UNIT- III

Bipolar Junction Transistor

→ Bipolar junction transistor (BJT) is a 3 terminal semiconductor device, in which the conduction depends on both majority & minority carriers. Hence it is named as "bipolar"

→ BJT consists of '2' junctions & 3 regions.

→ The 3 regions of BJT are named as Emitter (E), Base (B), & collector (C).

⇒ Emitter: It is outer region of BJT. It's functioning is to inject charge carriers into Base region.
  → It is heavily doped.
  → It has moderate area of region.

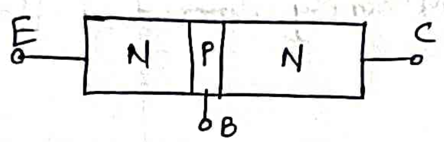
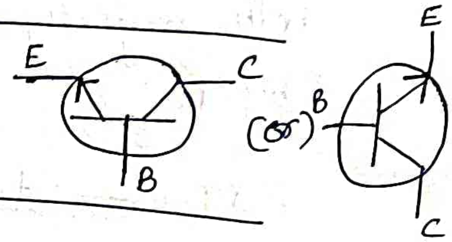
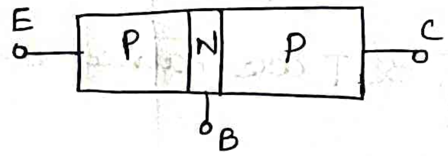
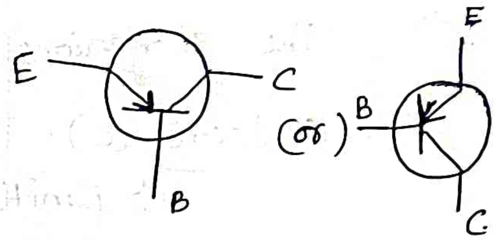
⇒ Base : It is in b/w emitter & collector regions of BJT.
  → It's functioning is to pass all the charge carriers into Collector region.
  → It is lightely doped.
  → It has thin area of region.

⇒ Collector: It is outer region of BJT. It's functioning is to collect charge carriers.
  → It is moderately doped.
  → It has large area of region.

	doping	size of area
E	heavily	moderate
B	lightely	low
C	moderately	high

→ BJT's are of two types

1. NPN Transistor
2. PNP Transistor.

	Constructional model	symbol
NPN Transistor		
PNP Transistor		

*→ Arrow mark on the emitter terminal indicates the "direction" of current.

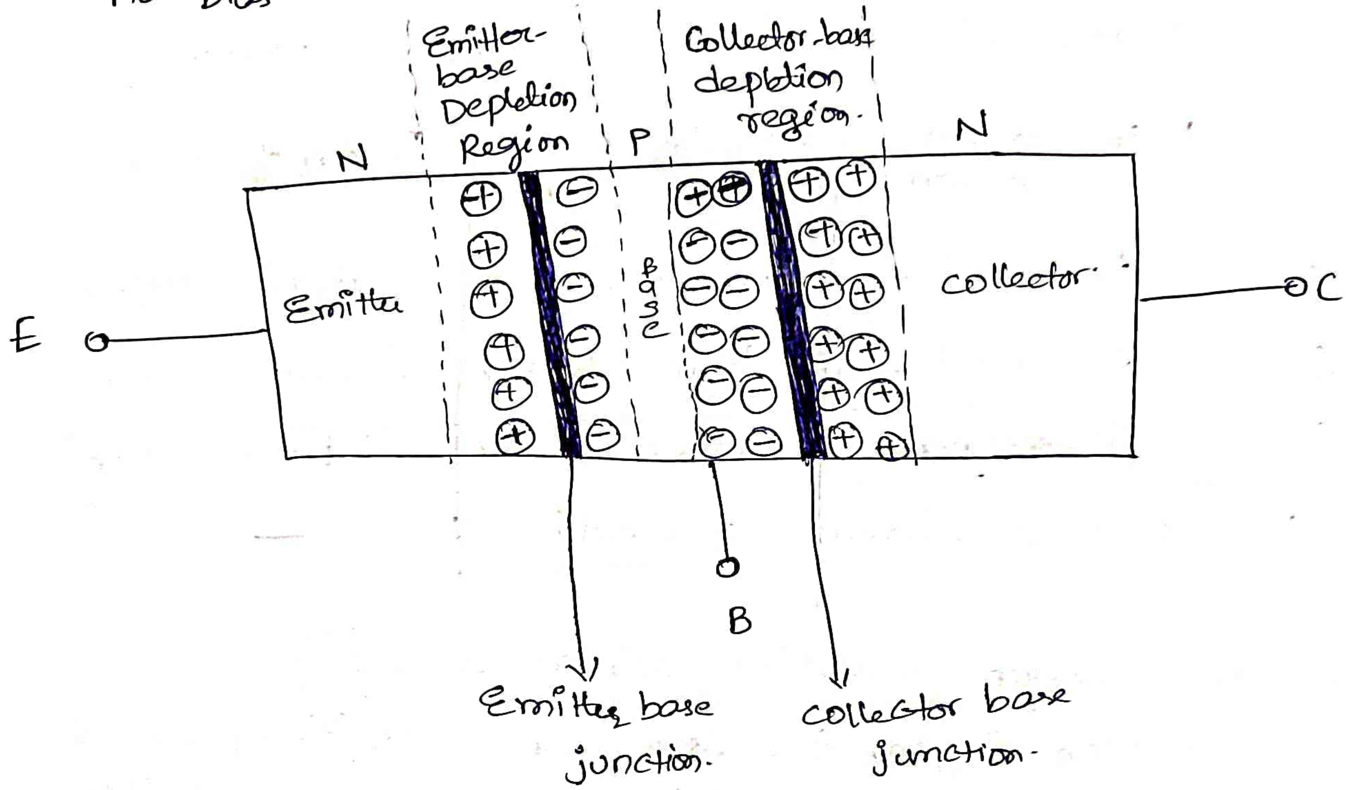
→ Among NPN & PNP transistors, NPN-transistor is widely used, as current conduction in NPN-transistor is mainely due to electrons. Hence conduction is higher in NPN than in PNP transistor,

*→ There are two junctions in BJT, named as
   i) Emitter-base junction.
   ii) collector-base junction.

*→ BJT is "Current controlled" device.

Principle of operation of Transistor:-

(1) Transistor with No bias: Consider NPN transistor with no bias



→ When no external DC is applied, then transistor is said to be unbiased.

→ In unbiased state, due to diffusion of charge carriers across 2 junctions, two depletion regions are formed.

→ width of depletion region across emitter base junction is smaller than the width of depletion region across collector base junction. This is due to heavely doped emitter region.

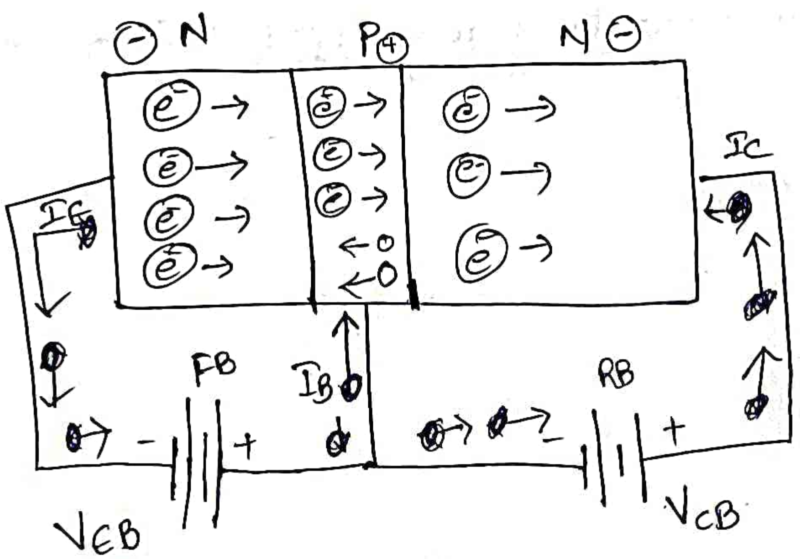
(2) Transistor with 'biasing' :- As there are '2' junctions in transistor, each of these two may be either forward (or) reverse biased. There are 4 possible ways of biasing these two junctions, which are called as "modes of operation of transistor"

mode	Emitter base junction	collector - base junction	Region of operation
1	forward biased	Reverse biased	Active region
2	forward biased	forward biased	Saturation region
3	Reverse biased	Reverse biased	Cut-off region
4	reverse biased	forward biased	—

→ In active Region, transistor acts as an amplifier.
→ In Saturation Region, transistor acts as ON/closed switch.
→ In Cut-off region, transistor acts as OFF/open switch.

Case (1) : operation of NPN Transistor (or) Biasing of NPN Transistor :

Consider a NPN transistor which is biased to operate in active region i.e i) Emitter base junction is forward biased &
ii) collector base junction is reverse biased.



→ As emitter- base junction is forward biased, lot of electrons are injected by emitter into base region. And few holes from base region move into emitter region.

→ This flow of $\bar{e}$s & holes generate emitter current I_E.

→ As base is lightely doped. no: of majority carriers i.e holes in base region are very small.

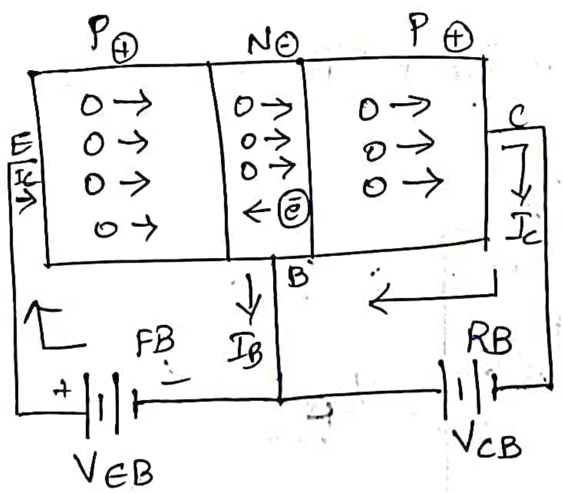
→ Hence a few electrons from emitter combine with holes to constitute a base current I_B.

→ The remaining electrons crosses into collector region to constitute collector current I_C.

→ Thus, base and collector current summed up to give emitter current I_E: $\boxed{I_E = I_B + I_C}$

Case(2) : operation of PNP Transistor(or) Biasing of PNP Transistor

→ Consider a PNP transistor which is biased to operate in active region i.e
i) emitter- base junction is forward biased &
ii) collector - base junction is reverse biased.



→ As emitter - base junction is FB, lot of holes are injected by emitter into base region. And few $\bar{e}$s from base region move into emitter region.

→ This flow of $\bar{e}$s & holes generate emitter current I_E.

→ As base is lightely doped, no: of majority carriers i.e $\bar{e}$s in base region are very small.

→ Hence few holes from emitter combine with $\bar{e}$s to form base current I_B.

→ The remaining holes crosses into collector region to constitute collector current I_C.

→ $\boxed{I_E = I_B + I_C}$

Transistor Configurations:

When BJT is connected in a circuit,

→ one terminal is used as i/p terminal

→ one terminal " " " o/p terminal.

→ one terminal is common to input & output.

→ Based on the name of common terminal used, transistor can be connected in 3 ~~sections~~ configurations, such as

1. Common base configuration (CB configuration)
2. Common Emitter configuration (CE configuration)
3. Common collector configuration (CC configuration)

Common Base Configuration:

In a CB configuration,

→ Emitter is input terminal

→ collector is output terminal

→ Base is common terminal for i/p & o/p.

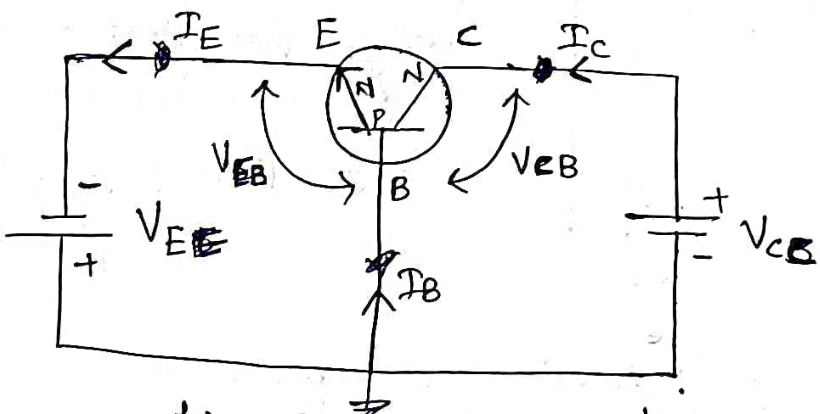
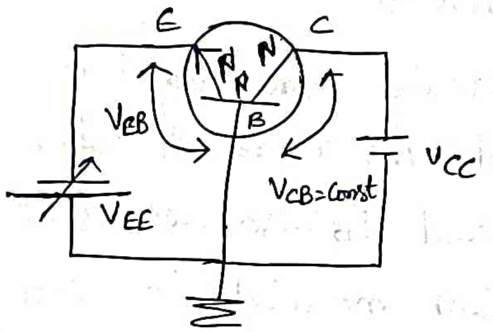


fig: Common base Configuration.

→ Behaviour of the transistor is analyzed with the help of input and output characteristics.

Input characteristics :- Input characteristics for CB configuration is "the relation b/w I/P current I_E and I/P voltage V_{EB} by maintaining output voltage V_{CB} at constant level".



→ To study I/P characteristics

Step 1 : V_{CB} is kept constant.

Step 2 : By varying supply voltage V_{EE}, note values of V_{BE} & I_E.

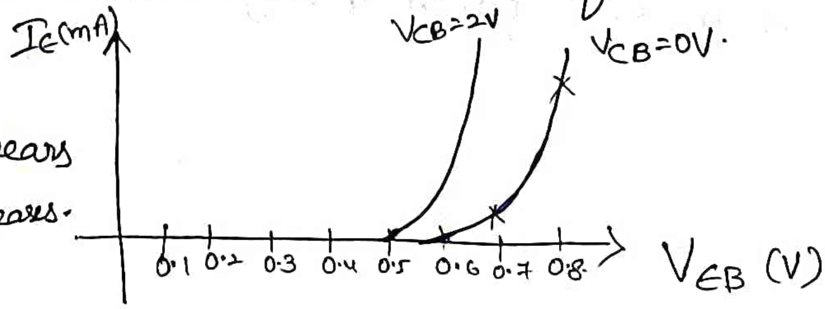
Step 3 : Repeat the steps ① & ② different constant values of V_{CB}.

(1) if $V_{CB}=0$: As Emitter-base junction is forward biased, by varying V_{EE} by small amount, there will be large current variation (indirectly V_{EB}) after cut-in voltage.

(2) if $V_{CB}=2V$: As collector-base junction is reverse biased, V_{CB} is negative voltage. As negative voltage is increased from $V_{CB}=0$ to $V_{CB}=2V$, width of depletion region increases across J_{CB}. As base region is lightly doped, depletion region penetrates more into base region, as a result I_B decreases.

→ If I_B decreases then I_C increases, if I_C increases then I_E increases.

→ hence curve appears to left, if V_{CB} increases.

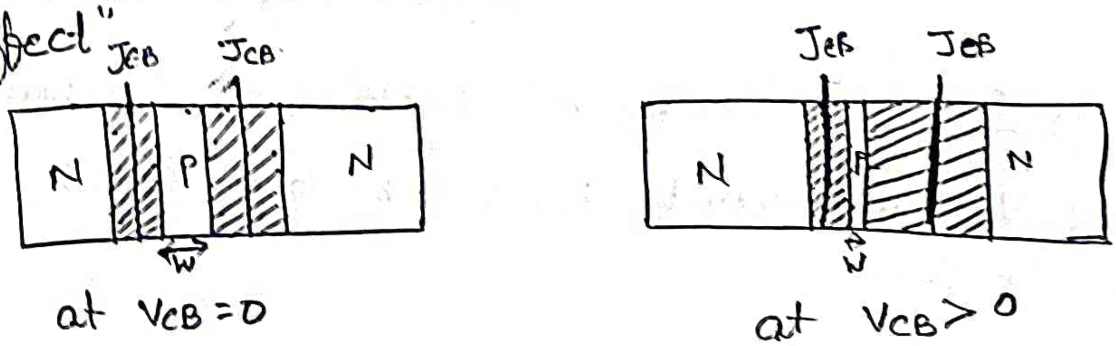


Base width modulation (or) Early Effect

→ When reverse biased voltage is increased from its zero level in BJT, then the width of the depletion region increases.

→ In case of CB-configuration, if V_{CB} is increased then depletion region across J_{CB} increases.

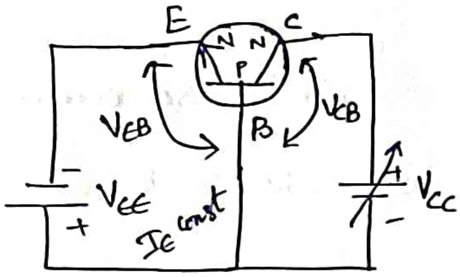
→ Increased depletion region penetrates more into base region as base is lightely doped. As a result width of the base region decreases, and I_B also decreases. This effect is called " based width modulation" (or) "early effect"



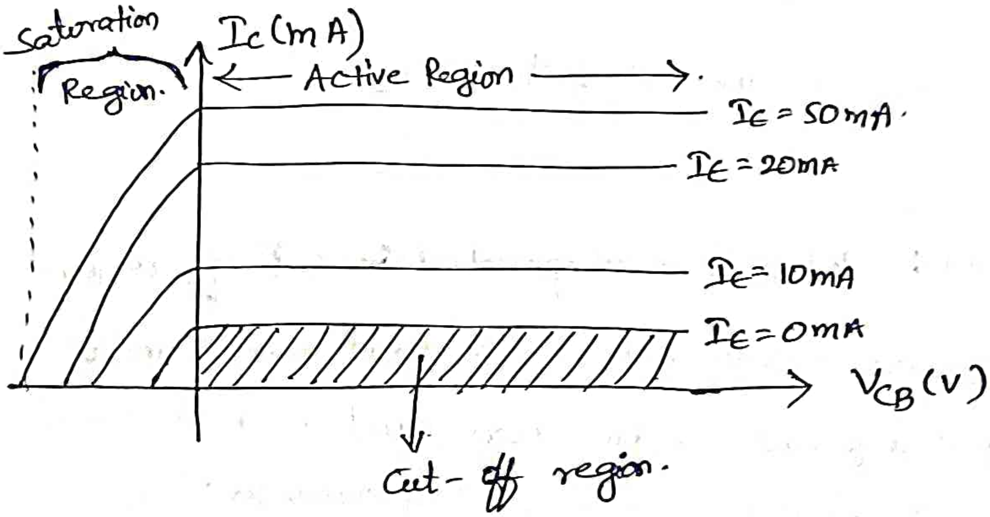
Punch through (or) Reach through effect

→ In case of CB-configuration if the reverse biased voltage is further increased, the base width keep on decreasing. At one reverse voltage value, the base will be disappeared. Then there exists only emitter, collector side by side, so that transistor is said to be damaged. This effect is known as " punch through (or) reach through effect".

Output Characteristics : output characteristics represents the graphical relation b/w output voltage & output current at constant input current.



→ In case of CB-configuration, O/P characteristics represents the graphical relation b/w V_{CB} & I_C at constant I_E.



→ O/P characteristics are explained in following regions.

① **Saturation Region** : The region in which output current (I_C) varies w.r.t O/P voltage (V_{CB}) is said to be saturation region. When both J_{EB} & J_{CB} junctions are forward biased then transistor operates in saturation Region.

② **Active Region** : The Region in which O/P current (I_C) is constant i.e independent of O/P voltage (V_{CB}) is said to be active region. When J_{EB} is forward biased & J_{CB} is reverse biased then transistor can operate in active region.

③ **Cut-off Region** : The Region under $I_E = 0mA$ is said to be cut-off region.

→ **Current gain:** The ratio of o/p current to i/p current is called as current gain.

*→ In case of CB configuration, current gain is also known as current amplification factor. And is reprented with α.

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

→ α lies in b/w 0.9 to 0.995

→ **Leakage current:** When BJT is operated in cut-off region, both J_{EB} & J_{CB} are reverse biased. so there is no current due to majority charge carriers. But there exist a small amount of current due to minority carriers, which is known as "leackage current".

→ In case of CB configuration it is represented with I_{CO}.

→ I_{CO} is in the range of μA (or) nA.

Case(1):

$$I_C = \alpha I_E + I_{CO} \rightarrow (1)$$

$$\alpha I_E = I_C - I_{CO}$$

$$\alpha = \frac{I_C - I_{CO}}{I_E} = \frac{I_C - I_{CO}}{I_B + I_C}.$$

Case(2):

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

$$I_C - \alpha I_C = \alpha I_B + I_{CO}$$

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

$$\boxed{I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CO}}{1-\alpha}.}$$

sub $I_E = I_B + I_C$ in (1)

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

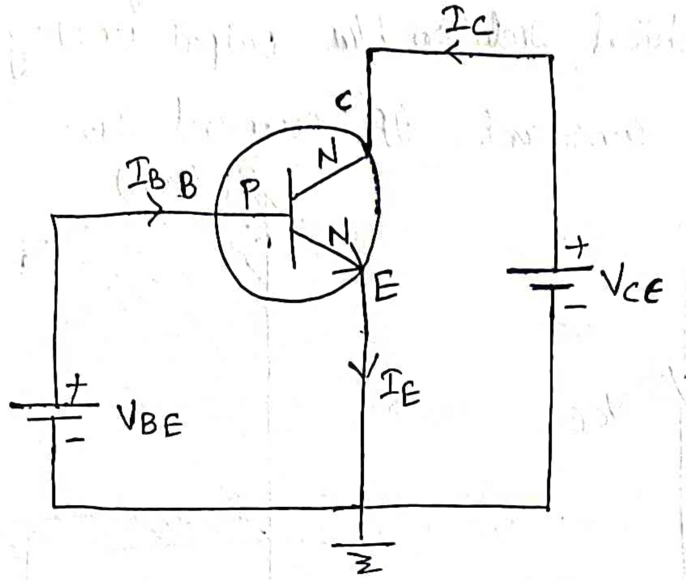
$$I_C - \alpha I_C = \alpha I_B + I_{CO}$$

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

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

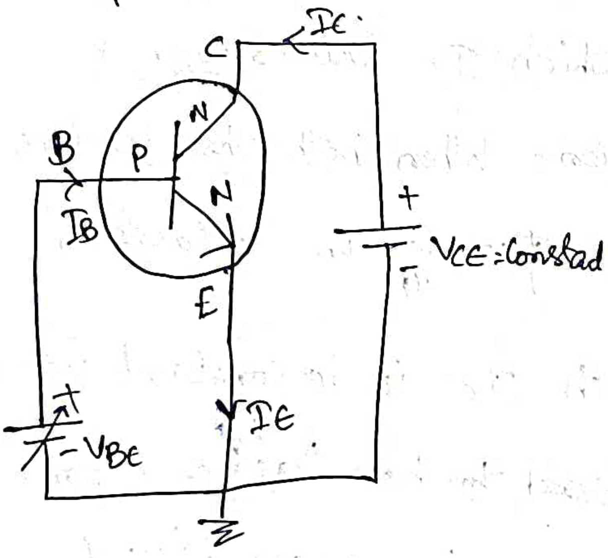
Common Emitter Configuration:- In CE configuration

→ Base is i/p terminal
→ collector is o/p terminal
→ Emitter is common terminal for i/p & o/p.



→ Behaviour of transistor is analyzed with the help of input and output characteristics.

Input characteristics: I/P characteristics for CE configuration gives the graphical relation b/w input voltage V_{BE} & i/p current I_B by maintaining output voltage V_{CE} at constant voltage.



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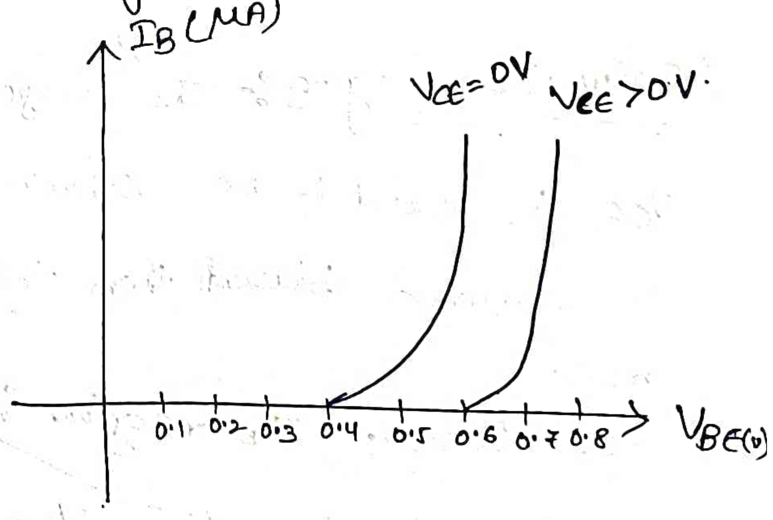
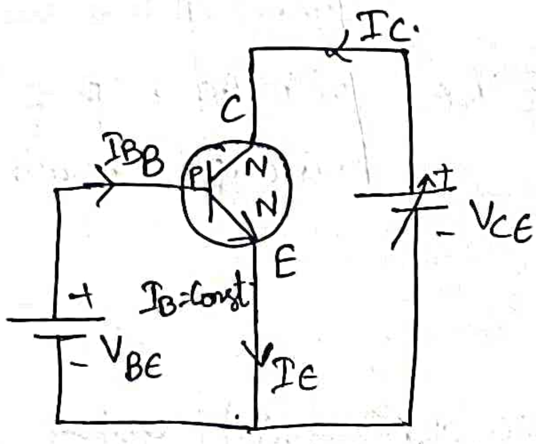


① At $V_{CE}=0V$: For $V_{CE}=0V$, as emitter base junction is forward biased, i/p characteristics resembles the V-I characteristics of diode.

② At $V_{CE}>0V$: As V_{CE} is reverse voltage, if it is increased then the width of the depletion region across

Collector base junction increases. This leads to reduce the base current I_B. Hence curve appears <u>to right</u> as V_{CE} increases.

Output characteristics:- O/P characteristics of CE configuration represents the graphical relation b/w output voltage V_{CE} and O/P current I_C for constant i/P current I_B.



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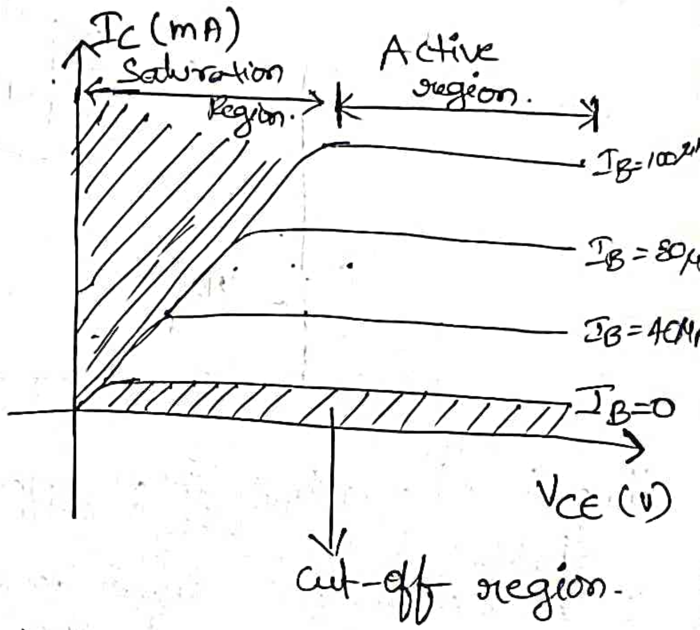


→ O/P characteristics have '3' regions.

① **Saturation Region**:- The region in which I_C varies w.r.t V_{CE} is said to be saturation region. When both the junctions are forward biased then transistor operates in saturation mode.

② **Active Region**: The region in which I_C is constant i.e., it doesn't depend on V_{CE} is said to be "active region".

→ When J_E is forward biased & J_C is reverse biased then transistor is said to be operated in "Active mode".

③ cut-off Region : The region under the O/P curve at $I_B = 0$ is said to be cut-off Region.

Current gain : Current gain for CE configuration is represented with 'β'. And is the ratio of O/P current I_C to input current I_B.

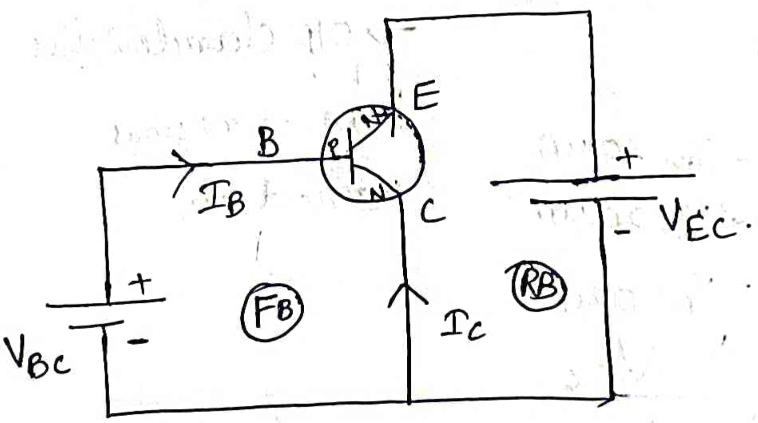
$$\boxed{\beta = \frac{I_C}{I_B}}$$

Leakage current: When BJT is operated in cut-off region, both J_E & J_C are reverse biased, so there is no current due to majority charge carriers. But there exist small amount of current due to minority carriers, which is known as "leakage current". Total collector current in CE is given by.

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

Common Collector Configuration :- In CC configuration

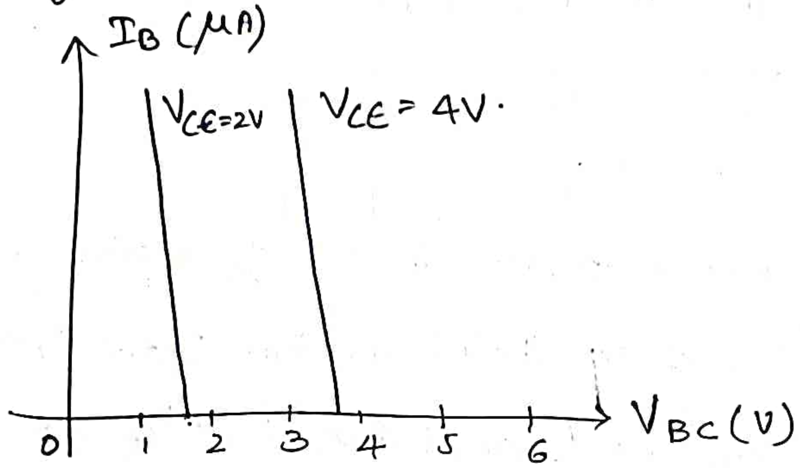
→ Base is i/p termal, → Emitter is o/p terminal, → Collector is common w.r.t i/p & o/p terminals.



→ CC configuration is also said to be "emitter follower".

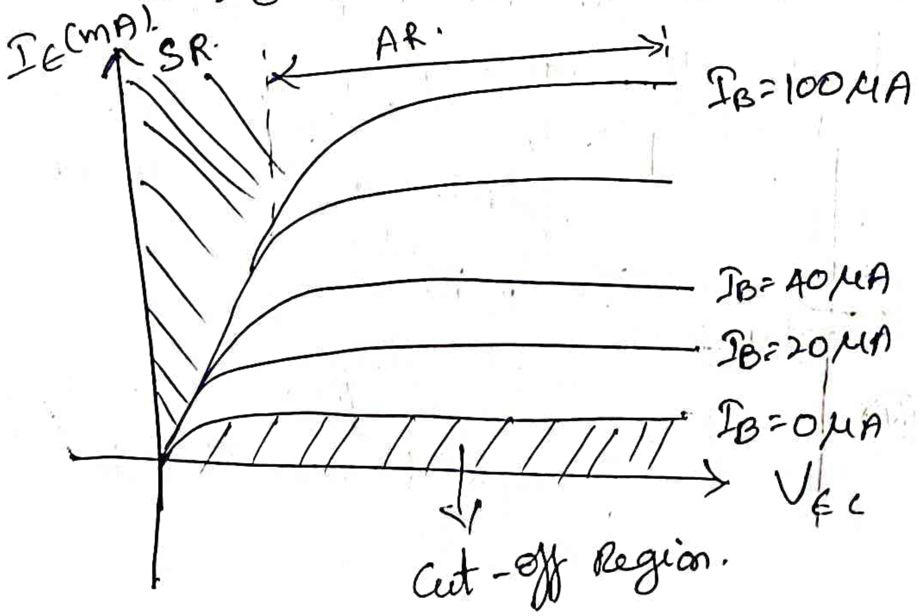
→ Behaviour of the transistor can be analyzed with the help of input & output characteristics.

Input Characteristics: It represents the graphical relation b/w i/p voltage V_{BC} & i/p current I_B by maintaining output voltage V_{EC} at constant value.



→ In CC Configuration V_{BC} is increased at uniform steps and corresponding increase in I_B is noted.

O/P characteristics :- Represents the graphical relation b/w output voltage V_{EC} & O/P current I_E by maintaining input current I_E at constant values.



→ O/P Characteristics have 3 regions named as

① Saturation Region : The region in which I_E increases (or) Varies w.r.t V_{EE};

② Active Region : the region in which I_E is Constant i.e., it is independent of V_{EC}.

③ Cut - off Region : The region under o/p curve at $I_B = 0\mu A$ is cut - off region.

Current gain : Current gain in CE configeration is represented with γ, and is defined as ratio of o/p current I_E to i/p current I_B.

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

Relation b/w α & β :

WKT $I_E = I_B + I_C \rightarrow ①$

div eqn ① w.r.t I_C

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

WKT $\alpha = \frac{I_E}{I_E}$, $\beta = \frac{I_C}{I_B}$.

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

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

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

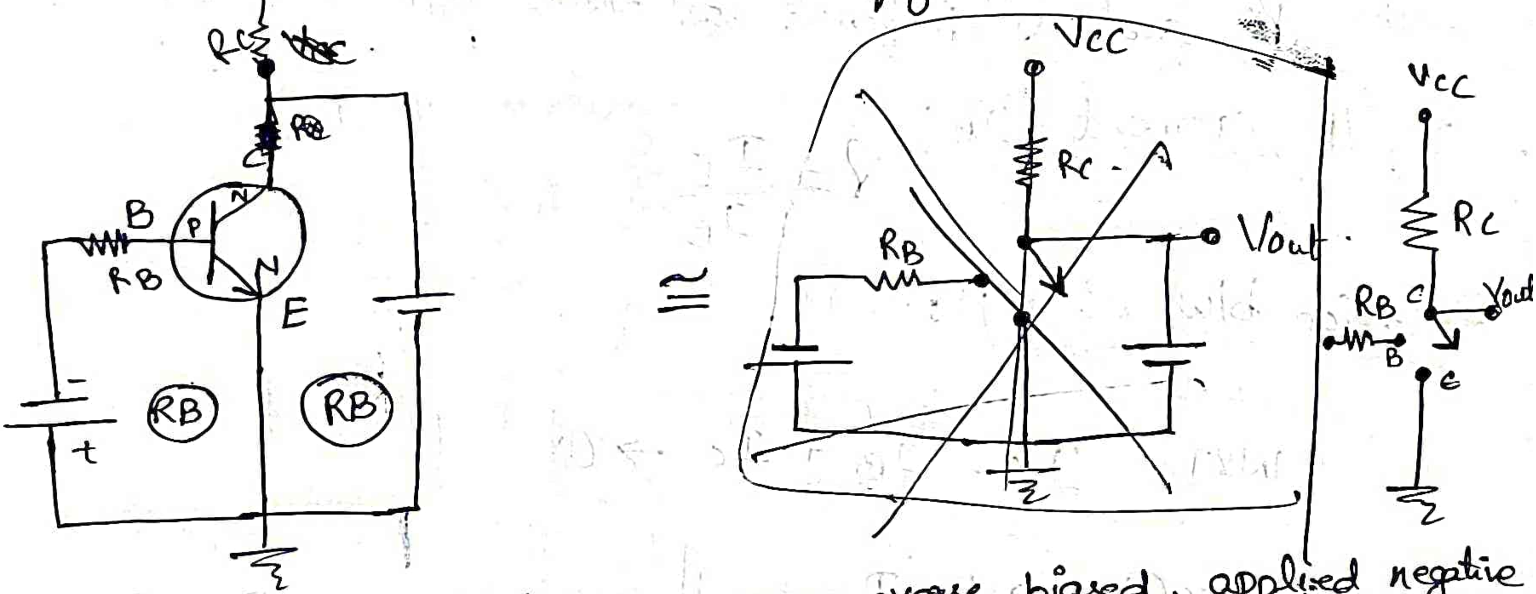
* Relation b/w I_{CBO} & I_{CEO}

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

Transistor as a switch :- Transistor can act as switch in cut-off region & in saturation Region.

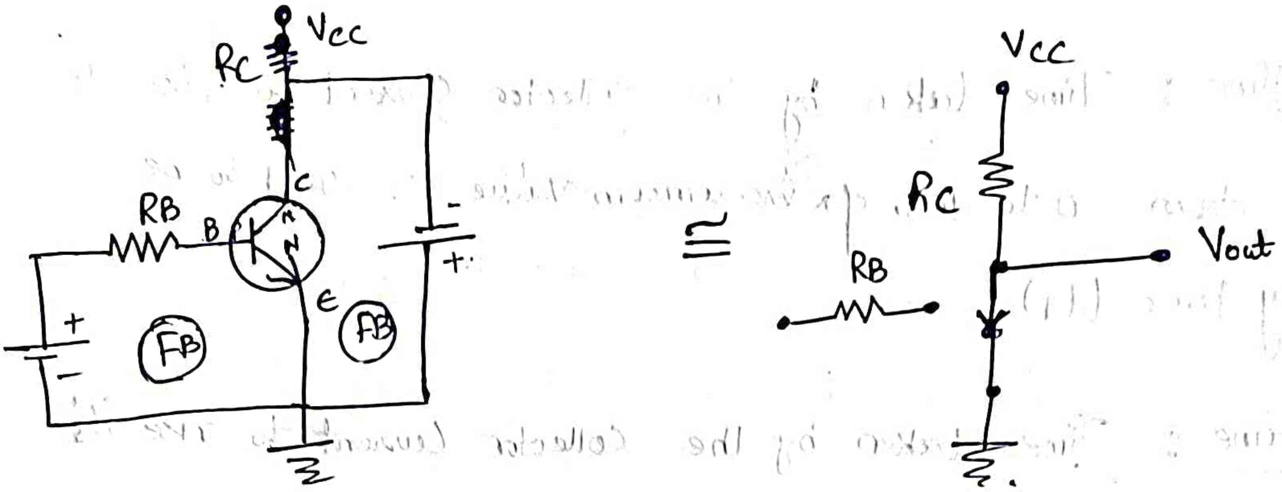
Cut-off Region : When both the transistor's junctions, such as Emitter junction (J_E) and collector junction (J_C) were reverse biased then transistor is said to be in cut-off region.

Let us consider CE-Configuration.



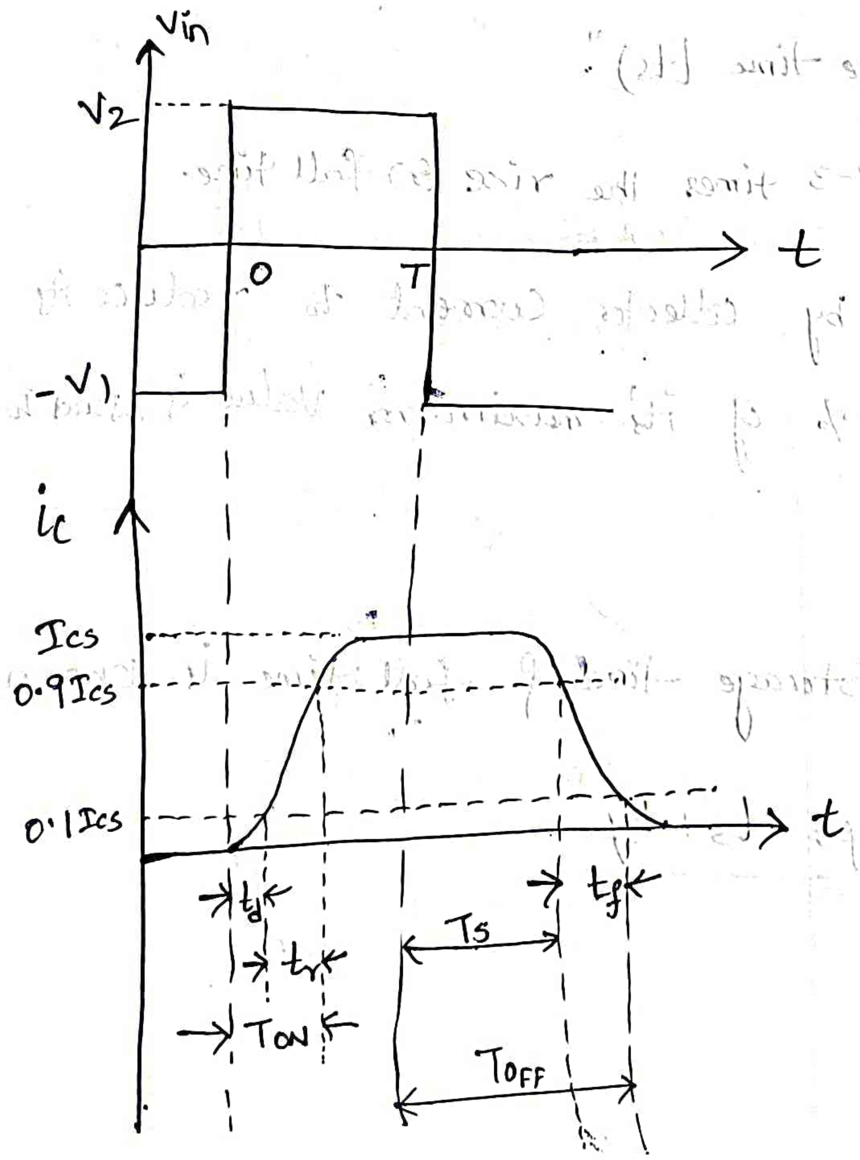
→ As both junctions were reverse biased, applied negative voltage will be less than the threshold voltage of transistor. Hence applied (-ve) voltage can't drive the transistor and hence transistor acts as " open switch".

Saturation-Region: When both the transistor's junctions, such as emitter junction (J_E) and collector junction (J_C) were forward biased then transistor is said to be in saturation region.



→ As both junctions were forward biased, applied forward voltage will be greaterthan the threshold voltage of transistor. Hence applied forward voltage can drive transistor and hence transistor can act as " ON switch".

Transistor switching times :



→ Assume that when i/p pulse is at V_1, transistor is in cut-off, and when the i/p pulse is at V_2, the transistor is in saturation.

→ The following switching times are associated with transistor.

1. delay time (t_d)
2. Rise time (t_r)
3. Storage time (t_s)
4. Fall time (t_f)
5. Turn off time (t_{off})

Delay time : Time taken by the collector current to rise its value from 0 to 10% of its maximum value is said to be "Delay time (t_d)".

Rise time : Time taken by the collector current to rise its value from 10% to 90% of its maximum value is known as "Rise time (t_r)".

Storage time :- Time duration for which collector current remains at its maximum value even after transistor is driven into cut-off region from saturation region is said to be "storage time (t_s)".

→ t_s may be 2-3 times the rise or fall time.

Fall time : Time taken by collector current to reduce its value from 90% to 10% of its maximum value is said to be "fall time (t_f)".

Turn off time : Sum of storage time & fall time is known as "turn-off time".

$$T_{off} = t_s + t_f$$

Relation b/w α & γ :-

~~WKT~~

$$\cancel{I_E = I_B + I_C \rightarrow (1)}$$

$$\cancel{\alpha = \frac{I_C}{I_E} \quad \& \quad \gamma = \frac{I_E}{I_B}}$$

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

$$\cancel{(1) \div I_E}$$

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

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

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

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

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

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

WKT

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

$$\alpha = \frac{I_C}{I_E} \quad \& \quad \gamma = \frac{I_E}{I_B}$$

$$(1) \div I_E$$

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

$$1 = \frac{1}{\gamma} + \alpha \rightarrow (2)$$

from (2)

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

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

(or)

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

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

Note:

1. In CB Configuration: $I_C = \alpha I_E + I_{CBO}$, $\alpha = \frac{I_C}{I_E}$.
2. In CE Configuration: $I_C = \beta I_B + I_{CEO}$, $\beta = \frac{I_C}{I_B}$.
3. In CC Configuration: $\gamma = \frac{I_E}{I_B}$

(P1) In a common base configuration, the value of collector current is 4.25mA, value of emitter current is 4.65mA. Calc. common base DC current gain.

Sol: $I_C = 4.25mA$, $I_E = 4.65mA$

for CB config $\alpha = \frac{I_C}{I_E} = \frac{4.25}{4.65} = 0.914.$

*note: α, β, γ are also known as amplification factors.

(P2) Calculate I_C & I_E for a transistor with $\alpha_{dc} = 0.99$, $I_{CBO} = 50\mu A$, I_B is measured as $20\mu A$

Sol:

$I_C = ?$

$I_E = ?$

$\alpha_{dc} = 0.99$

$I_{CBO} = 50\mu A$

$I_B = 20\mu A.$

for CB config

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

$$I_C = \alpha [I_B + I_C] + I_{CBO}.$$

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

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

$$I_C = \frac{\alpha I_B + I_{CBO}}{1-\alpha} \simeq 6.98mA$$

WKT

$I_E = I_B + I_C$

$= 20\mu A + 6.98mA$

(P3) Given NPN Transistor for $\alpha = 0.98$. A CE is connected with $V_{CC} = 12V$, $R_L = 4K\Omega$. What is minimum base current required in order that transistor enter into saturation state.

Sol: $I_B = ?$, $\alpha = 0.98$, $V_{CC} = 12V$, $R_L = 4K\Omega$

WKT for CE

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

*. I_{CEO} can be neglected.

$$I_C \simeq \beta I_B$$

$$I_B = \frac{I_C}{\beta}; \quad I_C = \frac{V_{CC}}{R_L}$$

$$= \frac{12}{4 \times 10^3}$$

$$= 3mA.$$

$$\therefore I_B = \frac{3 \times 10^{-3}}{\beta}.$$

WKT

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

$$\alpha + \alpha\beta = \beta$$

$$\alpha = \beta - \alpha\beta$$

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

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

$$\beta = \frac{0.98}{1-0.98}$$

$$\boxed{\beta = 49}$$

$$I_B = \frac{3 \times 10^{-3}}{49}.$$

$$= 61.22 \mu A.$$

(P4) A transistor work with $\alpha = 0.96$, Calc values of β & γ.

Sol:

EDC ASSIGNMENT-3 QUESTIONS

SAQ :

1. What is NPN transistor?
2. Draw common emitter configuration of BJT along with common collector configuration.
3. Discuss about base width modulation & ~~Early~~ reachthrough effect.
4. Draw the symbols of NPN & PNP transistors.

LAQ :

5. Compare characteristics of CE, CB, and CC configuration of BJT (or) compare performance of transistor in different configuration.
6. Explain in detail about principle of operation of BJT.
7. Draw and explain o/p characteristics of CE configuration.
8. Explain CB configuration of BJT in detail.
9. Explain the working of transistor as a switch.
10. The reverse leakage current of transistor when in CB configuration is 0.3 μA, while it is 16 μA when the same transistor is connected in CE configuration. Determine α, β and γ: