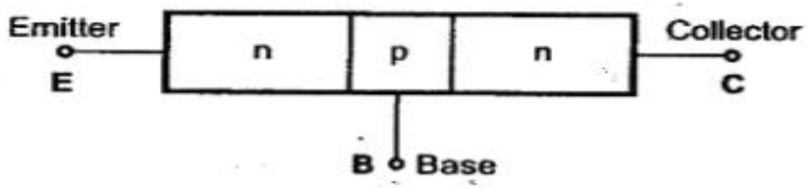
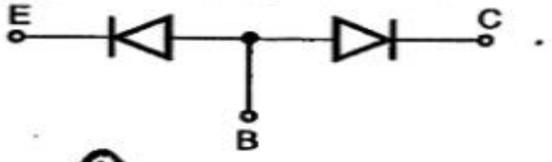
Transistor :-

A transistor consists of two PN junctions. The junctions are formed by Sandwiching either P-type or N-type semiconductor layers between a pair of opposite types as shown below. Transistors are of two types.

1) NPN Transistor :-

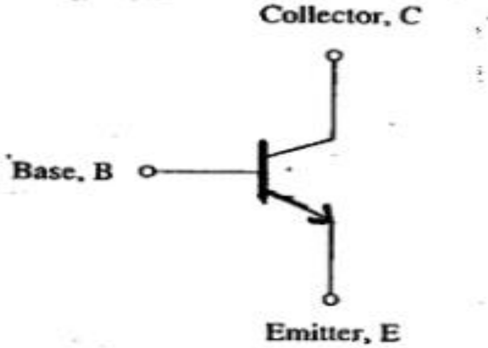


(a) n-p-n



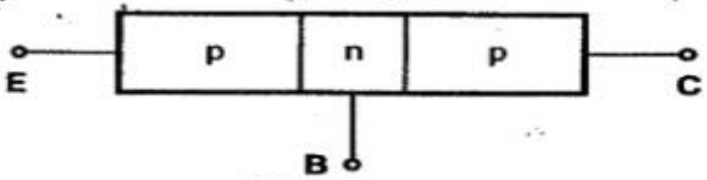
(b) n-p-n transistor

Fig. Two-diode transistor analogy

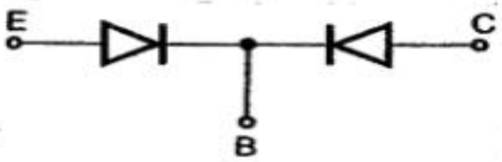


(c) Circuit symbol

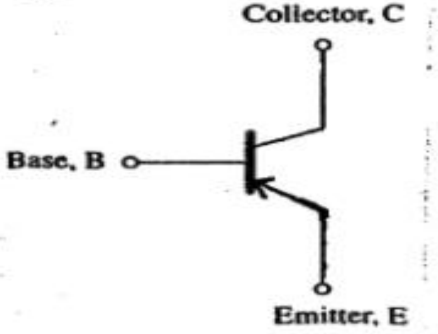
2) PNP Transistor :-



(a) p-n-p



(b) p-n-p transistor



(c) Circuit symbol

Transistor Terminals :-

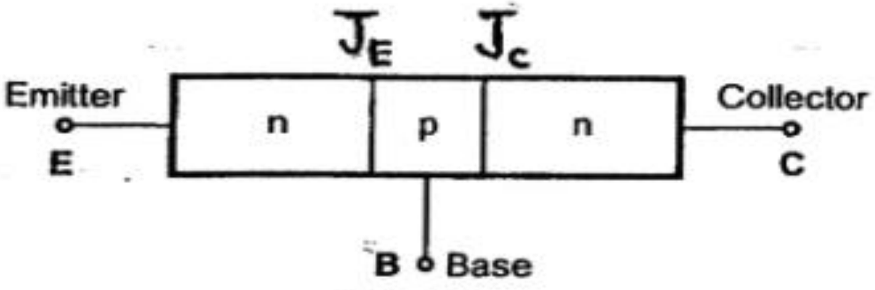
Transistor terminals are Emitter, Base & Collector.

- **Emitter (E):-**
  - Emitter is heavily doped than other two regions. Its function is to supply majority carriers (either electrons or holes) to the other two regions.
  - Emitter is always forward biased w.r.to base.

- **Base (B):-**
  - It is the middle region that forms two P-N junctions in the transistor.
  - The base is lightly doped & much thinner than the emitter & collector region.

- **Collector (C):-**
  - It is a region situated in the other side of transistor(i.e. the side opposite to the emitter), which collects charge carriers(i.e. holes & electrons).
  - The collector of a transistor is always larger than the emitter & base of a transistor.

Transistor Junctions :-

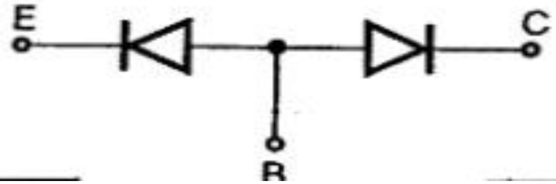


(a) n-p-n

The transistor has two PN junctions J_E & J_C as shown in figure. The junction J_E is a junction between emitter & base regions. Thus it is known as emitter-base junction.(Forward Biased).

Similarly, the junction J_C is a junction between collector & base regions. Thus it is known as Collector-base junction.(Reversed Biased).

Thus transistor is like two PN junction diodes connected back to back as shown in figure 2.



Transistor operation :-

i) Operation of NPN transistor :-

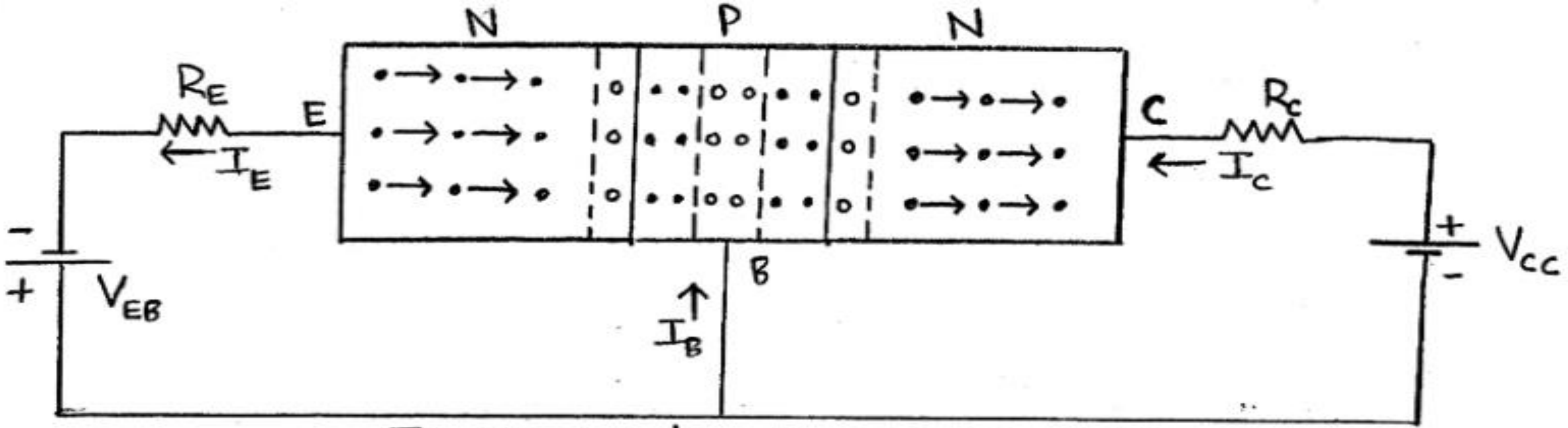


Fig ①: operation of NPN transistor

Figure1 shows an NPN transistor biased in active mode.

❖ In NPN transistor current is due to the movement of free electrons. The emitter to base of a transistor is forward biased & collector to base junction is reversed biased.

- When V_{EB} is greater than barrier potential ($V\gamma$), emitter to base junction is forward biased causes the free electons in the N-type emitter to flow towards the base region. This constitutes the emitter current I_E.

- As base is lightly doped, only few electrons combine with the holes & constitute base current I_B. Thus most of the electrons will diffuse to the collector region & constitutes collector current I_C.

- There is another component of collector current due to thermally generated carriers. This current component is called reverse saturation current & is quite small.

- The emitter current is given by $\mathbf{I_E=I_B+I_C}$

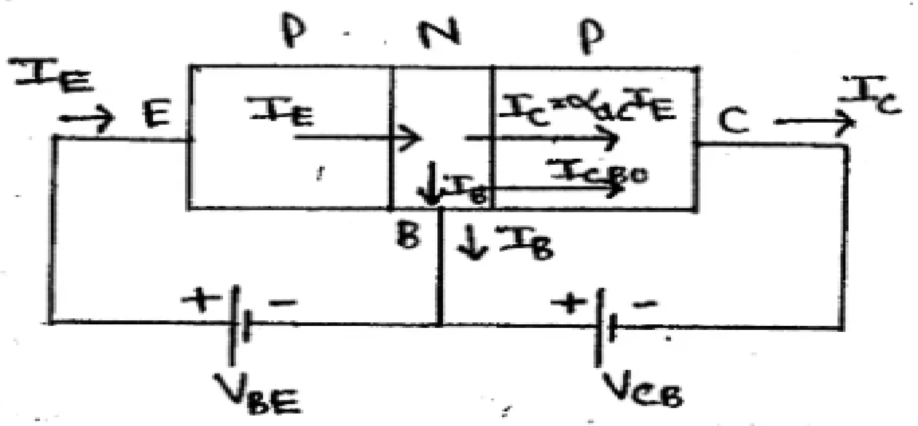
Transistor Currents :- (PNP)

- **Sketch & explain the current components crossing each junction of a transistor biased in the active region.**

Jan-04,6M, Jan-03,5M

- **With a neat sketch, clearly show the various current components in a PNP transistor & hence establish the relevant equations.**

June-04,6M Jan-05,10M Jan-06,7M Jan-07,6M



* In fig (1), the current flowing into the emitter terminal is referred to as a emitter current 'I_E'.

* Base current 'I_B' & collector current 'I_C' both flow out of the transistor, while 'I_E' flow into the transistor.

$$\therefore \quad \boxed{I_E = I_B + I_C} \longrightarrow (1)$$

* Almost all of emitter current 'I_E' crosses to the collector & only a small portion flow out of the base terminal. Typically 96% to 99.5% of I_E flow across the collector to base junction to become collector current.

$$\boxed{I_C = \alpha_{dc} I_E} \longrightarrow (2)$$

WKT

$\alpha_{dc} = \frac{I_C}{I}$

Where α_{dc} is the emitter to collector current gain & is typically 0.96 to 0.995.

Thus, the collector current is almost equal to the emitter current i.e. $I_C \approx I_E$.

* When C-B junction is reverse biased, a very small reverse saturation current 'I_{CBO}' flows across the junction called collector to base leakage current 'I_{CBO}' & it is very small & can be neglected.

* From eq ① & ②

$$\boxed{I_E = I_B + I_C} \longrightarrow ①$$

$$\boxed{I_C = \alpha_{dc} I_E} \longrightarrow ②$$

Substituting eq ① in eq ②

$$I_C = \alpha_{dc}[I_B + I_C]$$

$$I_C = \alpha_{dc} I_B + \alpha_{dc} I_C$$

$$\alpha_{dc} I_B = I_C - \alpha_{dc} I_C$$

$$\alpha_{dc} I_B = I_C[1 - \alpha_{dc}]$$

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

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

Where, $\beta_{dc} = \alpha_{dc}/1-\alpha_{dc}$

❖ **Draw a sketch to show the various current components in a NPN transistor & deduce the relation between various current components.**

Jan-08,8M

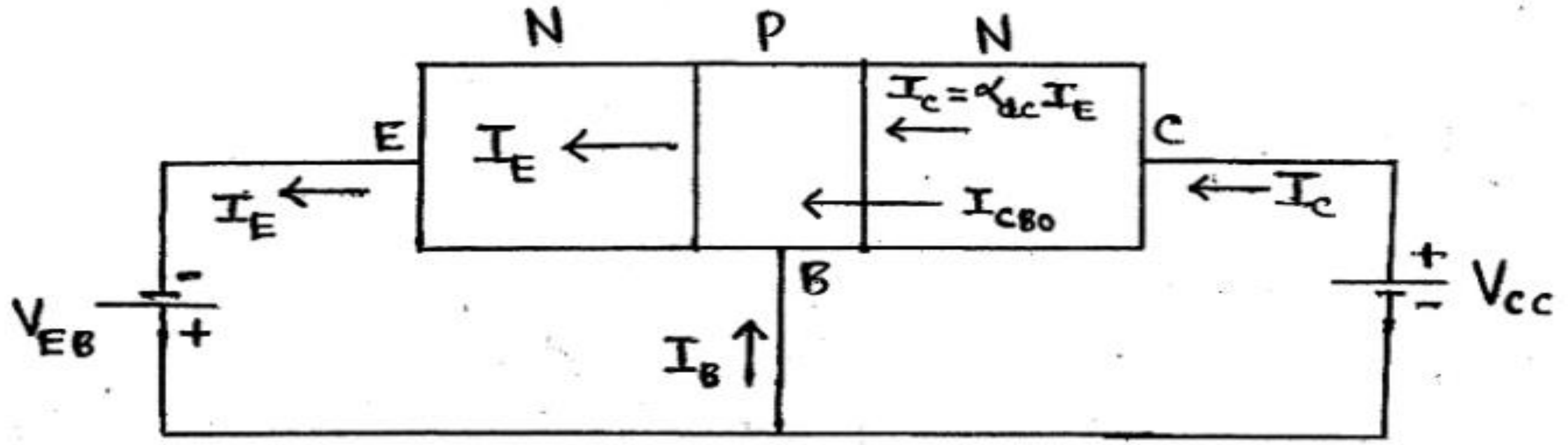


Fig ①: Currents in a NPN transistor

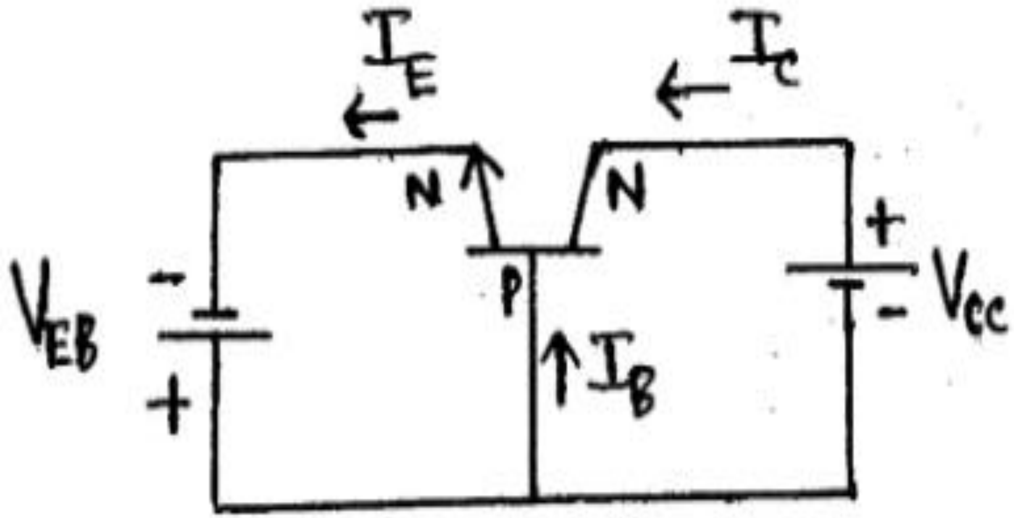


Fig ② : Currents in a NPN transistor.

* In NPN transistor, electrons are injected into the base. These electrons constitute the emitter current 'I_E'.

* Assume that 100 electrons are injected into the base region. Since the base is very thin, only few electrons say 2 in number, recombine with the holes. This constitute the base current 'I_B'. The remaining 98 electrons cross the base-collector, constituting collector current 'I_C'.

$$\therefore \quad \boxed{I_E = I_B + I_C} \longrightarrow (1)$$

WKT $\alpha_{dc} = \dfrac{I_C}{I_E}$

$$\boxed{I_C = \alpha_{dc} I_E} \longrightarrow (2)$$

α_{dc} is the emitter-collector current gain & is typically 0.96 to 0.995.

Thus $\boxed{I_C \approx I_E}$

* When collector - base junction is reverse biased, a very small reverse saturation current (I_{CBO}) flows across the junction, called collector to base leakage current 'I_{CBO}' & it is very small & can be neglected.

* Substituting eq ① in eq ②, we get

$$I_C = \alpha_{dc}[I_B + I_C]$$

$$I_C = \alpha_{dc} I_B + \alpha_{dc} I_C$$

$$I_C - \alpha_{dc} I_C = \alpha_{dc} I_B$$

$$I_C[1 - \alpha_{dc}] = \alpha_{dc} I_B$$

$$I_C = \frac{\alpha_{dc}}{1-\alpha_{dc}} \cdot I_B$$

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

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

* β_{dc} is the base - collector current gain: Typically β_{dc} ranges from 25 to 300.

Amplification :-

Current Amplification :-

(a) Current levels and current changes

(b) Base and collector currents

Figure
Increasing and decreasing I_B levels produces much larger changes in I_C and I_E

* A small change in the base current ΔI_B produces a large change in collector current ΔI_C & a large emitter current change ΔI_E

i.e. $\beta_{dc} = \dfrac{\Delta I_C}{\Delta I_B}$

* The common emitter ac current gain is given by

$$\boxed{\beta_{ac} = \frac{I_C}{I_B}}$$

* β_{ac} is also referred to as h_{FE}.

Voltage Amplification :-

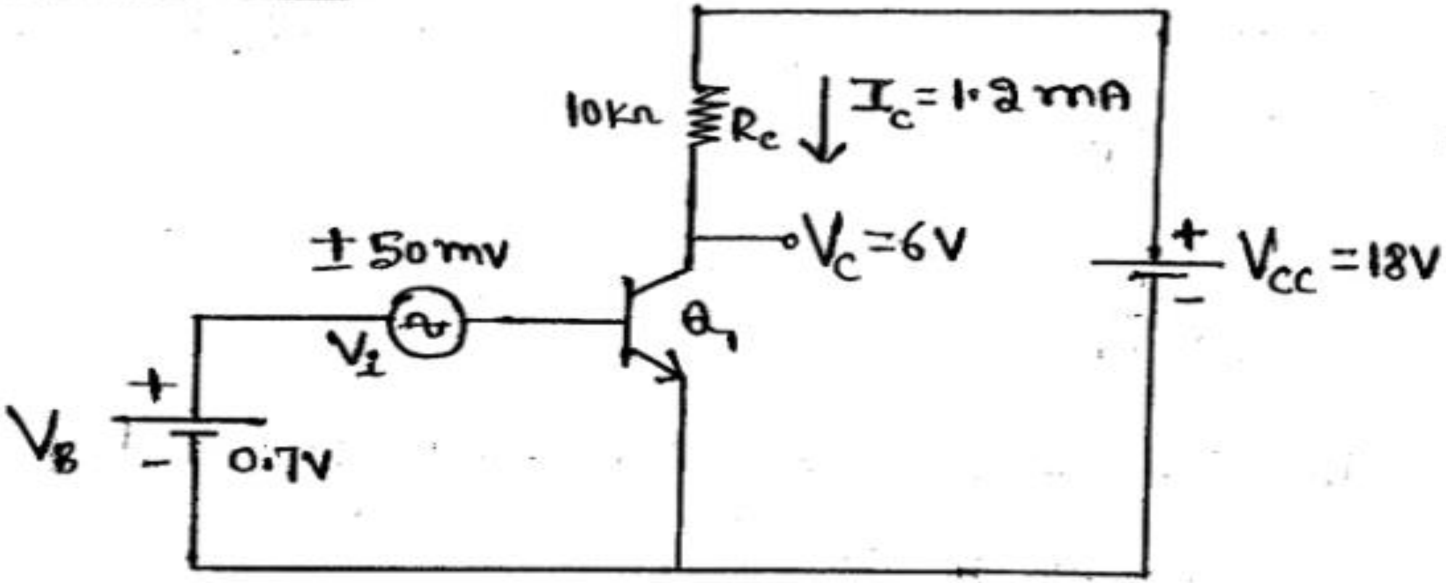


Fig ①: Transistor Ckt

* In Fig ①, assume that the transistor Q_1 has $\beta_{dc} = \beta_{ac} = 80$. Note that the 0.7V dc voltage source 'V_B' forward biases the transistor base-emitter junction.

* An ac Signal 'V_i' in Series with 'V_B' provides a ±50mV I/P voltage.

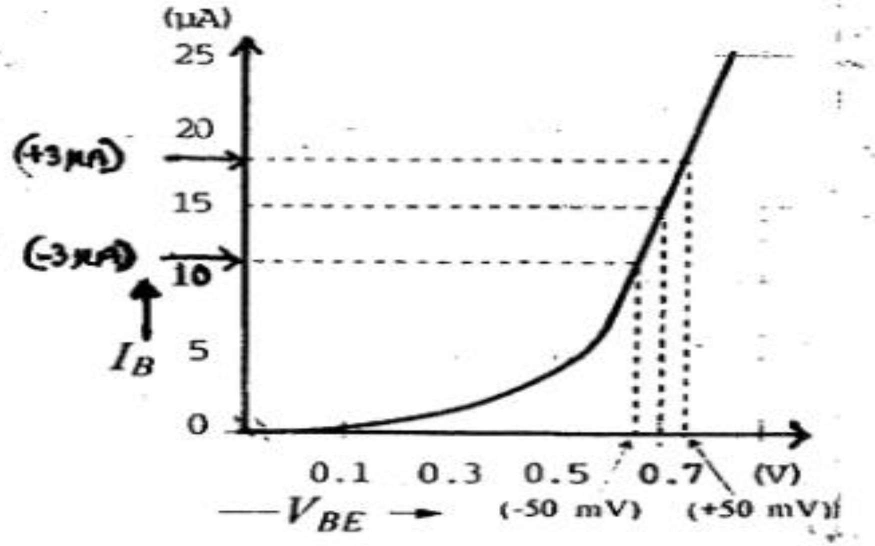
* The transistor Collector is connected to a 18V dc voltage Source V_{CC} via the 10kΩ collector resistor R_C.

* If Q_1 has the I_B/V_{BE} Characteristics Shown in fig ⓑ, the 0.7V level of V_B produces a 15 μA base Current.

i.e. $I_B = 15\,\mu A$ for $V_B = 0.7V$

$$I_C = \beta_{dc} I_B = 80 \times 15\,\mu A$$

$$\boxed{I_C = 1.2\,mA}$$



(b) V_{BE} I_B characteristic for Q_1.

* Applying KVL to Collector - emitter loop

$$V_{cc} - I_c R_c - V_c = 0$$

$$V_c = V_{cc} - I_c R_c$$

$$= 18V - (1.2mA \times 10k\Omega)$$

$$\boxed{V_c = 6V}$$

* From fig ②

$$I_b = \pm 3\,\mu A \text{ for } V_i = \pm 50mV$$

$$I_c = \beta_{ac} I_b = 80 \times (\pm 3\,\mu A)$$

$$I_c = \pm 240\,\mu A$$

* $V_o = I_C R_C$

$V_o = \pm 240\ \mu A \times 10\ k\Omega$

$V_o = \pm 2.4V$

* $A_v = \frac{V_o}{V_i} = \frac{\pm 2.4V}{\pm 50\ mV}$

$\boxed{A_v = 48}$

❖ **Obtain the relationship between α_{dc} & β_{dc}.** | Jan-11,4M | jan-09,4M |

WKT $\boxed{I_E = I_B + I_C} \longrightarrow (1)$

Dividing on both Sides of eq (1) by I_C

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

$$\boxed{\frac{I_E}{I_B} = \frac{I_B}{I_C} + 1} \longrightarrow (2)$$

WKT

$\beta = I_C / I_B$	$\alpha = I_C / I_E$
$1/\beta = I_B / I_C$	$1/\alpha = I_E / I_C$

Then eq ② becomes

$$1/\alpha = 1/\beta + 1$$

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

$$\therefore \boxed{\alpha = \frac{\beta}{1+\beta}} \longrightarrow ③$$

Eq ③ can be written as

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

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

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

$$\alpha = \beta[1-\alpha]$$

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

Transistor as an Amplifier :-

- **A transistor is capable of providing amplification. Explain the basic transistor amplifier with suitable diagrams.** **June-03,6M**
- **Show that a transistor could be used as an amplifier.**

June-06,5M June-08,6M

- A transistor increases the strength of the weak signal acting as an amplifier.

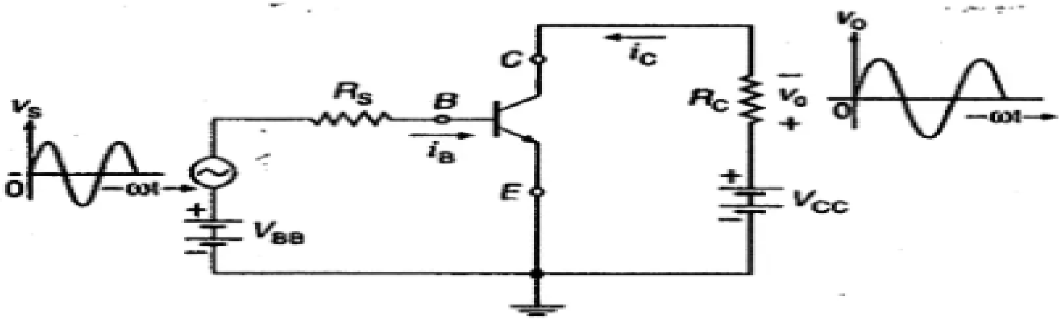


Fig. Basic common emitter amplifier.

- Figure shows basic transistor circuit of an amplifier. The supply voltage V_{BB} forward biases the emitter to base junction & V_{CC} reverse biases the collector to base junction. Thus transistor operates in active region.

- The magnitude of the ac input signal is such that it always forward bias the emitter to base junction regardless of the polarity of the ac input signal.
- During ***+ve half cycle*** of the input signal, the forward bias across the emitter to base junction is increased, which increases the collector current. The increased collector current ***produces greater voltage drop across the resistance 'R_C'.***
- During ***-ve half cycle*** of the input signal, the forward bias across the emitter to base junction is decreased, which decreases the

collector current. The decreased collector current ***produces smaller voltage drop across the resistance 'R_C'.***

- The small ac input signal produces a large ac output signal. Thus the transistor acts as an amplifier.

TRANSISTOR BIASING :-

The application of dc voltages across the transistor terminals is called biasing.

There are three modes of transistor operation.

SL No	Mode	Emitter-base junction	Collector-base junction
1	Active	Forward	Reverse
2	Saturation	Forward	Forward
3	Cut-off	Reverse	Reverse

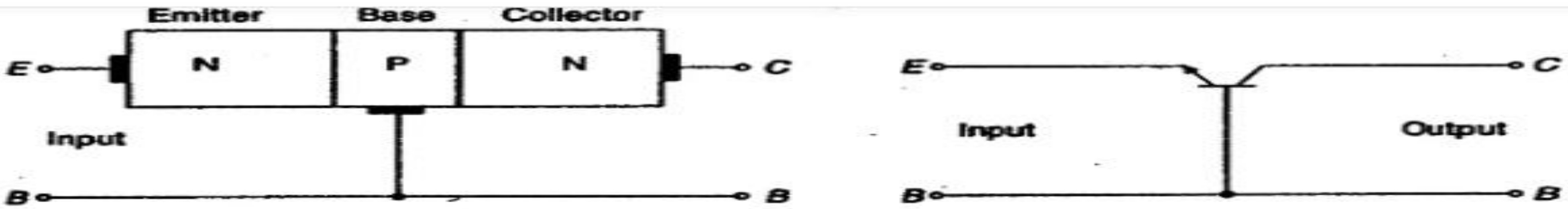
Transistor Configurations :-

Transistor has thre terminals namely **Emitter (E), Base(B)** & **Collector(C).** When a transistor is connected in a circuit, we require four terminals i.e. two terminals for input and two for output.

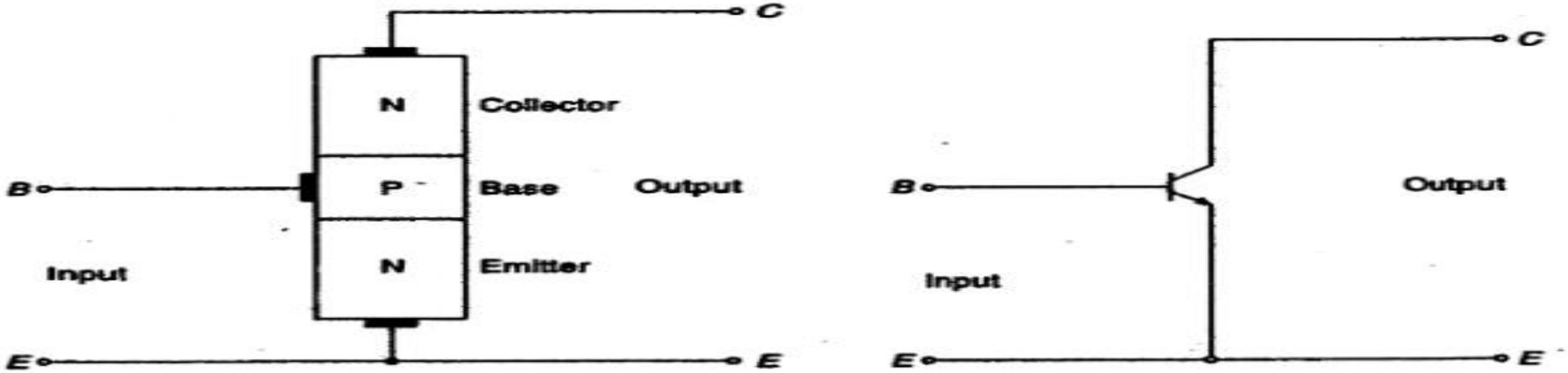
Thus out of three terminals, ***one terminal is made common to both input and output terminals.***

There are three different types of configurations or connection :

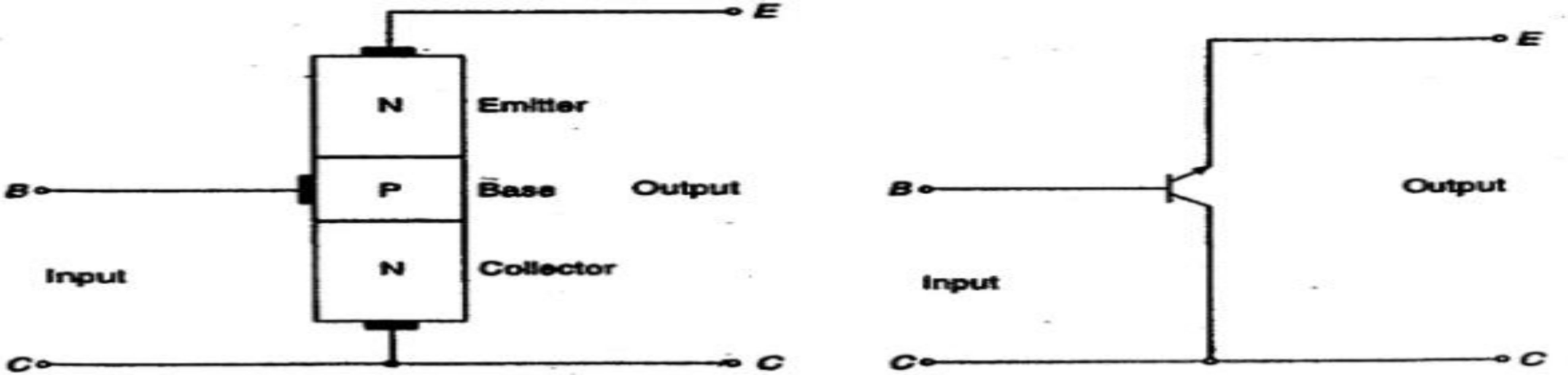
1) Common-Base Configuration (**CB**)
2) Common-Emitter Configuration (**CE**)
3) Common-Collector Configuration (**CC**)



(a) Common-base connection.



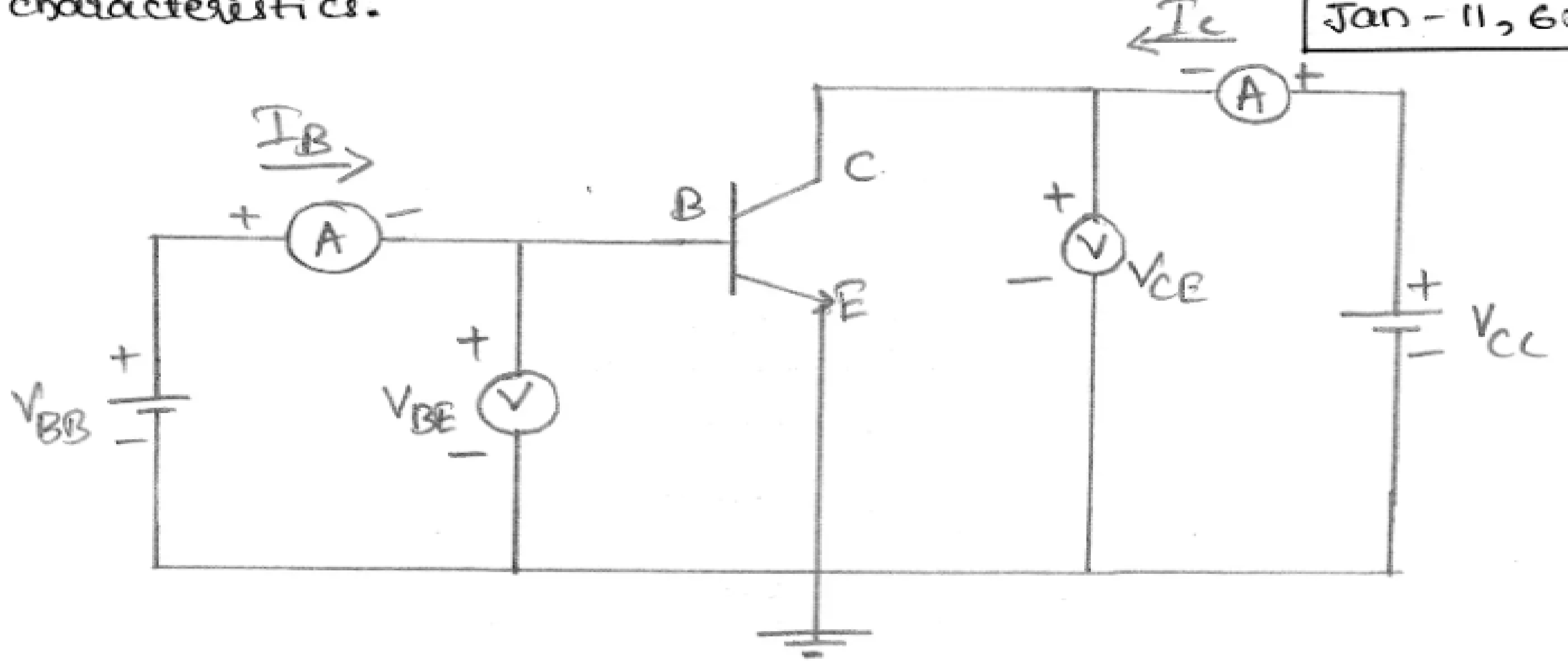
(b) Common-emitter connection.



(c) Common-collector connection.

* Explain the input and output characteristics for a CE configuration BJT circuit. Discuss each region on the characteristics.

Jan - 11, 6M (OLD)

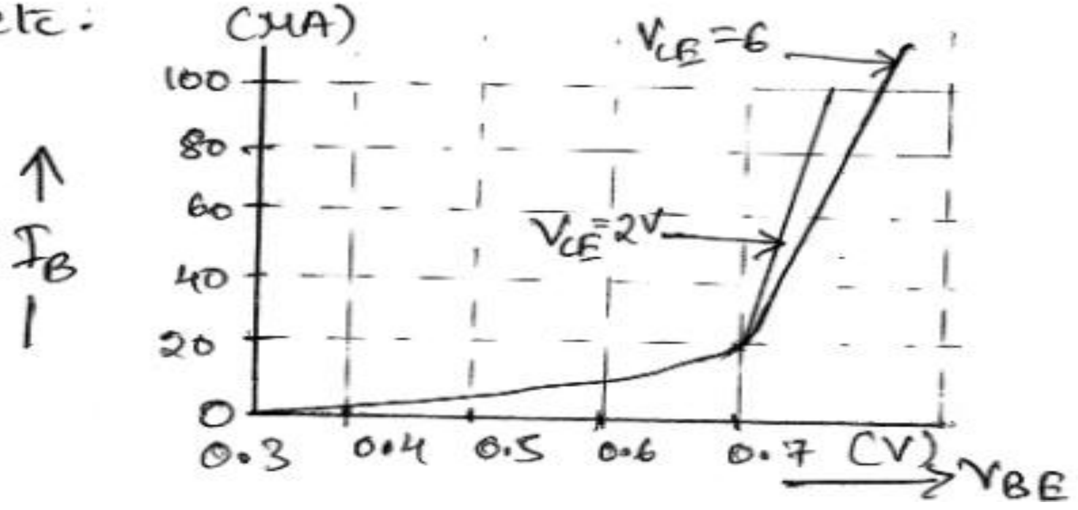


fig① : ckt for determining transistor common emitter characteristics.

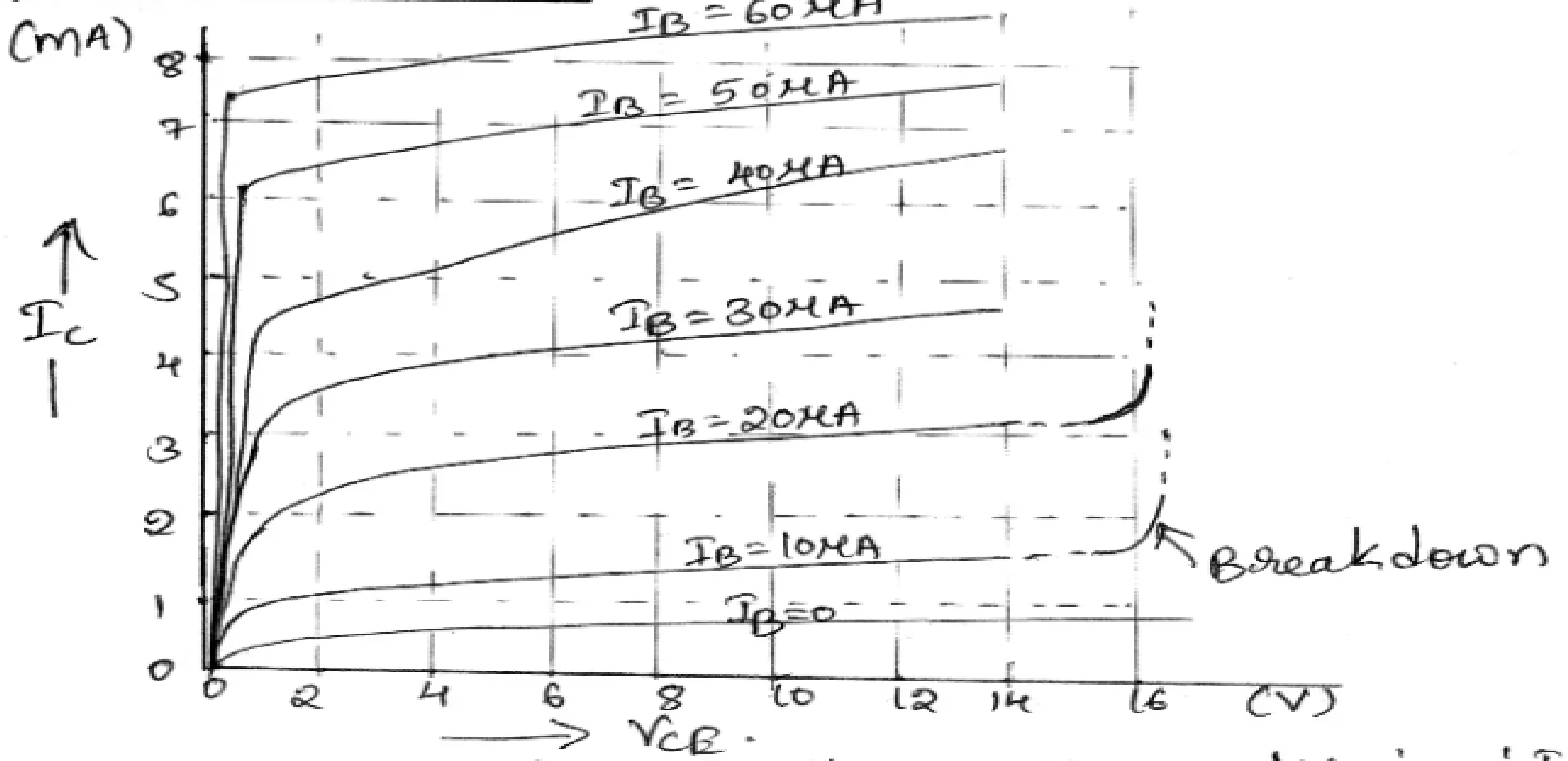
* These curves gives the relationship b/w the base current I_B & the base emitter voltage V_{BE} for a constant collector emitter voltage V_{CE}.

* To obtain I/p characteristic, the o/p voltage 'V_{CE}' is kept constant, I/p voltage 'V_{BE}' is varied in small Intervals & the corresponding change in I/p current 'I_B' is recorded.

* I_B is then plotted against V_{BE} as shown in fig②. The experiment is repeated for other values of 'V_{CE}' say 2V, 6V, ... etc.



O/P characteristics :-



* By using base-emitter voltage 'V_{BE}', 'I_B' is maintained constant at several convenient levels.

* 'V_{CE}' is varied in suitable steps & at each step I_C value is recorded. The same procedure is repeated for different settings of I_B.

* If we plot a graph with 'V_{CE}' voltage along horizontal axis & the collector current 'I_C' along the vertical axis, we shall obtain a o/p characteristics as shown in fig (3).

* o/p resistance 'r_o' is defined as the ratio of change in collector to emitter voltage 'ΔV_{CE}' to the resulting change in collector current 'ΔI_C' at constant base current 'I_B'.

$$\boxed{r_o = \frac{\Delta V_{CE}}{\Delta I_C}\Bigg|_{\text{constant } I_B}}$$

(10kΩ to 50kΩ)

* The o/p characteristics curve is divided into 3 regions namely:

1) Saturation region.
2) Active region.
3) cut-off region.

i) In saturation region, when the collector to emitter voltage 'V_{CE}' is increased above zero, the collector current 'I_C' increases rapidly to a saturation value, depending upon the value of base current.

* It may be noted that collector current I_C reaches to a saturation value when V_{CE} is about 0.5 V.

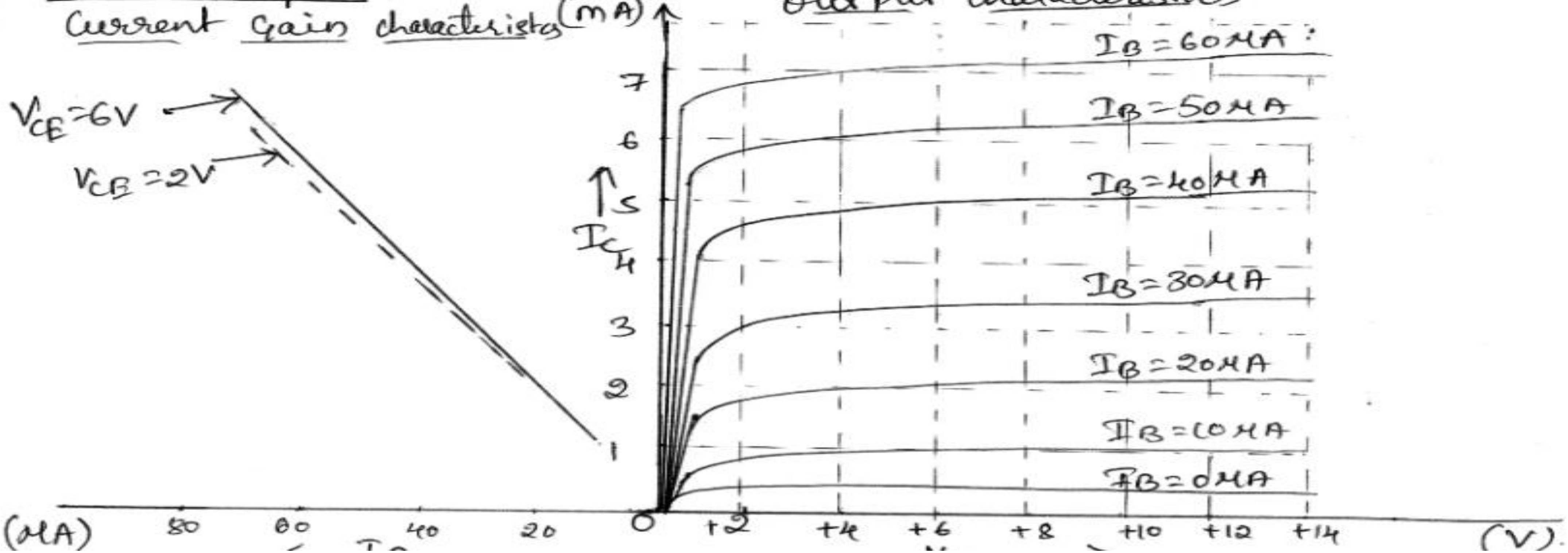
ii) In active region, the collector current is β_{dc} times greater than the base current. thus small I/P current 'I_B' produces a large o/p current I_C.

iii) In cutoff region, when base current is zero ($I_B=0$), collector current is not zero ($I_C \neq 0$), a small collector current exists called reverse leakage current 'I_{CEO}'.

Current Gain :-

Current Gain characteristics

output characteristics



* Common emitter current gain characteristics shows the variation of I_C as a function of I_B with constant 'V_{CE}'. i.e. 'V_{CE}' is held at a convenient level & I_B is varied in suitable steps and at each step I_C value is recorded. I_C is then plotted as a function of I_B.

* A vertical line is drawn through a selected V_{CE} value & the corresponding levels of I_C & I_B are read along the line.

FEEDBACK

- In the feedback process a part of output is sampled and fed back to the input.
- The fed back signal can be in phase with or out of phase with the original input signal.

Definition of feedback:

- Feedback is defined as the process in which a part of output signal (voltage or current) is returned back to the input.
- The amplifier that operates on the principle of feedback is known as feedback amplifier.

TYPES OF FEEDBACK

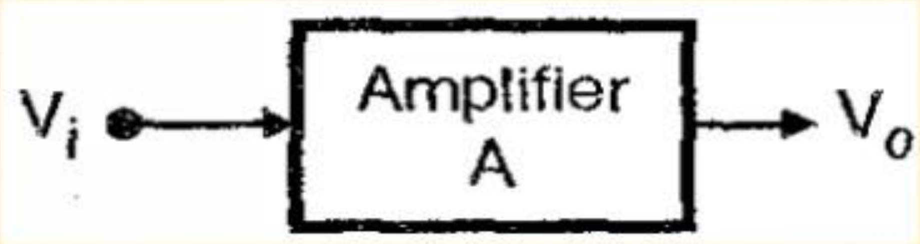
1. Positive feedback
2. Negative feedback.

If the original input signal and the feedback signal are in phase, the feedback is called as positive feedback.

However if these two signals are out of phase then the feedback is called as negative feedback.

AMPLIFIER WITHOUT FEEDBACK

gative feedback ,
unt Current series

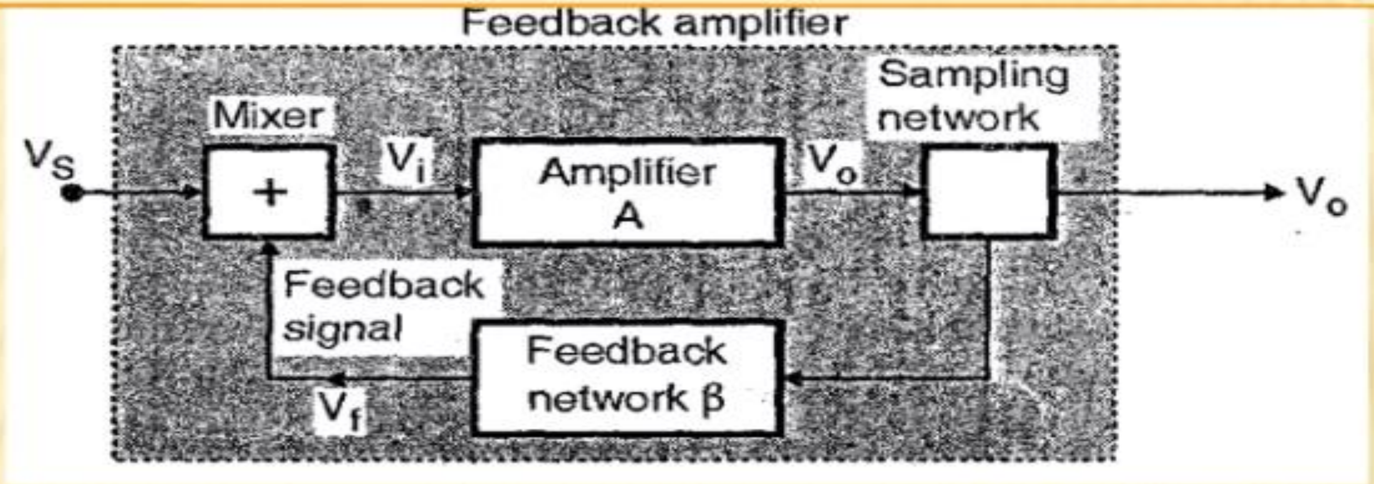


- The most important thing to understand from Fig. is that the output and input terminals of this amplifier are not connected to each other in any way.
- Therefore the amplifier of Fig. is an amplifier without any feedback,

Gain without feedback.

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

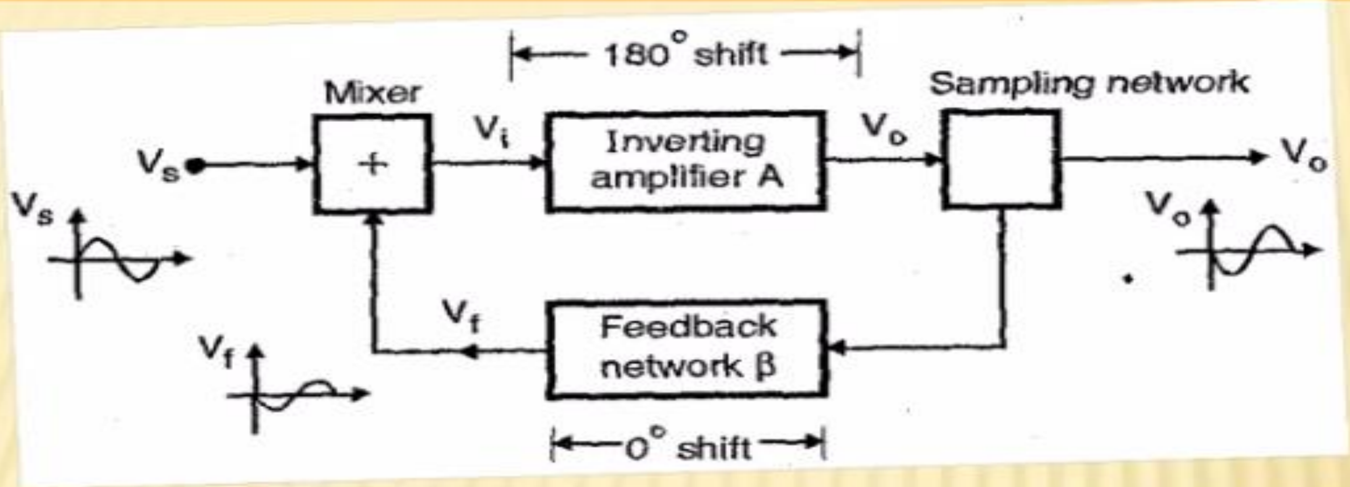
AMPLIFIER WITH FEEDBACK



- Refer to Fig. Here the same amplifier with a gain A is being used along with a mixer network, sampling network and a feedback network.
- The voltage gain of the feedback amplifier is given by,

Gain with feedback $$A_f = \frac{V_o}{V_S}$$

AMPLIFIER WITH A NEGATIVE FEEDBACK



- The block diagram of an amplifier with a Negative Feedback Fig.

$$V_f = \beta\, V_0$$

Where V_f = Feedback signal (output of the feedback network)

$$\text{Feedback factor } \beta = \frac{V_f}{V_0}$$

TYPES OF NEGATIVE FEEDBACK:

- Depending on the type of sampling and mixing networks, the feedback amplifiers are classified into four categories:

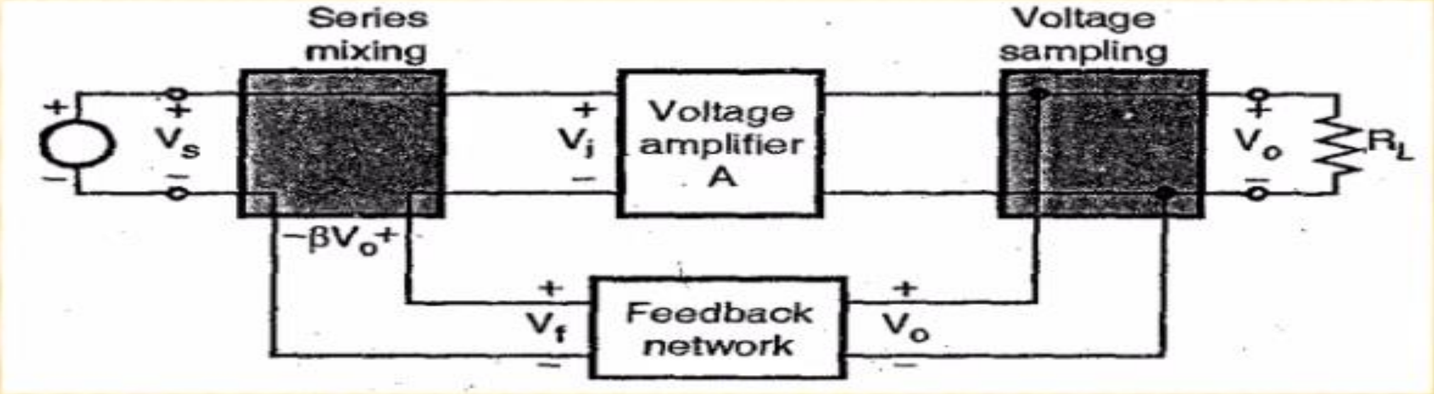
- Voltage series feedback
- Current series feedback
- Current shunt feedback
- Voltage shunt feedback

VOLTAGE SERIES FEEDBACK

Therefore,

voltage series feedback = voltage sampling + series mixing

The voltage series feedback is present in the voltage amplifiers.



A transistor amplifier which uses the voltage series feedback is the common collector or emitter follower amplifier:

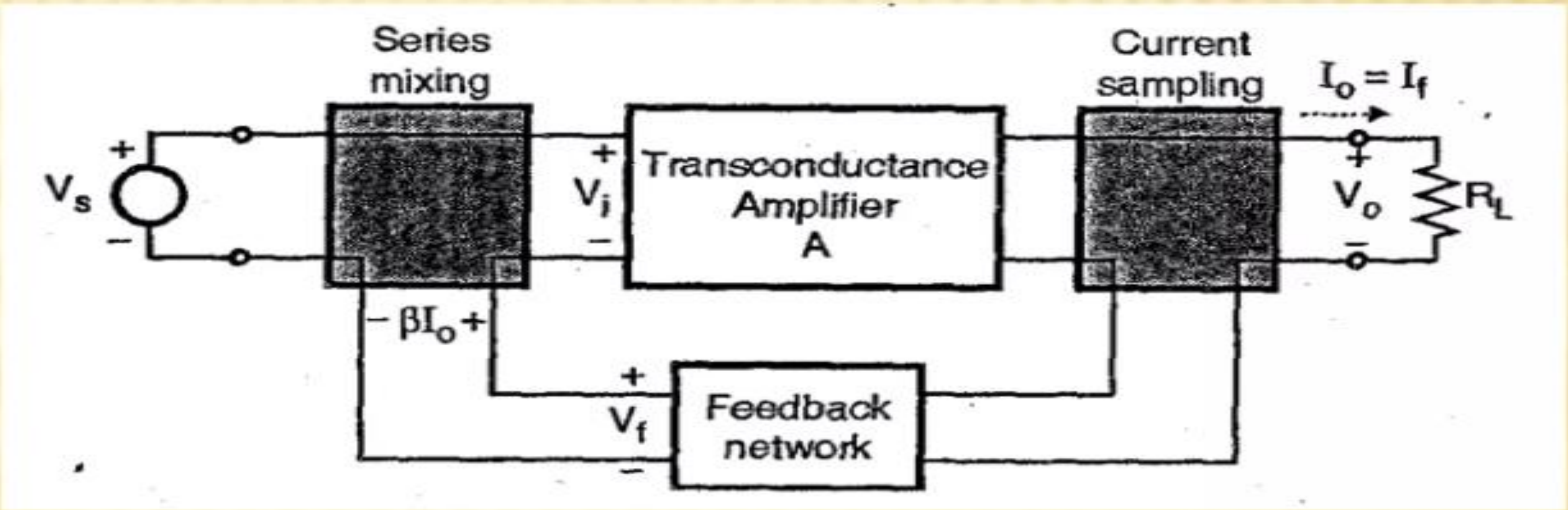
1. A common collector (or emitter follower) amplifier using BJT.
2. A common drain (or source follower) amplifier using FET.

CURRENT SERIES FEEDBACK

Therefore

Current sampling + Series mixing.

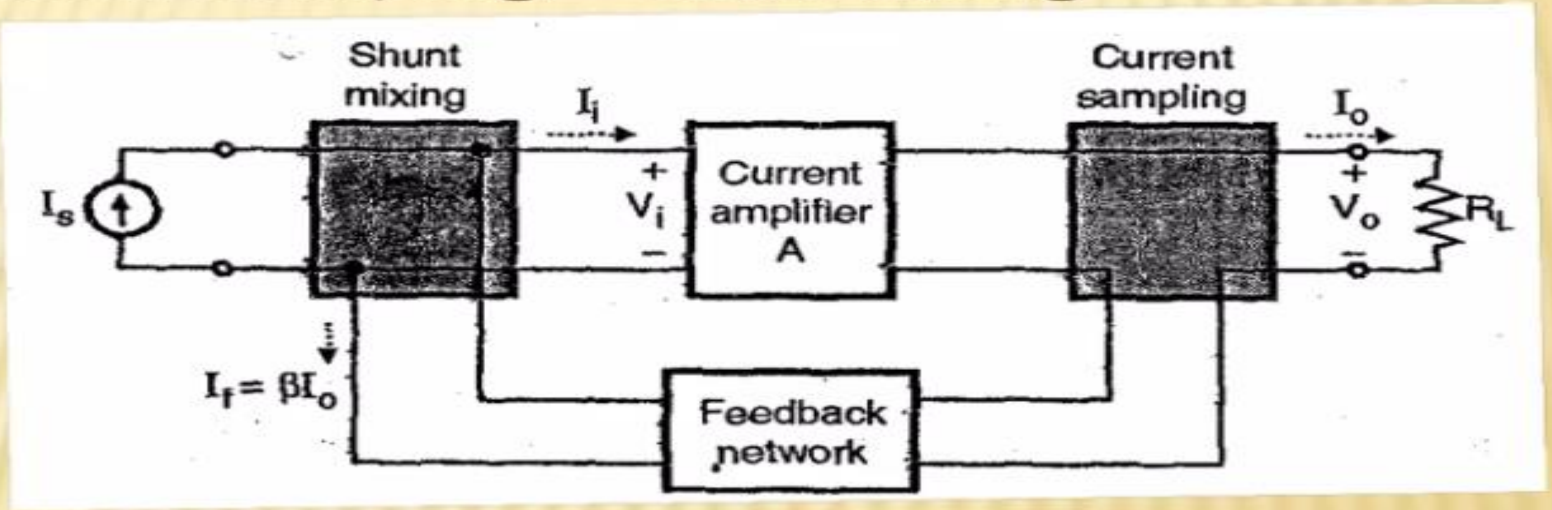
- Current series feedback is present in the transconductance amplifiers.



CURRENT SHUNT FEEDBACK:

- This is a combination of current sampling and shunt mixing. The block diagram of a feedback amplifier with current shunt feedback is shown in Fig.

Current sampling + Shunt mixing

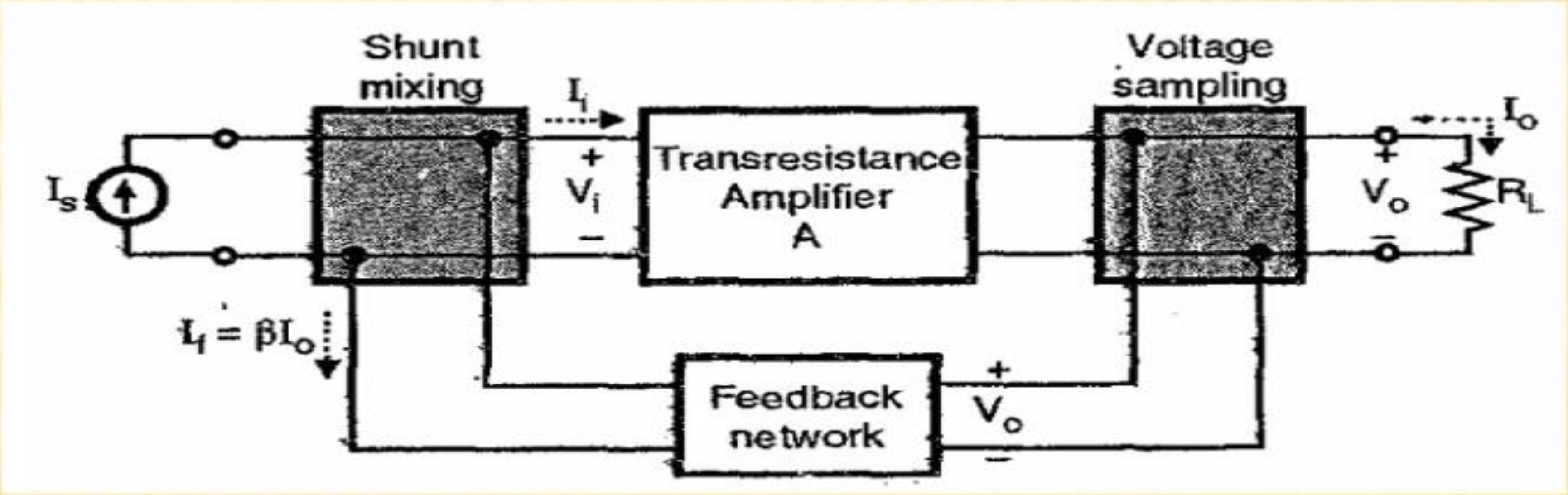


- Current shunt feedback is present in the current amplifiers.

VOLTAGE SHUNT FEEDBACK

- The block diagram of an amplifier with voltage shunt feedback amplifier is shown in Fig.

  Voltage Shunt Feedback = Voltage Sampling + Shunt Mixing.
- The voltage shunt feedback is present in the transresistance amplifier.



ADVANTAGES & DISADVANTAGES

Advantages

- Negative feedback stabilizes the gain of the amplifier.
- Input resistance increases for certain feedback configurations.
- Output resistance decreases for certain feedback configurations.
- Operating point is stabilized.

Disadvantages

- Reduction in gain.
- Reduction in input resistance in case of voltage shunt and current shunt type amplifiers.
- Increase in output resistance in case of current shunt and current series feedback amplifiers.

Applications of negative feedback

- In a1most all the electronic amplifiers.
- In the regulated power supplies.
- In wideband amplifiers (amplifiers having a large bandwidth)