T1

UNIT-3

⇒ Transistor is a solid state device, whose operation depends up on the flow of electric charge carriers ~~with~~ within the solid.

⇒ The Transistor is capable of amplification and in most respect it is analogous to vaccum triode.

⇒ The main difference b/w the two is transistor is a current control device whereas vaccum triode is a voltage control device. Transistor advantageous than vaccum tubes.

⇒ Transistor has compact size, light ~~wig~~weight, rugged construction, more resistive to shocks and vibrations, instantaneous operation (no heating required) Low operating voltage, high operating efficiency (no heat loss) and long life if ~~within~~ operated within permissible limits of temp & frequency.

⇒ However Transistor, in comparison to vaccum triodes, have some drawbacks also such as Loud hum noise, restricted operating temp (up to 75°c) and operating frequency (up to a few MHz only).

3/10/18
62, 63, 64, 65, 68, 71, 72, 80, 88, 89, 93
96, A3, A8, A9 B0 B1 B2 C0

Transistor is a three terminal, two junction semiconductor device. There are two categories. Bipolar & Unipolar. In bipolar transistors electrical conduction is due to holes and electron.

⇒ Transistor was invented by John Bardeen and W.H. Brattain in 1948.

⇒ Why the Name Transistor?

Under normal working operation of transistor, it has two junctions. One jn is F.W.B & another jun is R.B. F.W.B jn offers Low Resistance, where as reverse bias Jn offers high Resistance path. So giving a weak signal to Low resistance region and taking out put from the high Resistance region, we get an amplified signal. Hence Transistor indicates transfer of signal from Low Resistance to high Resistance.

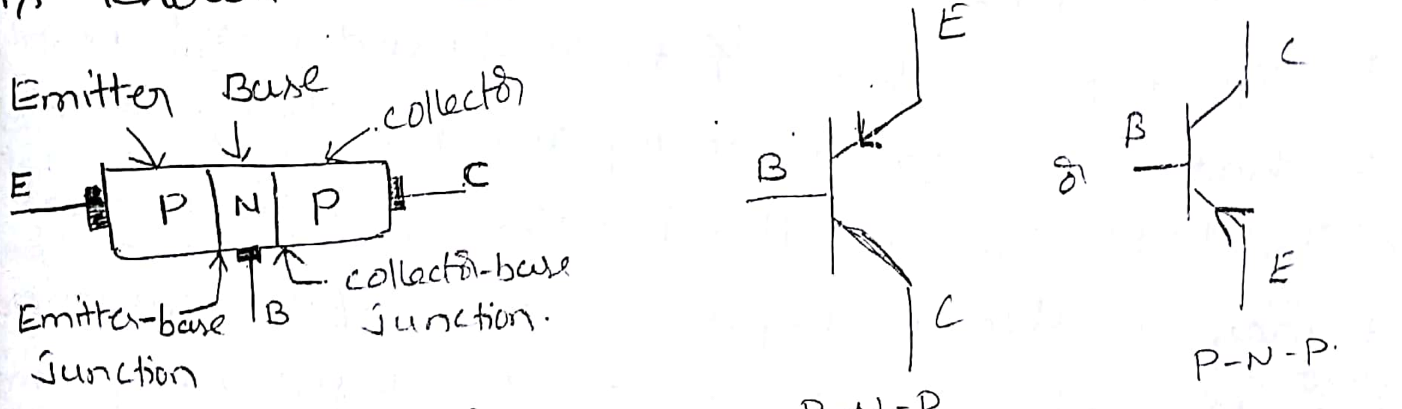
Transfer + Resistor = Transistor.

A junction Transistor is simply a sandwich of one type of semiconductor material b/w two layers of the other types. Accordingly, there are two types of Transistors NPN & PNP.

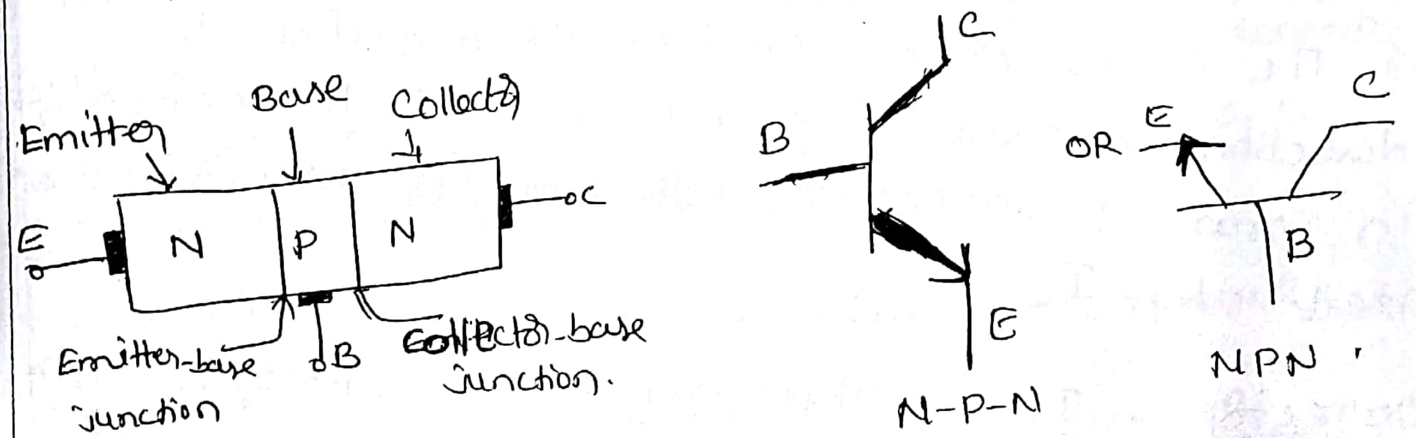
⇒ Transistors are made either from silicon or Germanium in more preferably Silicon transistor because Silicon has than German ium Transistor smaller cut off current I_{CBO}, smaller variations due to variations in temperature and heigher operating temperature.

⇒ When a layer of P-Type material is sandwiched b/w two layers of N-Type Material, The Transistor is known as N-P-N Transistor.

⇒ When a layer of N-Type material is Sandwiched b/w two layers of P-Type material, The Transistor is known as P-N-P Transistor.



P-N-P TRANSISTOR.



Each Type of Transistor has two P-N junctions. one junction b/w E & B, called Emitter-base junction or Simply the Emitter junction. and the other junction b/w B and C, called collector-base junction or Simply collector junction.

The two junctions give rise to three regions provided with three terminals called the Emitter (E), Base (B), and collector (C)

Emitter :- It is left hand section (or region) of the Transistor. and its main function is to supply the Majority charge carriers (electrons in case of NPN Tran) and holes in case of P-N-P Transistor) to the base. The Emitter is always forward biased w.r.t base so that it is able to supply majority charge carriers to the base. The emitter is heavily doped so that it may be able to inject a Large no of charge carriers it is Moderate size in order to maintain heavy doping without diluting it.

⇒ The arrow on the emitter lead specifies the direction of current flow when the E-B junction is in forward biased. The ~~Edt~~ Emitter current Represented by I_E.

collector :- It is the right hand section of Transistor and its main function is to collect majority charge carriers. collector is always Reverse biased. ~~So of~~ it is moderately doped, Large in size to with stand the temperature generated at the collector. collector current is Represented by I_C. No arrow Indicated on collector so that it indicates its reverse leakage current is always opposite to the direction of emitter current.

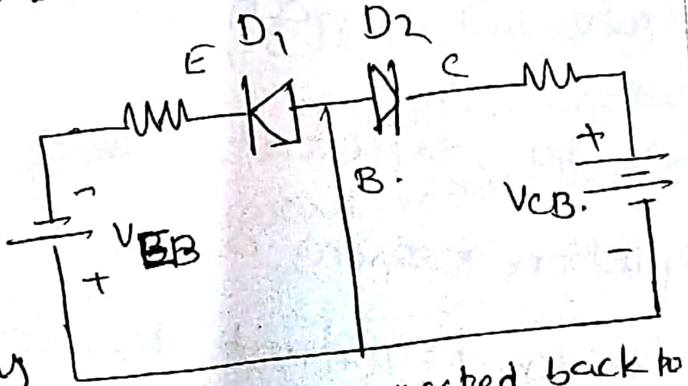
...se: It is middle section of the Transistor and its main function is it pass the most of the injected charge carriers to the collector. it is very lightly doped to reduce the recombination with in the base. so increase the Ic and it is very thin (order of 1μm) in comparison to either E and C.

⇒ It should be remembered that a Transistor is just like two diodes. The junction b/w E and B may be called as emitter base diode & Emitter diode. Similarly, The junction b/w base and collector may be called as collector base diode & simply collector diode.

⇒ Although, it is said ~~that~~ a Transistor is a device with two p-N diodes connected back to back, but it does not mean that two discrete diodes connected back to back as shown in fig, can work as a Transistor.

Why Two discrete diodes connected back to back can never work as a Transistor.

In such case, each diode has two equally doped regions (P & N) so that over all ckt has four equally doped regions. This would not work as base region is not the same as in Transistor.



Two diodes connected back to back

⇒ The key to the Transistor action is the lightly doped thin base b/w heavily doped emitter and Moderately doped collector.

⇒ In N-P-N Transistor, the free ē passing through the base to the collector region have a short life time. As long as base is thin, The free ē can reach the collector. But in case of two discrete back to back connected diodes there are four doped regions instead of three and there is nothing that resembles a thin base region b/w E and C. Hence two discrete diodes connected back to back can never work as a Transistor.

TRANSISTOR ACTION:

Unbiased Transistor:

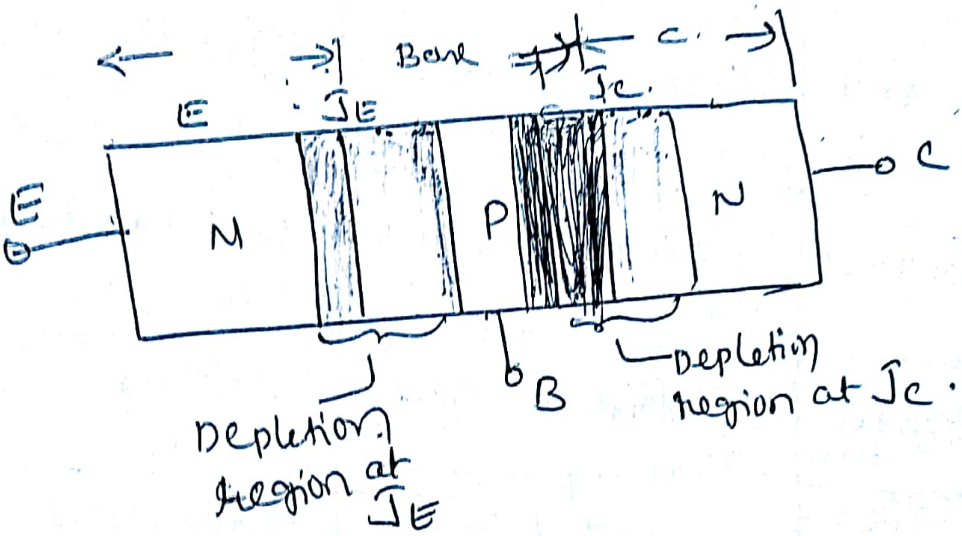
When no battery is connected b/w the terminals of Transistor is said to be Transistor is unbiased State or in an open circuit state.

Due to different ~~doping~~ levels of doping, the depletion regions at the two junctions are different.

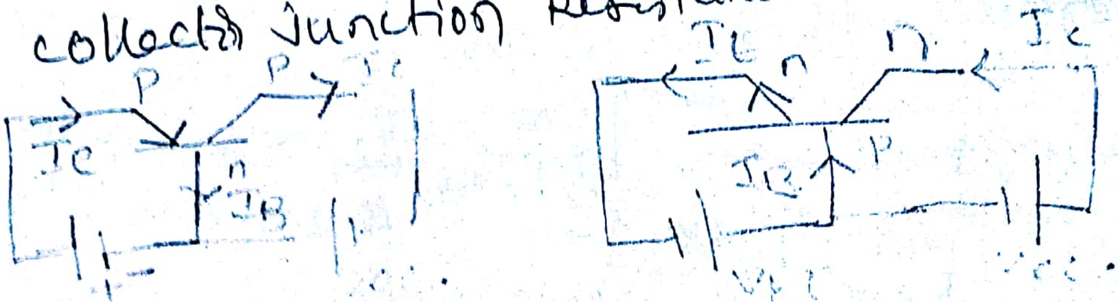
⇒ it is important to mention here that the depletion region penetrates more deeply in to lightly doped side.

The depletion region at E-J penetrates less in heavily doped emitter and extends more in base region.

⇒ Similarly the depletion region at collector junction penetrates less in ~~heav~~ moderately doped collector and extends more in base region. [collector is heavily doped than base]. so, the depletion region formed at collector junction is larger that depletion layer formed at Emitter junction.



To operate a transistor, it should be properly biased. The E-B Junction (J_E) is always F.W.B. while the collector - Base junction (J_C) is always is reverse biased. The Resistance of Emitter junction is very small (because it is in Forward biased) compared to collector Junction Resistance.

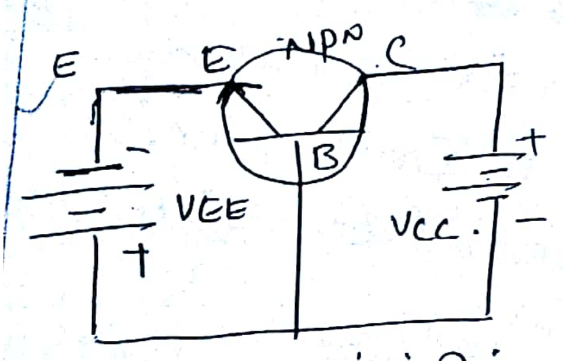


TRANSISTOR BIASING :

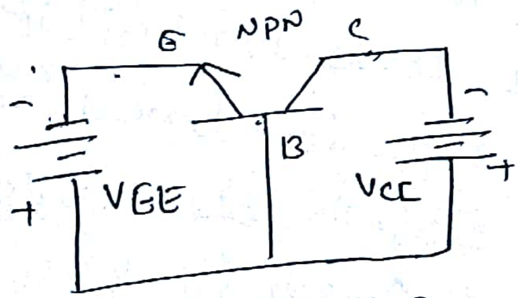
The Process of Applying DC voltage across different terminals of transistor is called Transistor biasing.

⇒ There are four possible ways of biasing a Transistor. These are called as modes of operation of Transistor.

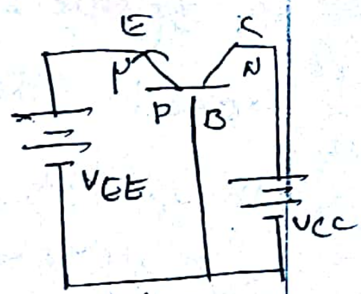
cases	E- B Junction	C- B Junction	Region of operation
I	Forward biased	Reverse biased	Active
II	Forward biased	Forward biased	saturation
III	Reverse biased	Reverse biased	cut-off
IV	Reverse biased	Forward biased	Inverted.



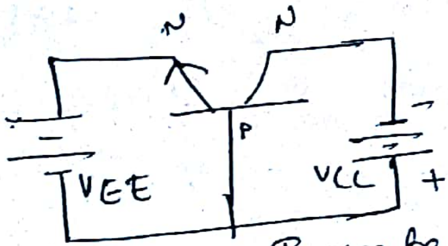
Active region.



saturation.



cut off



Inverted region.

In this region action of Transistor is very Poor

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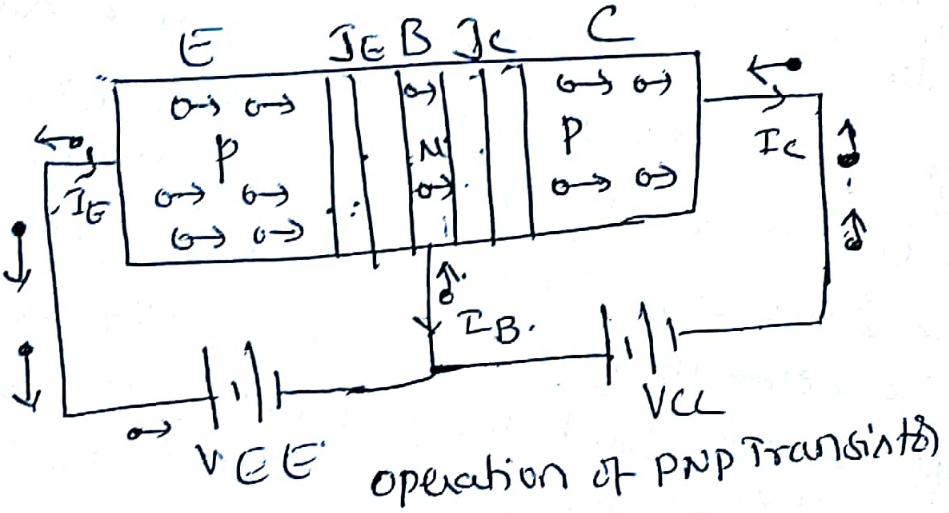
OPERATION OF P-N-P TRANSISTOR :

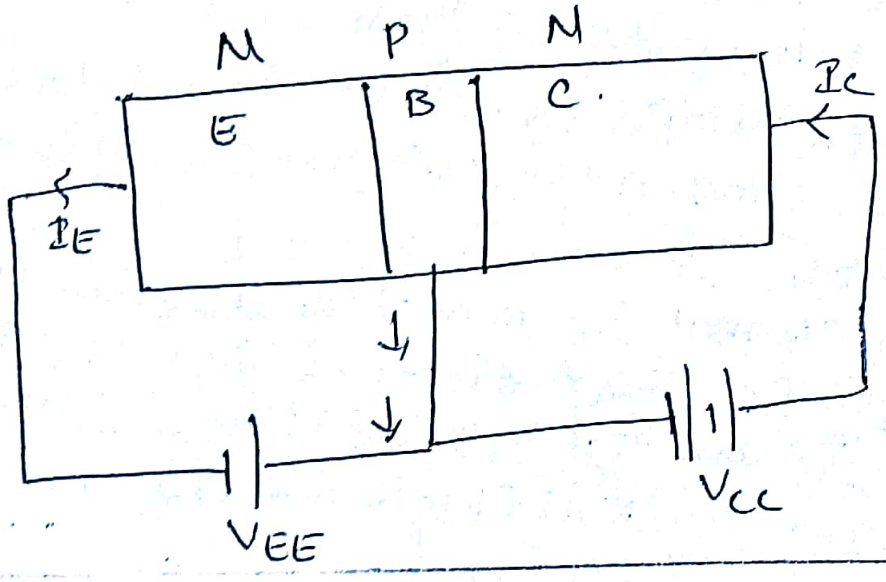
⇒ P-N-P Transistor with E-B junction as forward biased and C-B junction as reverse biased. The operation of P-N-P Transistor is as follows.
The holes in P region (emitter) are repelled by +ve terminal of battery V_{EE}. So the holes are moving toward to the base. Due to forward bias the potential barrier at emitter junction is reduced so depletion width is decreased, the holes are cross the junction & enter in to the base region & This constitute the emitter current I_E.
The width of the base region is very thin and it is lightly doped hence only two to 5 percent of holes recombine with the free $\bar{e}$ of N region. This constitute the base current I_B, but it is very small. The remaining holes (95% to 98%) are able to drift across the base and enter the collector region. They are swept up by -ve collector voltage V_{CC}.
This constitutes the collector current I_C.
⇒ current conduction with in the P-N-P Transistor takes place by hole conduction from E to C. i.e Majority charge carriers in a P-N-P Transistor are holes. The conduction in the external ckt is carried out by electrons.
⇒ The collector current I_C is slightly less than the Emitter current I_E. This is due to the fact that 2 to 5% of holes are lost in recombination with $\bar{e}$ in base region. So I_C is slightly less than I_E.

⇒ The collector current is a function of Emitter current i.e with increasing or decreasing in emitter current a corresponding change in collector current observed.
⇒ Beside hole current, there is a electron current which flows from base region to emitter region. This current depends upon emitter-base potential. As the width of the base region is very small, the ratio of hole current to electron current is very small. so for all practical purposes, the $\bar{e}$ current may be neglected. thus only the hole current plays the important role in the operation of P-N-P Transistor.



operation of PNP Transistor.

Operation of NPN Transistor.

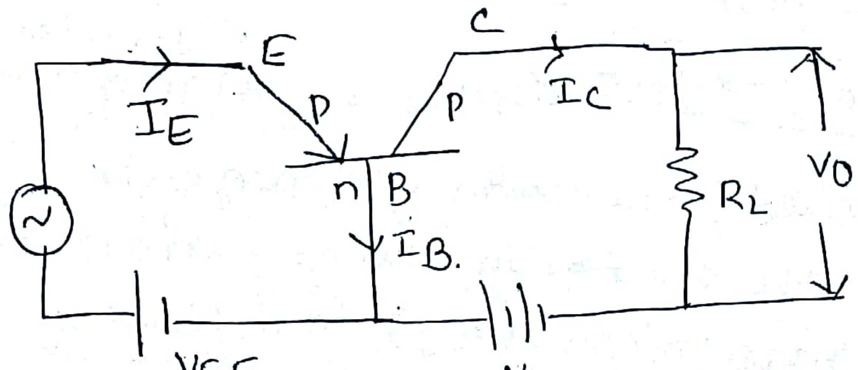


TRANSISTOR CONFIGURATIONS:

1:- Common-base (CB)
2:- Common-Emitter (CE).
3: Common - Collector (CC)

Here the term "common" is used to denote the transistor lead (terminal) which is common to the I/p and o/p circuits. This is beacuse, when a Transistor is connected in a circuit, Four terminals are required (two terminals for I/p, two for o/p) while transistor has only three terminals. To over come this difficulty we are using one terminal in common to both I/p & o/p. Generally the common terminal is grounded. Each configuration has specific advantages & disadvantages

1). Common - base Configuration.



⇒ In this Configuration, the I/p Signal is applied b/w Emitter and base while the o/p is taken from collector and base. As base is common to I/p and o/p hence name is common-base configuration.

current amplification factor (α) : when no signal is applied, then the ratio of the collector current to the emitter current is called dc alpha (α_{dc}) of a Transistor.

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

(-ve sign signifies that I_E flows in to transistor while I_C flows out of it).

if we write α_{dc} simply by α then

$$\boxed{\alpha = \frac{-I_C}{I_E}} \quad -(1)$$

α measures the quality of a transistor. Higher is the value of α better is the transistor in the sense that collector current approaches the emitter current.

consider only magnitudes of the currents

From eq (1)

$$I_B = I_E - I_C.$$

$$I_C = \alpha . I_E$$

$$I_E = -[I_B + I_C]$$

-ve Indicates outgoing current

$$I_B = I_E - \alpha I_E$$

$$\boxed{I_B = I_E[1-\alpha]} \quad -2$$

When signal is applied, the ratio of change in collector current to the change in emitter current at constant collector base voltage (V_{CB}) is defined as current amplification factor.

$$\alpha_{ac} = -\frac{\Delta I_C}{\Delta I_E}$$

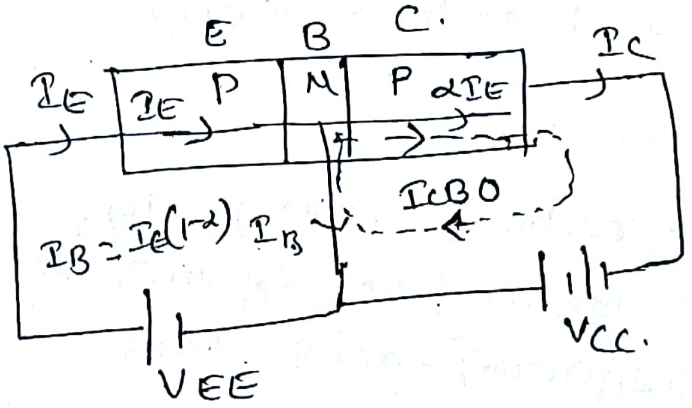
For all practical purpose $\alpha_{dc} = \alpha_{ac} = \alpha$.

α range is 0.9 to 0.99.

Total collector Current :- The total collector current consisting of two parts.

i: current produced due to Majority charge carriers and its value is $I_C = \alpha I_E$.

ii The leakage current $I_{leakage}$. This current is due to the motion of minority carriers across B-C junction on account of it being reverse biased. This leakage current is much smaller than αI_E. The leakage current is abbreviated as I_{CBO} i.e collector - Base current with emitter open.



Total collector current

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

if $I_E = 0$ (emitter open)

$I_C = I_{CBO}$

I_C can also expressed as.

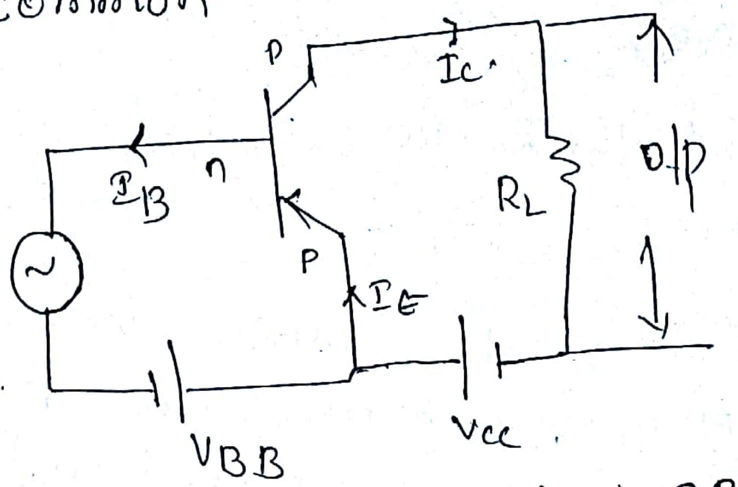
$$I_C = \alpha I_E + I_{CBO}$$

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

$$I_C[1-\alpha] = \alpha I_B + I_{CBO}.$$

$$I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}. \Rightarrow \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

2) COMMON-EMITTER (CE) CONFIGURATION.



Current gain = $\frac{o/p\ current}{I/p\ current}$

In this configuration I/p is applied b/w B & E, o/p is taken across collector & Emitter. Emitter is common to I/p and o/p. ckts. hence it is called as CE configuration

Base Amplification factor β: When no signal is applied, The ratio of I_C to I_B is called dc Beta (β_{dc}).

$$\beta_{dc} = \beta = \frac{I_C}{I_B} \quad -(1)$$

When signal is applied, the ratio of change in collector current to the change in base current is base current amplification factor. They defined as

$$\beta_{ac} = \beta = \frac{\Delta I_C}{\Delta I_B} \quad -(2)$$

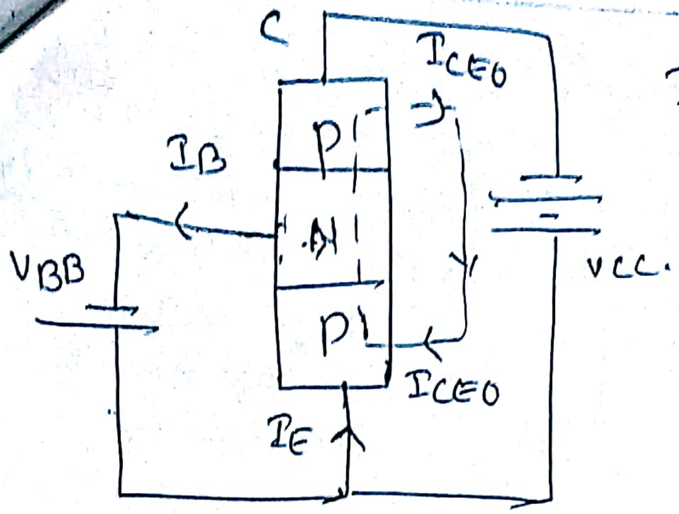
$$I_C = \beta I_B.$$

Almost in all Transistors, I_B is less than 5% of I_E. Due to this fact, β is generally greater than 20. β range is 20 to 500. Hence this configuration is frequently used.

The Total collector current:

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

I_{CEO} is the leakage current.



I_{CEO} is the leakage current

$I_C = \beta I_B + I_{CEO}$ — (3)

If I_B is zero

$\therefore I_C = I_{CEO}$.

We know

$I_E = I_B + I_C$.

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

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

$I_C [1 - \alpha] = \alpha I_B + I_{CBO}$

$I_C = \dfrac{\alpha}{1-\alpha} I_B + \dfrac{1}{1-\alpha} I_{CBO}$. — (4)

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

$\beta = \dfrac{\alpha}{1-\alpha} + 1 - 1$

$1 + \beta = \dfrac{\alpha + 1 - \alpha}{1-\alpha}$

$1 + \beta = \dfrac{1}{1-\alpha}$.

compare 3 & 4.

$\beta = \dfrac{\alpha}{1-\alpha}$ $\qquad I_{CEO} = \dfrac{1}{1-\alpha} I_{CBO}$.

substitute I_{CEO} value in eq (3)

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

Relation B/w α and β.

$\alpha = \dfrac{I_C}{I_E}$ $\qquad \beta = \dfrac{I_C}{I_B}$. $\qquad I_E = I_C + I_B$.

$I_B = I_E - I_C$.

$\beta = \dfrac{I_C}{I_E - I_C} = \dfrac{I_C / I_E}{1 - \dfrac{I_C}{I_E}} = \dfrac{\alpha}{1-\alpha}$.

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

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

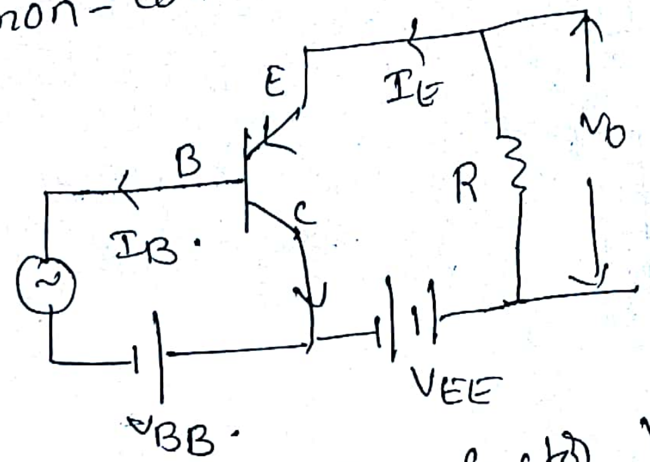
$\beta - \beta\alpha = \alpha$

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

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

$1 - \alpha = \dfrac{1}{1+\beta}$

Common-Collector configuration.



This configuration provides same current gain as CE configuration.
$\Delta I_E = \Delta I_C$.
But voltage gain is less than one.

current Amplification factor $\gamma = \frac{I_E}{I_B}$

When signal is applied. $\gamma = \frac{\Delta I_E}{\Delta I_B}$.

Total emitter current $I_E = I_C + I_B$.

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

$I_E = I_B + \alpha I_E + I_{CBO}$.

$I_E = I_B + \alpha I_E + I_{CBO}$.

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

$I_E = \frac{1}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$.

or $I_E = (1+\beta) I_B + (1+\beta) \cdot I_{CBO}$.

Application :- This configuration has very high i/p Resistance ($\approx 750 k\Omega$) and very low o/p resistance ($\approx 25\Omega$).

Relation B/w γ and α.

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

$$\gamma = \frac{I_E}{I_E - I_C} = \frac{1}{1 - \frac{I_C}{I_E}} = \frac{1}{1-\alpha}.$$

Relation B/w γ & β.

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

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

TRANSITOR AS AN AMPLIFIER:

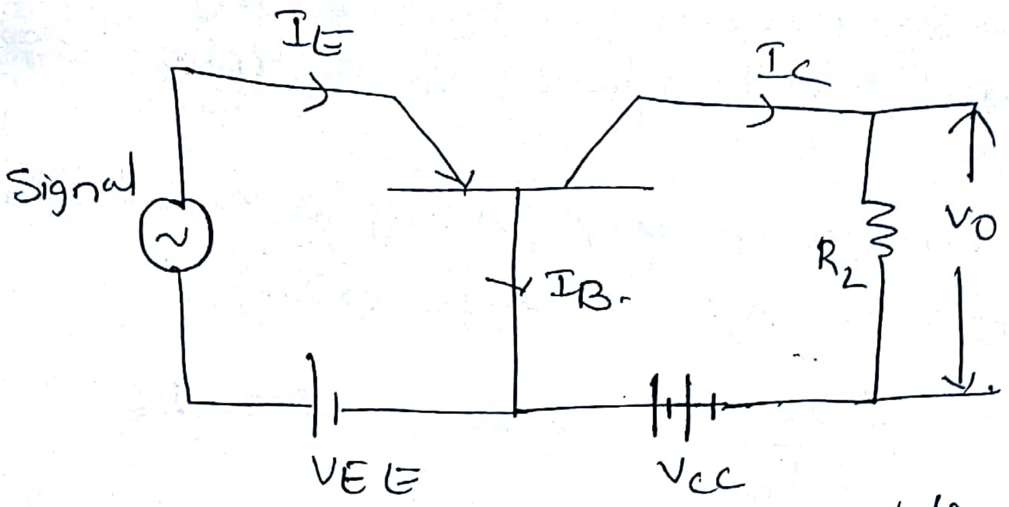


Fig: Transistor as an Amplifier.

⇒ The weak signal to be amplified is applied b/w emitter - base circuit and o/p is taken across the Load resistor R_L. The dc voltage VEE is also connected in the I/P circuit. Now the question is that why VEE is connected in the circuit?

⇒ Let, for the instant, VEE is not connected in the circuit. Now for the -ve peak of the applied signal, The E-B Junction will be reverse biased. This is not desirable beacause to achieve faithful amplification, the I/P ckt should always remain forward bias. For this purpose, emitter ~~base~~ bias battery VEE of such magnitude that I/P ckt is always forward biased regardless of the polarity of the signal is connected.

A small change in signal voltage produces an appreciable change in emitter current beacuse the I/P ckt has Low resistance. change in I_E causes same change in I_C.

When collector current I_c flows in R_L a large voltage is developed across it. So weak signal is applied in the O/P ckt appears as Amplified signal at O/P.

Let a small change in V_i (ΔV_i), a relatively Large emitter current change (ΔI_E).

$$\alpha = \frac{\Delta I_c}{\Delta I_E} \qquad \Delta I_c = \alpha \Delta I_E$$

The change in o/p voltage is

$$\Delta V_o = \Delta I_c \times R_L.$$
$$= R_L \alpha \Delta I_E.$$

voltage gain $A = \frac{\Delta V_o}{\Delta V_i}$

$$\Delta V_i = \Delta I_E \times r_e$$

where r_e is internal emitter resistance (or) (Dynamic resistance of emitter junction).

$$A = \frac{\alpha \cancel{\Delta I_E} R_L}{\cancel{\Delta I_E} r_e}$$

$$\boxed{A = \frac{\alpha R_L}{r_e}}$$

$R_L >> r_e$.

Q) Calculate the collector current and I_E for a Transistor with $\alpha_{dc} = 0.99$ $I_{CBO} = 50\mu A$ $I_B = 20\mu A$.

(10) T10

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

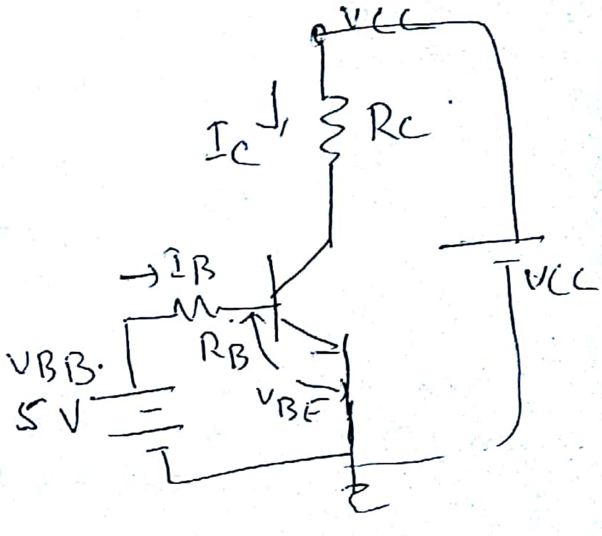
$= \alpha(I_C + I_B) + I_{CBO}$.

$I_C = 6980\ \mu A$.

$I_E = I_C + I_B$.

$I_E = 7mA$.

2). Determine I_B I_C I_E and V_{CE} for a CE ckt $V_{CC} = 15V$ $V_{BB} = 5V$ $R_B = 300k\Omega$. $R_C = 1k\Omega$ $V_{BE} = 0.7V$ $\beta = 100$



Apply the KVL.

$I_B R_B + V_{BE} = V_{BB}$

$I_B = \dfrac{V_{BB} - V_{BE}}{R_B}$.

$I_B = 14.3\ \mu A$.

$I_C = \beta I_B = 1.43\ mA$

$I_E = I_C + I_B = 1.45\ mA$

Applying KVL at O/P.

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

$= 13.57V$.

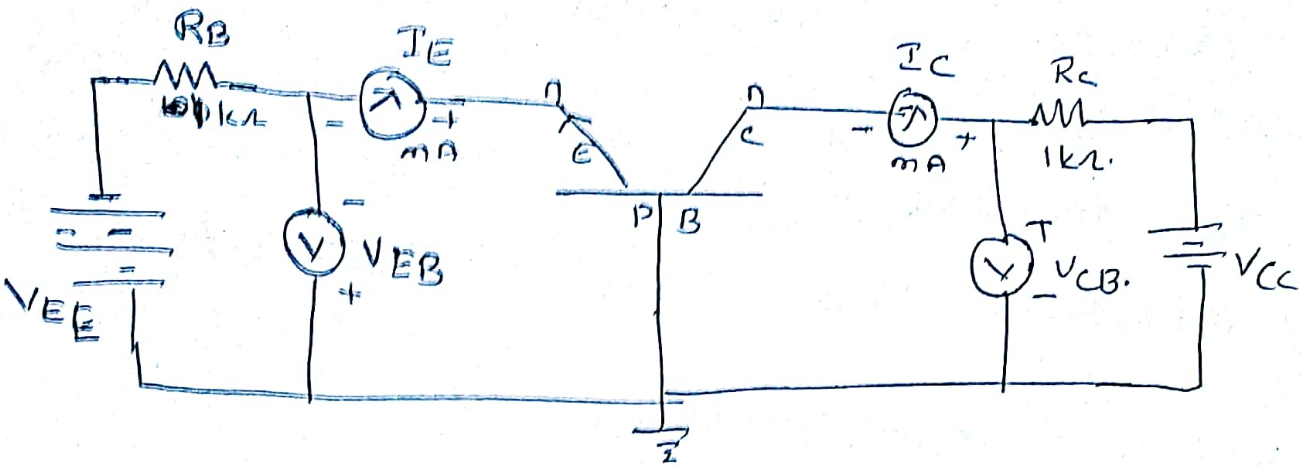
Typical n-p-n Transistor Junction voltages at 25°C

	$V_{CE(sat)}$	$V_{BE(sat)}$	V_{BE} Active	V_{BE} Cutin	V_{BE} Cut off
Si	0.3 V	0.7V	0.6V	0.5V	0.0
Ge	0.1 V	0.3 V	0.2V	0.1V	-0.1

Comparison of CB, CE, CC configuration.

Property	CB	CE	CC
) I/P Resistance	Low (about 100Ω) 100Ω ~~about 100Ω~~ (22.5Ω)	Moderate ~~about 750Ω~~ (1kΩ)	Very High ~~about 105 kΩ~~ 144 K.
) O/P Resistance	Very high About ~~100k~~ (1.72MΩ) (about 400kΩ)	Medium 45.5k about 50kΩ	Low 80.5Ω. about 50Ω
) A_I	Low (0.98) Less than unity	High 46.5	High 47.5
) A_V	Medium. High ~~(150)~~ about 150	High about 500	Low 0.99
) Phase shift.	0 or 360°	180°	0 or 360°
) Applications	For high freq ckt	Audio freq. Amp	For Impedance Matching

CHARACTERISTICS OF Common Base CIRCUIT.

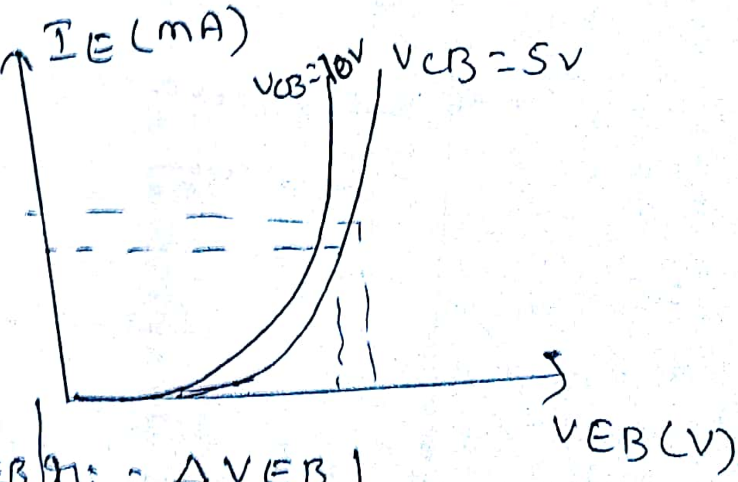


⇒ Supply Voltage VEE makes E-B is in F.W.B & Vcc makes C-B Junction is Reverse bias.

⇒ **INPUT CHARACTERISTICS:**

⇒ It is the curve between an I/p voltage VEB and Input current IE at constant VCB. IE is taken along y-axis & VEB is taken along x-axis.

⇒ when VEE is increases After cut in voltage (barrier potential)(0.7 for Si 0.3v for Ge), The Emitter current IE ↑ rapidly with small increases in VEB



$r_i = \frac{\Delta VEB}{\Delta IE}$ | VCB = constant.

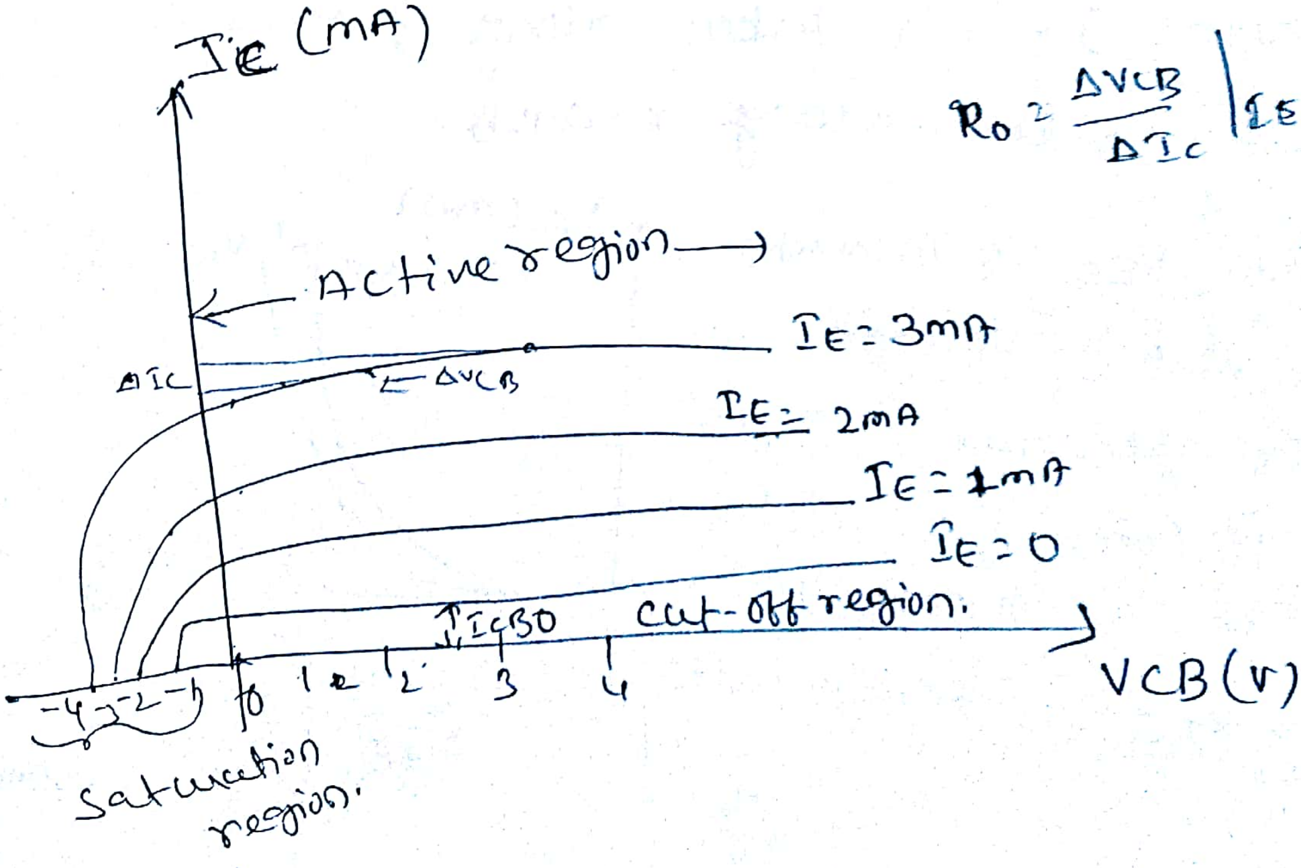
⇒ It can be observed that there is a [illegible] increases in I_E with increase in V_{CB}. This is due to decreasing in base width under Reverse bias condition.

⇒ V_{CB} is +ve for n-p-n, -ve for p-n-p Transistor. on other hand V_{EB} is -ve for n-p-n, +ve for p-n-p

OUTPUT CHARACTERISTICS:-

⇒ The curve b/w collector current I_C and collector-base voltage V_{CB} at constant emitter current I_E represents the o/p characteristics.

⇒ Output characteristics has three basic regions. Active, cut-off, and saturation.



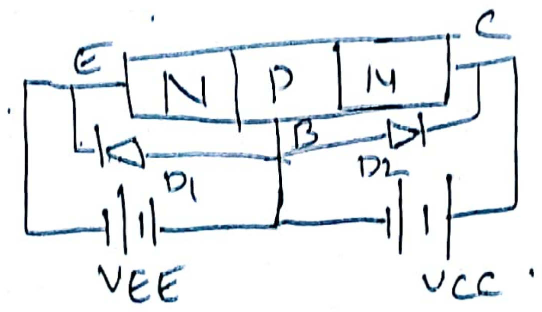
$$R_o = \frac{\Delta V_{CB}}{\Delta I_C}\Big|_{I_E \text{ constant}}$$

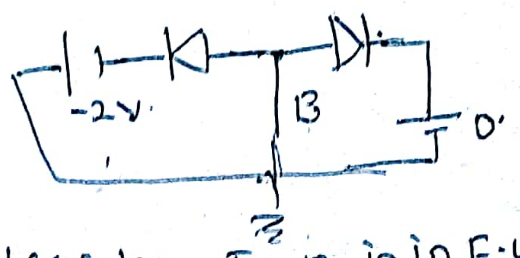
(14)

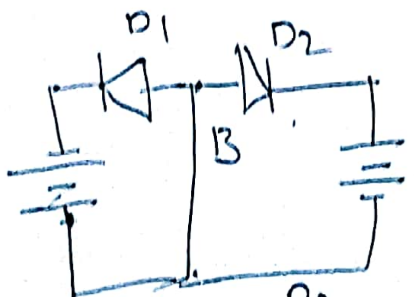
In cut-off region, (both J_E & J_C are Reverse biased), a small amount of collector current flows even when emitter current $I_E = 0$.
This is collector leakage current I_{CBO}.
~~ICBO nothing back~~ [$V_{EE}=0$, $I_E=0$, $V_{EB}=0$].

ii In the saturation region (Both J_E & J_C are Forward bias). The collector current I_C flows even when $V_{CB}=0$. Actually, in n-p-n Transistor, V_{CB} is slightly $-ve$ in this region and because of this Forward biasing. This results Large change in I_C with small change in collector voltage.

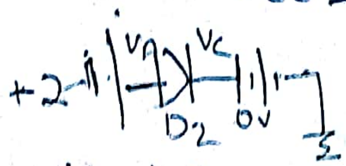
$V_{EE}=2V$, $I_E=2mA$.
V_{CC} is ↑ from 0V.
$V_{CC}=0V$ Now C-B is F.W.B.



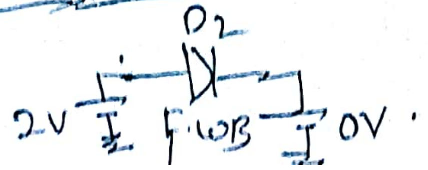




$V_{CC}=1V$. J_{C-B} is in F.W.B
$V_{CC} > 2V$ onwards J_C is in Reverse bias.



$V_A > V_C$



⇒ To keep I_E value is constant (eg: 2mA) we ~~have to~~ have to increase V_{EE} value upto some extent. For example $V_{EE} = 2V$ to get $I_E = 2mA$.

~~when $V_{EE} = 2V$~~, Now vary the V_{CC} from 0V onwards V_{CC} is 0V, 1V, upto 2V the J_C is In Forward bias. beacuse of V_{EE} V_{EE}. $V_{EE} > V_{CC}$ whenever $V_{EE} < V_{CC}$ onwards J_{C-B} is in Reverse biased.

Active region: In this region J_{E-B} is in F.B J_{C-B} is in Reverse bias, The collector current is essentially independent of collector voltage and depends only upon Emitter current. In this region I_C is almost constant. So Transistor can be said to work as constant-current source. This provides very high dynamic o/p resistance.

$$R_o = \frac{\Delta V_{CB}}{\Delta I_C}\Big|_{I_E \text{ constant}}$$

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