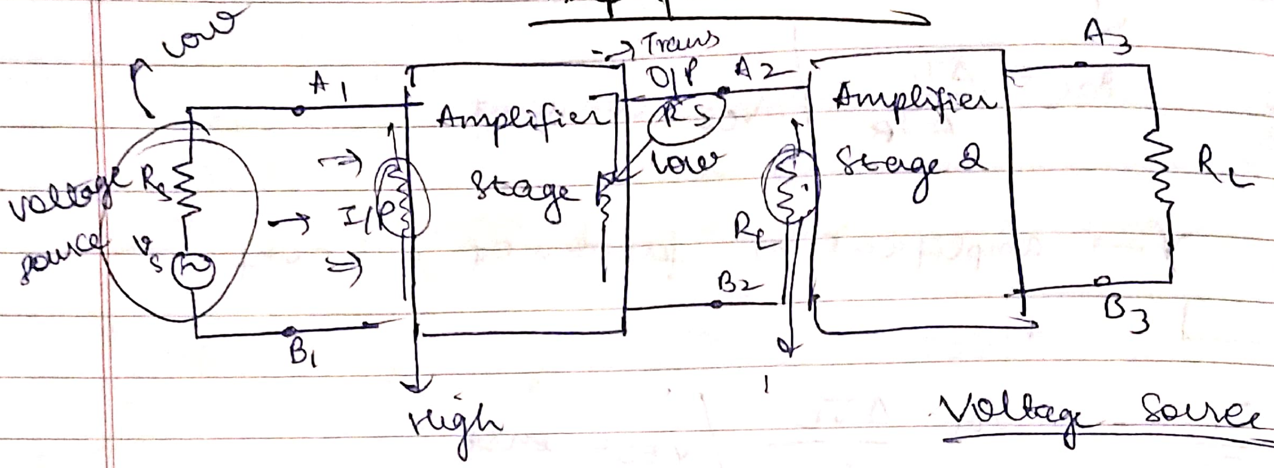
$\gamma = \frac{\alpha}{1-\alpha} + 1$

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

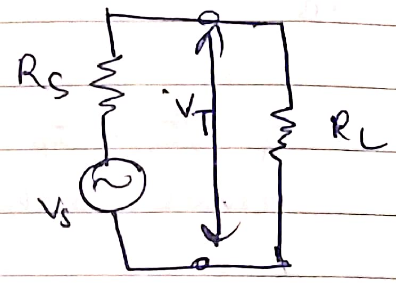
$\boxed{\gamma = \beta + 1 = \frac{1}{1-\alpha}}$

Date ___/___/___

Why CE configuration is widely used in Amplifier Circuits



Voltage Source



$$V_T = \frac{R_L}{R_S + R_L} \times V_s$$

$$V_T \simeq V_s = \frac{V_S}{1 + \frac{R_s}{R_L}}$$

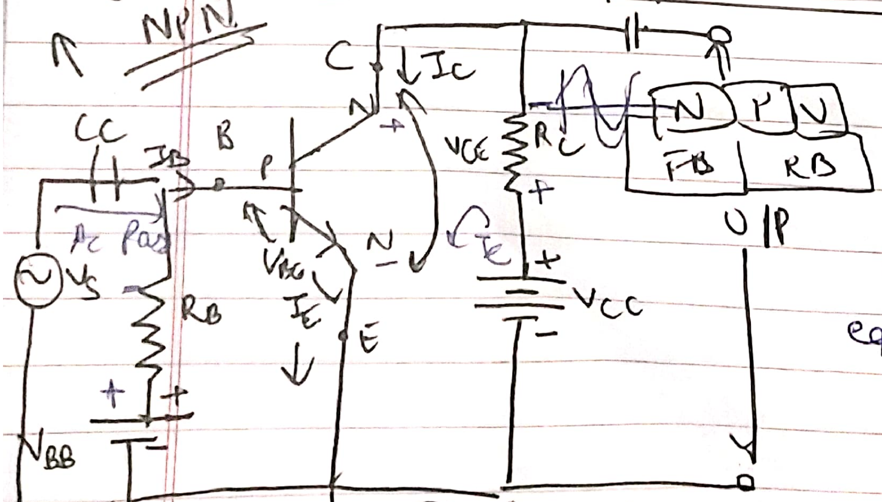
$V_S \cong V_T$ (good voltage source)

I/P resis (Rs) ⇒ low
O/P resis (RL) ⇒ High

CB = I/P ⇒ 20 Ω	= O/P ⇒ 1 MΩ
CE → I/P = 1 kΩ	O/P = 10 kΩ
CC ⇒ I/P = 150 kΩ	O/P = 800 Ω

coupling capacitor

Basic CE Amplifier and DC load line



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

O/P section eqn

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

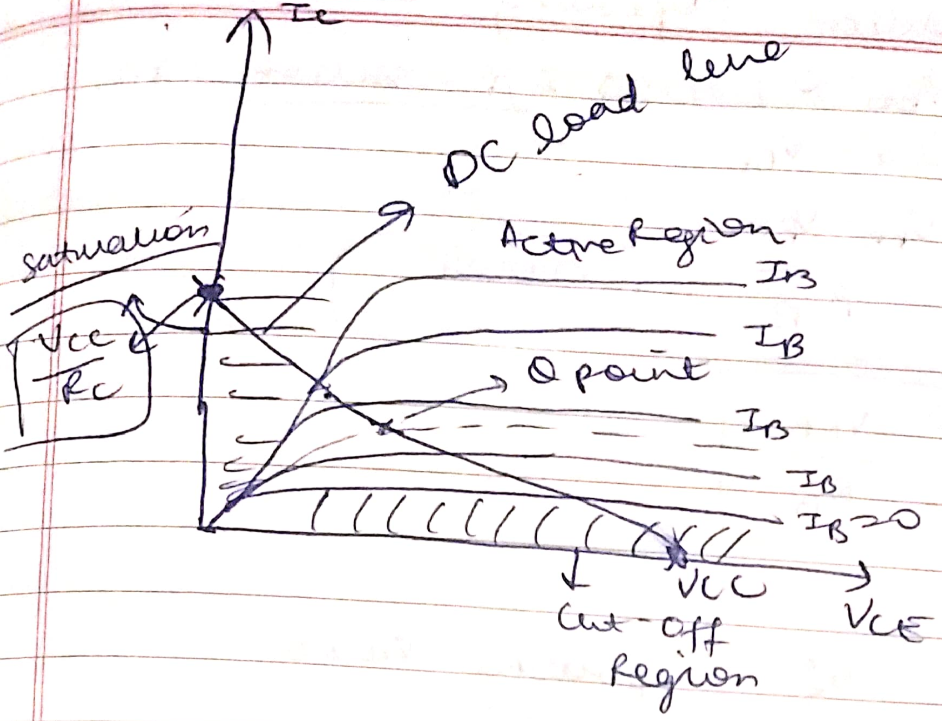
eqn of straight line

$$\boxed{Y = mx + C}$$

$$\underset{y}{I_C} = \frac{V_{CC} - V_{CE}}{R_C} = \underset{\text{const}}{\frac{V_{CC}}{R_C}} - \frac{V_{CE}}{R_C}$$ (x)

[Active Region EB → FB
CB → RB]

Date ___ / ___ / ___



Quiscent condition

When no signal on the base

$$I_c = \left(-\frac{1}{R_c}\right) V_{CE} + \frac{V_{CC}}{R_c}$$

$$y = mx + c$$

$$\boxed{\text{slope of line} = -\frac{1}{R_c}}$$

On Y axis

$V_{CE} = 0$

$V_{CC} - I_c R_c - 0 = 0$

$$\boxed{I_c = \frac{V_{CC}}{R_c}}$$

On x-axis

$I_c = 0$

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

DC load line is formed when we join I_c & V_{CC}

Date **Quiescent Condition** (Operating Point)

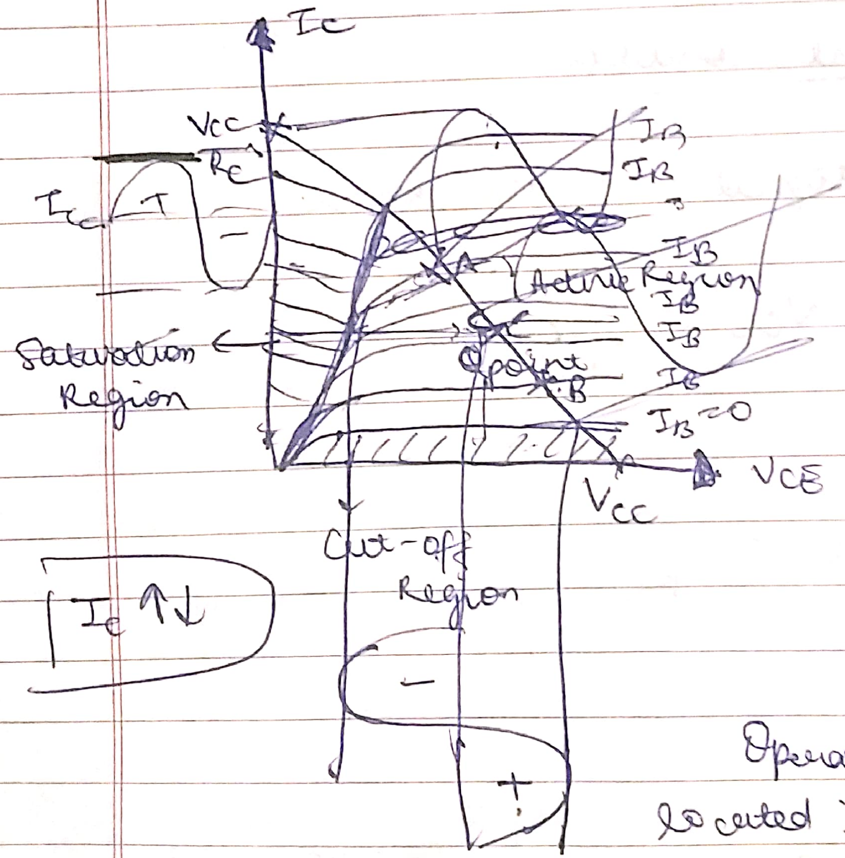
$V_{BB} - I_B R_B - V_{BE} = 0$ → I/P section eqn

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

$I_B = \frac{V_{BB} - V_{BE}}{R_B}$ 0.7V → Si

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

Selection of Operating Point



$\boxed{I_c \uparrow\downarrow}$

$I_c \uparrow\downarrow$

1. Transistor parameter

$\beta \rightarrow$ Current gain

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

2. Temp $I_c \uparrow\downarrow$

Operating point should be located in middle of DC load line so we get the same output as the input given. This is known as faithful amplification.

Bias Stabilization & Stability factor

Stabilization :- The process of making operating point independent of temperature changes and variation in transistor parameters is known as stabilization

Causes of Unstabilization

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

$\Downarrow$

Reverse leakage current

$\Downarrow$

Minority charge carriers

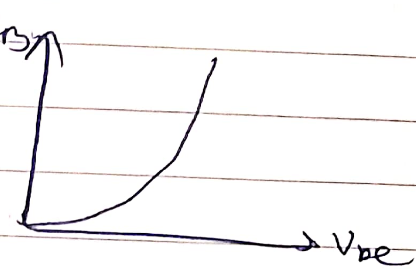
$T \uparrow\downarrow$

10°C Rise in Temperature

I_{CBO} = Double

$T\uparrow$ $I_{CBO}\uparrow$ $I_C\uparrow$. $T\uparrow \rightarrow V_{be}$ (2.5 mV decrease / °C $\uparrow$)

$\boxed{I_C \propto T}$



② Current gain (β) $\rightarrow I_C \uparrow\downarrow$

Stability factor — The rate of change of collector current (I_C) wrt leakage current (I_{CBO}) at constant Input voltage (V_{BE}) and amplification factor (β) is called stability factor.

Lower the value of S, system will be more stable

$$S = \frac{dI_C}{dI_{CBO}} \Big|_{\text{const } V_{BE} \ \& \ \beta}$$

$$S' = \frac{dI_C}{dV_{BE}} \Big|_{\text{const } I_{CBO} \ \& \ \beta}$$

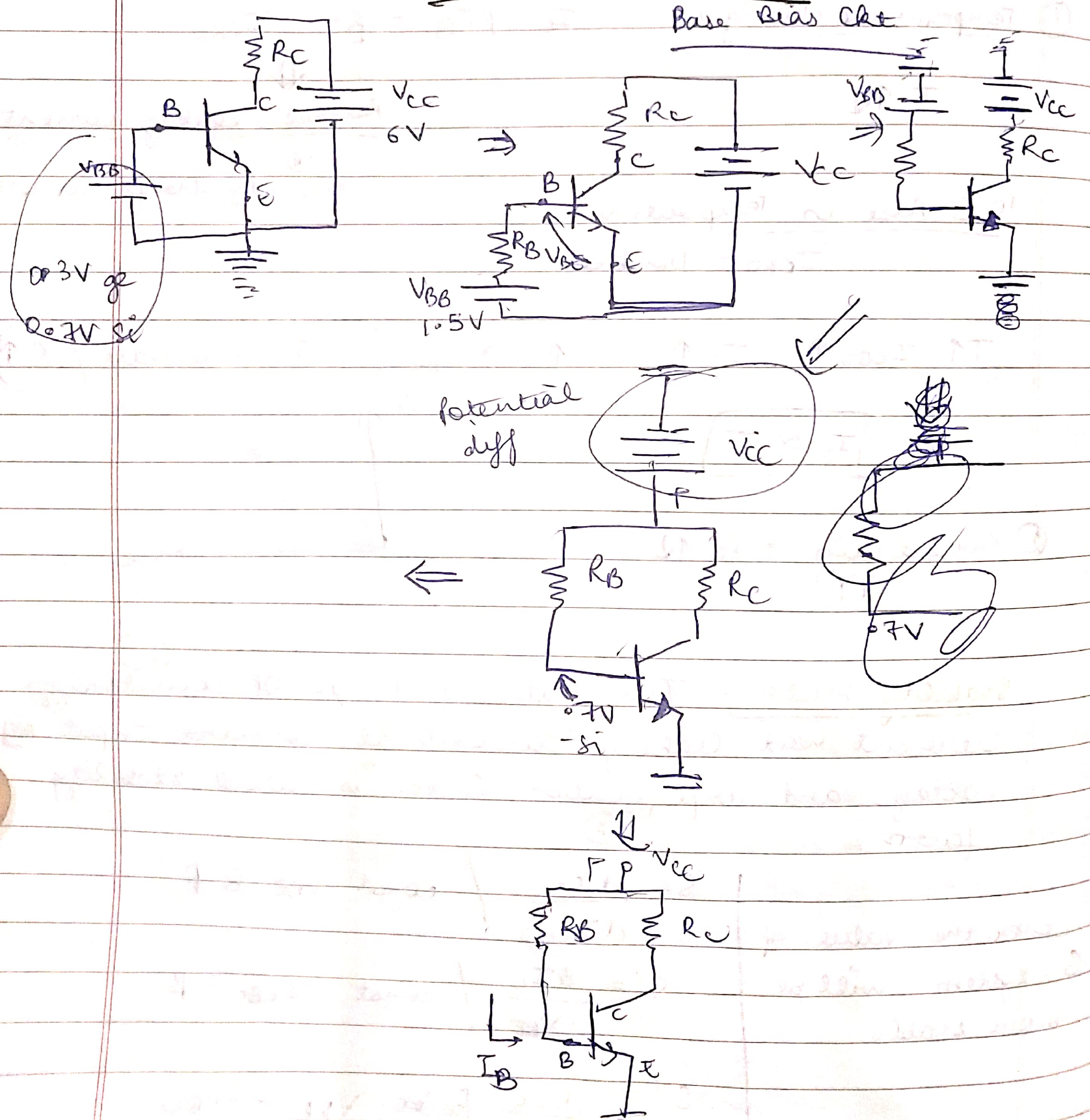
$$S'' = \frac{dI_C}{d\beta} \Big|_{\text{const } V_{BE} \ \& \ I_{CBO}}$$

Date ___/___/______

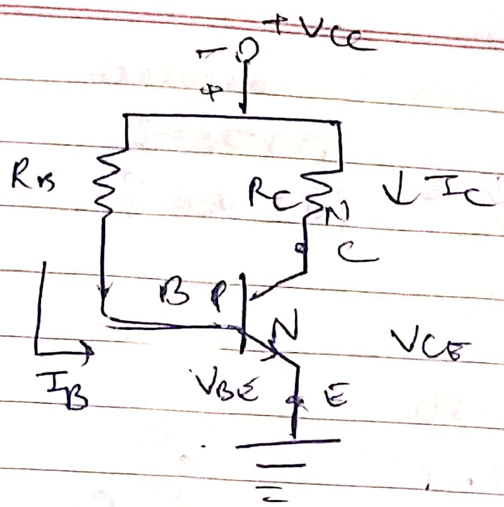
Requirement for Biasing Circuit

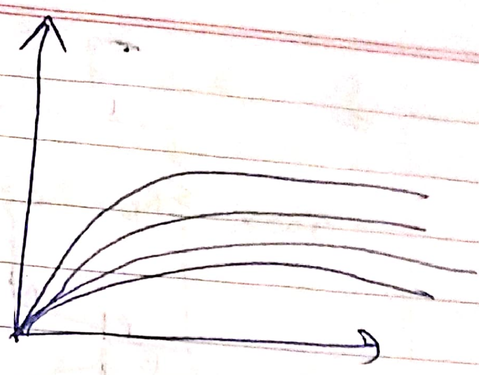
① Selection of operating point - Middle of load line
② Stabilization against temp variations of I_c
③ Free from transistor parameter variations

Fixed Bias Circuit



Date ___/___/___





I/P section

$V_B \simeq 0.7V$

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

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

$\boxed{I_B \simeq \frac{V_{CC}}{R_B}}$

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

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

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

$I_C \simeq \beta I_B$

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

O/P section

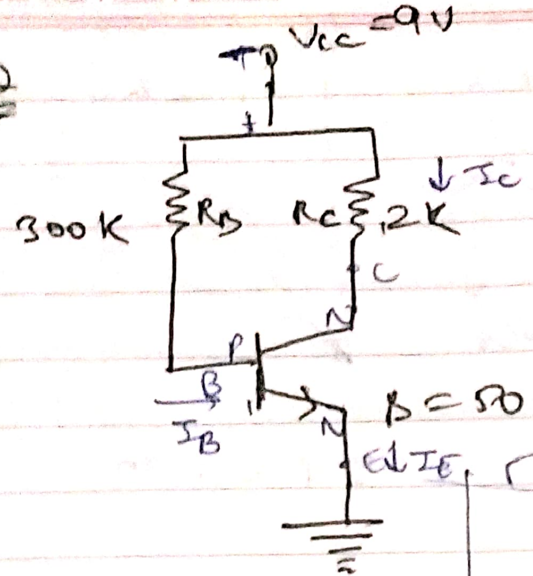
$+V_{CC} - I_C R_C - V_{CE} = 0$

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

(1) operating point in the middle - R_B (Design flex)

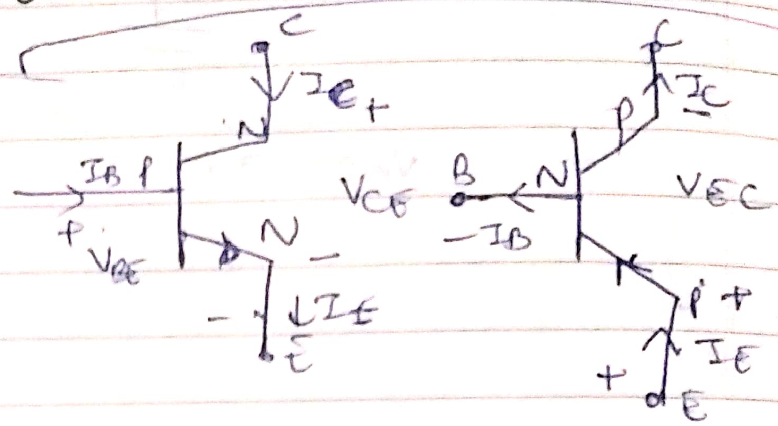
Date ___ / ___ / ___

Q



Calculate
(i) $I_C = ?$
(ii) V_{CE} ?

$\boxed{I_C = \beta I_B}$



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

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

I/P Section

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

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

$I_B \simeq \frac{V_{CC}}{R_B}$

$= \frac{9V}{300k\Omega} = \frac{9}{300\times10^3} = \frac{3}{10^5} = 3\times10^{-5}A$

$\boxed{I_B = 30\mu A}$

$I_C = \beta I_B$
$= 50\times30\times10^{-6}$
$= 1500\times10^{-6}$

$\boxed{I_C = 1.5mA}$

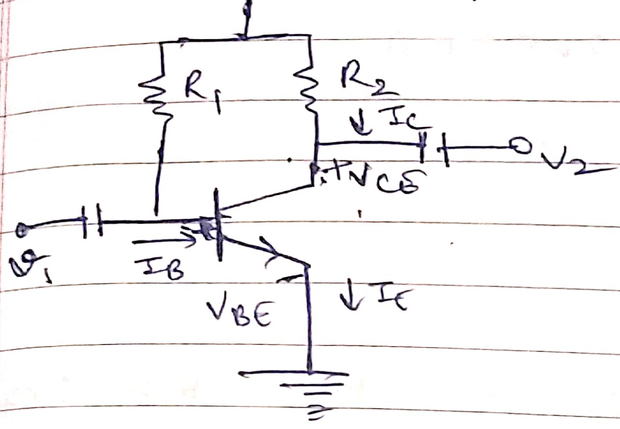
O/P Section

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

$V_{CE} = 9 - (1.5mA\times 2k\Omega)$
$= 9 - 3$

$\boxed{V_{CE} = 6V}$

Q In amplifier ckt shown value of R_1 & R_2 are such that the transistor is operating at $V_{CE} = 3V$ & $I_C = 1.5mA$ when $\beta = 150$. For a transistor with $\beta = 200$, calculate the operating point



$V_{CE} = 3V$ $I_C = 1.5 mA$ $\beta = 150$

$I_C = \beta I_B$

$\frac{1.5}{150} = I_B$

$\boxed{I_B = 10 \mu A}$

$X_C = \frac{1}{2\pi fC} = \frac{1}{0} = \infty$

dc f = 0

Hence dc analysis

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

$R_1 = \frac{V_{CC} - V_{BE}}{I_B}$

$R_1 = \frac{6 - 0.7}{10 \mu A} = 5.3 \times 10^5$

$\boxed{R_1 = 530k\Omega}$

O/P section

$V_{CC} - I_C R_2 - V_{CE} = 0$

$R_2 = \frac{V_{CC} - V_{CE}}{I_C}$

$= \frac{6 - 3}{1.5 mA} =$

$\boxed{R_2 = 2k\Omega}$

(ii) $V_{CC} = 6V$, $R_1 = 530k\Omega$, $R_2 = 2k\Omega$, $\beta = 200$

$I_C = \beta I_B$

$V_{CE} - I_B R_B - V_{BE}$

$I_B = \frac{V_{CC} - V_{BE}}{R_1} = \frac{6V - 0.7V}{530k\Omega} = \frac{5.3}{530} k\Omega$

$I_B = 10 \mu A$

O/P section

$$V_{CC} - I_C R_2 - V_{CE} = 0$$

$$V_{CE} = V_{CC} - I_C R_2$$

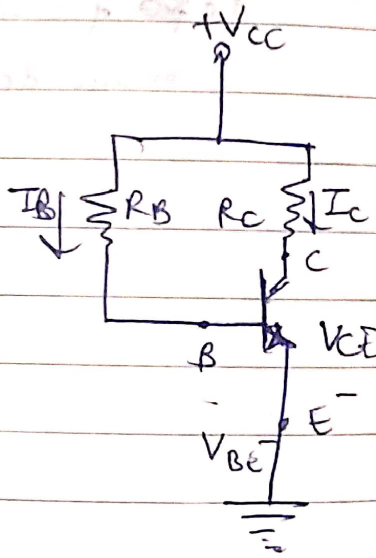
$$= 6V - 2mA\ 2k\Omega$$

$$= 6 - 4 = 2$$

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

Stability factor for Fixed Bias circuit

$$S = \frac{dI_C}{dI_{CBO}}\Big/ \text{const } V_{BE}\ \&\ \beta$$



Step I

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

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

Step II

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

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

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

Differentiate wrt I_C with const V_{BE} & β

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

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

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

General Eqn for Stability factor

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

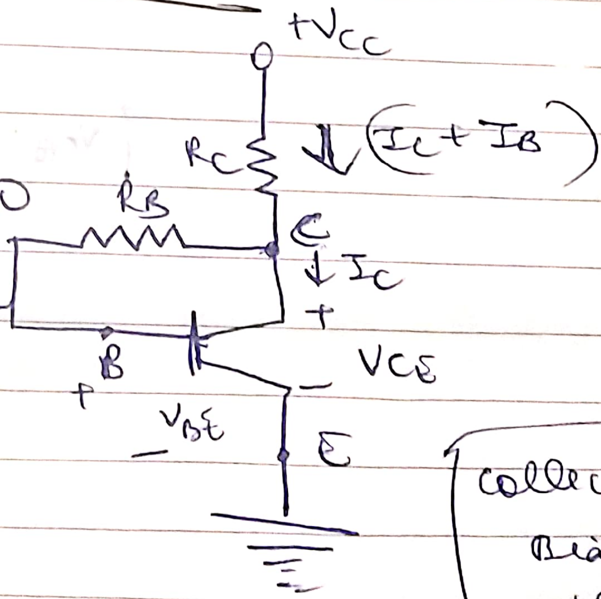
$$1 = \beta\frac{dI_B}{dI_C} + (\beta+1)\frac{1}{S}$$

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

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

Collector to Base Bias Circuit

Input Section (KVL)



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

$$-I_CR_C - I_BR_C - I_BR_B - V_{BE} = 0$$

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

collector feedback Bias Ckt
voltage F/B ckt

Output section

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

$$V_{CC} - I_CR_C - V_{CE} = 0 \qquad I_B << I_C$$

$$\boxed{V_{CE} = V_{CC} - I_C R_C} \quad (2)$$

Put eqn (2) in eqn (1)

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

$T \uparrow$ $I_{CBO} \uparrow$; $I_C \uparrow$ $\rightarrow$ $V_{CE} \downarrow$ $\rightarrow$ $I_B \downarrow$ $\rightarrow$ $I_C \downarrow$

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

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

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

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

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

$\beta + 1 \simeq \beta$

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

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

$\beta R_C >> R_B$

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

free from β