

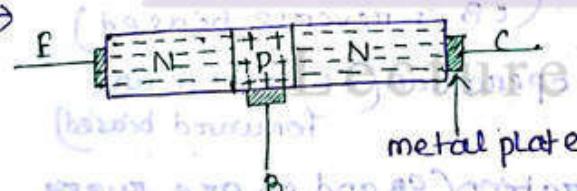
# BIPOLAR JUNCTION TRANSISTOR (BJT)

## Bipolar junction transistor:

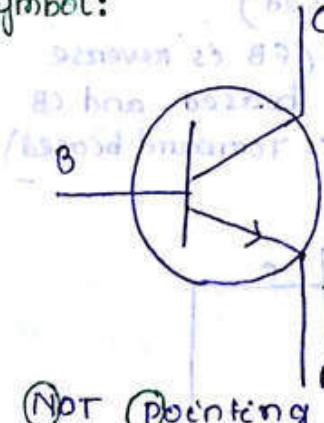
- It's a three terminal device whose terminals represented as emitter, base, collector.
- The transistor is called BJT because both holes and electrons take part in current conduction process.
- It is an active device.
- The main function of a transistor is amplification (Active mode of operation).
- It is also used in switching ckt (saturation and cutoff mode of operation).
- According to structure, transistors are divided into two types.
  - ↪ (i) NPN transistor
  - ↪ (ii) PNP transistor

## NPN

- When p-type semiconductor is sandwiched between two n-type semiconductors, it is called NPN transistor.



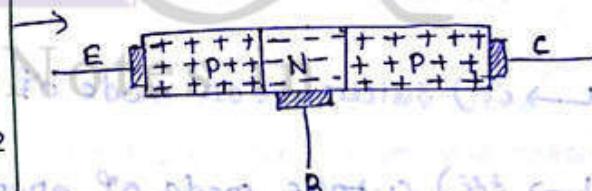
Symbol:



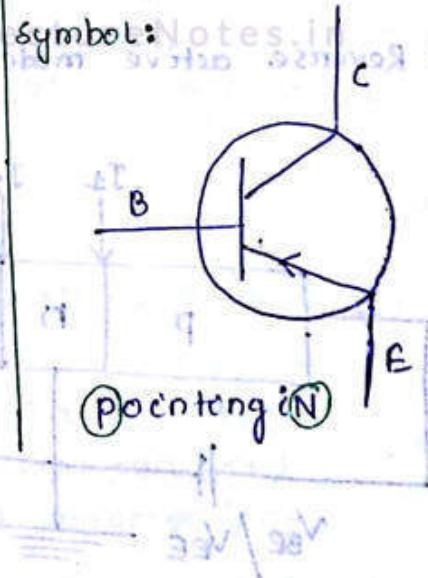
NOT pointing iN,

## PNP

- When n-type semiconductor is sandwiched between two p-type semiconductors, it is called PNP transistor.



Symbol:



Pointing iN,

## Terminals BJT:

↳ i) Emitter

↳ ii) Base

↳ iii) collector

i) Emitter: It is heavily doped silicon region as it emits charge carriers.

ii) Base: The width of the base is very less than emitters and collectors. Base is lightly doped. It controls the flow of electricity from emitter to collector.

iii) collector: The name collector suggests that it collects the charge carriers and it is moderately doped. The width of the collector region is larger than emitter and base.

Q. Why NPN transistor is mostly used in amplification and switching?

→ In NPN transistor the majority charge carriers are  $e^-$ , whereas in PNP holes are the majority charge carriers. The mobility of  $e^-$  is much higher than holes. Due to high mobility, the operation becomes faster.

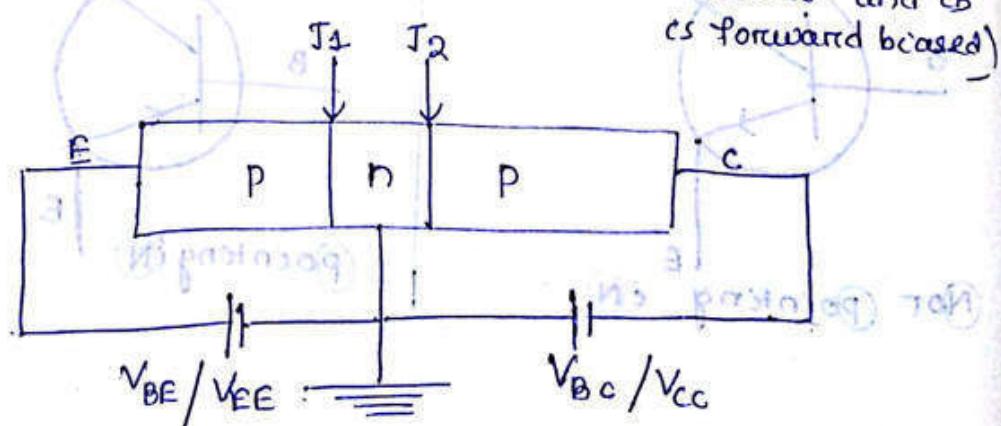
## Modes of operation:

↳ i) Active mode of operation ( $BE$  is forward biased  
 $cB$  is reverse biased)

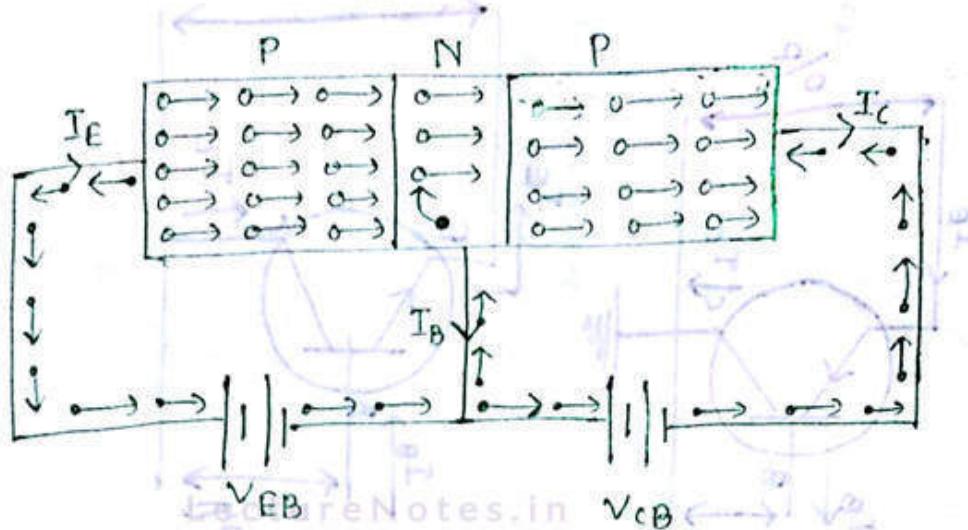
↳ ii) saturation mode of operation ( $EB$  and  $cB$  are forward biased)

↳ iii) cutoff mode of operation ( $EB$  and  $cB$  are reverse biased)

↳ iv) Reverse active mode of operation ( $EB$  is reverse biased and  $cB$  is forward biased)



## OPERATION OF PNP TRANSISTOR :



→ According to the figure c/p voltage is applied between emitter and base while o/p voltage is in between collector and base.

- The c/p section is forward biased i.e. emitter is connected +ve w.r.t to base.
- The o/p is reverse biased i.e. collector is connected -ve w.r.t base.
- The forward bias causes the holes in the p-type emitter to flow toward the base. Hence emitter current results.
- When these holes flow through the N-type base, they tend to combine with  $e^-$ s. As the base is lightly doped and very thin, only a few holes (less than 5%) combines with  $e^-$ s. Hence base current ( $I_B$ ) results.
- The remainder (more than 95%) cross over into the collector region resulting collector current.
- In this way almost the entire emitter current flows in the collector circuit. Therefore, the emitter current is the sum of collector and base currents i.e.

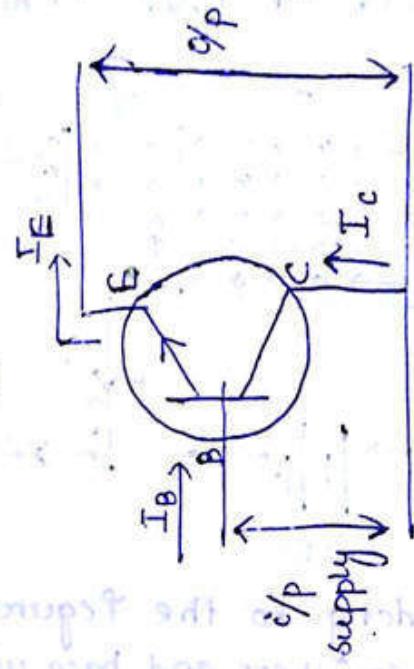
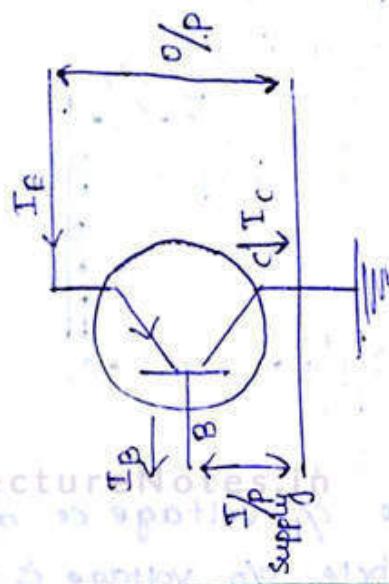
$$I_E = I_B + I_C$$

Q. What are the 3 configurations of BJT to work as an amplifier?

- - ↳ i) common base (CB)
  - ↳ ii) common emitter (CE)
  - ↳ iii) common collector (CC)

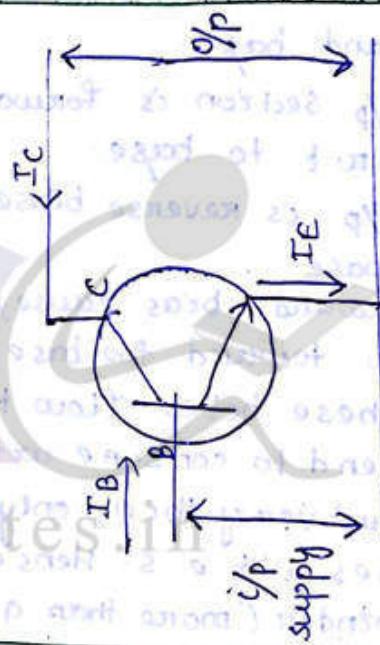
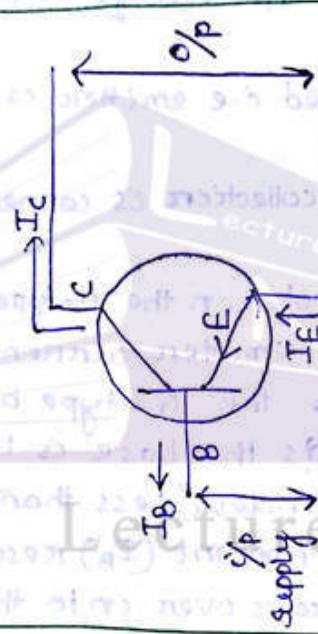
common collector

→ collector terminal is common to both c/p and o/p



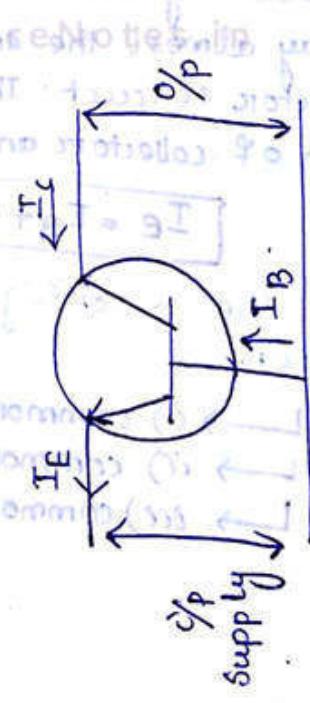
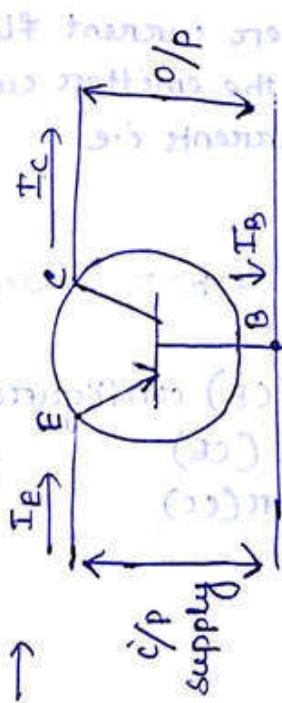
common Emitter

→ emitter terminal is common to both c/p and o/p

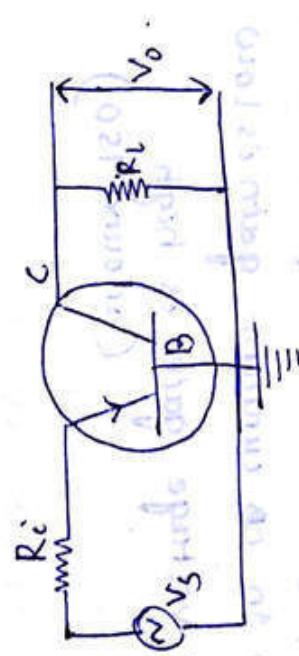


common Base (CB)

→ base terminal is common to both c/p and o/p



→ Amplifier connection:



Characteristics:

- ↳ c/p characteristics
- ↳ o/p characteristics
- ↳ i/p characteristics -  $\Delta I_E(\text{mA})$

$$V_{CB} = 10V$$

$$V_{CE} = \text{constant}$$

$$V_{CE} = 5V$$

$$V_{CE} = \text{constant}$$

$$V_{CE} = 10V$$

$$V_{CE} = \text{constant}$$

$$V_K = 0.7V$$

$$V_E = 3.7V$$

$$V_E = 5.7V$$

$$V_E = 10V$$

$$\frac{\Delta V_{BE}}{\Delta I_E} = \text{const}$$

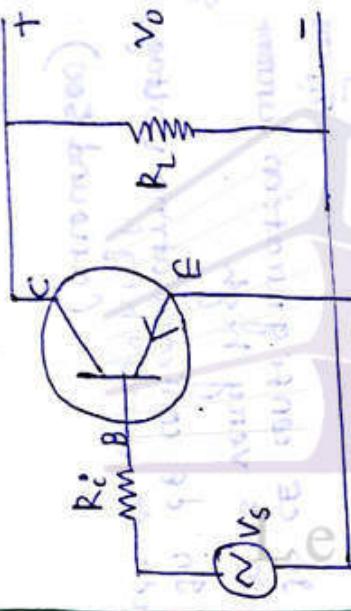
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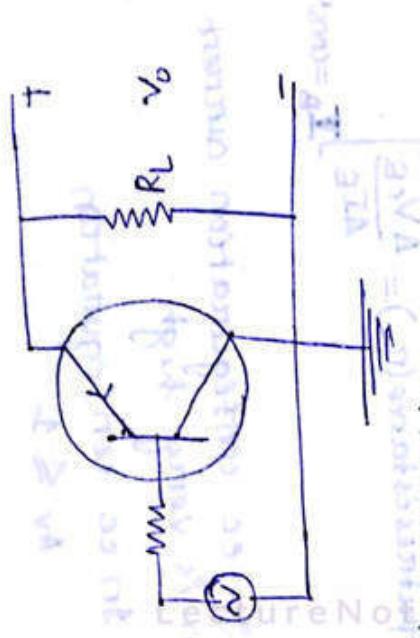
$$V_{EB} = \text{const}$$

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$$V_{EB} = 5.7V$$

$$V_{EB} = 10V$$

→ Amplifier connection:

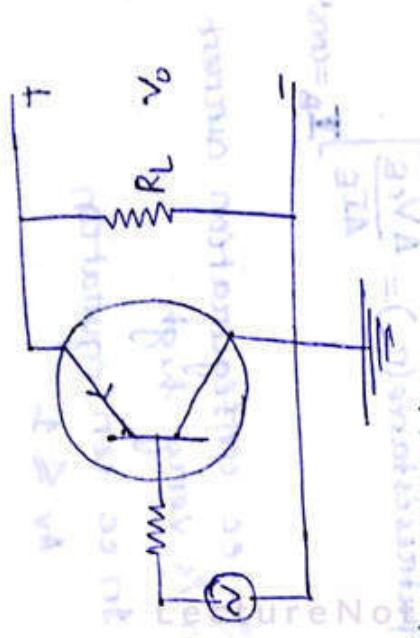


Characteristics:

- ↳ c/p characteristics
- ↳ o/p characteristics
- ↳ i/p characteristics

$$I_B = \frac{V_{CE} - V_{BE}}{R_L + r_{ce}}$$

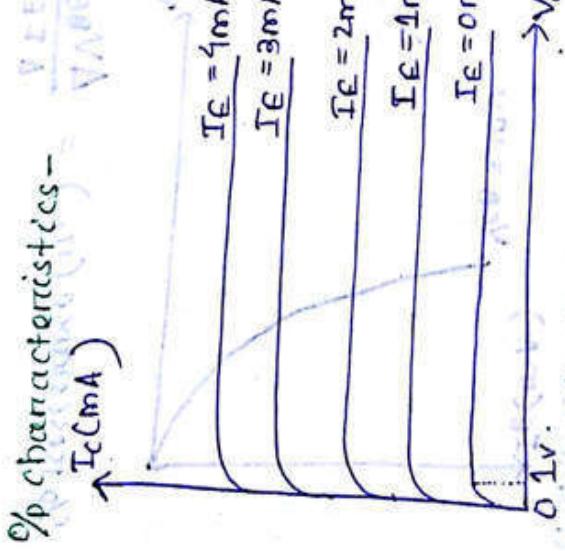
→ Amplifier connection:



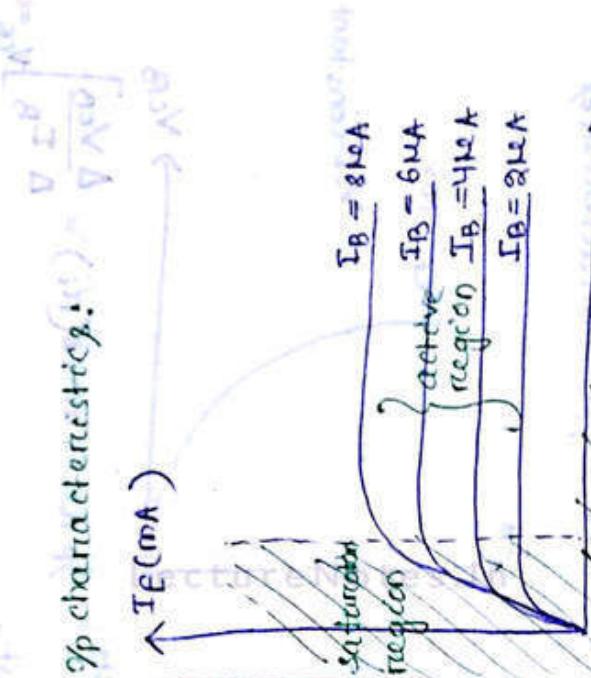
Characteristics:

- ↳ c/p characteristics
- ↳ o/p characteristics
- ↳ i/p characteristics

$$I_B = \frac{V_{CE} - V_{BE}}{R_L + r_{ce}}$$



$\eta_p$  characteristics :-



$$\text{output resistance} (r_o) = \frac{\Delta V_{CE}}{\Delta I_C} - I_C = \text{const}$$

why CE is mostly used as an amplifier ckt :-

$$\text{output resistance} (r_o) = \frac{\Delta V_{CE}}{\Delta I_E} = \text{const}$$

$\Rightarrow$  In CE configuration current gain is very high  
(around 150)

$\Rightarrow$  In CE configuration current gain is very high.  
In CE configuration voltage gain is very high.

(around 500)

$\rightarrow$  In CC configuration current gain is very high.

$\rightarrow$  In CC configuration current gain is very high.

$A_V \leq 1$

→ In CB configuration  
c/p impedance is low

(nearly  $100\Omega$ )

$\rightarrow \frac{E}{I_A} = q$   
c/p impedance is high  
(around  $750\Omega$ )

→ I/p impedance is very high  
(around  $750k\Omega$ )

→ I/p impedance is very high

(nearly  $450k\Omega$ )

→ I/p impedance is high  
(around  $45k\Omega$ )

→ power gain is high  
→ power gain is medium

$$\frac{V_{TE}}{V_{TA}} = q$$

### current amplification factor :

It is the ratio between change in o/p current and change in i/p current.

cB current amplification factor: ( $\alpha$ )

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

cE current amplification factor: ( $\beta$ )

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

cc current amplification factor: ( $\gamma$ )

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

Relation between  $\alpha$  &  $\beta$ :

We know

$$I_E = I_C + I_B$$

$$\Delta I_E = \Delta I_C + \Delta I_B$$

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

$$= \frac{\Delta I_C}{\Delta I_C + \Delta I_B} = \frac{\beta \Delta I_B}{\beta \Delta I_B + \Delta I_B} \quad (\because \beta = \frac{\Delta I_C}{\Delta I_B})$$

$$= \frac{\beta \Delta I_B}{(\beta + 1) \Delta I_B} = \frac{\beta}{\beta + 1}$$

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

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

$$= \frac{\alpha \Delta I_E}{\Delta I_E - \alpha \Delta I_E}$$

$$= \frac{\Delta I_E \alpha}{\Delta I_E (1 - \alpha)}$$

$$\left( \because \alpha = \frac{\Delta I_C}{\Delta I_E} \right)$$

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

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

Relation between  $\beta$  &  $\gamma$ :

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

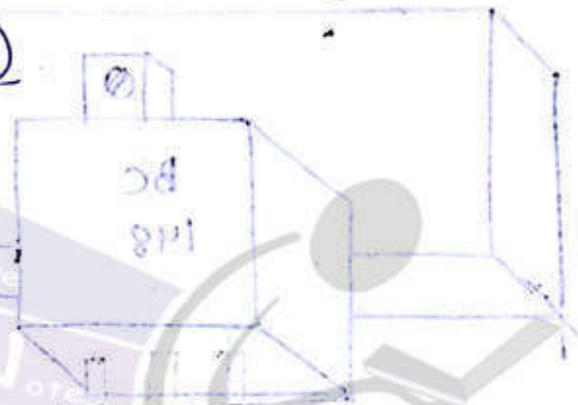
$$\beta = \frac{\Delta I_E - \Delta I_B}{\Delta I_B}$$

$$\gamma = \frac{\Delta I_E - \Delta I_B}{\Delta I_B} \quad (\text{where } \gamma = \frac{\Delta I_E}{\Delta I_B})$$

$$= \frac{\Delta I_B (\gamma - 1)}{\Delta I_B}$$

$$\Rightarrow \beta = \gamma - 1$$

$$\Rightarrow \gamma = \beta + 1$$



Transistor Leakage Current:

CB:

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

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

leakage current

CE:

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

$$\therefore I_C = \beta I_B + I_{CBO}$$

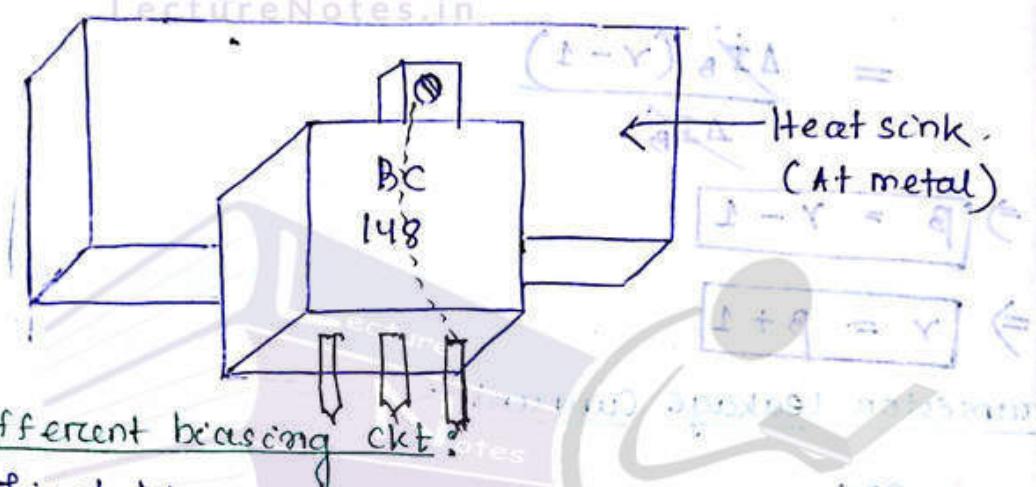
leakage current

## Thermal runaway:

The self destruction of unstabilized transistors with excessive generation of heat at collector (due to collision of charge carriers) is called thermal runaway.

Q. How thermal runaway can be avoided?

→ By connecting a heat sink made up of aluminum metal at the collector terminal, we can ensure that, the maximum amount of heat gets absorbed by the metal plate which ultimately saves BJT.



Different biasing ckt:

- ↳ fixed bias
- ↳ Emitter bias / Emitter stabilized bias
- ↳ voltage divider bias
- ↳ DC bias with voltage feedback / DC bias with collector biasing ckt.

It is a ckt arrangement around the BJT which helps in amplifying the i/p signal in such a way that maximum and faithful o/p with stability can be obtained.

### DC analysis

→ In dc signals analysis all ac signals are removed along with capacitors.

→ Objective is to find -

- a point (operating point)
- dc load line

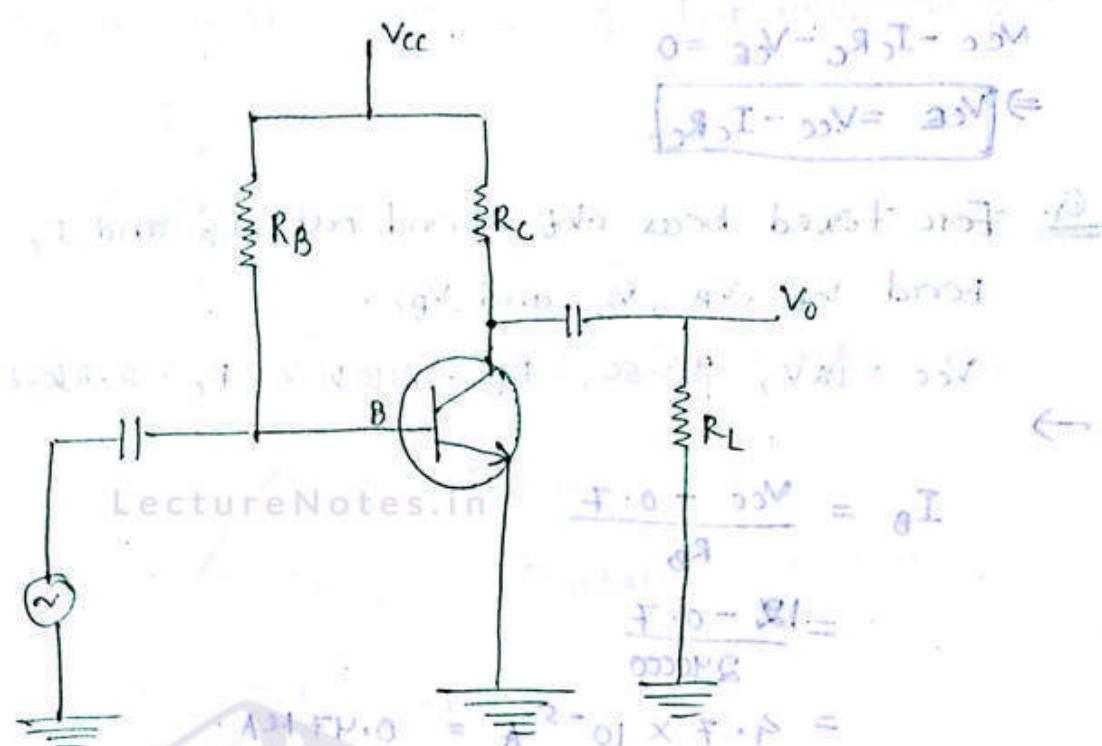
### AC analysis

→ All dc sources reduce to zero.

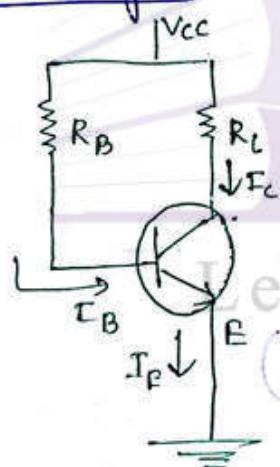
→ Objective to find -

- voltage gain
- current gain
- i/p impedance
- o/p impedance

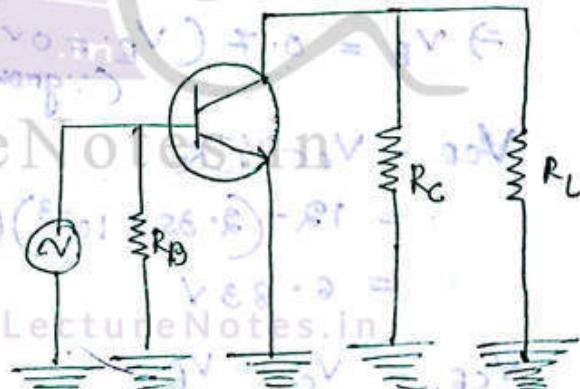
fixed bias ckt :



dc analysis



Ac analysis



from c/p

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

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

$$\Rightarrow I_B = \frac{V_{CC} - 0.7}{R_B} \quad (\text{for sc})$$

$$\frac{I_C}{I_B} = \beta \quad (\text{for sc})$$

$$\Rightarrow I_C = \beta I_B$$

From O/P :

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

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

Q. For fixed bias ckt find ext.  $I_B$  and  $I_C$ .

Find  $V_{BE}$ ,  $V_B$ ,  $V_C$ , and  $V_{BC}$ .

$$V_{CC} = 12V, \beta = 50, R_B = 240k\Omega, R_C = 2.2k\Omega.$$

→

$$I_B = \frac{V_{CC} - 0.7}{R_B}$$

$$= \frac{12 - 0.7}{240000}$$

$$= 4.7 \times 10^{-5} A = 0.47 \text{ mA}$$

$$I_C = \beta I_B = 4.7 \times 10^{-5} \times 50 = 2.35 \times 10^{-3} A$$

$$V_{BE} = 0.7V$$

$$\Rightarrow V_B - V_E = 0.7$$

$$\Rightarrow V_B = 0.7 (V_E = 0V) \quad (\because \text{grounded})$$

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

$$= 12 - (2.35 \times 10^{-3})(2.2 \times 10^3)$$

$$= 6.83V$$

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

$$\Rightarrow V_{CE} = V_C - 0 \Rightarrow V_{CE} = V_C$$

$$\Rightarrow V_C = 6.83V$$

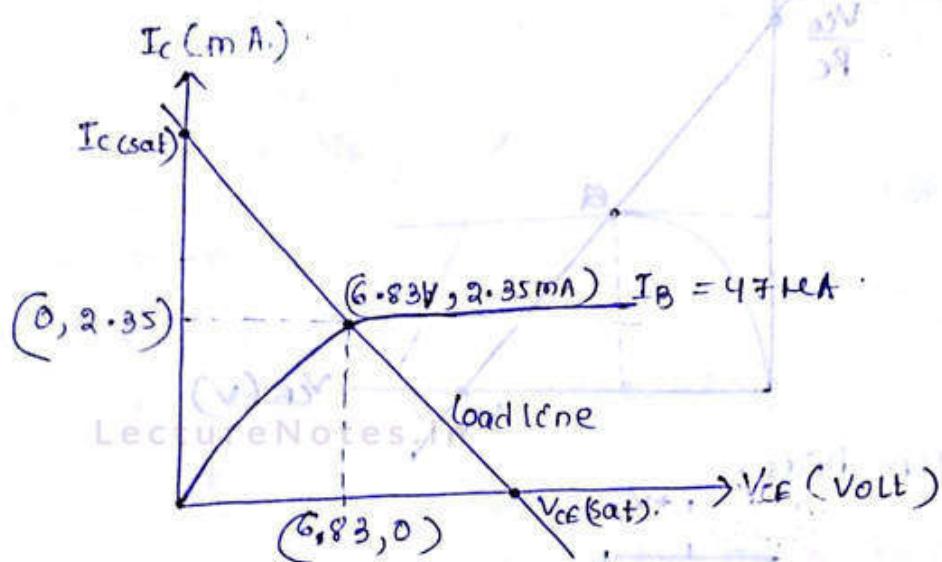
$$V_{BC} = V_B - V_C$$

$$= 0.7 - 6.83 = -6.13V$$

Load Line:

It is a straight line joining saturated value of  $I_P$  current and saturated value of O/P voltage.

operating point : it is an intersection point of  $I_B$  & loadline in CE O/P characteristics.



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

$$\Rightarrow V_{CE(sat)} \Big|_{I_C=0} = V_{CC}$$

$$\Rightarrow I_{C(sat)} \Big|_{V_{CE}=0} = \frac{V_{CC}}{R_C}$$

Q. why it is called fixed ckt?

$$\rightarrow I_B = \frac{V_{CC} - 0.7V}{R_B}$$

LectureNotes.in

$\therefore V_{CC}$ ,  $0.7$  and  $R_B$  are constant value.

$\Rightarrow I_B$  is also constant.

$\therefore$  All the values are constant.

so it is called fixed bias ckt.

\*  $I_B = \frac{V_{CC} - 0.7}{R_B}$

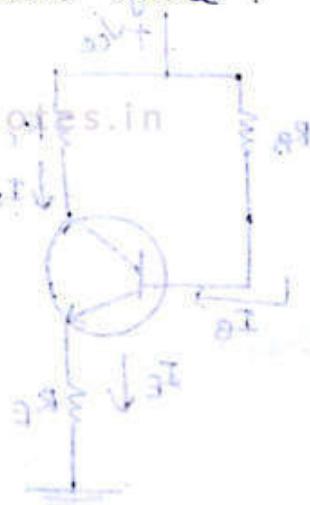
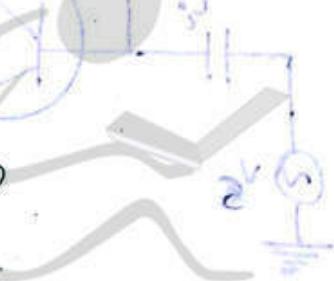
$$I_C = \beta I_B$$

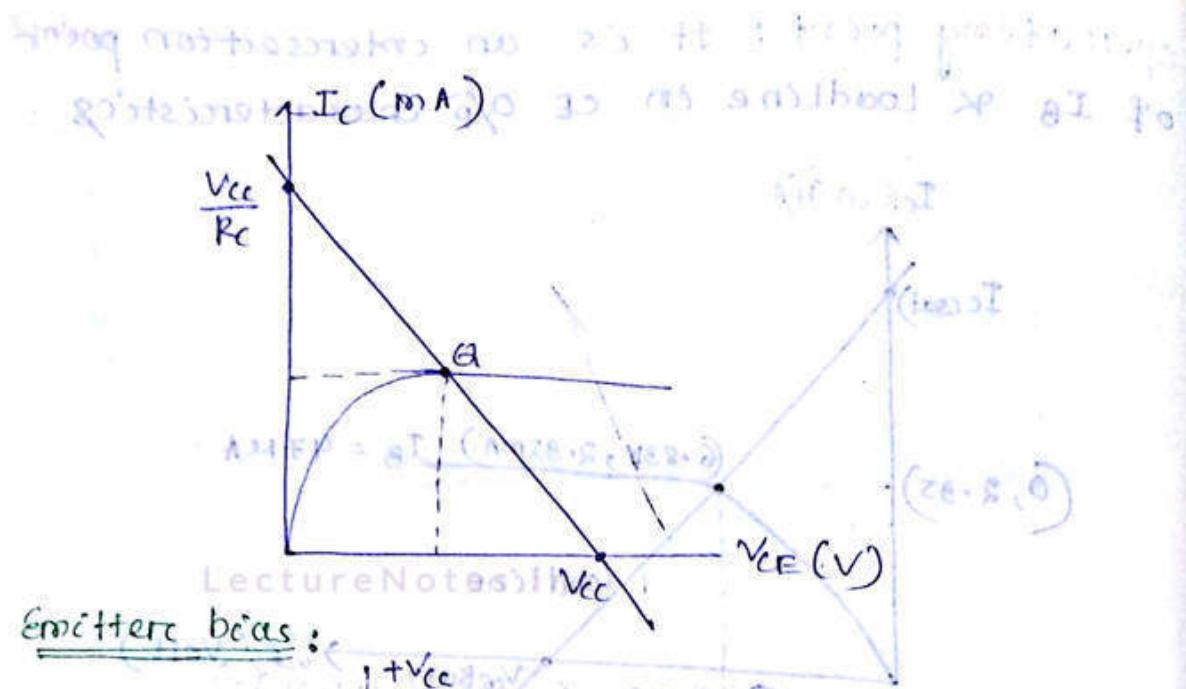
$$V_{CE} - I_C R_C - V_{CE} = 0$$

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

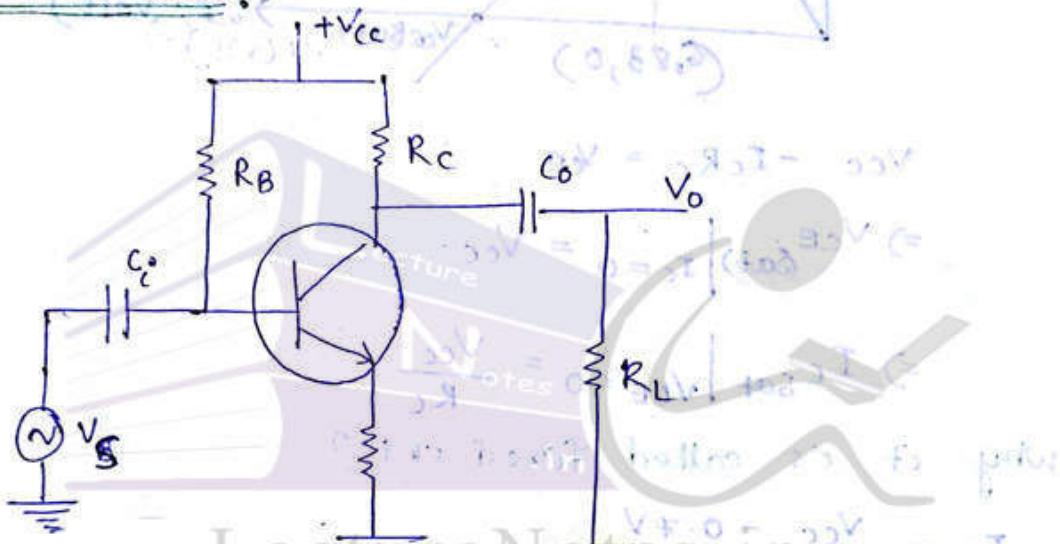
$$\Rightarrow V_{CE(sat)} = +V_{CC} (\because I_C = 0)$$

$$\Rightarrow I_{C(sat)} = V_{CC}/R_C (\because V_{CE} = 0)$$

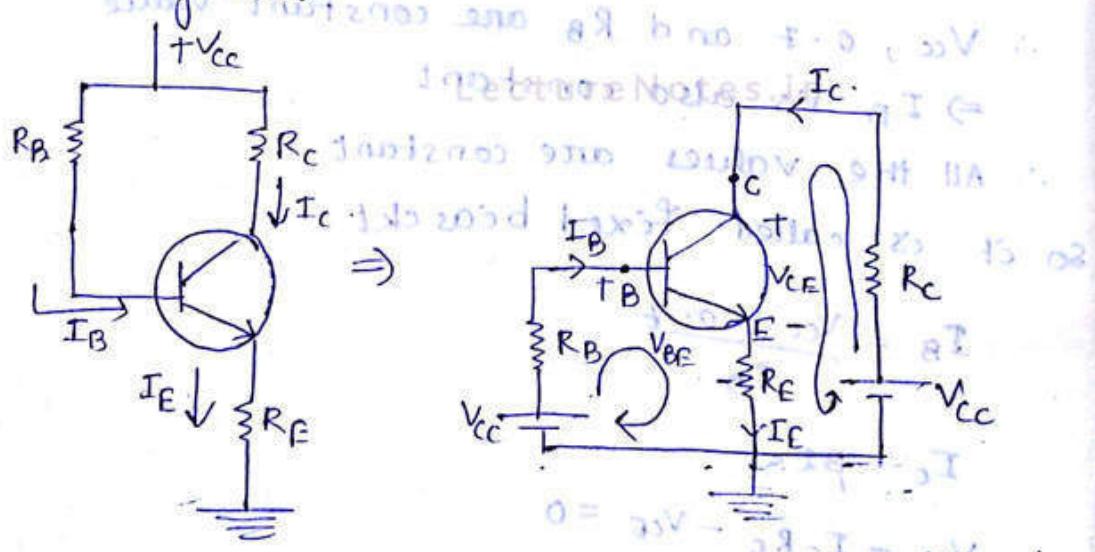




Emitter bias:



dc biasing ckt:



Apply KVL at c/p loop

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

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

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

Apply KVL at o/p loop

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

$$\Rightarrow V_{CC} - I_C R_C - V_{CE} - I_C R_E = 0 \quad (\because I_C = I_E)$$

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

\* A good biasing ckt must be independent of ' $\beta$ ' because ' $\beta$ ' is strongly depends on temperature.

\* If temp  $\uparrow$ ,  $\beta \uparrow$ . Ultimately  $I_C \uparrow$

\*  $I_C$  should be independent of  $\beta$

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

$$\Rightarrow I_E = \frac{(V_{CC} - 0.7)(\beta + 1)}{R_B + (\beta + 1) R_E}$$

$$\Rightarrow I_E = \frac{V_{CC} - 0.7V}{\frac{R_B}{\beta + 1} + R_E}$$

$$\text{If } \frac{R_B}{\beta + 1} \ll R_E$$

$\frac{R_B}{\beta + 1}$  can be neglected

$$\Rightarrow I_E = \frac{V_{CC} - 0.7V}{R_E}$$

$$\text{We know, } \frac{I_C}{I_E} = \alpha$$

The maximum value of  $\alpha = 1$

So  $I_C \approx I_E$ . Hence,

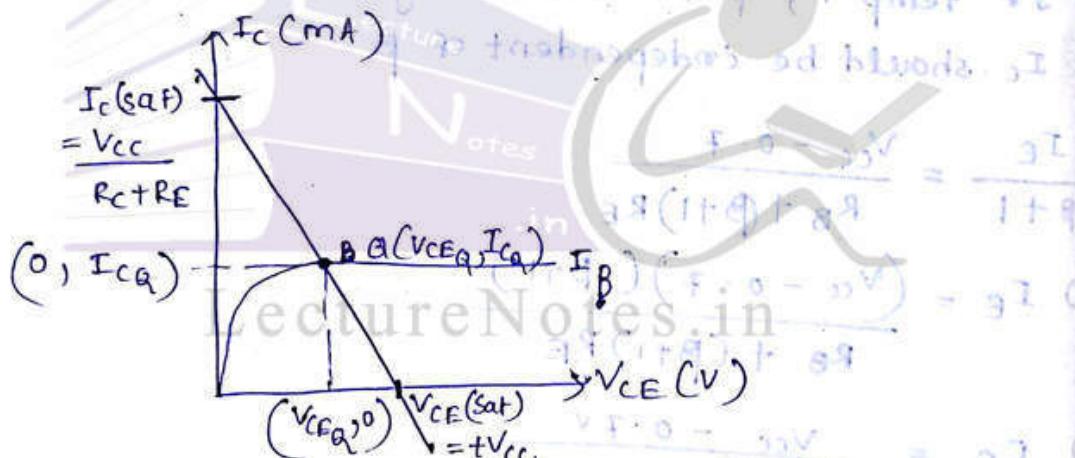
$$I_C = \frac{V_{CC} - 0.7V}{R_E}$$

- The  $I_c$  current eqn is independent of  $\beta$  because even if temperature increases, or leakage current increases, the  $I_c$  current almost remains fixed.
- The  $R_E$  resistor provides negative feedback to the ckt which helps in maintaining the operating point and also stability of the ckt.
- If a ckt is independent of  $\beta$ , that ckt is known as self biased.

$$\rightarrow \text{we know } V_{CE} = V_{CC} - I_C(R_C + R_E)$$

$$V_{CE}(\text{sat}) \mid I_C = 0 = +V_{CC}$$

$$I_C(\text{sat}) \mid V_{CE} = 0 = \frac{V_{CC}}{R_C + R_E}$$



$V_{CE}$  → collector Voltage w.r.t emitter.

$V_C$  → collector voltage w.r.t ground.

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

$$\Rightarrow V_C = V_{CC} - I_C R_C$$

$V_B$  → Base voltage w.r.t ground.

$$V_B - V_{BE} - I_E R_E = 0$$

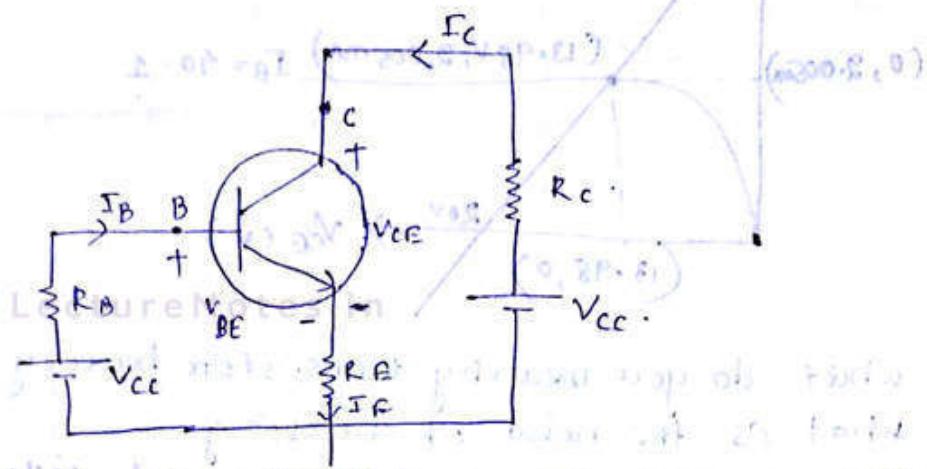
$$\Rightarrow V_B = V_{BE} + I_E R_E$$

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

$$\Rightarrow V_{BE} = V_B - I_E R_E \Rightarrow V_B = V_{BE} + I_E R_E$$

Q. For emitter bias ckt  $R_B = 190k\Omega$ ,  $R_C = 2k\Omega$ ,  
 $R_E = 1k\Omega$ ,  $V_{CC} = 20V$ ,  $\beta = 50$ . The  $I_F$ , o/p  
and bypass capacitors  $10\mu F$  each. Find  $I_B$ ,  $I_C$ ,  
 $I_E$ ,  $V_{CE}$ ,  $V_C$ ,  $V_E$ ,  $V_B$ ,  $V_{BE}$ .

→



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

$$= \frac{20 - 0.7}{430000 + (51 \times 1000)}$$

$$= 4.01 \times 10^{-5} A$$

$$I_C = \beta I_B = 50 \times 4.01 \times 10^{-5} = 2.005 \times 10^{-3} A$$

$$V_C = V_{CC} - I_C R_C = 20 - (2.005 \times 10^{-3}) \times 2000 = 15.99 V$$

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

$$= 20 - (2.005 \times 10^{-3}) \times (2000 + 1000)$$

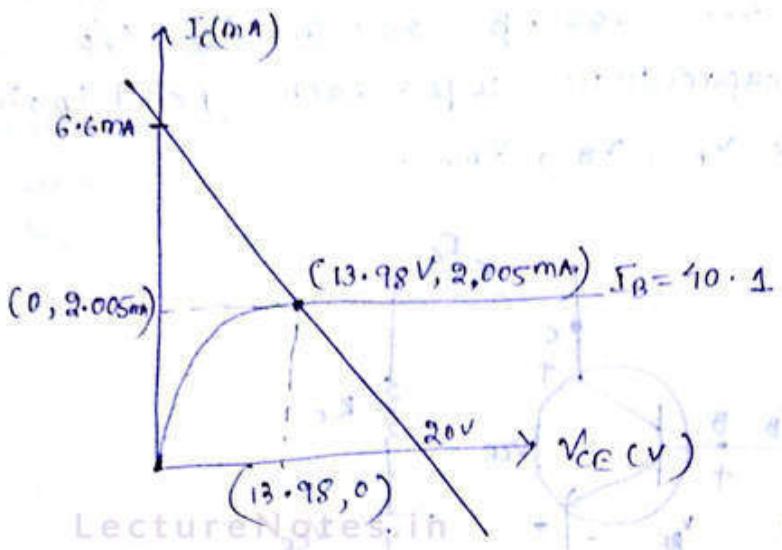
$$= 13.985 V$$

$$V_E = I_E R_E \approx I_C R_E = 2.005 \times 10^{-3} \times 1000$$

$$= 2.005 V$$

$$V_{CE(\text{sat})} = V_{CC} = 20 V$$

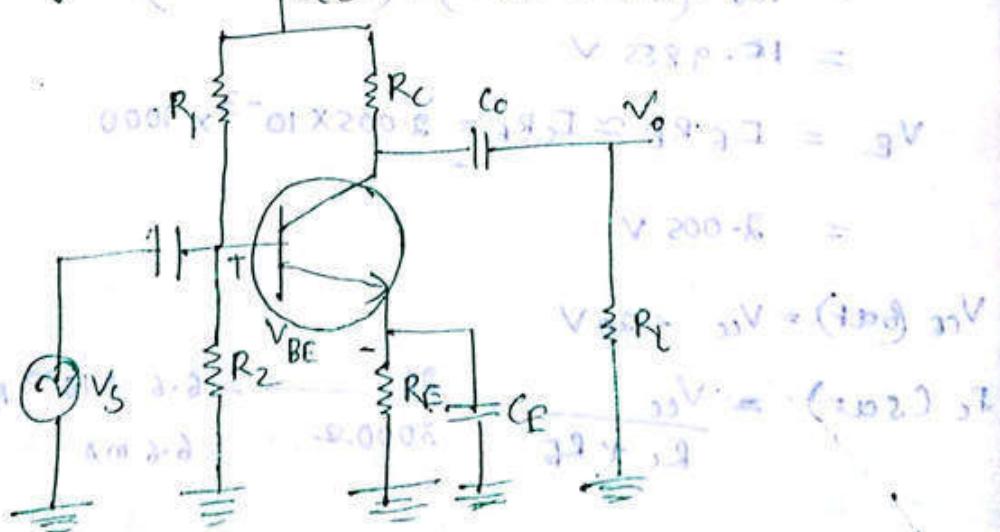
$$I_C(\text{sat}) = \frac{V_{CC}}{R_C + R_E} = \frac{20}{3000 \Omega} = 6.6 \times 10^{-3} A = 6.6 \text{ mA}$$



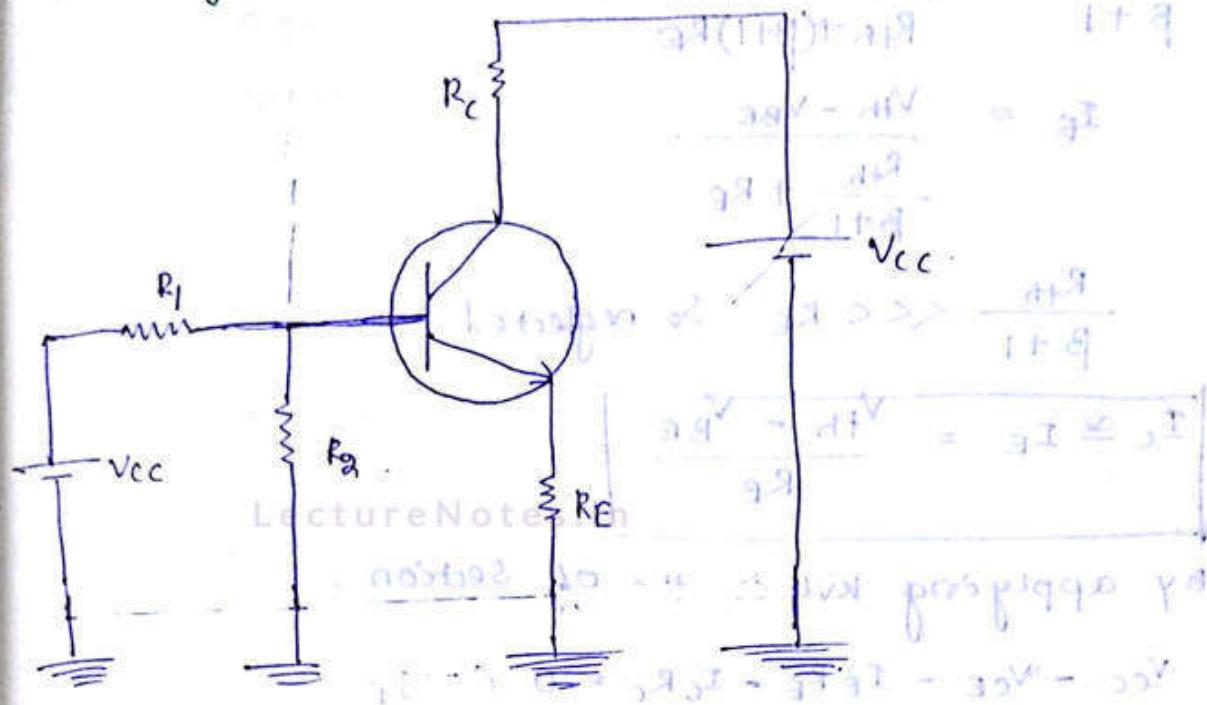
Q. what do you mean by transistor biasing?  
what is the need of biasing?

- The proper flow of zero signal collector current (flow of dc current) and the maintenance of operating point during the passage of signal.
- The operating point is established nearly the middle of the active region.
- The Ic is stabilized against temperature variation.
- The operating point should be independent of 'p'.

Voltage divider biasing:

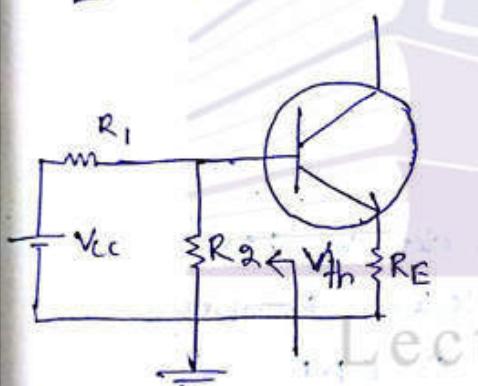


Dc analysis :

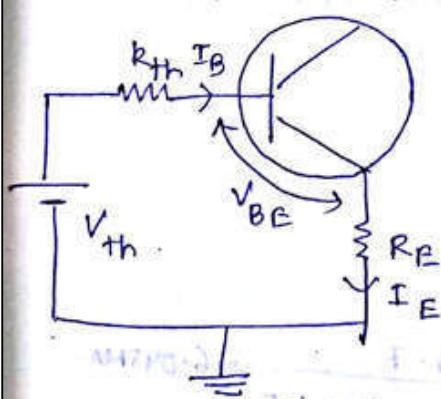


c/p section:

Thevenin resistance =  $3k\Omega$



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



By KVL

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

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

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

$$I_E = \frac{V_{th} - V_{BE}}{\frac{R_{th}}{\beta + 1} + R_E}$$

$\frac{R_{th}}{\beta + 1} \ll R_E$ . So neglected

$$I_C \approx I_E = \frac{V_{th} - V_{BE}}{R_E}$$

By applying KVL in the O/p section.

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

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

$$V_{CE(\text{sat})} \Big|_{I_C=0} = +V_{CC}$$

$$I_C(\text{sat}) \Big|_{V_{CE}=0} = \frac{V_{CC}}{R_C + R_E}$$

For a voltage divider bias ckt  $V_{CC} = 22V$

$R_1 = 39k\Omega$ ,  $R_2 = 3.9k\Omega$ ,  $R_C = 10k\Omega$ ,  $R_B = 1.5k\Omega$

$B = 140$ . Coupling capacitors C's  $10\mu F$ .

Bypass capacitor  $50\mu F$ . Find  $I_C$ ,  $I_B$ ,  $I_E$ ,

$V_{CE}$ ,  $V_C$ ,  $V_B$ ,  $V_E$ ,  $V_{BE}$ ,  $I_C(\text{sat})$ ,  $V_{CE(\text{sat})}$ .



$$R_{th} = \frac{R_1 R_2}{R_1 + R_2} = 3.54k\Omega$$

$$V_{th} = \left( \frac{V_{CC}}{R_1 + R_2} \right) R_2 = 2V$$

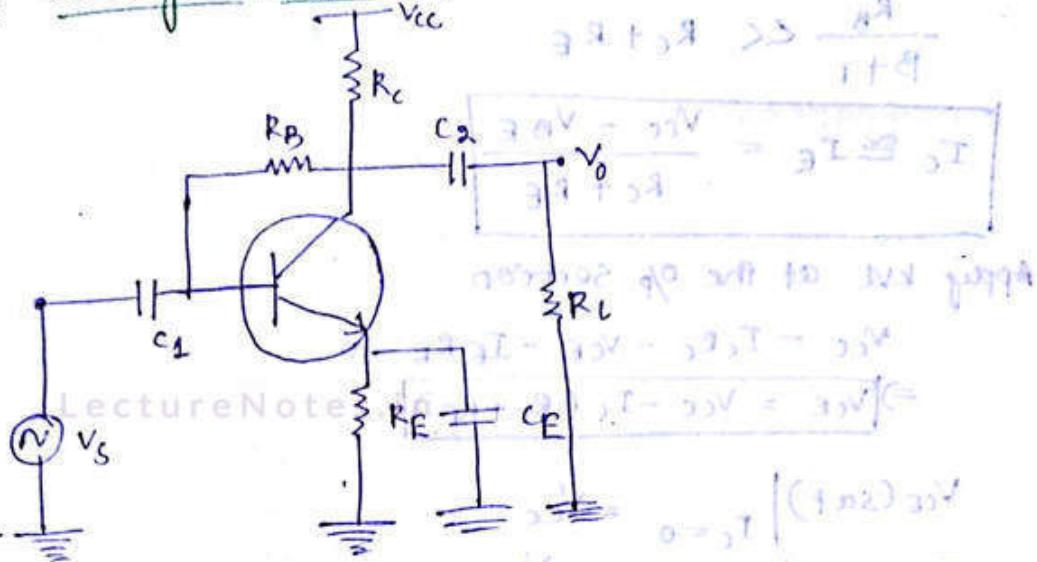
$$I_B = \frac{V_{th} - V_{BE}}{R_{th} + (\beta + 1)R_E} = \frac{2 - 0.7}{3.54 + 141 \times 1.5} = 6.045mA$$

$$I_C = \frac{V_{th} - V_{BE}}{R_E} = \frac{2 - 0.7}{1.5} = 0.86$$

$$V_{IE} = V_{CC} - I_E (R_C + R_E)$$

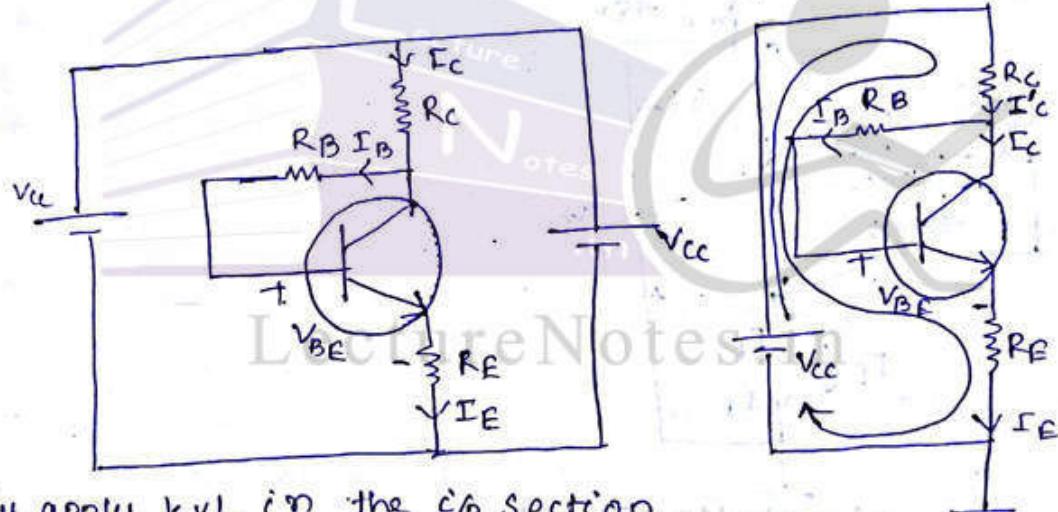
$$= 12.11V$$

DC bias voltage feedback:



DC analysis:

o/p section:



By applying KVL in the o/p section.

$$V_{CC} - I'_C R_C - I_B R_B - V_{BE} - I_E R_E = 0$$

$$\Rightarrow V_{CC} - I_C R_C - I_B R_B - V_{BE} - I_E R_E = 0 \quad (\because I'_C \approx I_C \approx I_E)$$

$$\Rightarrow V_{CC} - I_E R_C - I_B R_B - V_{BE} - I_E R_E = 0 \quad (\because I_C \approx I_E)$$

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

$$\Rightarrow V_{CC} - V_{BE} = I_E (R_C + R_E) + I_B R_B$$

$$= (\beta + 1) I_B (R_C + R_E) + I_B R_B \quad (\because I_E = (\beta + 1) I_B)$$

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

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

$$\frac{R_B}{\beta + 1} \ll R_C + R_E$$

$$I_C \approx I_E = \frac{V_{CC} - V_{BE}}{R_C + R_E}$$

Apply KVL at the op section

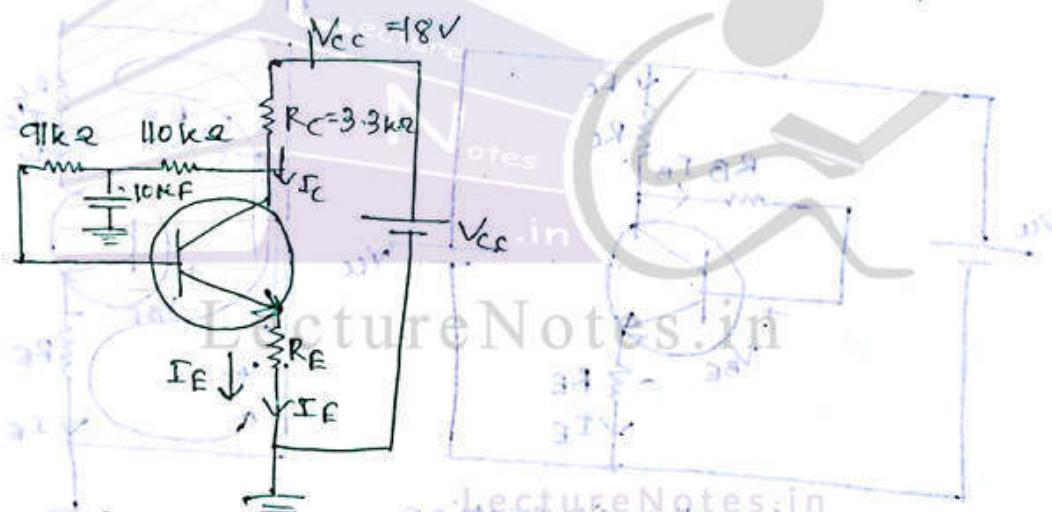
$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

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

$$V_{CE(\text{sat})} \Big|_{I_C = 0} = V_{CC}$$

$$I_C(\text{sat}) \Big|_{V_{CE} = 0} = \frac{V_{CC}}{R_C + R_E}$$

A.



$$I_C, I_B, I_F = ?$$

$$V_{CE} = ?$$

Biasing with two supply voltage:

