Bipolar Junction Transistor

- Developed by William Schockley
- which can amplify electronic signal.

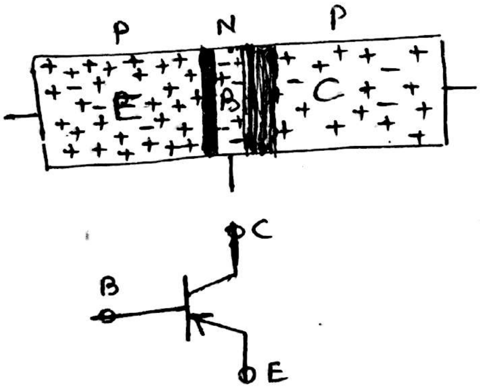
Bipolar ← b/c current conduction is responsible by two types of charge carriers (Both Electron & Hole)

- The Device has <u>three Terminal</u>
  - Emitter (heavily Doped)
  - Base (Very lightly Doped)
  - Collector (Lightly Doped) or Moderately Doped

- It has <u>two P-N Junctions</u>
  - Base Emitter Junction
  - Collector Base Junction

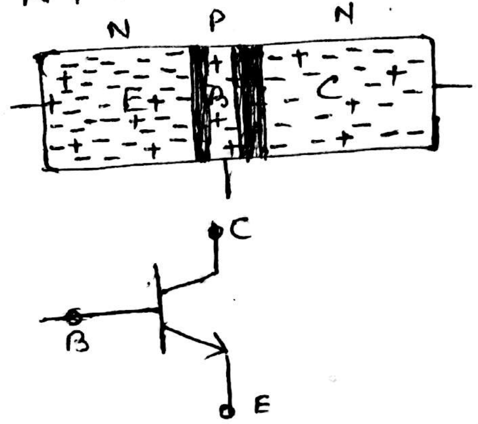
BJT

PNP



(Symbol)

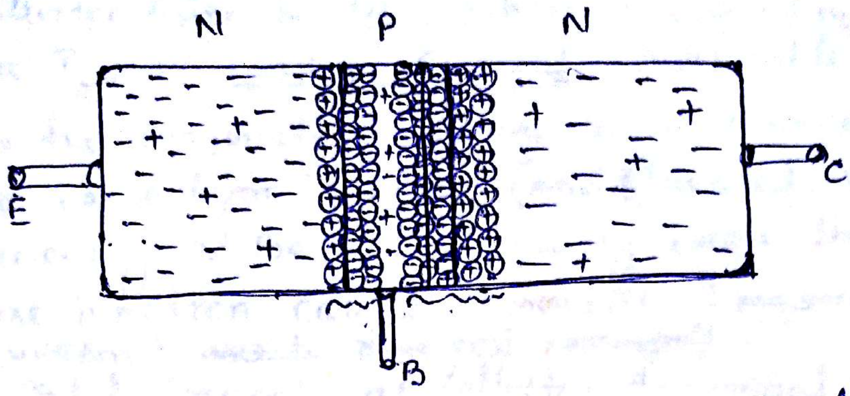
NPN



(Symbol)

- The arrowhead at emitter shows the current directions of the device.

Unbiased Transistor



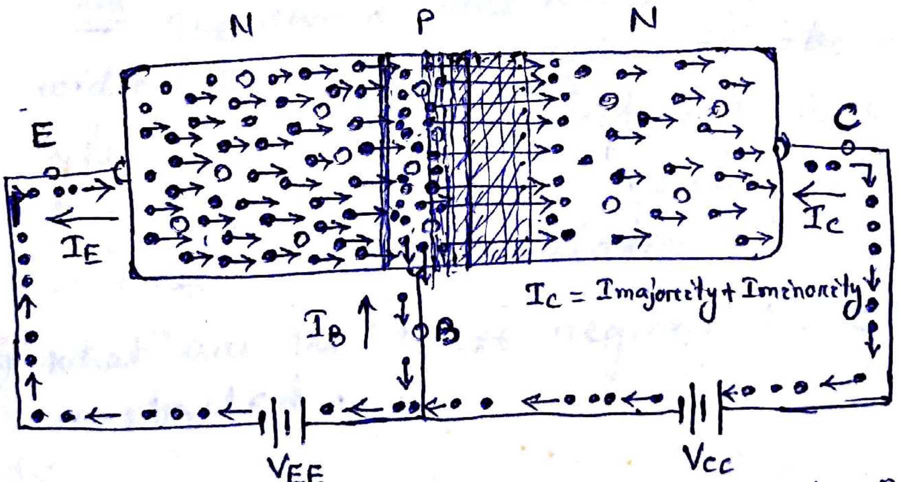
- The depletion region penetrates more deeply into the lightly doped side.
- Collector is less doped as emitter so the depletion width is higher at collector Base junction than emitter base junction.

Transistor Operation

	Base Emitter Junction	Collector Base Junction
Active —	Forward Biased	Reverse Biased
Cutoff —	Reverse Biased	Reverse Biased
Saturation —	Forward Biased	Forward Biased

Active Operation

- Base Emitter is Forward Biased
- Collector Base is Reversed Biased.



- The majority carriers flow from emitter to Base through the Base Emitter junction (Forward Biased)
- Some of the majority carriers flow through the Base causes Base current (I_B). others are treated as minority carriers at Base.
- The Collector Base junction is increased due to Reverse Bias and there will be no flow of majority Carrier.

- The minority carriers of the Base will flow the collector Base junction, which causes $I_{minority}$ or I_{CO} or <u>Leakage Current</u>. (Undesireable)
- And the majority carriers from emitter who are came from emitter (and treated as minority at Base) can easily cross the collector base junction caused current $I_{majority}$ (The desired current) ~~due to injected carrier~~.
- So Total Current at Collector terminal is

$$I_C = I_{majority} + I_{minority}.$$

- Finally the fundamental current relation is

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

(Q) In a transistor emitter current is 1.02 times larger from collector current. If $I_E = 12mA$ then find Base current.

(Q) Draw the schematic of an NPN transistor indicating various current components and explain how each one of them arises.

(Q) What do you mean by Early Effect or Base Width Modulation.

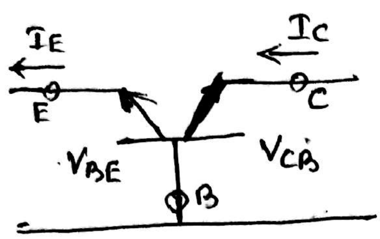
<u>Ans</u> The reverse bias voltage increases, the width of depletion region is also increases. which reduces the electrical Base Width, this effect is called "Early Effect" or "Base Width Modulation".

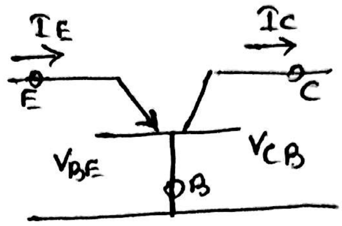
(Q) What are the three regions, the BJT constructed.

Transistor Configuration

- Common Base (CB)
- Common Emitter (CE)
- Common Collector (CC)

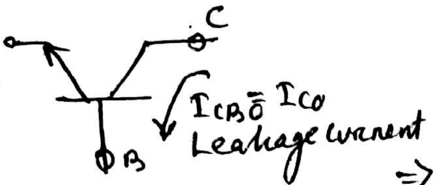
Common Base →





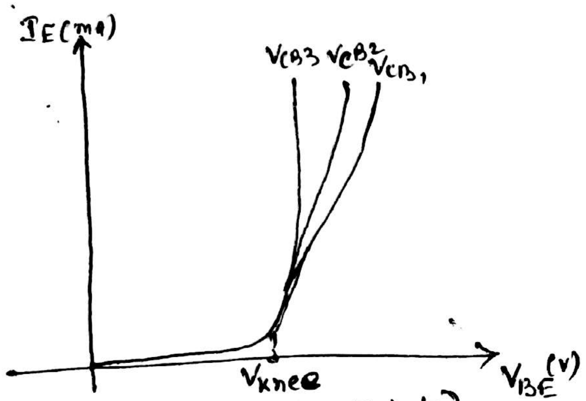
The Current Amplification factor $\boxed{\alpha = \frac{I_C}{I_E}}$

when $I_E = 0$

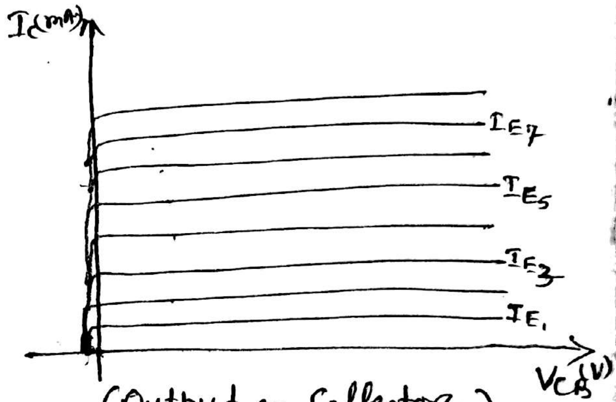


$$\Rightarrow \alpha = \frac{I_C - I_{CBO}}{I_E}$$

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

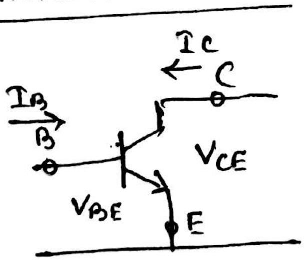


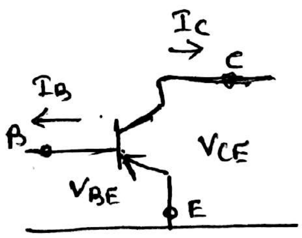
(Input or Driving Point characteristic)



(Output or Collector characteristic.)

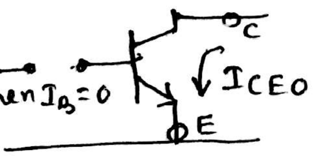
Common Emitter →



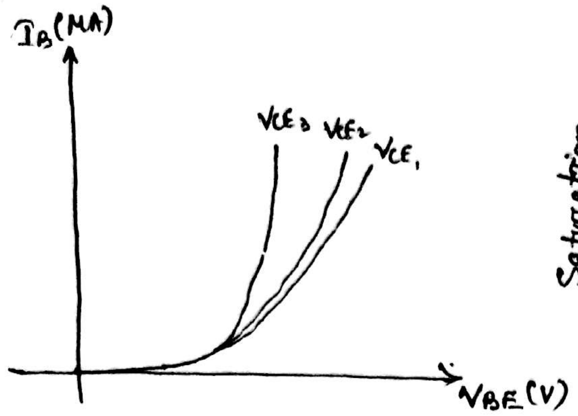


The Current Amplification factor $\boxed{\beta = \frac{I_C}{I_B}}$

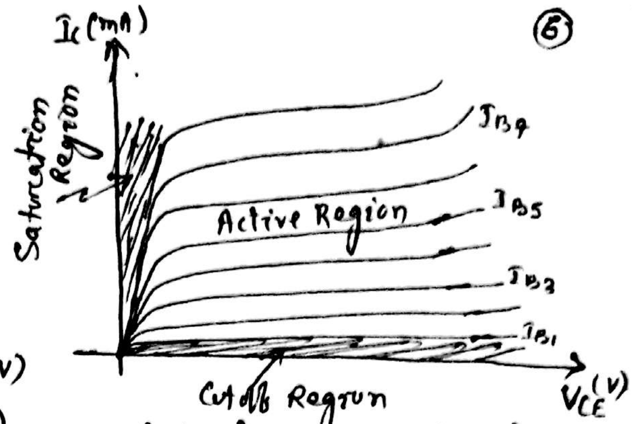
when $I_B = 0$



$\boxed{I_{CEO} = \frac{I_{CBO}}{1-\alpha}}$ with $I_B = 0\mu A$

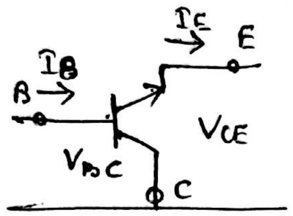


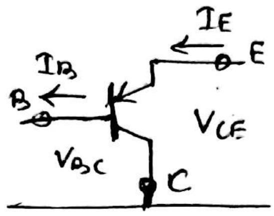
(Input or Base Characteristic)



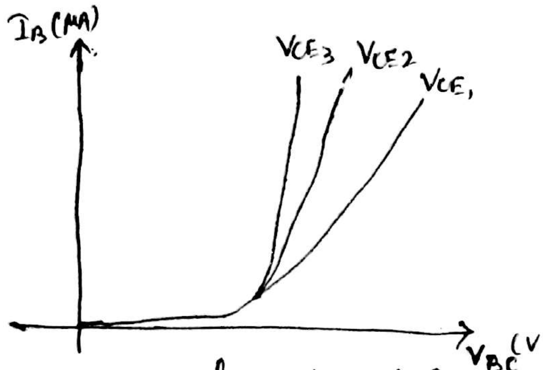
(o/p characteristics) of CE config.

Common Collectore →

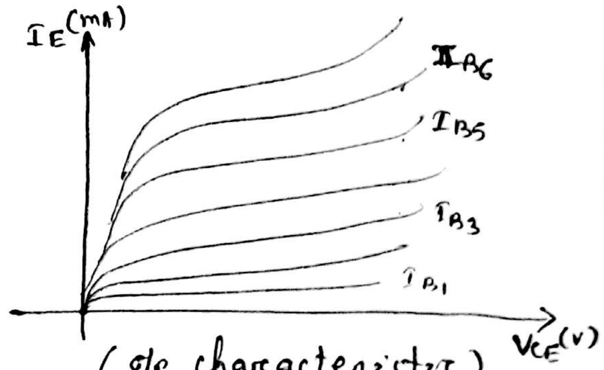




The current amplification factor $\boxed{\gamma = \frac{I_E}{I_B}}$



(I/p characteristic)



(o/p characteristic)

Current Relations

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

$$\Rightarrow I_C - I_{CBO} = \alpha I_E$$

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

$$\Rightarrow I_C\left[\frac{1}{\alpha} - 1\right] = I_B + \frac{I_{CBO}}{\alpha}$$

$$\Rightarrow I_C = \left(\frac{\alpha}{1-\alpha}\right) \cdot I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO}$$

$$\Rightarrow I_C = \beta I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO} \quad \left[\because \beta = \frac{\alpha}{1-\alpha}\right]$$

$$\Rightarrow \boxed{I_C = \beta I_B + (1+\beta) I_{CBO}} \quad \left[\because 1 + \frac{\alpha}{1-\alpha} = \frac{1}{1-\alpha}\right]$$

This term is Reverse Leakage current in CE config. $\boxed{I_{CEO} = (1+\beta) I_{CBO}}$

(Q) Prove . $\alpha = \frac{\beta}{\beta+1}$

Ans We know $I_E = I_B + I_C$

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

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

$$\Rightarrow \frac{I_C}{\alpha} = \frac{I_C}{\beta} + I_C$$

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

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

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

(Q) Prove (a) $\beta = \frac{\alpha}{1-\alpha}$.

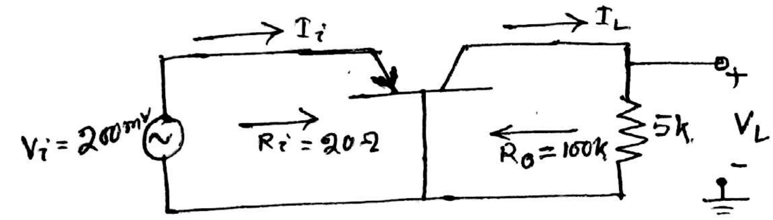
(b) $I_E = (1+\beta) I_B$

(c) $\frac{1}{1-\alpha} = \beta + 1$

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

Transistor Amplifying Action

In a CB configuration



Here $I_i = \frac{V_i}{R_i} = \frac{200mV}{20\Omega} = 10mA$

As it is a CB config., assuming $\alpha = 1$ (by $I_C \cong I_E$)

$$I_L = I_i = 10mA$$

So $V_L = I_L R$

$\cong (10mA)\, 5k\Omega = 50V$

So voltage Gain $= A_V = \frac{V_L}{V_i} = \frac{50V}{200mV} = 250$

*** So the Basic amplifying is —

Low Resistance $\Rightarrow$ High Resistance ← Amplifying

Transferring the Current

✓ Transfer + Resistor = Transistor

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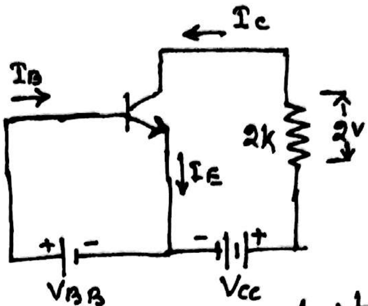
(Q) For a transistor $\beta = 100$ and voltage drop across R_C ($2k\Omega$) is 2 volts. Find the Base current for given ckt.

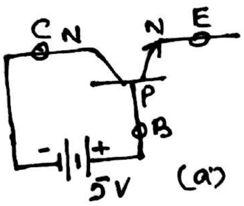


Ans

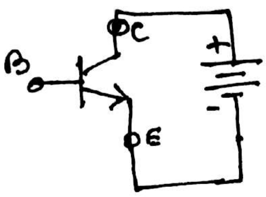
$$I_C = \frac{V_{RC}}{R_C} = \frac{2V}{2k\Omega} = 1mA$$

$$I_B = \frac{I_C}{\beta} = \frac{1mA}{100} = 10\mu A$$

(Q) An npn transistor has its emitter open and it collector current at room temperature is $0.2\mu A$ as shown in fig (a). For the same transistor its base is kept open its collector current at room temperature is $20\mu A$ as show in fig (b). Find α, I_E and I_B when collector current is 2mA.



(a)



(b)

Ans In fig (a) The current $I_C = I_{CBO} = 0.2\mu A$

In fig (b) ~~The current I_C~~ with Base open, $I_{CEO} = 20\mu A$

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha}$$

$$\Rightarrow 20\mu A = \frac{0.2\mu A}{1-\alpha} \Rightarrow \boxed{\alpha = 0.99}$$

Here $I_C = 2mA$

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

$$\Rightarrow 2mA = 0.99\, I_E + 0.2\mu A$$

$$\Rightarrow I_E = \frac{2*10^{3} - 0.2*10^{-6}A}{0.99}$$

$$\Rightarrow \boxed{I_E = 2.02mA}$$

$$I_B = I_E - I_C$$

$$= 2.02mA - 2mA$$

$$\Rightarrow \boxed{I_B = 20\mu A}$$

(Q) Sketch the o/p characteristic of NPN Bipolar Junction transistor in common emitter configuration. Indicate Active, Cutoff & Saturation Region.

Analysis or Design of BJT Amplifier

- DC Analysis
- AC Analysis

DC Biasing

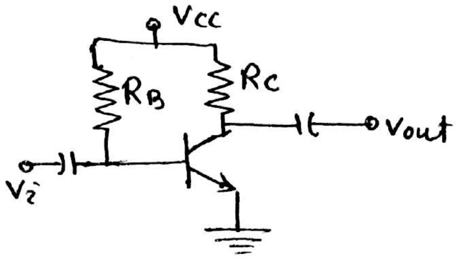
When a network is designed using BJT 1st it is desired to achieve a fixed level of dc-current & voltages at BJT.

- dc-current
  - I_C
  - I_B
  - I_E
- voltages
  - V_{BE}
  - V_{CE}
  - V_{CB}

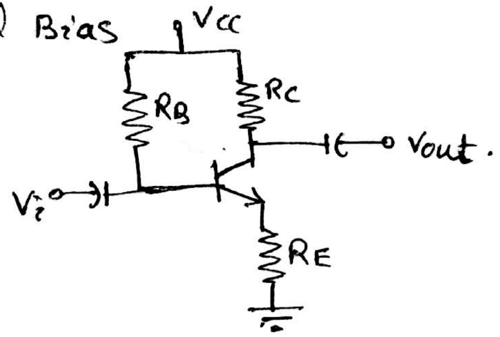
To achieve a fixed level of dc current & voltage different network with different dc supply provided to BJT known as Biasing.

Biased Networks

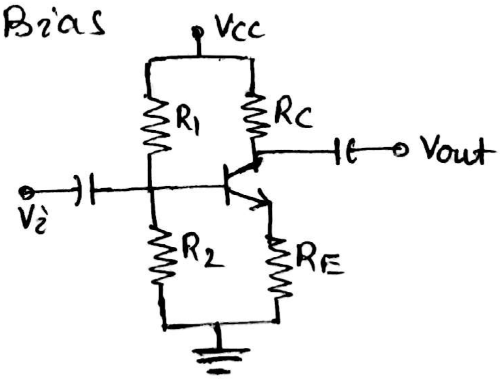
① Fixed Bias



② Emitter Stabilized Bias



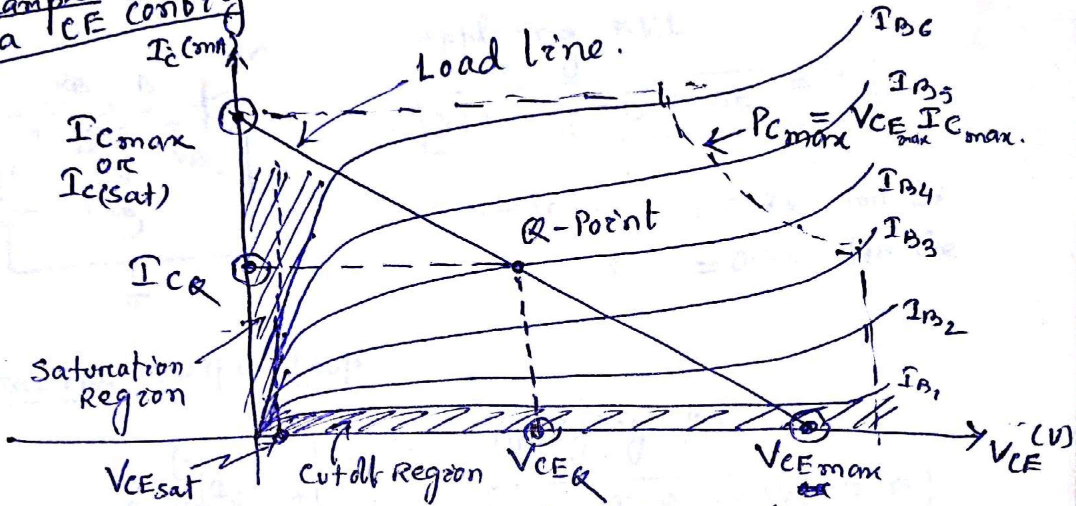
③ Voltage Divider Bias



Operating Point or Bias Point or Q-Point or Quiescent Point

- It is the intersection point of load line and o/p characteristic curve on o/p characteristic.
- Load line is a line between max current & maximum voltage of a given network. ($V_{CE\,max}$ & $I_{C\,max}$)
- The Q-Point indicates the dc current(I_{CQ}) & dc voltage (V_{CEQ}) achieved by a particular network with a particular biased circuit.

As example in a CE config



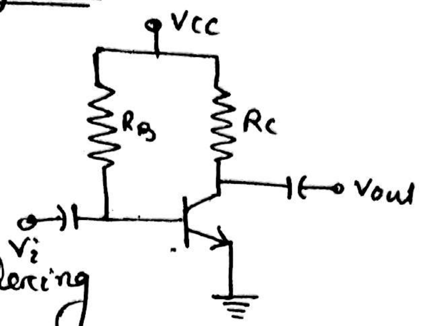
Let a CE configuration network gives
maximum o/p or collector current = $I_{C(sat)}$
maximum o/p or Collector to Emitter Voltage = $V_{CE\,max}$
& for the particular network the Base Current is $I_B = I_{B4}$
∴ So the Q-Point will be as shown in figure.

The intersection Point = (V_{CEQ}, I_{CQ})
or Bias Point

Note The operating point is changed if the biasing of the network is changed.

Fixed Biased Circuit Analysis

- When we go for dc analysis the capacitor will be treated as open ckt.

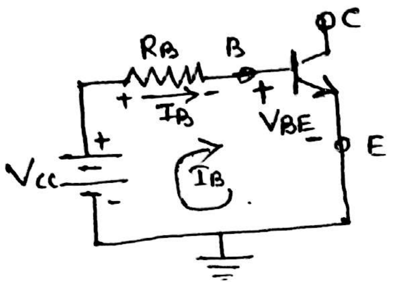


(Fixed Biased ckt)

- Analysis performed by considering two Loops.

Base Emitter loop or Input Loop — Collector Emitter loop or Output Loop.

Redrawing Input loop



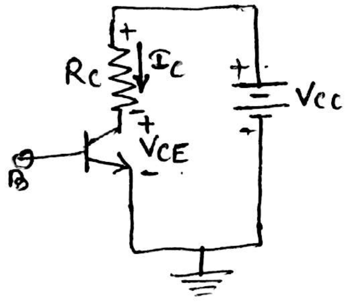
Applying KVL

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

Here $V_{BE} = 0.7V$ for Si

$\quad\quad\;\; = 0.3V$ for Ge

Redrawing Output Loop



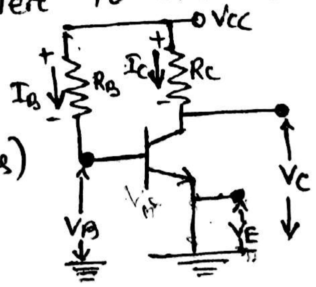
Applying KVL

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

V_B = It is the voltage from Base to Ground.

V_C = It is the voltage from Collector to Ground.

V_E = It is the voltage from Emitter to Ground.



$V_{CE} = V_C - V_E$

$\Rightarrow \boxed{V_{CE} = V_C}$ $\quad \because (V_E = 0$ in fixed Bias$)$

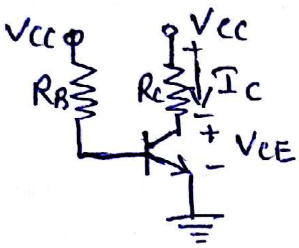
$V_{BE} = V_B - V_E$

$\Rightarrow \boxed{V_{BE} = V_B}$ $\quad (\because V_E = 0$ in fixed Bias$)$

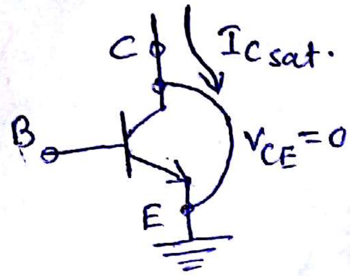
Transistor At Saturation

- Saturation indicates maximum.
- So for a particular design if ~~the~~ maximum current & maximum voltage appear at Transistor then called as transistor is at saturation.

In a fixed biased ckt.



if $V_{CE} = 0$ then the I_C is called $I_{C\,sat}$ or $I_{C\,max}$



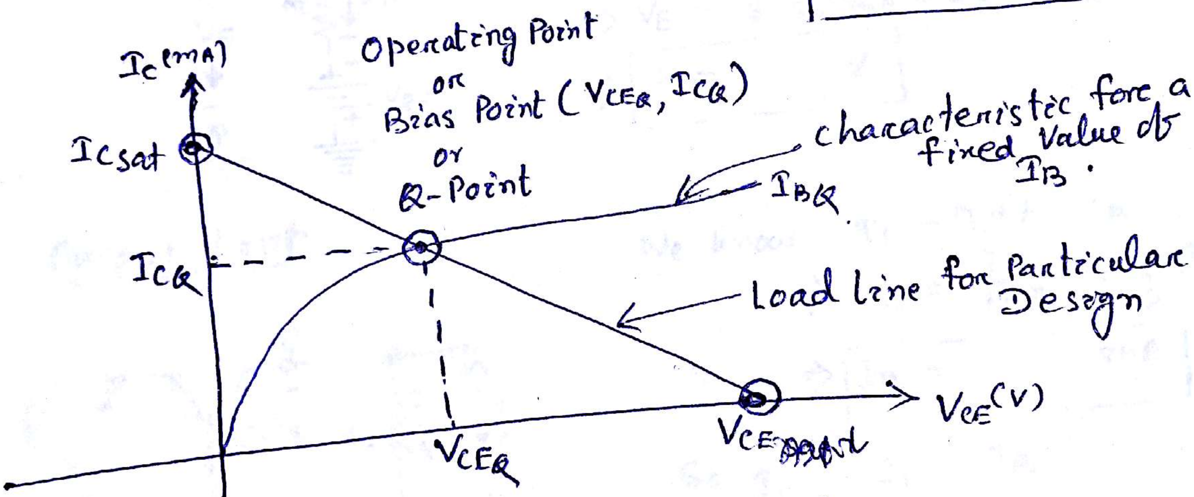
O/P loop → $V_{CC} - I_C R_C - V_{CE} = 0$

If $V_{CE} = 0$

then $\boxed{I_{C\,sat} = \frac{V_{CC}}{R_C}}$

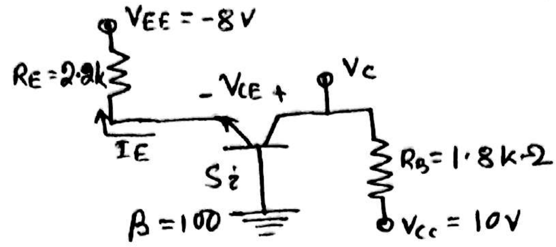
If $I_C = 0$

then $\boxed{V_{CE\,max} = V_{CC}}$



<u>Note</u> So Q-Point indicates the operating -
Collector Current I_{CQ}
Base Current I_{BQ}
Collector Emitter Voltage V_{CEQ}.

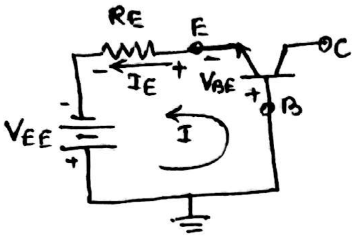
(8) For the ckt. shown, determine I_E, V_C, V_E, I_B, V_{CB}, I_C.



Ans

Input Loop

Assuming $V_{BE} = 0.7V$

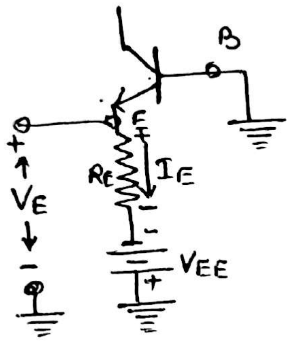


Applying KVL

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

$$\Rightarrow I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{8V - 0.7V}{2.2k}$$

$$\Rightarrow \boxed{I_E = 3.3182\ mA}$$

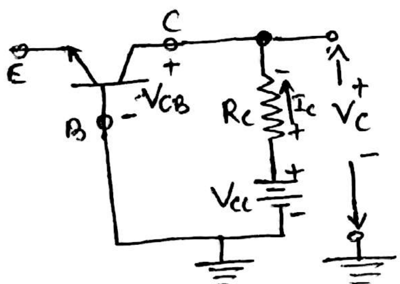


$$V_E - I_E R_E + V_{EE} = 0$$

$$\Rightarrow V_E = 3.3182mA * 2.2k\Omega + 8V$$

$$\Rightarrow \boxed{V_E = \quad V}$$

Output Loop



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

$$\Rightarrow I_B = \frac{I_E}{1+\beta} = \frac{3.3182mA}{101}$$

$$\Rightarrow \boxed{I_B = \quad mA}$$

So $I_C = I_E - I_B$

$$\Rightarrow I_C = 3.3182mA - \quad mA$$

$$\Rightarrow \boxed{I_C = \quad mA}$$

Applying KVL

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

$$\Rightarrow V_{CB} = V_{CC} - I_C R_C = 10V - \quad mA * 1.8k\Omega$$

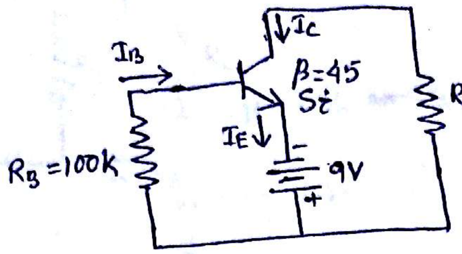
$$\Rightarrow \boxed{V_{CB} = \quad V}$$

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

$$\Rightarrow V_C = V_{CC} - I_C R_C = 10V - \quad mA * 1.8k\Omega$$

$$\Rightarrow \boxed{V_C = \quad V}$$

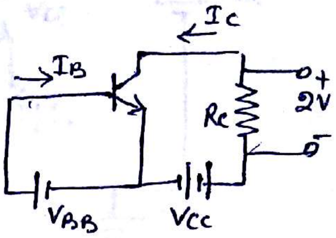
(Q.) Calculate I_B, I_C, I_E & V_{CE}



(Q) What do you understand by Q-Point? What is its significance?

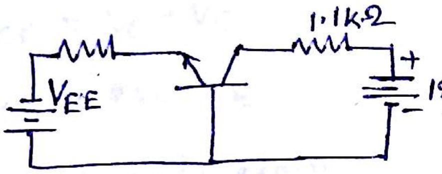
(Q) Why Biasing is neccessary in BJT amplifier?

(Q) For a transistor $h_{FE} = 100$. and voltage drop across R_C is 2 Volts. Find the Base current.

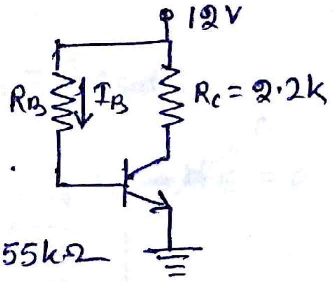


(Q) What is α_{dc} & β_{dc} of a transistor. For a transistor the base current is 100 μA and collector current is 2.9 μA. Find α_{dc} & β_{dc}.

(Q) In the ckt Find I_C when $V_{CB} = 8V$ and V_{CB} when $I_C = 2mA$.



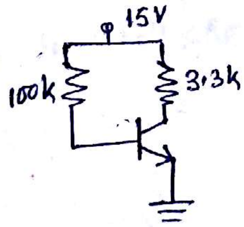
Ans = $I_C = 3.636mA$
& $V_{CB} = 9.8V$



(Q) For the transistor the $\beta_{dc} = 120$ Calculate the value of R_B that will just saturate the transistor. Assume $V_{CE_{sat}} = 0.3V$

Ans $R_B = 255k\Omega$

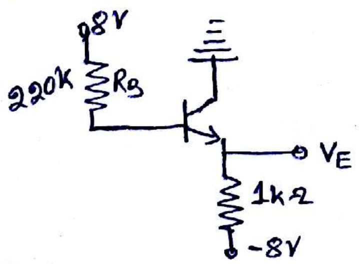
(Q)



(a) Find V_{CE} when $I_C = 1mA$.
(b) Find I_C when $V_{CE} = 10V$
(c) Find V_{CE} when $I_C = 0$

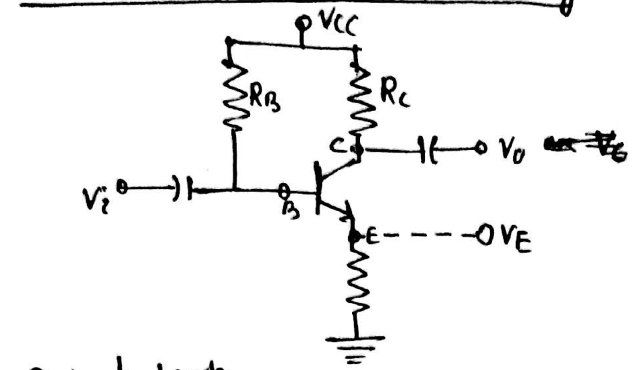
Ans $V_{CE} = 11.7V$
$I_C = 1.5mA$
$V_{CE} = 15V$

(Q) Determine I_E, V_E & V_{CE} for the give ckt.

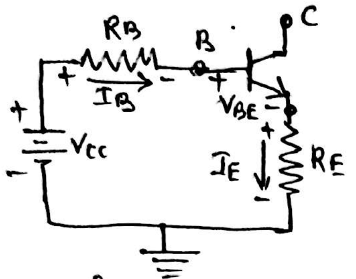


Ans
$I_E = 4.81mA$
$V_E = -3.186V$
$V_{CE} = 3.186V$

Emitter Stabilized Biasing



Input loop



Applying KVL

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

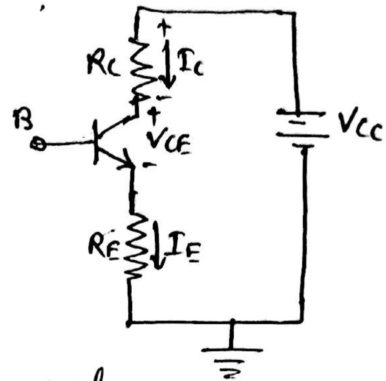
$$\Rightarrow V_{CC} - I_B R_B - V_{BE} - (1+\beta) I_B R_E = 0$$

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

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

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

O/p loop



Applying KVL

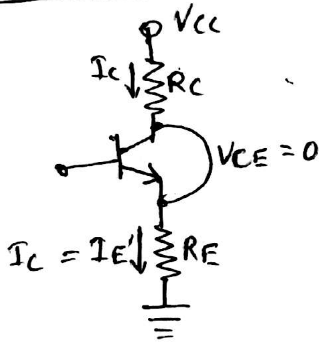
$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

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

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

$$\left[\because \begin{array}{l} V_E = I_E R_E \\ V_C = V_{CC} - I_C R_C \end{array} \right]$$

At Saturation



Here

$$I_C = I_E = I_{C\,max} = I_{C\,sat}$$

Put $V_{CE} = 0$

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

$$\Rightarrow \boxed{I_{C\,sat} = \frac{V_{CC}}{R_C + R_E}}$$

Put $I_C = 0$

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

$$\Rightarrow \boxed{V_{CE\,sat} = V_{CC}}$$