

BIPOLAR JUNCTION TRANSISTORS

①

Syllabus: Bipolar Junction Transistor: BJT operation, BJT Voltage and currents, BJT amplification, common base, common emitter and common collector characteristics, Numerical examples if applicable.

K Introduction:

- The first transistor was invented in 1947 (23. Dec) at the Bell Telephone Laboratories (USA) by Dr. William Shockley, Dr. John Bardeen & Dr. Walter H. Brattain.
- Transistor is an electronic device consisting of two PN junctions formed by sandwiching either P-type or n-type Semiconductor between a pair of opposite types.
- Transistor is a three terminal (three layers) & two junction electronic device. (2 port device)
- Transistor is a current controlled device (ie output current, voltage and/or power are controlled by its input current)
- Transistor can be considered as connection of two back-to-back diodes (big ③) & (big ⑥)
- The term transistor is derived from TRANSfer of RESISTOR (\because amplification is achieved by passing input current from a region of low resistance to a region of high resistance)
- Transistor can be used as switch and amplifier [amplification of weak signals (current & voltage)]
- Three blocks [(P, n, P) @ (n, P, n)] are grown out of same crystal by adding corresponding impurities in turn.

→ Type of transistors (Based on number of charge carriers):

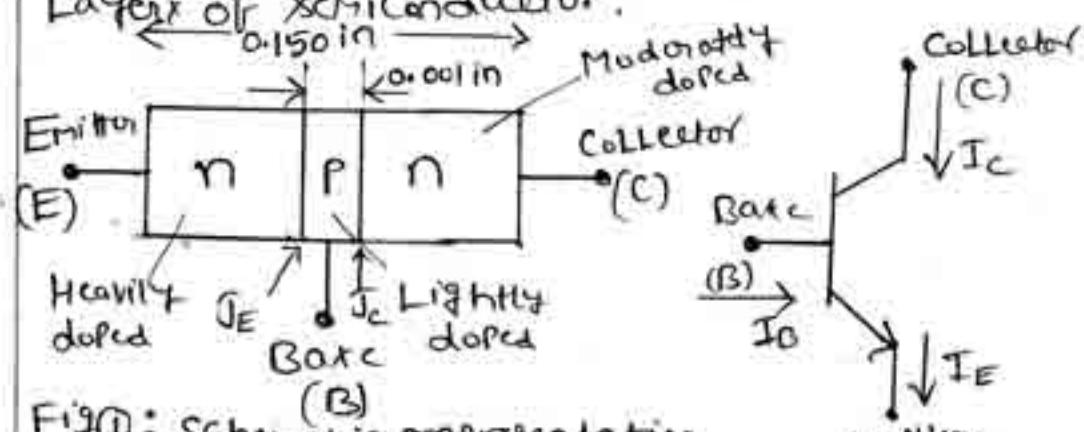
- Unipolar Junction Transistor (UJT): Current conduction is only due to one type of charge carriers [either electrons or holes (majority carriers)]
- Bipolar Junction Transistor (BJT): Current conduction is due to both the types of charge carriers [holes & electrons (Majority & minority carriers)]

→ Type of Bipolar Junction transistors (Construction):

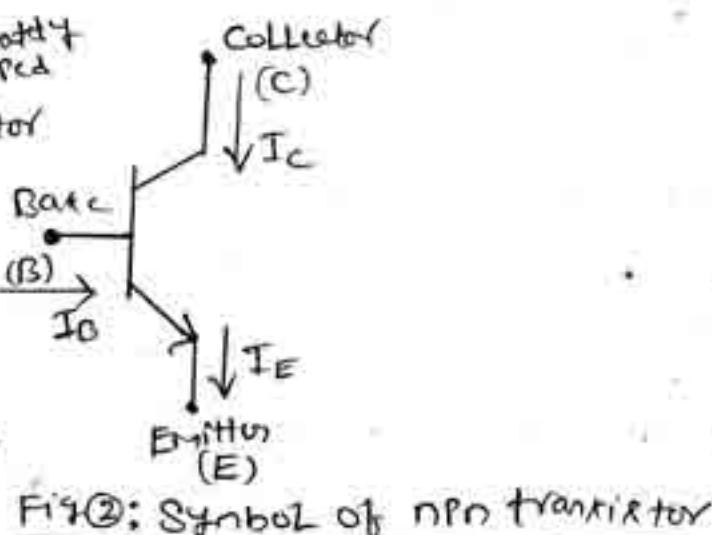
There are two types of BJTs

① nPn transistor

- nPn transistor is obtained when a P-type layer of semiconductor is sandwiched between two n-type layers of semiconductor.



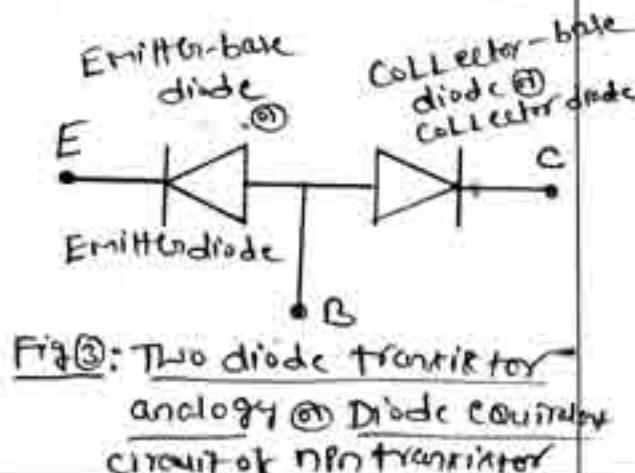
Fig①: Schematic representation of nPn transistor



Fig②: Symbol of nPn transistor

- There are three terminals, one taken from each type of semiconductor (Emitter, Base & Collector)

~ Emitter: The section on one side that supplies charge carriers (electrons) is called the emitter.



Fig③: Two diode transistor analogy @ Diode equivalent circuit of nPn transistor

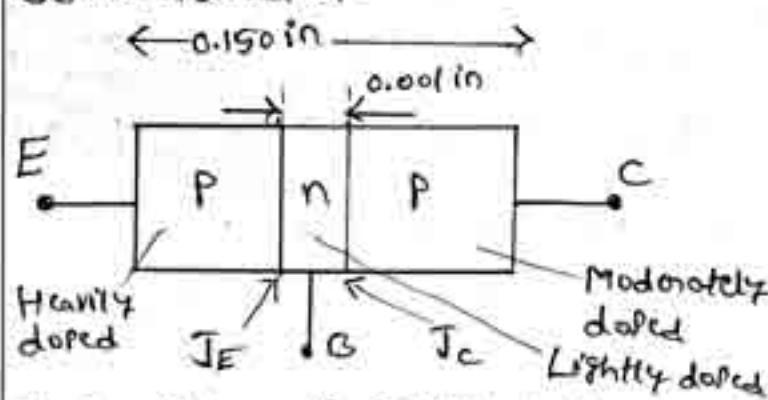
- ⇒ It is a heavily doped region
- ⇒ It is always forward biased w.r.t base & provides low resistance in the emitter.
- Base: ⇒ The middle layer (or section or region) between the emitter & collector is called the base.
- ⇒ It is thin & lightly doped region.
- Collector: ⇒ The section on the other side which collects charge carriers (electrons) is called the collector
- ⇒ It is moderately doped region & larger than emitter & base.
- ⇒ It is always reverse biased w.r.t base & provides high resistance in the collector.

Note: During transistor operation, much heat is produced at the collector junction, so collector is made larger to dissipate the heat.

- Transistor has two PN junctions (ie it is like two diode)
- ⇒ The junction between emitter & base is emitter-base junction (J_E) @ emitter-base diode (Always forward bias)
- ⇒ The junction between the base & collector is collector-base junction (J_C) @ collector-base diode @ collector diode (Always Reverse bias)
- The ratio of the total width to center layer (Base) is $0.150/0.001 = 150:1$
- The ratio of doping level of outer layer (E_{AC}) to center layer (B) is typically $10:1$ @ less
- The direction of arrow head (fig②) indicates the direction of conventional current flow in transistor.
- Free electrons are majority carriers & holes are minority carriers.

(b) PnP transistor

- PnP transistor is obtained by sandwiching a n-type semiconductor layer between two p-type layers of semiconductor.



- Emitter supplies holes to other two regions
- collector collects holes
- Holes are the majority carrier & electrons are minority carriers.

→ Transistor manufacturing technique

Basic techniques used for transistor manufacturing techniques are

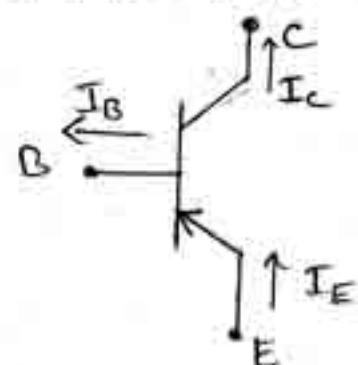
- Grown-junction
- Alloy
- Diffused-junction
- Epitaxial.

→ Transistor package types:

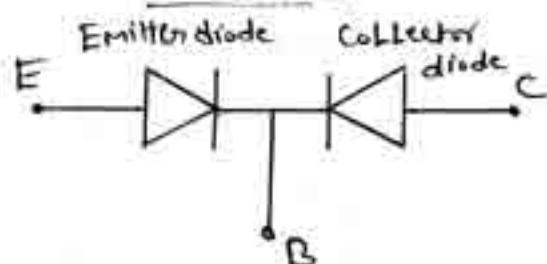


Fig(5): Transistor package types

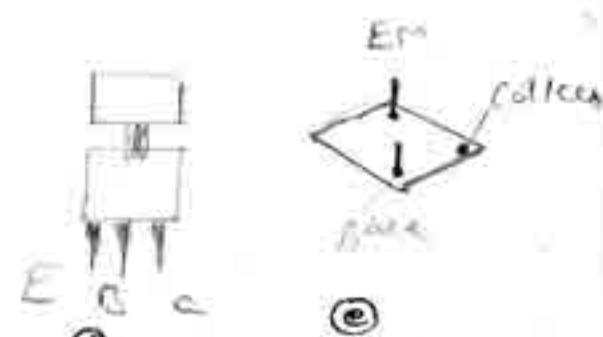
Low Power transistors: (a), (b), (c)



Fig(5): Symbol of PnP transistor



Fig(6): Diode equivalent circuit of PnP transistor



Metal can-type (d), (e), (e)

Plastic enclosure (c)

* Unbiased transistor: Depletion regions & Barrier Voltages of an unbiased transistor)

① nPn transistor:

→ A transistor with no external dc voltage E is called unbiased transistor.

→ The base layer is very thin & lightly doped compared to the outer layers.

→ The outer layers are more heavily doped than the base layer.

→ During diffusion, depletion regions penetrate more deeply into the base from either side, thus the distance between the two depletion layers within the base is reduced.

→ Junction barrier voltages are positive on the emitter & collector and negative on the base ($0.3V$ for Ge & $0.7V$ for Si) (Electrons are majority carriers)

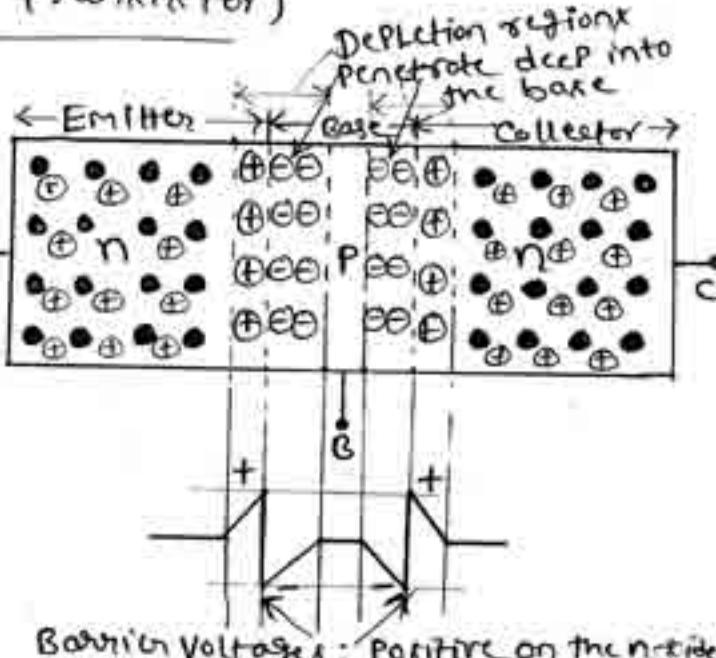
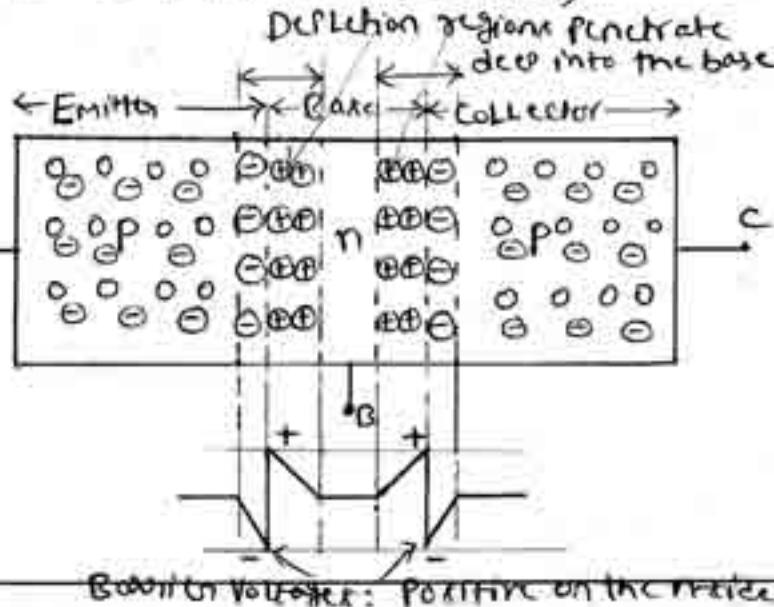


Fig ⑧: Depletion regions & barrier Voltages at the junctions of an unbiased nPn transistor

② PnP transistor:

Fig ⑨: Depletion regions & barrier voltages at the junctions of an unbiased PnP transistor

Explanation of form of nPn \rightarrow



Barrier voltages: Positive on the p-side

→ A PnP transistor behaves exactly like a nPn transistor with the exception that the holes are majority carriers.

→ Junction barrier voltages are positive on the base and negative on the emitter & collector

Note:

- ① Model of transistor operation ② Different ways of biasing a transistor ③ Regions of operation of BJT
- ④ Operating regions of a transistor:

APPLICATION of suitable DC voltages across the transistor terminals is called biasing.

A transistor can be operated in four different regions.

- ⑤ Active region
- ⑥ Linear region
- ⑦ Forward-active region
- ⑧ Saturation region
- ⑨ Cut-off region
- ⑩ Reverse-active region

⑪ Active region: (Fig 10)

→ The Emitter-base junction (J_E) is forward biased (FB) & the Collector-base junction (J_C) is reverse biased (RB).

→ For NPN transistor:

FB source: The negative terminal of a battery is connected to N-side & Positive terminal to P-side.
RB source

The positive terminal of a

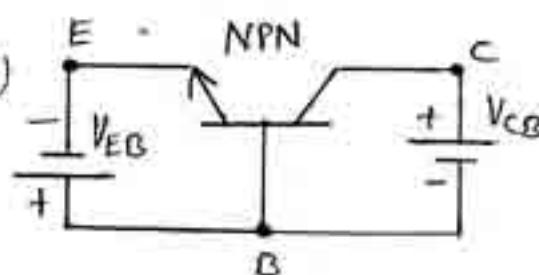


Fig 10 ⑪ Forward-active (NPN)

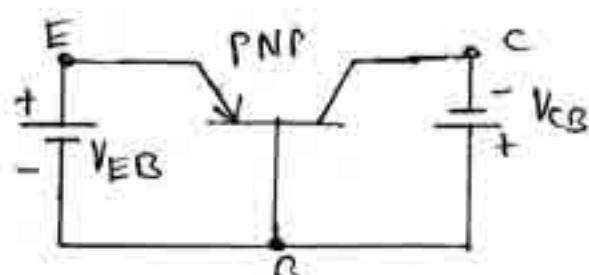


Fig 10 ⑫ Forward-active (PNP)

battery is connected to N-side & negative terminal to P-side.

- The collector current consists of two components:
 - (i) current due to the forward biasing of EB junction &
 - (ii) current due to reverse biasing of CB junction [I_{C0} @ I_{CB0}] (Very small in magnitude)

④ Saturation region: (Fig 11)

→ Both the Emitter-base & collector-base junctions are forward biased.

→ I_C increases rapidly for a very small change in V_{CB} .

⑤ Cut-off region: (Fig 12)

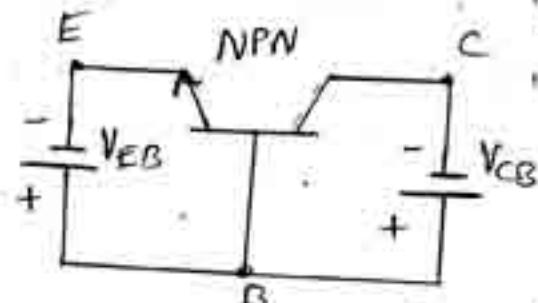
→ Both the emitter-base & collector-base junctions are reverse biased.

→ The current is very small & transistor is said to be in off-state.

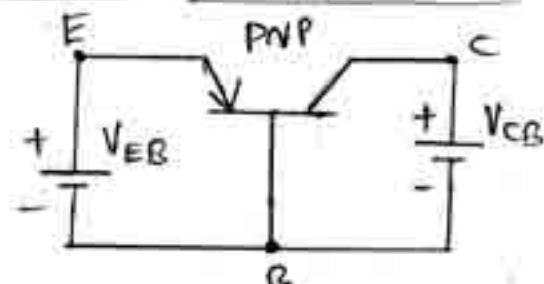
⑥ Reverse-active region: (Fig 13)

→ The Emitter-base junction is reverse biased & the collector-base junction is forward biased.

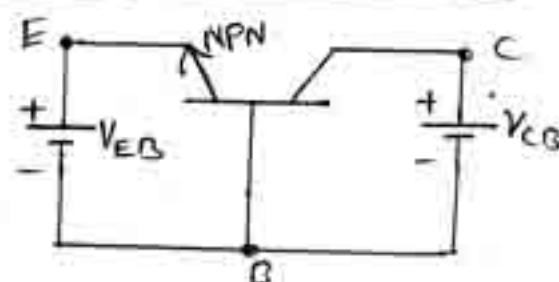
→ It is used for less amplification.



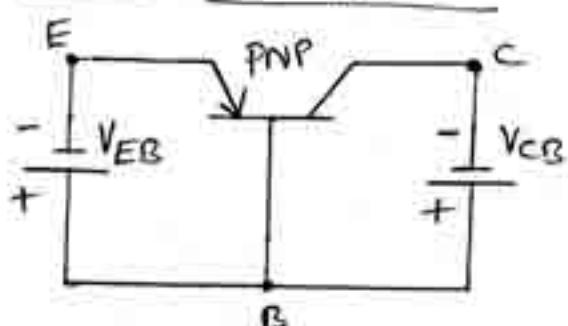
Fig(11)@: Saturation (NPN)



Fig(11)B: Saturation (PNP)



Fig(12)@: Cut-off (NPN)



Fig(12)B: Cut-off (PNP)

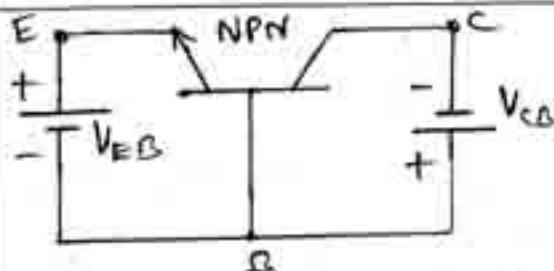


Fig 13(a): Reverse active (NPN)

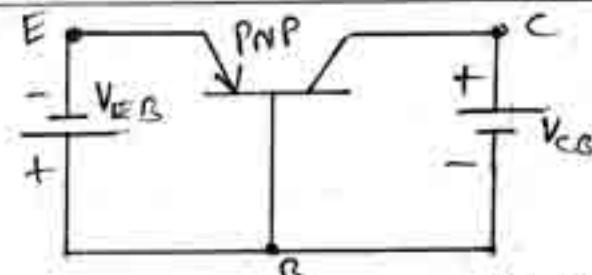


Fig 13(b): Reverse active (PNP)

| Region of operation | Emitter-Base junction J _E | Collector-Base junction J _C | Application |
|---------------------|---|---|--------------------|
| ① Active | F _B | R _B | Good amplification |
| ② Saturation | F _B | F _B | Closed switch (ON) |
| ③ Cut-off | R _B | R _B | Open switch (OFF) |
| ④ Reverse - active | R _B | F _B | Less amplification |

R Biased transistor ⑦ Principle of operation of transistor:

- ① NPN transistor:
(principle of operation)
→ Emitter-base junction is forward biased & collector-base junction is reverse biased.
→ The forward bias on the emitter-base junction causes the electrons in the n-type emitter to flow towards the base (repelled by negative potential of V_{EB}). This constitutes emitter current (I_E) (opposite to flow of electrons).

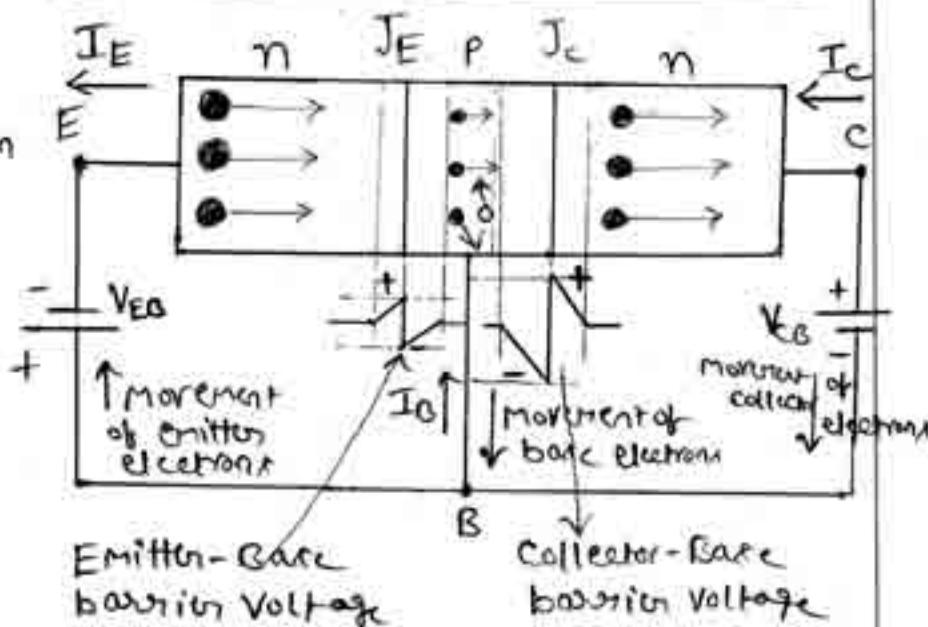


Fig (a): Operation of NPN transistor

- The base is lightly doped & very thin, so only a few electrons (less than 5%) coming from the emitter

- Combine with the holes causing bare current (I_B) (MA) (nA)
- The remaining electrons (more than 95%) will diffuse to the collector & constitute Collector Current (②)
Injected Current (I_c). (mA)
- There is another component of collector current due to thermally generated carriers. This current component (Very small) is called reverse saturation current (I_{CBO}) (MA) (nA)
- It is clear that emitter current is the sum of collector & bare currents

$$\text{ie } I_E = I_B + I_c$$

Note:

- ① Collector current is also called as injected current because this current is produced due to electrons injected from the emitter region.
- ② The resistances R_E & R_C may be connected in series with emitter & collector to limit the magnitude of current in the transistor.
- ③ ^{Reason} that most of the electrons from emitter continue their journey through the base to collector to form collector current are ② The base is lightly doped & very thin. Therefore, there are a few holes which find enough time to combine with electrons ③ The reverse bias on collector is quite high & exerts attractive forces on these electrons.
- ④ Collector current, $I_c = \alpha I_E + I_{CBO}$
 - I_c current
with emitter terminal open
 - I_c current
with emitter terminal open
 - I_c current
with emitter terminal open

(Current due to majority of electrons (more than 95%) from emitter)

↳ Reverse saturation current (Due to thermally generated carriers) ② minority current component Leakage current

② PNP transistor:

(Principle of operation of PNP transistor)

→ Emitter-base junction is forward biased & collector-base junction is reverse biased.

→ The forward bias on the emitter-base junction causes the holes in the emitter region to move towards the base (repelled by positive potential of V_{EB}).

This constitutes the emitter current (I_E) (mA)

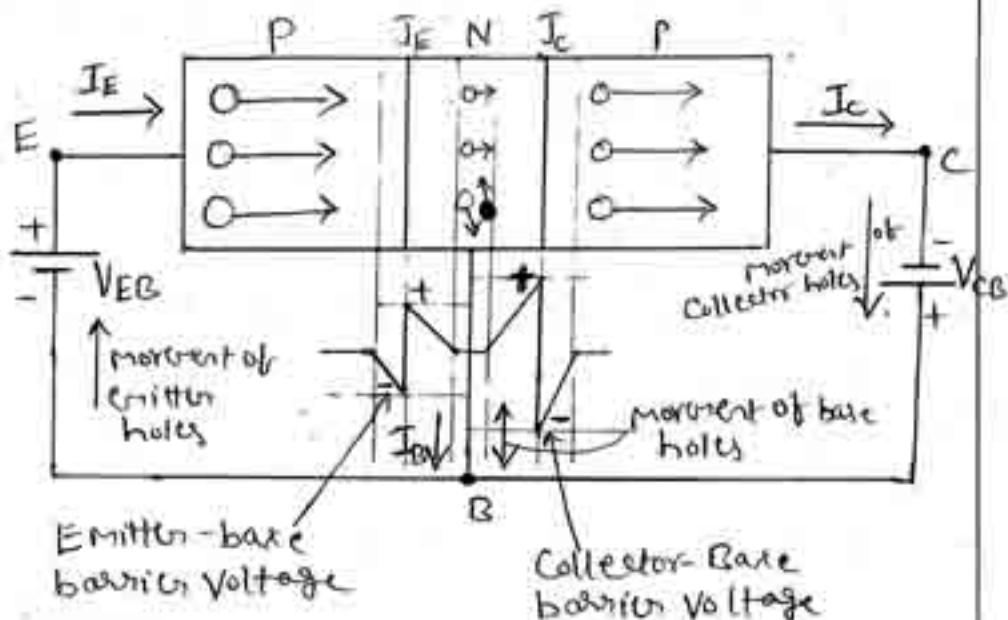
→ The base is lightly doped & very thin, so only a few holes (less than 5%) coming from the emitter combine with the electrons causing base current (I_B) (mA)

→ The remaining electrons (more than 95%) will diffuse to the collector & constitute collector current (I_C) (mA)

→ There is another component of collector current due to thermally generated carriers. This current component (very small) is called reverse saturation current (I_{CBO}) (mA)

→ It is clear that the emitter current is the sum of collector & base currents.

$$\text{ie } I_E = I_B + I_C$$



Fig(13): Operation of PNP transistor

* BJT Voltages and currents:

① BJT voltages (Terminal voltages):

② NPN transistor:

Fig 16 shows the terminal voltages for NPN transistor.

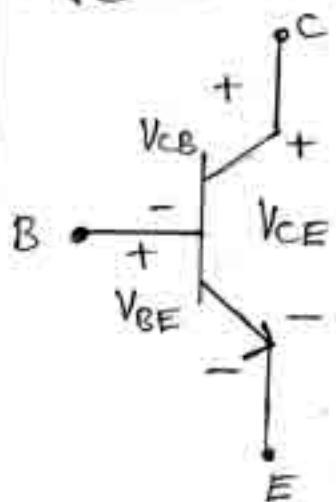


Fig 16 : Terminal voltages

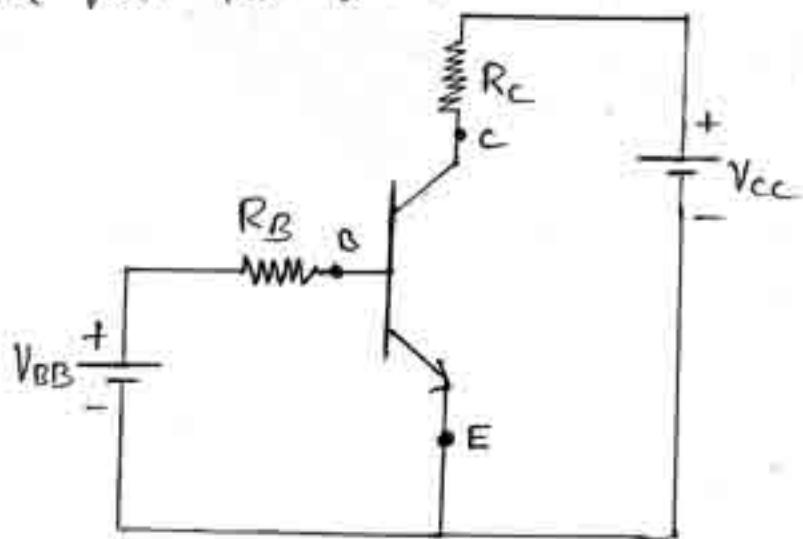


Fig 17: Voltage source connection

For NPN transistor,

- Base voltage must be positive w.r.t the emitter.
- collector voltage must be positive w.r.t the base.
- collector voltage must be positive w.r.t the emitter

Fig 17 shows Voltage source connection to NPN transistor via Transistor.

- Base bias voltage (V_{BB}) is connected via resistor (R_B) & the collector supply (V_{CC}) is connected via resistor (R_C).
- The negative terminals of V_{BB} & V_{CC} are connected at the transistor emitter terminal.
- To ensure reverse biasing of collector-base junction, V_{CC} must be much larger than V_{BB} .

Typical voltages: $V_{CE} \approx 0.3V$ for Ge & $0.7V$ for Si

$$V_{CE} = 3V \text{ to } 20V$$

⑥ For PNP transistor

Fig ⑧ Shows the terminal voltages for PNP transistor.

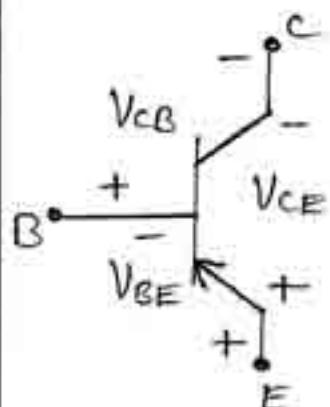


Fig ⑧: Terminal Voltages

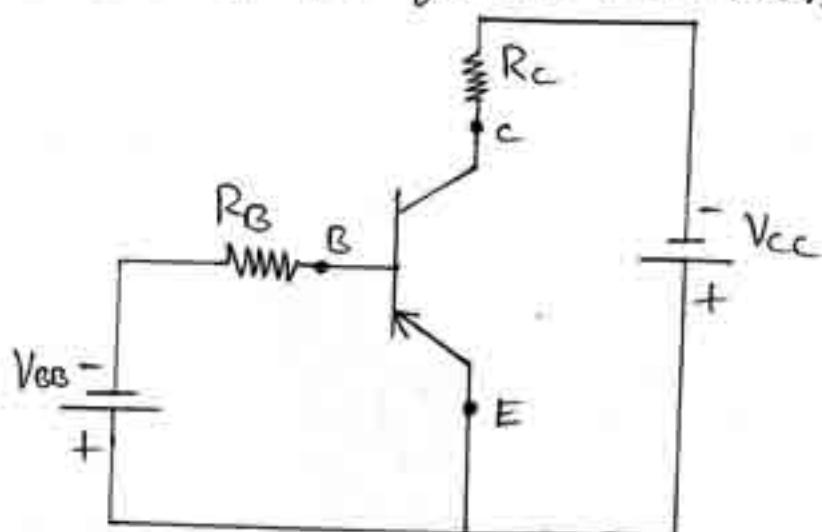


Fig ⑨: Voltage Source Connection

For PNP transistor

- Base voltage must be negative w.r.t the emitter
- Collector voltage must be negative w.r.t the base.
- Collector voltage must be negative w.r.t the emitter.

Fig ⑩ Shows Voltage source connection to PNP transistor via resistors.

- Base bias voltage V_{BB} is connected via resistor R_B
- The collector supply V_{CC} is connected via resistor R_C .
- The positive terminals of V_{BB} & V_{CC} are connected at the transistor emitter terminal.
- To ensure reverse biasing of collector-base junction, V_{CC} must be much larger than V_{BB} .

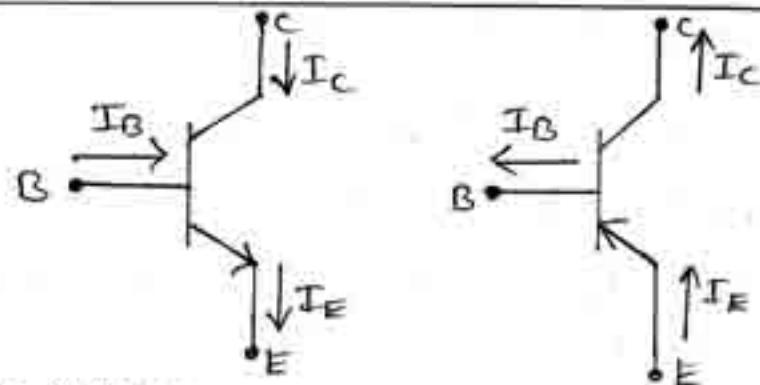
⑦ BJT currents:

Fig ⑪ Shows nPn & pNP transistor Limit Currents.

Applying KCL to the transistor (as if it is a single node),

$$I_E = I_C + I_B$$

Note: The ratio of the transistor output current to the input current is called current gain of a transistor



①: NPN transistor ②: PNP transistor
Fig ②: Currents in transistor

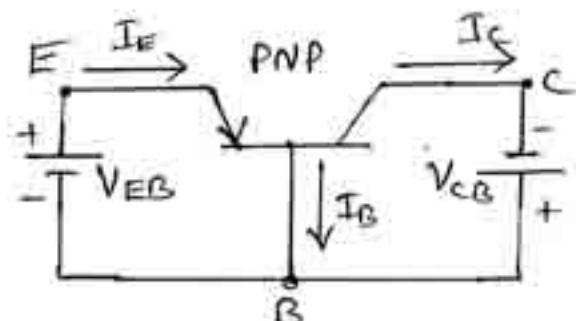
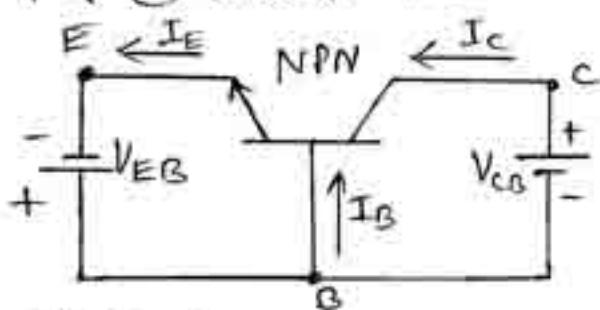
* Transistor Configurations @ Connections:

There are three configurations of transistor.

- ① Common base connection
- ② Common emitter connection.
- ③ Common collector connection.

① Common base configuration:

Fig ① shows the common base transistor circuit.



① NPN transistor

② PNP transistor

Fig ①: common base transistor

→ Input is applied between the emitter & base terminals.

→ The output is taken between the collector & base terminals.

→ The emitter current is the input current & collector current is the output current.

→ Input and output current may be either direct

Current @ alternating Current.

④ Common base dc current gain ⑤ Current

amplification factor ⑥ Small signal current gain ⑦

Common base, short circuit amplification factor ⑧

Common base, short circuit current gain (α_{dc})

It is defined as the ratio of collector current (I_c) to the emitter current (I_E). It is denoted by ⑨ α_{dc} ⑩ h_{FB}

i.e

$$\alpha_{dc} = \frac{I_c}{I_E}$$

⑪ Common base ac current gain (α_{ac})

It is defined as the ratio of small change in collector current (ΔI_c) to the small change in emitter current (ΔI_E) for a constant collector-to-base voltage (V_{CB})

⑫

It is defined as the ratio of change in collector current to the change in emitter current at constant collector-base voltage (V_{CB})

It is designated by α_0 . ⑬ α_{ac} ⑭ h_{fb}

i.e

$$\alpha_{ac} = \frac{\Delta I_c}{\Delta I_E}$$

⑮

$$\alpha_{ac} = \frac{\Delta I_c}{\Delta I_E}$$

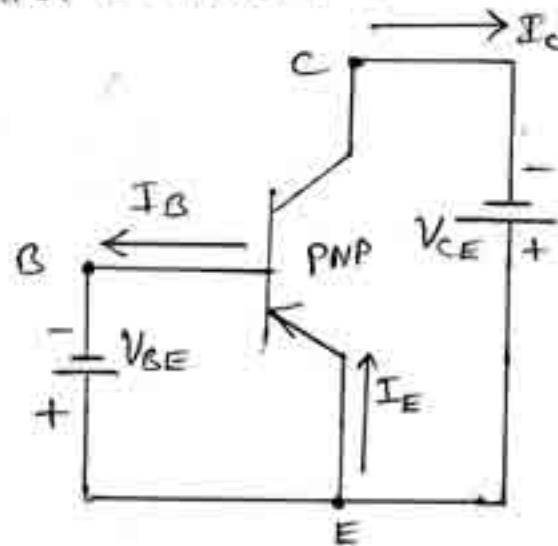
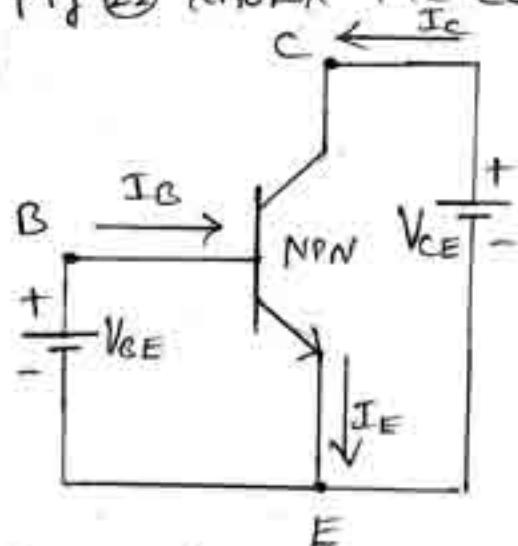
$| V_{CB} = \text{constant}$

- In practice, $\alpha_{dc} = \alpha_{ac}$

- α_{dc} is typically from 0.90 to 0.998

② Common Emitter Connection:

Fig ② shows the common emitter transistor circuit.



① NPN transistor

② PNP transistor

Fig ②: Common Emitter Transistor

→ The base current is the input current & the collector current is the output current.

- ⓐ common emitter dc current gain ⓑ Large Signal Common-emitter current gain ⓒ Base current amplification factor ⓓ Common-emitter Short circuit current gain ⓔ Current gain from base to collector: (β_{dc})

It is defined as the ratio of collector current (I_c) to the base current (I_B). It is denoted by β ⓑ β_{dc} ⓒ h_{FE} .

$$\text{ie } \beta_{dc} = \frac{I_c}{I_B}$$

- ④ Common emitter ac current gain (β_{ac}) ⓑ ΔI_c

It is defined as the ratio of change in collector current to the change in base current (ΔI_B) for a constant collector-to-emitter voltage (V_{CE}).

It is denoted by β_0 ⓒ β_{ac} ⓒ h_{fe}

ie

$$\beta_{ac} = \frac{\Delta I_c}{\Delta I_B}$$

or

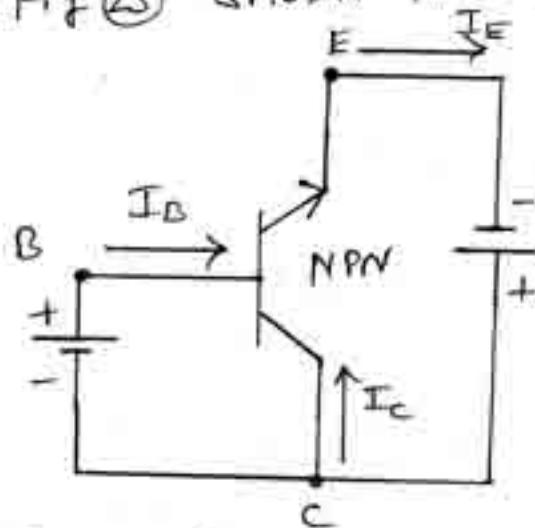
$$\beta_{ac} = \frac{\Delta I_c}{\Delta I_B}$$

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

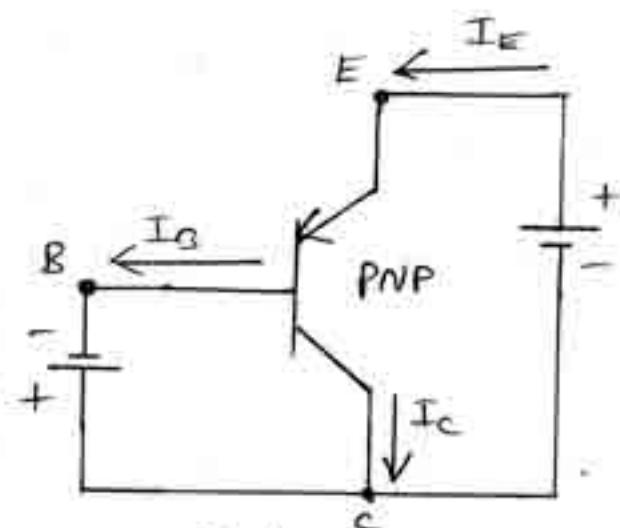
- In practice, $\beta_{ac} = \beta_{dc}$
- β_{dc} is typically from 20 to 500

③ Common collector configuration:

Fig ②3) Shows the common collector transistor circuit



④ NPN transistor



⑤ PNP transistor

Fig ②3): common collector transistor

→ The base current is the input current & emitter current is the output current.

⑥ Common - collector dc current gain (γ_{dc})

It is defined as the ratio of emitter current (I_E) to the base current (I_B). It is denoted by γ_{dc} @ hfc

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

⑦ Common - collector ac current gain (γ_{ac})

It is defined as the ratio of change in emitter current (ΔI_E) to the change in base current (ΔI_B)

for a constant Emitter-to-collector Voltage (V_{EC})

It is denoted by $\gamma_o @ \gamma_{ac} @ h_{fc}$

$$\text{i.e } \gamma_{ac} = \frac{\Delta I_E}{\Delta I_B} \quad \text{---(1)}$$

$$\gamma_{ac} = \frac{\Delta I_E}{\Delta I_B} \quad | \quad V_{EC} = \text{constant}$$

- In Practice, $\gamma_{ac} = \gamma_{dc}$
- γ_{dc} is typically from 21 to 50.

* Relation between α_{dc} & β_{dc}

We know that

$$I_E = I_C + I_B \quad \text{---(2)}$$

Dividing (2) by I_C , we get

$$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C} \quad \text{---(3)}$$

We have $\alpha_{dc} = \frac{I_C}{I_E}$ & $\beta_{dc} = \frac{I_C}{I_B}$ --- (4)

$$\Rightarrow \frac{1}{\alpha_{dc}} = \frac{I_E}{I_C} \quad \text{---(5)} \Rightarrow \frac{1}{\beta_{dc}} = \frac{I_B}{I_C} \quad \text{---(6)}$$

Using (5) & (6) in (3), we get

$$\frac{1}{\alpha_{dc}} = 1 + \frac{1}{\beta_{dc}} \quad \text{---(7)}$$

$$\Rightarrow \frac{1}{\alpha_{dc}} = \frac{\beta_{dc} + 1}{\beta_{dc}}$$

$$\Rightarrow \alpha_{dc} = \frac{\beta_{dc}}{\beta_{dc} + 1} \quad \text{---(8)}$$

Now from (5), we can write.

$$\frac{1}{\beta_{dc}} = \frac{1 - \alpha_{dc}}{\alpha_{dc}}$$

$$\frac{1}{\beta_{dc}} = \frac{1 - \alpha_{dc}}{\alpha_{dc}}$$

$$\Rightarrow \boxed{\beta_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}}} - \textcircled{7}$$

* Relation between β_{dc} & γ_{dc} :

Consider eqn ①

$$I_E = I_C + I_B$$

÷ by I_B

$$\frac{I_E}{I_B} = \frac{I_C}{I_B} + 1 - \textcircled{8}$$

$$\text{We have, } \gamma_{dc} = \frac{I_E}{I_B} - \textcircled{9}$$

Using ⑧ & ⑨ in ⑧, we get

$$\boxed{\gamma_{dc} = \beta_{dc} + 1} - \textcircled{10} \Rightarrow \boxed{\beta_{dc} = \gamma_{dc} - 1} - \textcircled{11}$$

* Relation between α_{dc} & γ_{dc} :

Using ⑦ in ⑩, we get

$$\gamma_{dc} = \frac{\alpha_{dc}}{1-\alpha_{dc}} + 1$$

$$\Rightarrow \gamma_{dc} = \frac{\alpha_{dc} + 1 - \alpha_{dc}}{1-\alpha_{dc}}$$

$$\boxed{\gamma_{dc} = \frac{1}{1-\alpha_{dc}}} - \textcircled{12}$$

$$\Rightarrow 1-\alpha_{dc} = \frac{1}{\gamma_{dc}}$$

$$\Rightarrow 1 - \frac{1}{\gamma_{dc}} = \alpha_{dc}$$

$$\Rightarrow \boxed{\alpha_{dc} = \frac{\gamma_{dc}-1}{\gamma_{dc}}} - \textcircled{13}$$

* Relation among α_{dc} , β_{dc} & γ_{dc} :

We know that

$$\gamma_{dc} = \frac{I_E}{I_0}$$

$$\Rightarrow \gamma_{dc} = \frac{I_E / I_C}{I_C / I_C}$$

$$\Rightarrow \gamma_{dc} = \frac{1/\alpha_{dc}}{1/\beta_{dc}}$$

$$\Rightarrow \boxed{\gamma_{dc} = \frac{\beta_{dc}}{\alpha_{dc}}} \quad - 14$$

Note:

④ I_C in terms of I_B & α_{dc}

We have $\alpha_{dc} = \frac{I_C}{I_E}$

$$\Rightarrow I_C = \alpha_{dc} I_E$$

$$\Rightarrow I_C = \alpha_{dc} (I_C + I_B) \quad (\because I_E = I_C + I_B)$$

$$\Rightarrow I_C (1 - \alpha_{dc}) = \alpha_{dc} I_B$$

$$\boxed{I_C = \frac{\alpha_{dc} I_B}{1 - \alpha_{dc}}} \quad - 15$$

⑤

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

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

$$\boxed{I_C = \frac{\beta_{dc} I_B}{1 - \beta_{dc}}}$$

$$\left(\because \beta_{dc} = \frac{\alpha_{dc}}{1 - \alpha_{dc}} \right)$$

② NPN transistor \rightarrow Not Pointing in
 PNP transistor \rightarrow Pointing in

③ β_{dc} is defined by a simple ratio of dc currents at an operating point, whereas the β_{ac} is sensitive to the characteristics in the region of interest.

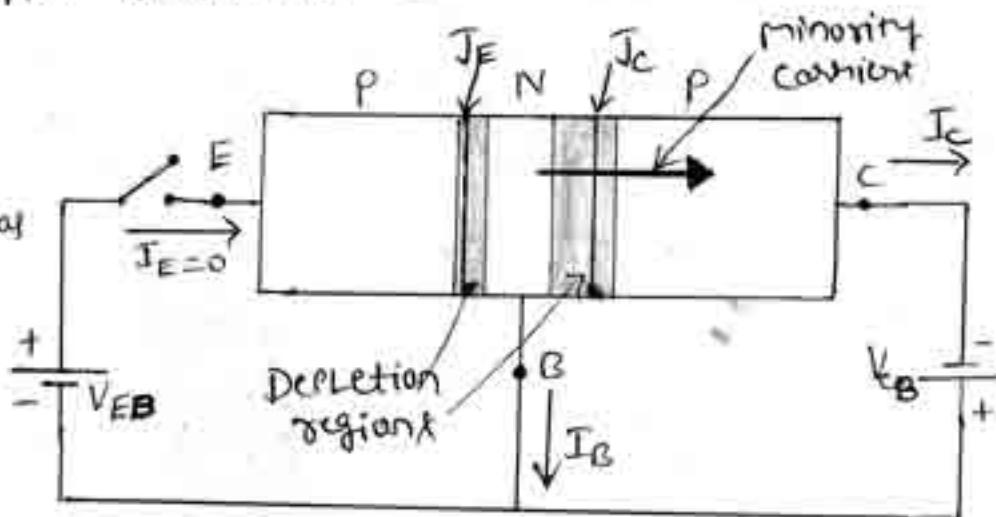
④ Expression for Collector Current:

Consider a PNP transistor circuit as shown in fig(24)

⑤ When switch is

Closed:

The forward bias voltage V_{EB} injects holes in the base region. The reverse bias voltage V_{CB} on the collector-base junction attracts the majority of holes from the base region & constitute collector current (injected current).



Fig(24): Common base PNP transistor

the collector-base junction attracts the majority of holes from the base region & constitute collector current (injected current)

$$\text{ie } I_C = \alpha_{dc} I_E \quad (\text{Due to majority carrier}) \quad (16)$$

⑥ When switch is open:

There is no emitter current & therefore no base current & no collector current. The minority carrier diffuse across the collector-base junction & hence produce a current known as leakage current (I_{CBO}) @ zero reverse saturation current @ collector cut-off current @

saturation current with emitter terminals open (I_{CO})

$$\text{ie } I_C = I_{CBO} \quad (\text{Due to minority carrier @ thermally generated carriers}) \quad (17) \quad (\text{NA @ NA})$$

The total collector current

$$I_C = \alpha_{dc} I_E + I_{CBO} \quad (18)$$

$$\Rightarrow I_C = \alpha_{dc} (I_C + I_B) + I_{CBO} \quad (\because I_E = I_C + I_B)$$

$$\Rightarrow I_c - \alpha_{dc} I_c = \alpha_{dc} I_B + I_{CBO}$$

$$\Rightarrow I_c(1 - \alpha_{dc}) = \alpha_{dc} I_B + I_{CBO}$$

\Rightarrow

$$I_c = \frac{\alpha_{dc}}{1 - \alpha_{dc}} I_B + \frac{1}{1 - \alpha_{dc}} I_{CBO} \quad \text{--- (18)}$$

$$I_c = \beta_{dc} I_B + (1 + \beta_{dc}) I_{CBO}$$

$$\frac{1}{1 - \alpha_{dc}} = \frac{1}{1 - \beta_{dc}} \cdot \frac{1}{1 + \beta_{dc}}$$

$$\Rightarrow = \frac{1}{1 + \beta_{dc} - \beta_{dc}}$$

$$\frac{1}{1 - \alpha_{dc}} = 1 + \beta_{dc} \quad \text{--- (20)}$$

⑤ At room temperature

For Si transistor, $I_{CBO} @ I_C \rightarrow 0 \text{ A}$ (can be neglected)

For Ge transistor, $I_{CBO} @ I_C \rightarrow 0 \text{ A}$ (cannot be neglected)

⑥ The value of I_{CBO} is strongly temperature dependent for both Si & Ge. It doubles for every 10°C increase in temperature.

⑦ Si transistors can be used upto 200°C

Ge transistors can be used upto 100°C

⑧ For common emitter configuration. (Common collector)

$$I_c = \beta_{dc} I_B + (1 + \beta_{dc}) I_{CEO}$$

$$\Rightarrow I_c = \beta_{dc} I_B + I_{CEO} \quad \text{--- (21)}$$

Where, $I_{CEO} \rightarrow \underbrace{\text{Collector-Emitter current with base open}}$

$$= (1 + \beta_{dc}) I_{CBO} \quad \text{--- (22)}$$

Emitter current,

$$I_E = I_c + I_B$$

Using (21) we get

$$I_E = \underline{\beta_{dc} I_B} + \underline{I_{CEO}} + \underline{I_B}$$

$$I_E = (1 + \beta_{dc}) I_B + I_{CEO} \quad \text{--- (22)}$$

* BJT amplification (① Transistor as an amplifier):

① Current amplification (② Transistor as a current amplifier):

→ The current amplifier (NPN transistor) is shown in fig ⑤.

→ A small change (Increase or decrease) in base current I_{Bc} (ΔI_B) produces a large change (Increase or decrease) in collector current (ΔI_c) & a large emitter current change (Increase or decrease) (ΔI_E) [Shown in fig ⑥ (a) & (b)]

→ The common emitter current gain is the ratio of change in collector current (ΔI_c) (output current) to the change in base current (ΔI_B) (input current).

It is denoted by B_{ac} or h_{fe}

$$\text{i.e } B_{ac} = \frac{\Delta I_c}{\Delta I_B}$$

Where, $\Delta I_c \rightarrow$ AC collector current, denoted by I_c

$\Delta I_B \rightarrow$ AC base current, denoted by I_B

$$\therefore B_{ac} = \frac{I_c}{I_b}$$

Ex: If $I_b = \pm 1 \text{ mA}$ (Assume $\beta = 100$), then,

$$I_c = B_{ac} I_b = 100 \times \pm 1 \text{ mA} = \pm 0.1 \text{ mA}$$

∴ A small change in the base current, produces a large change in collector current.

Hence transistor acts as current amplifier.

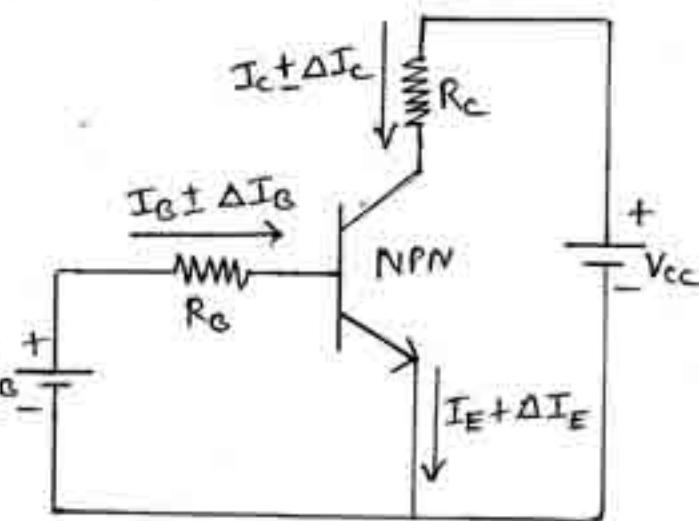


Fig ⑤: Current amplification

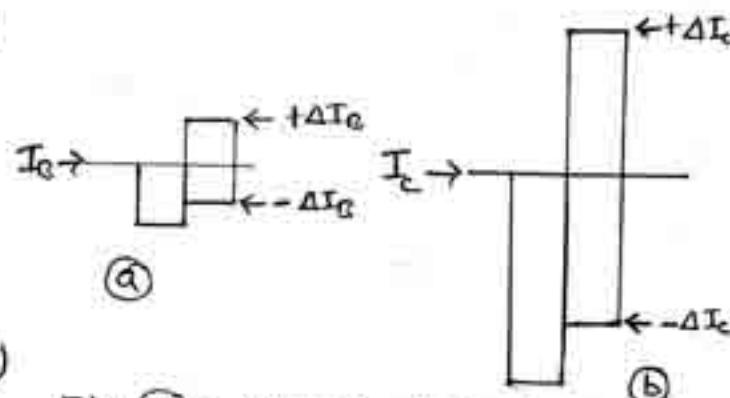


Fig ⑥: Base & collector currents

② Voltage amplification @ Transistor as a voltage amplifier:

→ The voltage amplification (NPN transistor) is shown in fig ⑦.

→ The dc voltage $V_{BE} = 0.7V$ forward biases the base-emitter junction.

→ An AC voltage source (V_i) in series with V_{BE} provides a $\pm 20mV$ input voltage variation.

→ Let the transistor is connected to a $V_{CC} = 20V$ dc voltage source via $R_C = 12k\Omega$. Let $B_{dc} = 50$

→ The V_{BE} vs I_B characteristics is shown in fig ⑧

→ Calc(i): When $V_i = 0V$, $V_{BE} = 0.7V$
From the characteristic,
 $I_B = 20mA$

Collector current,

$$I_C = B_{dc} I_B = 50 \times 20 \times 10^{-3} = 1mA$$

Collector Voltage, (APPLYING KVL to loop containing V_{CC} , R_C & V_C)

$$V_C = V_{CC} - I_C R_C = 20V - 1 \times 10^{-3} \times 12 \times 10^3 = 8V$$

- Calc(ii): When $V_i = \pm 20mV$

From the characteristic, change in base current,

$$\Delta I_B = \pm 5mA$$

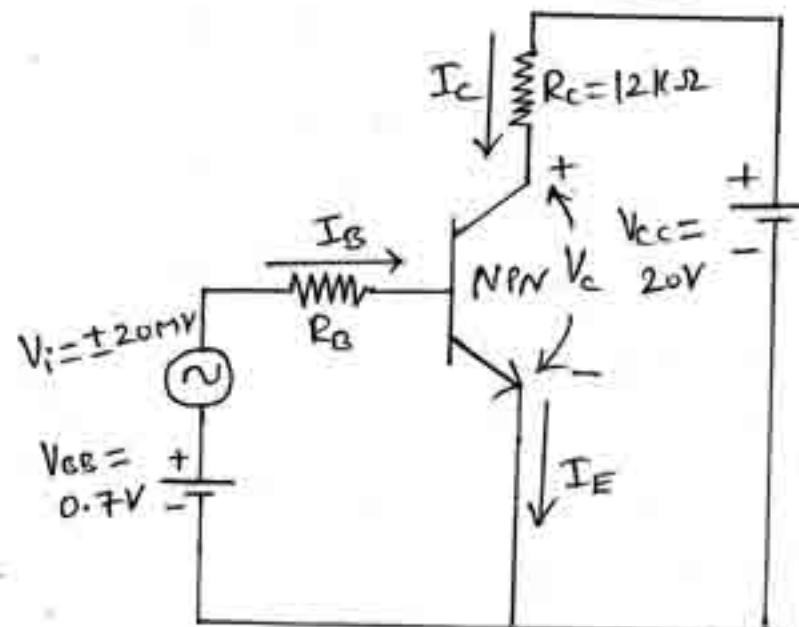


Fig ⑦: Voltage amplification

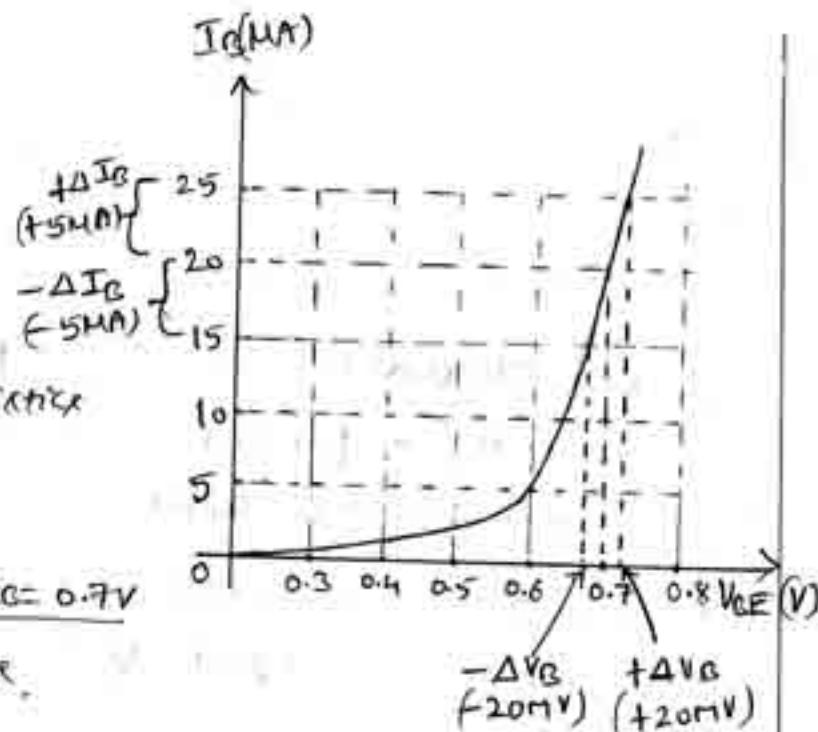


Fig ⑧: V_{BE} vs I_B Characteristics

Change (Variation) in collector current,

$$\Delta I_c = \beta_{dc} I_B = 50 (\pm 5 \text{ mA}) = \pm 250 \text{ mA}$$

Change (Variation) in collector voltage,

$$\Delta V_c = \Delta I_c \times R_C = \pm 250 \text{ mA} \times 12 \text{ k}\Omega = \pm 3 \text{ V}$$

→ Since the output voltage ($\Delta V_c = \pm 3 \text{ V}$) is greater than the input voltage ($\Delta V_B = \pm 20 \text{ mV}$), the transistor circuit is a voltage amplifier.

→ Voltage gain (A_v) is the ratio of the output voltage to the input voltage.

$$i.e. A_v = \frac{\Delta V_c}{\Delta V_B} = \frac{\pm 3 \text{ V}}{\pm 20 \text{ mV}} = 150$$

* Transistor characteristics @ Characteristics of transistor

The important characteristics of transistor are

- ① Input characteristics
- ② Output characteristics
- ③ Current gain characteristics.

① Input characteristic: It is a plot of input current as a function of input voltage, keeping the output voltage constant.

② Output characteristic: It is a plot of output current vs output voltage at constant input current.

③ Current gain characteristic @ Forward transfer characteristic: It is a plot of output current vs input current at constant output voltage.

① Common base configuration:

Fig(29) shows Common base PNP transistor.

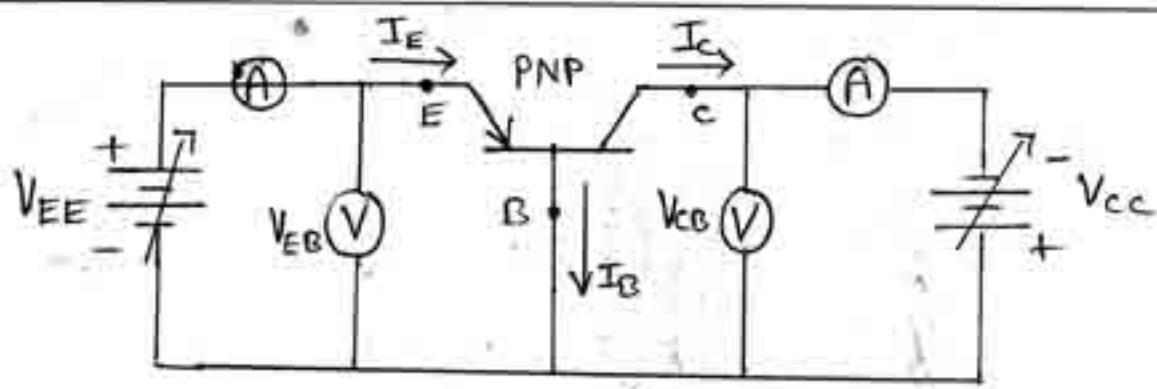


Fig (29): Common base PNP transistor

→ Input Characteristics: (Fig 30)

- It is a plot of input current (I_E) vs input voltage (V_{EB}) at constant output voltage (V_{CB}).

• Procedure:

- ① Keeping V_{CB} constant at particular value, increase V_{EB} in small suitable steps & notedown the corresponding values of I_E .
- ② The above step is repeated for different output voltage (V_{CB}) values.
- ③ A graph of I_E along Y-axis & V_{EB} along X-axis for each value of V_{CB} is plotted.

• Observations:

- ① Below threshold voltage ② Offset Voltage ③ cut-off voltage ④ Knee Voltage ' V_n ', I_E is negligibly small ($V_n \approx 0.3V$ for Ge & $0.7V$ for Si)
- ⑤ Beyond V_n , for a fixed V_{CB} voltage, the I_E increases rapidly with a small increase in V_{EB}
- ⑥ As V_{CB} is increased, the curves shift upwards.
- ⑦ AC input resistance.

$$R_i = \frac{\Delta V_{EB}}{\Delta I_E} \quad | \quad V_{CB} = \text{constant} \quad \begin{cases} (I_t \text{ is very low}) \\ (\text{typically } 50\Omega) \end{cases}$$

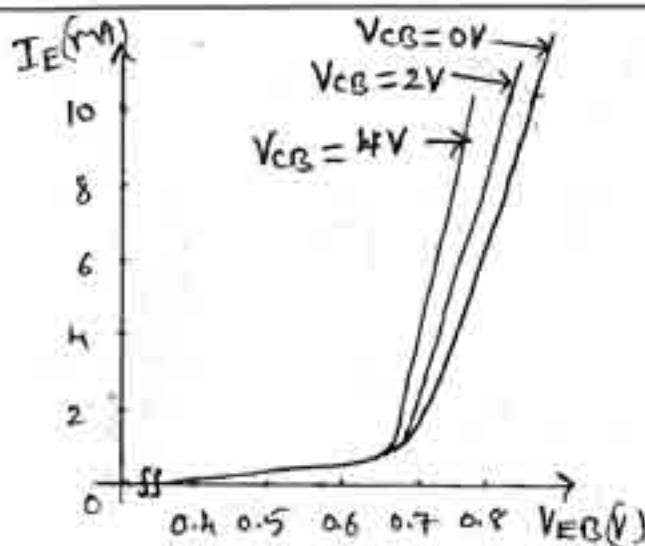


Fig ⑩: Input characteristics

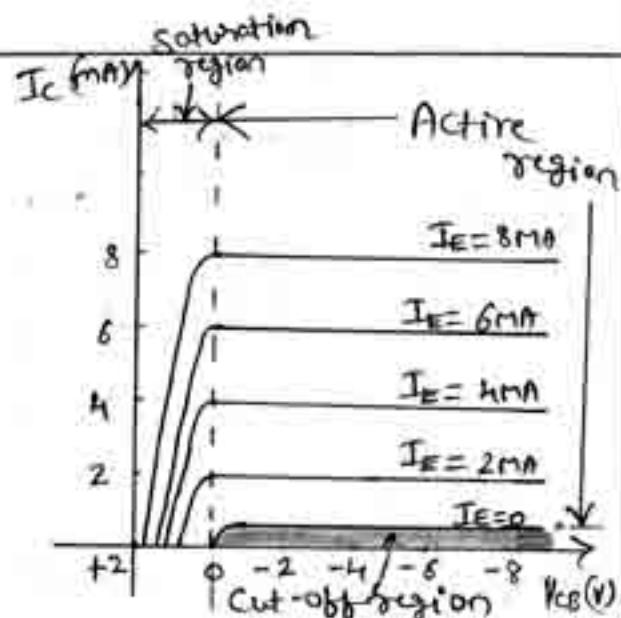


Fig ⑪: Output characteristics

→ Output characteristics (Fig 31)

- It is a plot of output current (I_c) vs output voltage (V_{CB}) at constant input current (I_E).
- Procedure:
 - ① Keeping I_E constant at particular value, increase V_{CB} in suitable steps & notedown (record) the corresponding value of I_c .
 - ② The above step is repeated for different input current values (I_E)
 - ③ A graph of V_{CB} along X-axis & I_c along Y-axis for each value of I_E is plotted.
- Observations:
 - ① The output characteristic has three important regions namely Saturation region, active region & cut-off region.

Saturation region

- ② It is the region to the left of the vertical dashed line
- ③ In this region, both emitter-base & collector-base

junctions are forward biased.

- ④ In this region, a small change in V_{CB} results in a large value of current I_C .

Active Region

- ⑤ It is the region between the vertical dashed line & the horizontal axis.
- ⑥ In this region, emitter-base junction is forward biased & collector-base junction is reverse biased.
- ⑦ In this region, the collector current is constant and is equal to the emitter current.

Cut-off Region

- ⑧ It is the region along the horizontal axis as shown by a shaded region.
- ⑨ In this region, both emitter-base & collector-base junctions are reverse biased.
- ⑩ It corresponds to the curve marked $I_E = 0$.
- ⑪ I_C flows even when the V_{CB} is zero.
- ⑫ A small collector current (Leakage current ' I_{CBO} ') flows even when $I_E = 0$.
- ⑬ I_C is practically independent of V_{CB} in the active region. However, if V_{CB} is increased beyond a certain large value, the collector current increases rapidly due to avalanche breakdown (not shown in fig) & the transistor action is lost.
- ⑭ AC output resistance.

$$R_o = \frac{\Delta V_{CB}}{\Delta I_C} \Big| I_E = \text{constant} \quad (\text{It is very high & typically about } 500 \text{ k}\Omega)$$

(28)

→ Current gain characteristic (Forward transfer characteristic) (Fig 32)

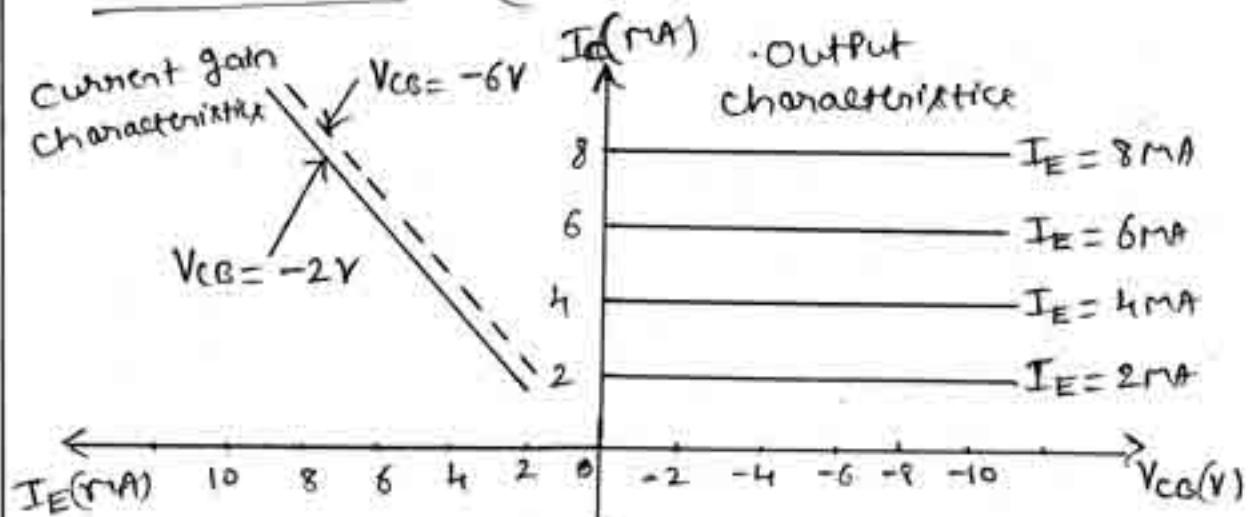


Fig 32: Current gain characteristic

- It is a plot of output current (I_C) versus input current (I_E) at constant output voltage (V_{CE}).
- Procedure:
 - ① Keeping V_{CB} constant at particular value, I_C is measured for various levels of I_E .
 - ② A graph of I_C vs I_E is plotted.

2) Common Emitter Configuration:

Fig 33 Shows Common Emitter PNP transistor.

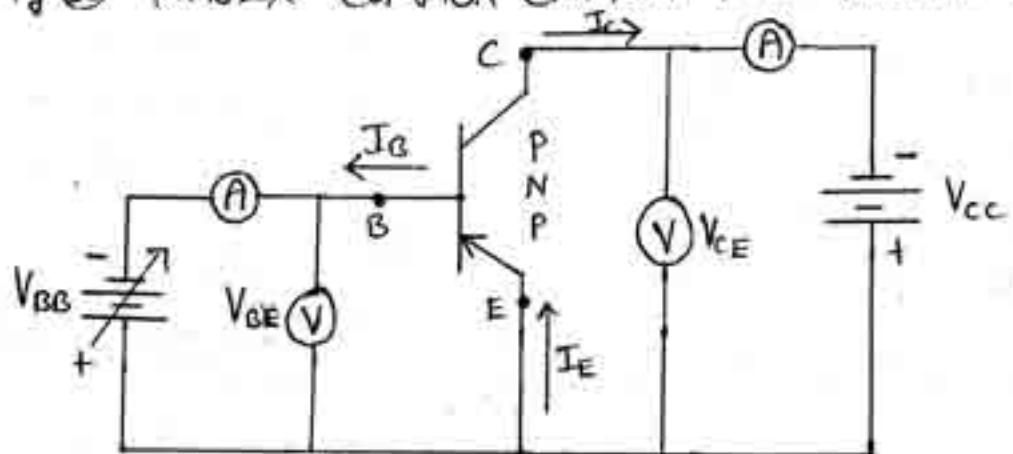


Fig 33: Common Emitter PNP transistor

\rightarrow Input Characteristics (Fig 34)

- It is a plot of input current (I_B) vs input voltage (V_{BE}) at constant output voltage (V_{CE}).

• Procedure:

- Keeping V_{CE} constant at particular value, increase V_{BE} in small suitable steps & notedown the corresponding values of I_B .
- The above step is repeated for different output voltage (V_{CE}) values.
- A graph of I_B along Y-axis & V_{BE} along X-axis for each value of V_{CE} is plotted.

• Observations:

- Below threshold voltage @ knee voltage ' V_n ', I_B is negligibly small.
- Beyond V_n , for a fixed V_{CE} voltage, the I_B increases rapidly w/ a small increase in V_{BE} .
- As V_{CE} is increased, the curves shift downwards.
- AC input resistance.

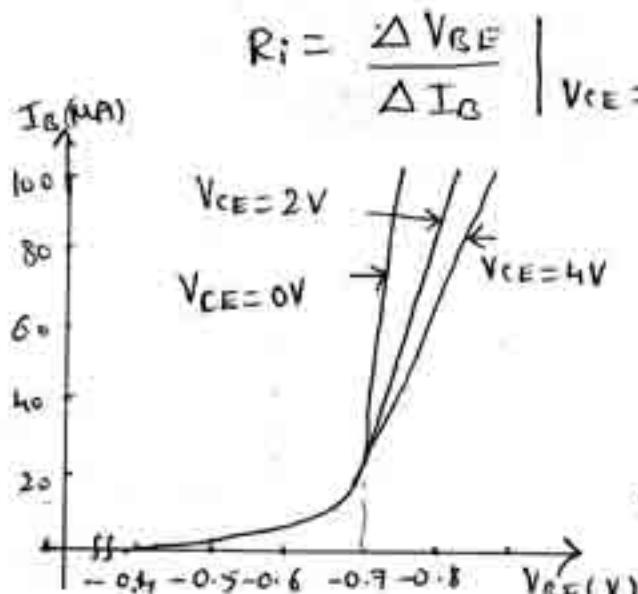


Fig 34: Input characteristics

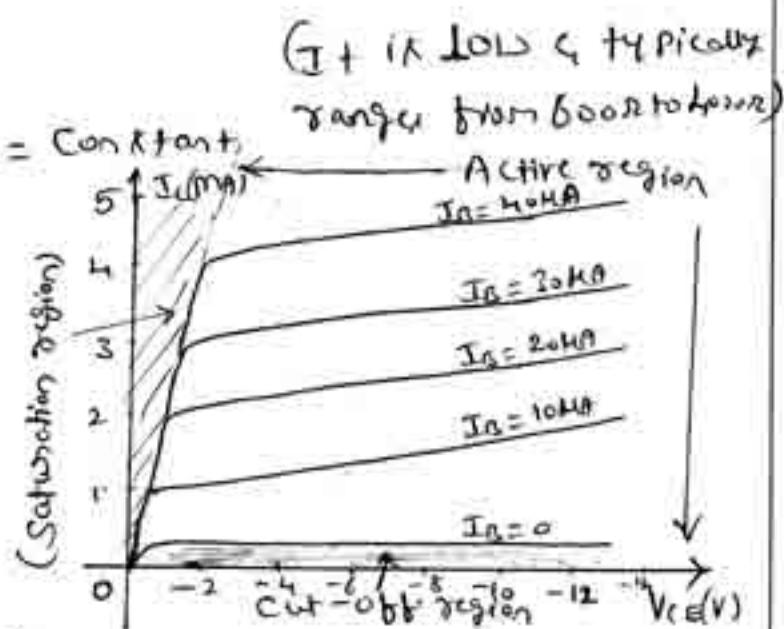


Fig 35: Output characteristics

→ Output Characteristics (Fig 35)

- It is a plot of output current (I_C) vs output voltage (V_{CE}) at constant input current (I_B).

• Procedure:

- ① Keeping I_B constant at particular value, increase V_{CE} in suitable steps & note down the corresponding values of I_C .
- ② The above step is repeated for different input current values (I_B).
- ③ A graph of V_{CE} along x-axis & I_C along y-axis for each value of I_B is plotted.

• Observation:

- ① The output characteristics has three important regions namely saturation region, active region & cut-off region.

Saturation region:

- ④ It is the region shown by the shaded area.
- ⑤ In this region, both base-emitter & collector-emitter junctions are forward biased.
- ⑥ In this region, a small change in V_{CE} results in a large value of current I_C .

Active region

- ⑦ It is the region between the saturation & cut-off region.
- ⑧ In this region, base-emitter junction is forward biased & collector-emitter junction is reverse biased.
- ⑨ In this region, when V_{CE} is increased further, I_C increases slightly.

Cut-off region

- ① It is the region along the horizontal axis as shown by a shaded region (Corresponds to curve marked $I_B = 0$)
- ② In this region, both base-emitter & collector-emitter junctions are reverse biased.
- ③ I_C increases rapidly to a saturation value when V_{CE} is increased above zero (depending upon the value of I_B)
- ④ A small collector current (leakage current I_{C00}) flows even when $I_B = 0$.
- ⑤ If V_{CE} is increased beyond a certain value, the I_C increases rapidly due to avalanche breakdown (not shown in fig) & the transistor action is lost.
- ⑥ AC output resistance.

$$R_o = \left. \frac{\Delta V_{CE}}{\Delta I_C} \right|_{I_B=\text{constant}} \quad \begin{array}{l} (\text{It is high & typically ranges}) \\ \text{from } 10\text{ k}\Omega \text{ to } 50\text{ k}\Omega \end{array}$$

→ Current gain ⑦ Forward transfer characteristic (Fig 36)

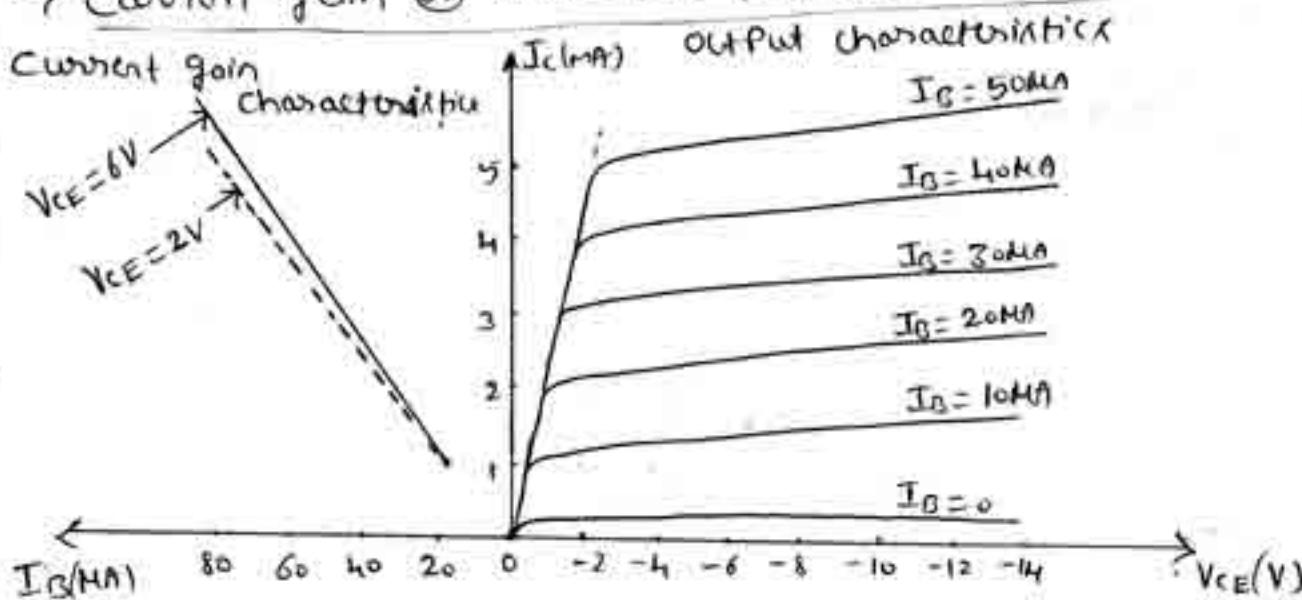


Fig 36: Current gain characteristics

- It is a Plot of Output current (I_C) Versus Input current (I_B) at constant output voltage (V_{CE}).

- Procedure

- ① Keeping V_{CE} constant at particular value, I_C is measured for various levels of I_B .
- ② A graph of I_C vs I_B is plotted.
- Current gain characteristic can be obtained experimentally (Fig 33) or derived from the output characteristic (Fig 36).

- ③ Common Collector Configuration:

Fig 37 Shows Common collector PNP transistor

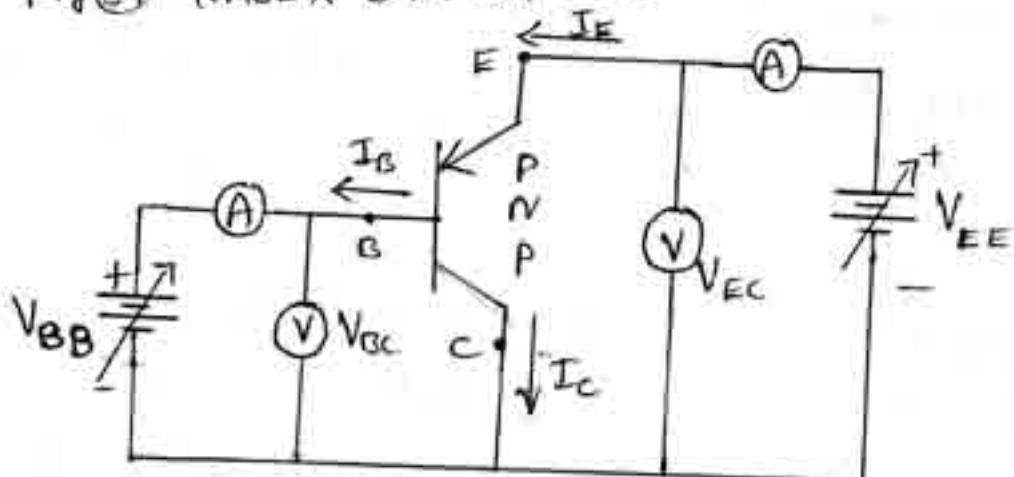


Fig 37: Common collector PNP transistor

→ Input Characteristic (Fig 39)

- It is a plot of input current (I_B) vs input voltage (V_{BC}) at constant output voltage (V_{EC}).

- Procedure:

- ① Keeping V_{EC} constant at particular value, increase V_{BC} in small suitable steps & note down the corresponding values of I_B .
- ② The above step is repeated for different output voltage values (V_{EC}).
- ③ A graph of I_B along y-axis & V_{BC} along x-axis

for each value of V_{EC} is plotted.

- Observations:

- ① Applying KVL around the transistor, (Fig 37 or Fig 38)

$$V_{EC} - V_{EB} - V_{BC} = 0$$

\Rightarrow

$$V_{EB} = V_{EC} - V_{BC}$$

- ② Increasing V_{BC} with V_{EC} held

constant reduces the V_{EB} & thus

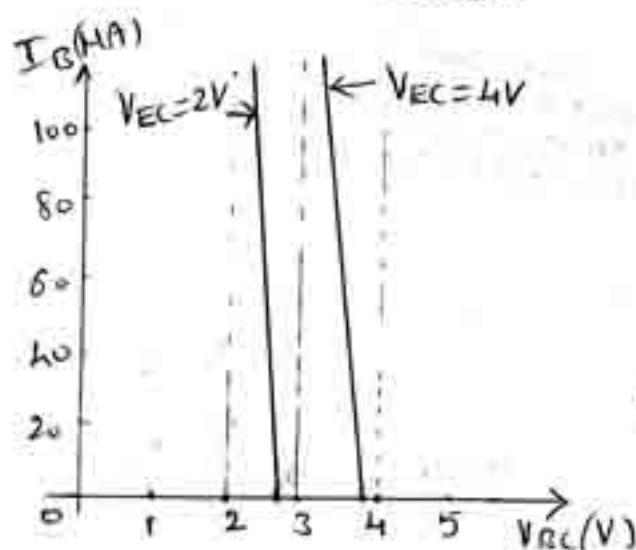
reduces I_B . This explains the slope of the CC Input Characteristic.

- ③ As V_{EC} is increased, the curve shift right side.

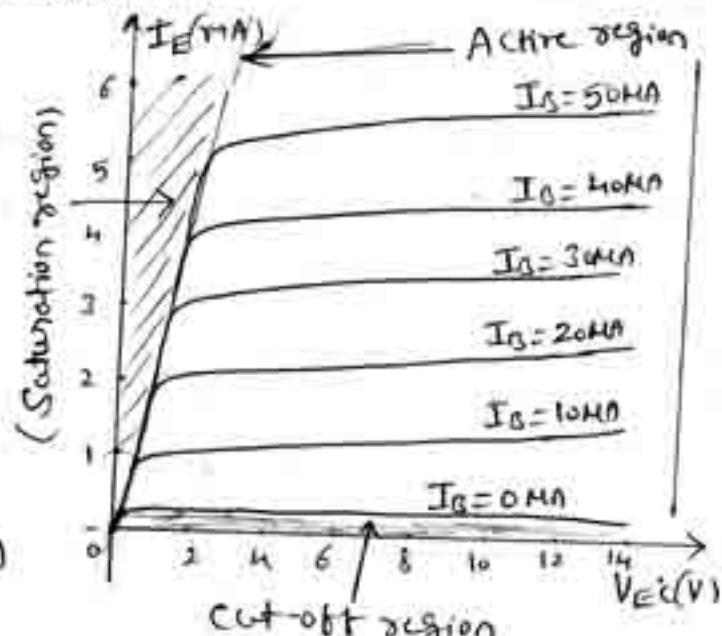
- ④ AC input resistance

$$R_i = \frac{\Delta V_{BC}}{\Delta I_B} \quad | \quad V_{EC} = \text{constant}$$

(It is very high \approx about $750\text{ k}\Omega$).



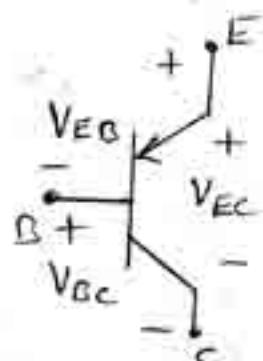
Fig(39): Input characteristics



Fig(40): Output characteristics

→ Output Characteristics (Fig 40)

- It is a plot of output current (I_E) vs output voltage (V_{EC}) at constant input current (I_B).



Fig(38): Common collector CC

• Procedure:

- ① Keeping I_B constant at Particular Value, increase V_{EC} in Suitable Steps & notedown the Corresponding Value of I_E
- ② The above step is repeated for different Input Current Values I_B .
- ③ A graph of V_{EC} along x-axis & I_E along y-axis for each value of I_B is plotted.

• Observations:

- ① The Output Characteristic has three important regions namely Saturation, active & cut-off region.

Saturation region

- ② It is the region shown by the shaded area.
- ③ In this region, both base-collector & emitter-collector junctions are forward biased.
- ④ In this region, a small change in V_{EC} results in a large value of current I_E .

Active region

- ⑤ It is the region between the saturation & cut-off region.
- ⑥ In this region, base-collector junction is forward biased & emitter-collector junction is reverse biased.
- ⑦ In this region, when V_{EC} is increased further, I_E increases slightly.

Cut-off region

- ⑧ It is the region along the horizontal axis at $I_B = 0$, shown by a shaded area (corresponds to curve marked

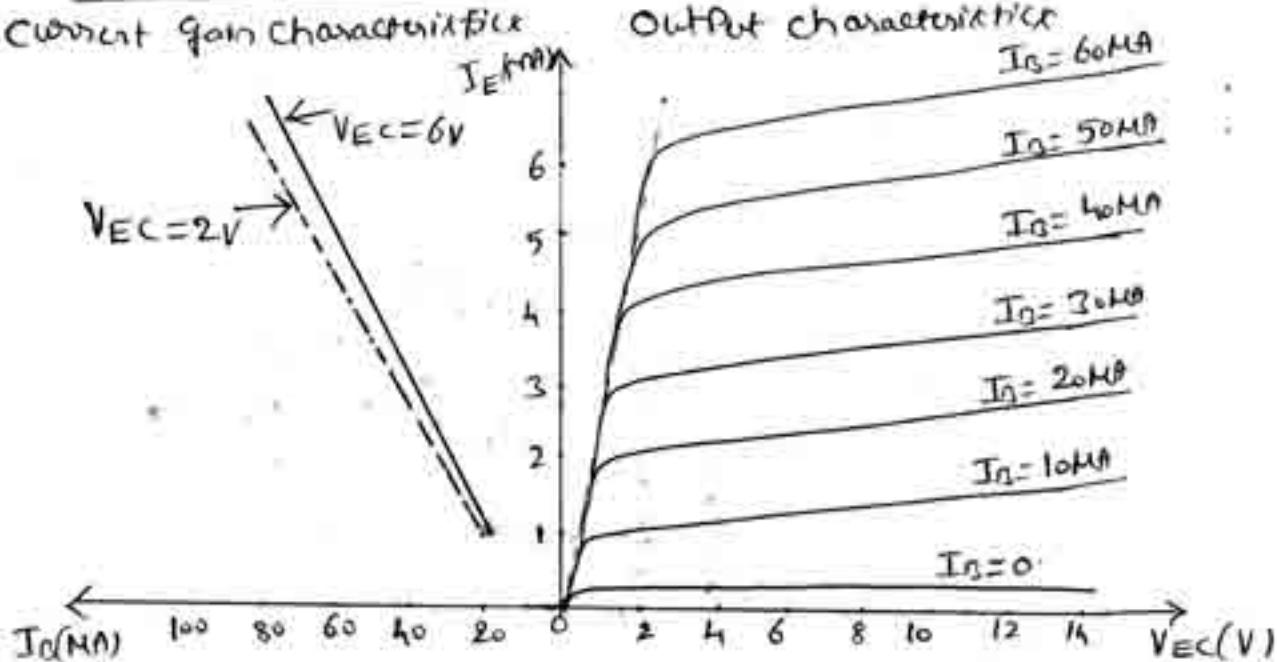
- ⑥ In this region, both base-collector & emitter-collector junctions are reverse biased.
- ⑦ I_E increases rapidly to a saturation value, when V_{EC} is increased above zero (depending upon the value of I_B)
- ⑧ A small collector current (leakage current I_{CBO}) flows even when $I_B = 0$.
- ⑨ In V_{EC} is increased beyond a certain value, the I_C increases rapidly due to avalanche breakdown (not shown in fig) & the transistor action is lost.
- ⑩ AC output resistance

$$R_o = \frac{\Delta V_{EC}}{\Delta I_E} \quad | I_B = \text{constant} \quad \left(\begin{array}{l} \text{It is very low & it} \\ \text{about } 50\Omega \end{array} \right)$$

→ Current gain @ Forward bias for characteristic (Fig 41)

Current gain characteristic

Output characteristic



Fig(41): Current gain characteristic

- It is a plot of output current (I_E) versus input current (I_B) at constant output voltage (V_{EC})
- Current gain characteristic can be obtained experimentally (Fig 37) or derived from the output characteristic (Fig 41)

• Procedure

- (1) Keeping V_{EC} constant at particular value, I_E is measured for various values of I_B .
- (2) A graph of I_E vs I_B is plotted.

Note: (1) In transistor, voltage breakdown occurs in two types namely

(2) Avalanche breakdown: It is a form of voltage breakdown that arises, when the electrons & holes in the semiconductor are accelerated enough by the applied voltage. The accelerated electrons & holes collide with the bound electrons and produce more free electrons. This causes even more collisions due to which current increases to a large value.

(3) Punch through or reach-through: It is a form of voltage breakdown that arises due to the increased width of collector or base junction depletion region with increased collector-base junction voltage. (This phenomenon of reducing the base width is called carrier effect or base-width modulation). The depletion region at a junction is the region of fixed ions on both sides of the junction. As the applied voltage across the junction increases, the depletion region penetrates deeper into the base. Since the base is very thin, therefore it is possible that at moderate voltages, the depletion region will have spread completely across the base to reach the emitter-base junction. As a result of this, the current increases to a very large value.

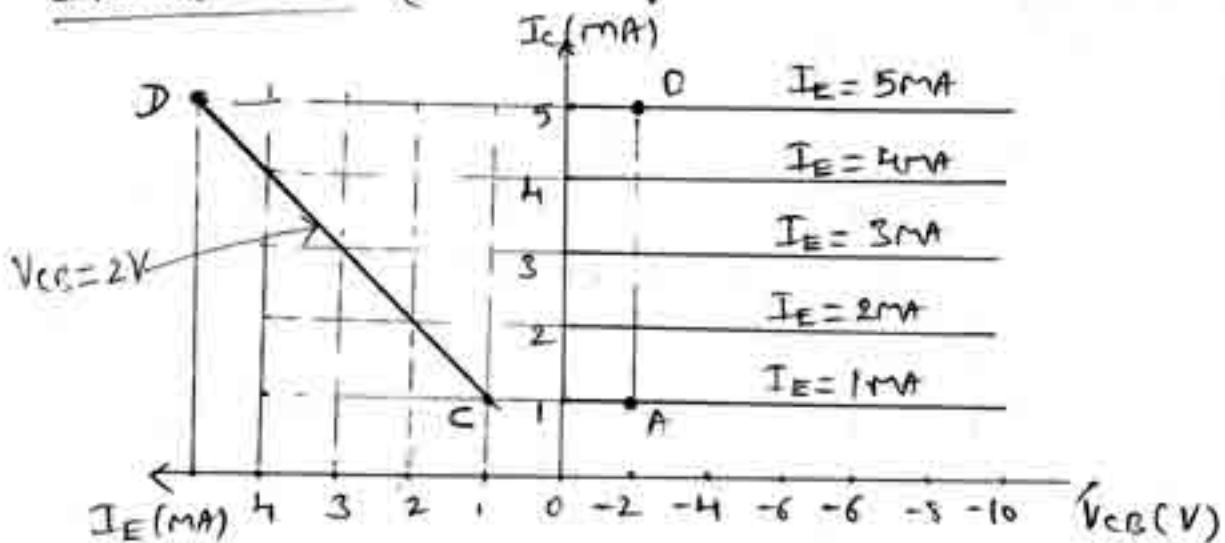
② Common emitter circuit is most efficient

Main reasons are

- ① High current gain: In CE connection, $I_c = \beta I_B @$
 $I_c = \beta I_B + I_{CBO}$. As β_{ac} is very large, the output current I_c is much more than I_B .
 \therefore current gain in CE arrangement is very high (20 to 500)
- ② High Voltage & Power gain: Due to high current gain, CE Ckt has the highest Voltage & Power gain.
- ③ Moderate output to input impedance ratio: In CE Ckt, the ratio of output impedance to input impedance is small (about 20). So it is ideal one for coupling between various transistor stages. [In CB & CC Ckt this ratio is very large]

③ During current gain characteristic from output

characteristic (Considering CB configuration)



Let $V_{CB} = -2\text{V}$

Step 1: Draw a vertical line through given V_{CB} value.

Step 2: Line intersects the characteristic at points A & B
 (Notedown $I_E \approx I_t$) (Here $I_E \approx I_C$)

Step 3: Plot Points C & D for the output characteristic

at the corresponding JRC of I_C & I_E .

Step 4: Draw the characteristic through points C & D.

(A) Advantages, Disadvantages & Applications of Transistor

Advantages:

- They are mechanically strong
- Much Smaller
- More Compact
- Light Weight
- Practically unlimited life (Last for many years)
- No heater requirement
- Transistors along with resistors and diodes can be integrated to produce ICs
- No heater loss
- Low operating voltage
- No warm-up period
- Less power consumed by the device itself
- High voltage gain

Disadvantages:

- Drive circuit of BJT is complex
- Storage charge in base reduces switching frequencies
- Cannot be used in high power applications
- Lower input impedance
- Temperature dependence
- Inherent variation of parameters (β for 148 transistors may vary between 100 & 600)

Applications:

- | | |
|--------------------------------------|----------------------|
| • Switched Mode Power Supply(SMPS) | • Amplifiers |
| • DC to DC converter(Choppers) | • Switches |
| • Bridge inverters | • Impedance matching |
| • Power factor correction techniques | |

(3) Comparison of CB, CE & CC Configurations

| SL no. | Characteristic | CB | CE | CC |
|--------|------------------------------|---------------------------------|----------------------------------|---------------------------------|
| 1) | Input resistance | Very low (50Ω) | Low (600Ω) | Very high ($750k\Omega$) |
| 2) | Output resistance | Very high ($500k\Omega$) | High ($10k\Omega$) | Low (50Ω) |
| 3) | Current gain | Less than unity | Greater than unity | Greater than unity |
| 4) | Voltage gain | Medium (about 100) | Medium (about 500) | Low (< 1) |
| 5) | Input current | I_E | I_B | I_B |
| 6) | Output current | I_C | I_C | I_E |
| 7) | Input terminals | $E \& B$ | $B \& E$ | $B \& C$ |
| 8) | Output terminals | $C \& B$ | $C \& E$ | $E \& C$ |
| 9) | Current amplification factor | $\alpha_{dc} = \frac{I_C}{I_E}$ | $\beta_{dc} = \frac{I_C}{I_B}$ | $\gamma_{dc} = \frac{I_E}{I_C}$ |
| 10) | Phase between input & output | In-Phase (0°) | Out-of-Phase (180°) | In-Phase (0°) |
| 11) | Applications | For high frequency applications | For audio frequency applications | For impedance matching |

Problems

- ① In a common base connection, a certain transistor has an emitter current of 10mA & a collector current of 9.8mA. Calculate the value of the base current.

Sol: Given $I_E = 10\text{mA}$, $I_C = 9.8\text{mA}$, $I_B = ?$

$$\text{We have, } I_E = I_C + I_B$$

$$\begin{aligned} \Rightarrow I_B &= I_E - I_C \\ &= 10 \times 10^{-3} - 9.8 \times 10^{-3} \\ &\boxed{I_B = 0.2\text{mA}} \end{aligned}$$

- ② In a common-base connection, the emitter current is 6.28mA & the collector current is 6.20mA. Determine the common-base dc current gain.

Sol: Given $I_E = 6.28\text{mA}$, $I_C = 6.20\text{mA}$, $\alpha_{dc} = ?$

$$\text{We have, } \alpha_{dc} = \frac{I_C}{I_E} = \frac{6.20 \times 10^{-3}}{6.28 \times 10^{-3}} = \underline{\underline{0.987}}$$

- ③ The common-base dc current gain of a transistor is 0.967. If the emitter current is 10mA, what is the value of base current?

Sol: Given $\alpha_{dc} = 0.967$, $I_E = 10\text{mA}$, $I_B = ?$

$$\begin{aligned} \text{We have, } I_C &= \alpha_{dc} I_E \quad \left(\because \alpha_{dc} = \frac{I_C}{I_E} \right) \\ &= 0.967 \times 10 \times 10^{-3} \\ I_C &= 9.67\text{mA} // \end{aligned}$$

$$\text{But } I_E = I_C + I_B$$

$$\begin{aligned} \Rightarrow I_B &= I_E - I_C = 10 \times 10^{-3} - 9.67 \times 10^{-3} \\ &\therefore \boxed{I_B = 0.33\text{mA}} // \end{aligned}$$

- ⑤ ④ A transistor has an α of 0.975, what is the value of β ⑥ if $\beta = 200$, what is the value of α ?

Sol: ④ Given $\alpha = 0.975, \beta = ?$

We have, $\beta = \frac{\alpha}{1-\alpha}$

$$\begin{aligned} &= \frac{0.975}{1-0.975} \\ &= 39 // \end{aligned}$$

⑤ Given, $\beta = 200, \alpha = ?$

We have, $\alpha = \frac{\beta}{1+\beta}$

$$\begin{aligned} &= \frac{200}{200+1} \\ &= 0.995 // \end{aligned}$$

- ⑥ A transistor has a typical β of 100. If the collector current is 40mA, what is the emitter current?

Sol: Given $\beta = 100, I_C = 40\text{mA}, I_E = ?$

We have $I_B = \frac{I_C}{\beta} \quad (\because \beta = \frac{I_C}{I_B})$

$$\begin{aligned} &= \frac{40 \times 10^{-3}}{100} \\ &= 0.4 \text{mA} @ 400 \text{mA} // \end{aligned}$$

Now, $I_E = I_C + I_B = 0.4 \times 10^{-3} + 40 \times 10^{-3} = \underline{\underline{40.4 \text{mA}}}$

- ⑦ A transistor has $\beta = 150$. calculate the approximate collector & base currents, if the emitter current is low

Sol: Given, $\beta = 150, I_E = 10\text{mA}, I_B = ?, I_C = ?$

We have $\alpha = \frac{\beta}{1+\beta} = \frac{150}{1+150} = 0.993$

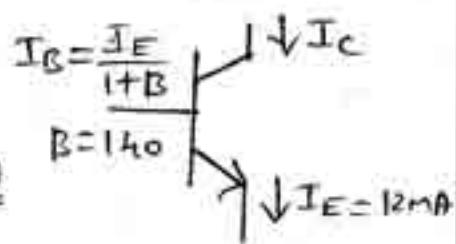
Also $\alpha = \frac{I_C}{I_E}$

$$\Rightarrow I_C = \alpha I_E = 0.993 \times 10 \times 10^{-3} = 9.93 \text{mA} //$$

Now, $I_B = I_E - I_C = 10 \times 10^{-3} - 9.93 \times 10^{-3} = \underline{\underline{0.07 \text{mA}}} \quad (\because I_E = I_C + I_B)$

(3)

- ⑦ Determine the value of I_C & I_B for circuit shown in fig ⑦



Sol:

$$\text{Given } I_E = 12 \text{ mA}, \beta = 140, I_B = \frac{I_E}{1 + \beta}$$

$$\therefore I_B = \frac{12 \times 10^{-3}}{1 + 140} = 0.085 \text{ mA}$$

$$\text{Now } I_C = I_E - I_B = 12 - 0.085 \times 10^{-3} = 11.915 \text{ mA}.$$

- ⑧ A transistor has $I_B = 10.5 \text{ mA}$ & $I_C = 2.05 \text{ mA}$. Find
 ① β ② α ③ I_E ④ If I_B changes by 27 mA &
 I_C changes by 0.65 mA , find the new value of β .

Sol: Given $I_B = 10.5 \text{ mA}$, $I_C = 2.05 \text{ mA}$. ① $\beta = ?$, ② $\alpha = ?$, ③ $I_E = ?$

① $I_B' = I_B + 27 \text{ mA}$, $I_C' = I_C + 0.65 \text{ mA}$, $\beta' = ?$

$$\textcircled{1} \quad \beta = \frac{I_C}{I_B} = \frac{2.05 \times 10^{-3}}{10.5 \times 10^{-6}} = 19.5\%.$$

$$\textcircled{2} \quad \alpha = \frac{\beta}{1 + \beta} = \frac{19.5}{1 + 19.5} = 0.95\%.$$

$$\textcircled{3} \quad I_E = I_B + I_C = 10.5 \times 10^{-6} + 2.05 \times 10^{-3} = 2.155 \text{ mA}.$$

$$\textcircled{4} \quad I_B' = I_B + 27 \text{ mA} = 10.5 \times 10^{-6} + 27 \times 10^{-6} = 132 \times 10^{-6} \text{ A}$$

$$I_C' = I_C + 0.65 \text{ mA} = 2.05 \times 10^{-3} + 0.65 \times 10^{-3} = 2.7 \times 10^{-3} \text{ A}$$

New value of β , $\beta' = \frac{I_C'}{I_B'} = \frac{2.7 \times 10^{-3}}{132 \times 10^{-6}} = 20.5$

- ⑨ A certain transistor has $\alpha = 0.98$, $I_{C0} = 5 \text{ mA}$ & $I_{B0} = 100 \text{ nA}$. Find the values of Collector & Emitter Currents.

Q1: Given $\beta = 0.98$, $I_{C0} = 5 \text{ mA}$, $I_B = 100 \mu\text{A}$, $I_C = ?$, $I_E = ?$

$$\text{Ans: } I_C = \frac{\beta}{1-\beta} I_B + \frac{I_{C0}}{1-\beta}$$

$$= \frac{0.98}{1-0.98} 100 \times 10^{-6} + \frac{5 \times 10^{-6}}{1-0.98}$$

$$\boxed{I_C = 5.15 \text{ mA}}$$

$$\text{Ans: } I_E = I_B + I_C = 100 \times 10^{-6} + 5.15 \times 10^{-6} = \underline{5.25 \text{ mA}}$$

- (10) A transistor has a maximum power dissipation of 500 mW at 25°C . The derating factor is $2.28 \text{ mW}/^\circ\text{C}$. What is the maximum power dissipation at 70°C ?

Q1: Given $P_{D(\max)} = 500 \times 10^{-3} \text{ W}$ at 25°C

$$\text{DF} = 2.28 \text{ mW}/^\circ\text{C}$$

$$P_{D(\max)} = ?, \text{ at } T = 70^\circ\text{C}$$

$$\text{Ans: } P_{D(\max)}(70^\circ\text{C}) = P_{D(\max)} - \text{DF}(T-25)$$

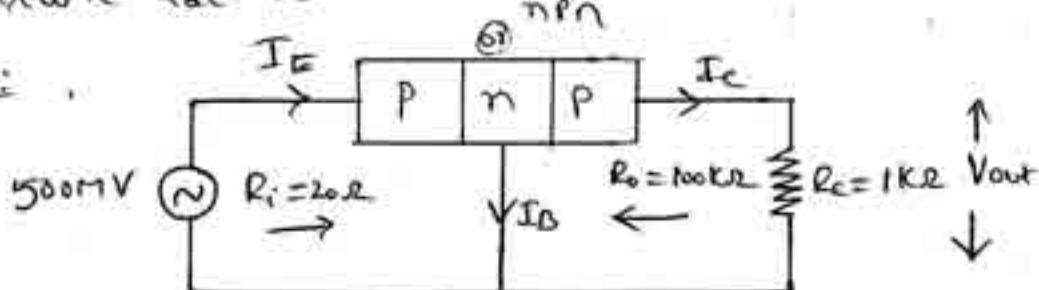
$$= 500 \times 10^{-3} - 2.28 \times 10^{-3} (70-25)$$

$$= \underline{0.397 \text{ W}}$$

- (11) A common base transistor amplifier has an input resistance of $20 \text{ k}\Omega$ & output resistance of $100 \text{ k}\Omega$. The collector load is $1 \text{ k}\Omega$ if a signal of 500 mV is applied between emitter and base, find the voltage amplification.

Assume β to be nearly one.

Q1:



Input current, $I_E = \frac{\text{Input Voltage}}{\text{Input Resistance}}$

$$= \frac{500 \times 10^{-3}}{20}$$

$$I_E = 25 \text{ mA}$$

Now, $I_C = I_E$

$$\underline{I_C = 25 \text{ mA}}$$

Output voltage,

$$V_{\text{out}} = I_C R_C$$

$$= 25 \times 10^{-3} \times 1 \times 10^3$$

$$= 25 \text{ V} //$$

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

$$I = \frac{I_C}{I_E} \quad \therefore \alpha_{dc} \approx 1$$

$$I_E = I_C$$

Voltage amplification (Voltage gain) is,

$$A_V = \frac{V_{\text{out}}}{\text{i/p Vtg}} = \frac{25}{500 \times 10^{-3}} = 50 //$$

- (12) In a Common base connection, the emitter current is 1mA. If the emitter circuit is open, the collector current is 50mA. Find the total collector current
Given $\alpha = 0.92$

Fol: Given, $I_E = 1 \text{ mA}$, $I_{CBO} = 50 \text{ mA}$. $I_C = ?$, $\alpha = 0.92$

Ans, $I_C = \alpha I_E + I_{CBO} = 0.92 \times 1 \times 10^{-3} + 50 \times 10^{-6}$

$$\boxed{I_C = 0.97 \text{ mA}} //$$

- (13) In a common base connection, $\alpha = 0.95$. The voltage drop across $2k\Omega$ resistance which is connected in the collector is 2V. Find the base current.

Fol: Fig (13) shows common base Ckt.

Given, $\alpha = 0.95$, $R_C = 2k\Omega$, $V_C = 2V$, $I_B = ?$

* We have, $I_C = \frac{V_C}{R_C} = \frac{2V}{2k\Omega} = 1mA$

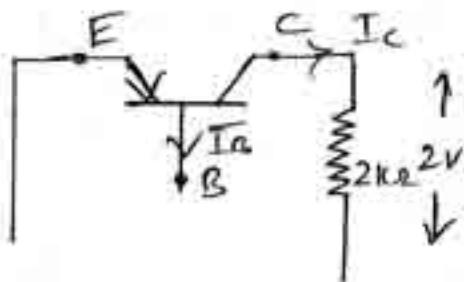


Fig 13

We have, $I_E = \frac{I_C}{\alpha} \quad (\because \alpha = \frac{I_C}{I_E})$
 $= \frac{1 \times 10^{-3}}{0.95}$
 $= 1.05mA$

Note $I_A = I_E - I_C = 1.05 \times 10^{-3} - 1 \times 10^{-3} = 0.05mA$

(4) For the common base C.R.T shown in fig 14, determine I_C & V_{CB} . Assume Si transistor.

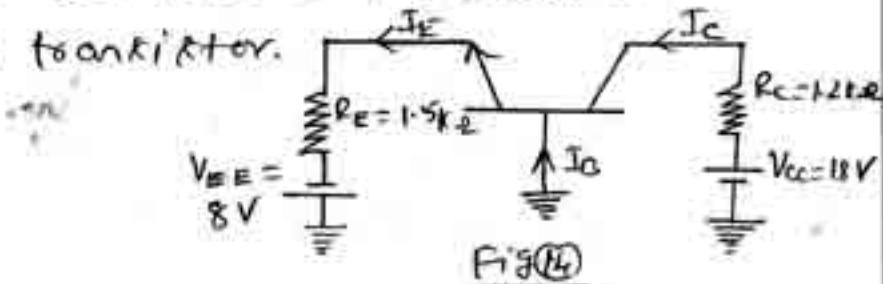


Fig 14

Sol: Given, $R_E = 1.5k\Omega$, $V_{EE} = 8V$, $R_C = 1.2k\Omega$, $V_{CC} = 18V$, $V_{BE} = 0.7V$ (Given Si transistor)

Applying KVL to emitter-side loop,

$$V_{EE} = I_E R_E + V_{BE}$$

$$\Rightarrow I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{8 - 0.7}{1.5 \times 10^3} = 4.87mA$$

Let $I_C \approx I_E \approx 4.87mA$...

Applying KVL to collector-side loop,

$$V_{CC} = I_C R_C + V_{CB}$$

$$\Rightarrow V_{CB} = V_{CC} - I_C R_C = 18 - 4.87 \times 10^{-3} \times 1.2 \times 10^3$$

$$V_{CB} = 12.16V$$

Actually

$$I_E = \frac{-V_{BE}}{R_E}$$

$$= \frac{-(V_{EE} - V_{CB})}{R_E}$$

(5) A transistor has $\alpha = 0.9$. If $I_E = 10mA$, find β , η , I_A

$\therefore I_C$

Given $\alpha = 0.9$, $I_E = 10mA$.

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = 9$$

$$\eta = 1 + \beta = 10$$

$$I_C = \alpha I_E = 0.9 \times 10 \text{mA} = 9 \text{mA} //$$

$$I_B = I_E - I_C = 10 \times 10^{-3} - 9 \times 10^{-3} = 1 \text{mA} //$$

Q6 Calculate α_{Bd} & β_{dc} for the transistor, if $I_C = 1 \text{mA}$.
 $I_B = 25 \mu\text{A}$. Determine the new base current to give
 $I_C = 5 \text{mA}$.

Given $I_C = 1 \text{mA}$, $I_B = 25 \mu\text{A}$.

$$\alpha_{dc} = ?, \quad \beta_{dc} = ?$$

Soln. $\beta_{dc} = \frac{I_C}{I_B} = \frac{1 \times 10^{-3}}{25 \times 10^{-6}}$

$$\boxed{\beta_{dc} = 40} //$$

Note,

$$\alpha_{dc} = \frac{\beta_{dc}}{1 + \beta_{dc}} = \frac{40}{1 + 40}$$

$$\boxed{\alpha_{dc} = 0.975} //$$

$$I_B' = ?$$

$$I_C' = 5 \text{mA}$$

We have

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

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

$$= \frac{5 \times 10^{-3}}{40}$$

$$\boxed{I_B' = 0.125 \text{mA}} //$$