Bipolar Junction Transistor and Biasing Techniques

Transistor: The transistor is a semiconductor device which transfers a weak signal from low resistance circuit to high resistance circuit. The word trans means transfer property and istor mean resistance Property offered to the junction. It is a switching device which regulates and amplifies the electrical signal likes voltage or current.

Transistor consists two PN diode connected back to back. It has three terminals namely emitter, base and collector.

The bas is the middle section which is made up of thin layers.

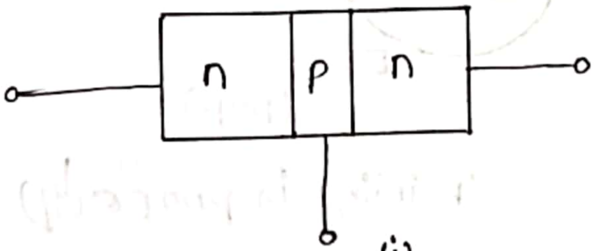
The right part of the diode is called emitter diode and the left part is called collector-base diode.

The emitter based junction of the transistor is connected to forward bias and the collector base junction is connected in reverse bias which offers a high resistance.

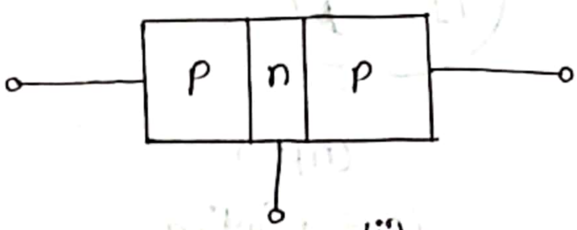
Types of transistor:

(i) n-p-n transistor

(ii) p-n-p transistor



(i)



(ii)

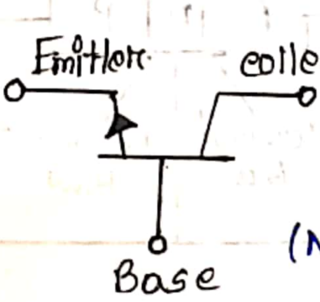
n-p-n: An n-p-n transistor is composed of two n-type semiconductors separated by a thin section of p-type as shown in (i).

p-n-p: A p-n-p transistor is formed by two p-sectio separated by a thin section of n-type as shown in (ii).

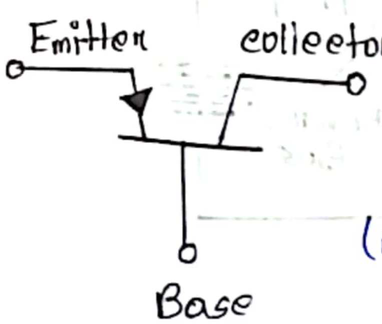
Transistor symbols:

→ The transistor which has two blocks of n-type semicond tor material and one block of p-type semiconductor material is known as $\boxed{\text{NPN transistor.}}$

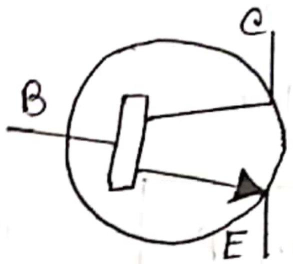
→ The transistor which has one layer of N-type material and two-layers of p-type material is know as $\boxed{\text{PNP transistor.}}$



(NPN)

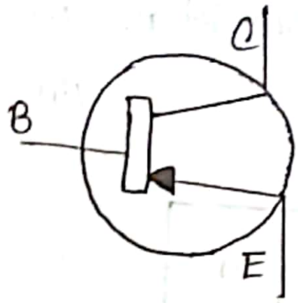


(PNP)



(npn)

(Not pointing in properly)

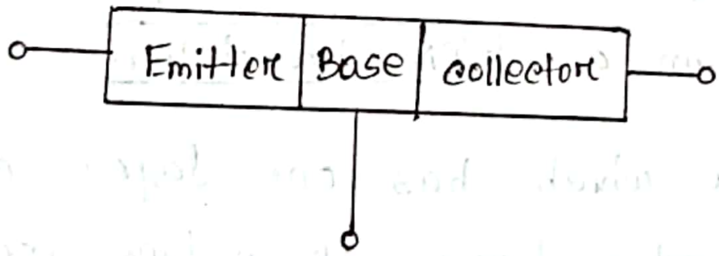


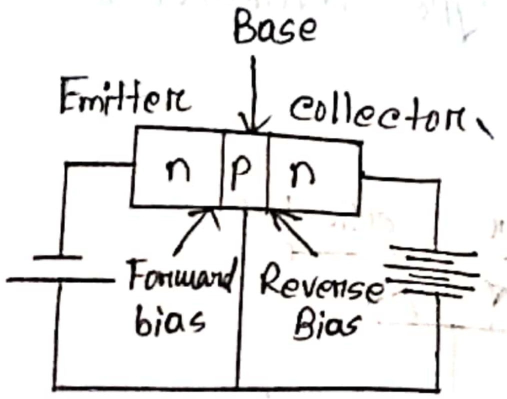
(pnp)

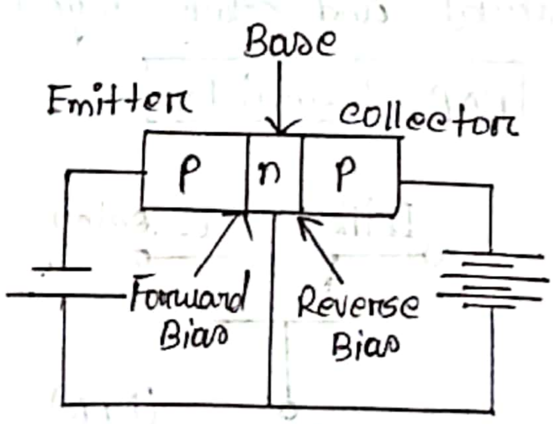
(Pointing in properly)

Transistor terminals: A transistor has 3 sections of doped semiconductors.

The section on one side is the emitter and the section on the opposite side is the collector. The middle section is called the base and forms two junctions between the emitter and collector.







Emitter: The section that supplies the large section of majority charge carrier is called emitter.

⇒ Emitter is always connected in forward bias with respect to the base so that it supplies the majority charge carrier to the base.

⇒ It is heavily doped and moderate in size.

Collector: The section which collects the major portion of the majority charge carrier supplied by the emitter is called a collector.

⇒ Collector base junction is always in reverse bias.

⇒ It is moderately doped, but larger in size so that it can collect most of the charge carrier supplied by the emitter.

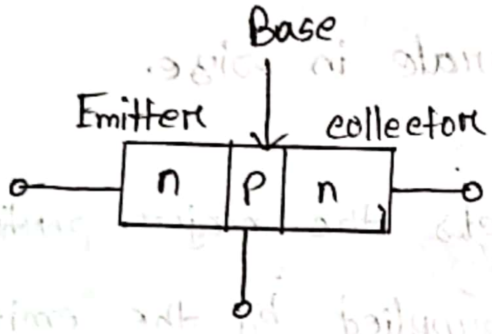
Base: The middle of the transistor is known as the base.

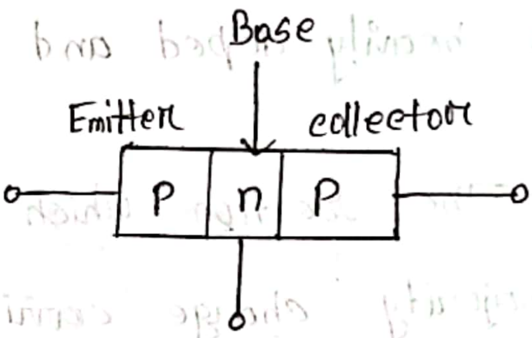
⇒ The base forms two circuits, the input circuit with the emitter and the output circuit with the collector.

⇒ The emitter-base circuit is in forward bias and offered the low resistance to the circuit.

⇒ The collector base junction is in reverse bias and offers the higher resistance to the circuit.

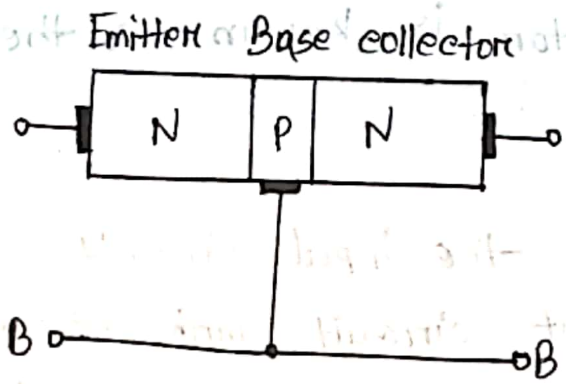
⇒ It is highly doped and very thin due to which it offers the majority charge carrier to the base.

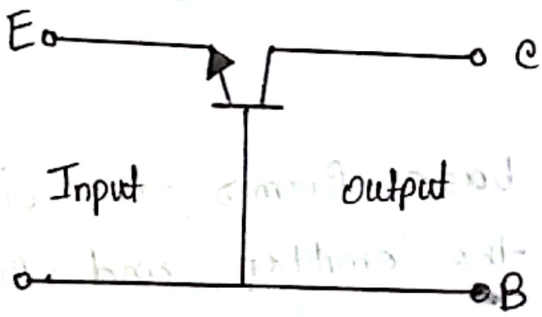




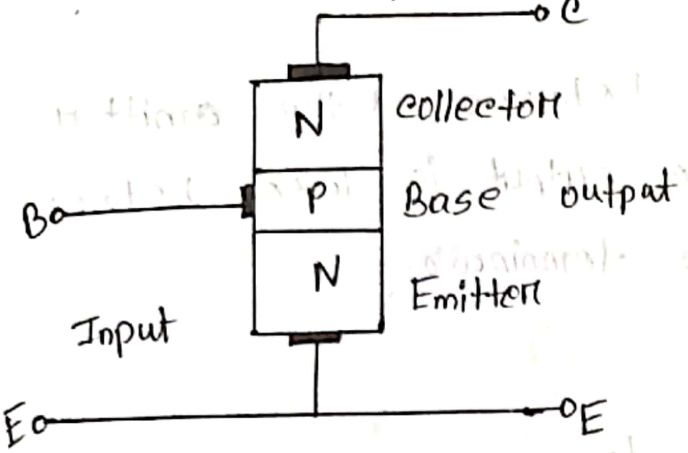
Transistor configuration: Transistor can be connected three different configurations.

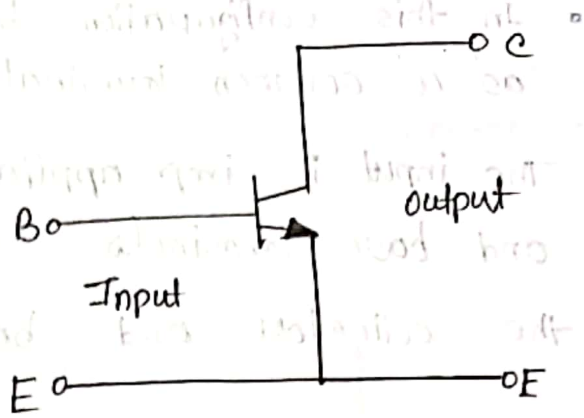
1. Common base configuration: has voltage gain but no current gain.



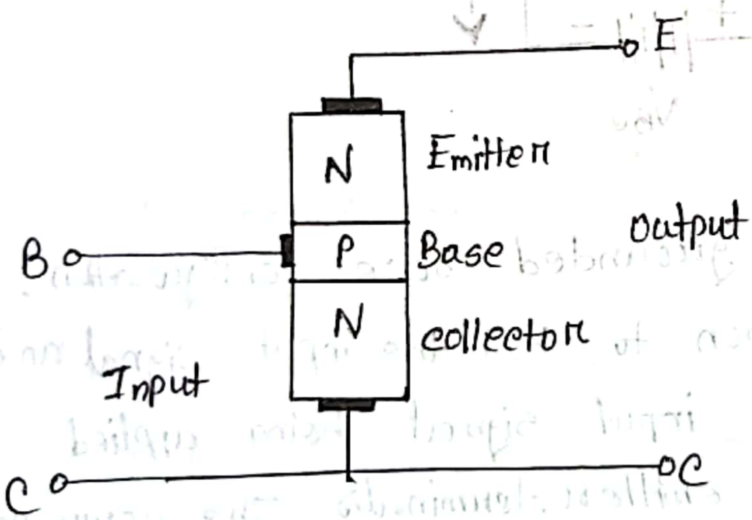


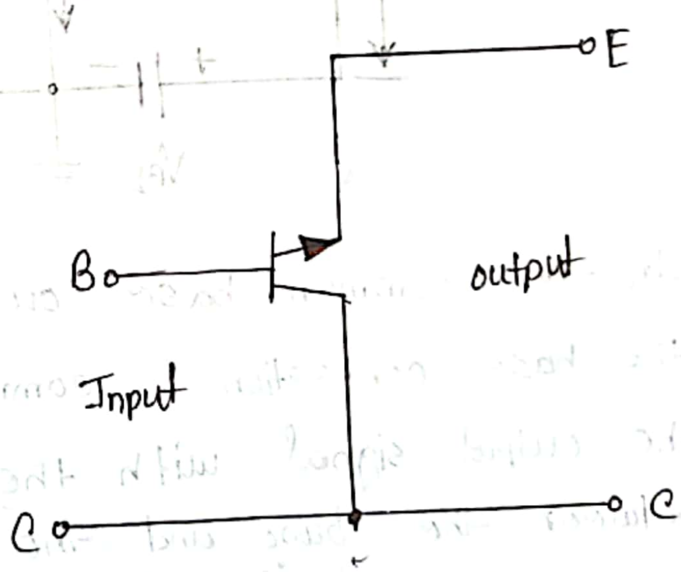
2. <u>Common emitter configuration</u> – has both current and voltage gain.





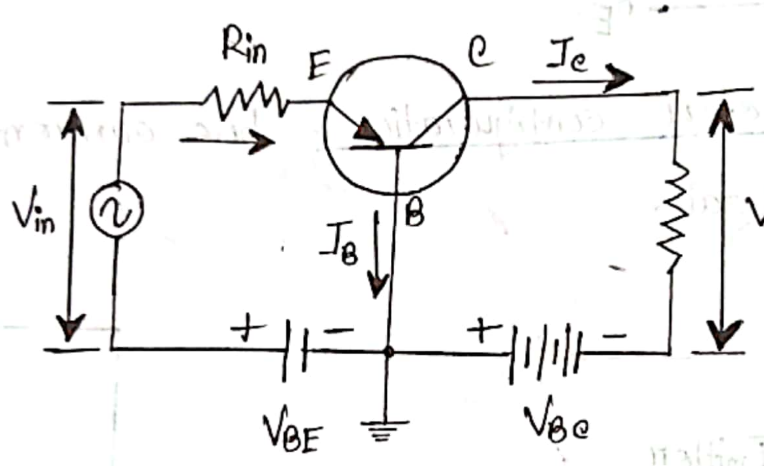
3. <u>Common collector configuration</u> – has current gain but no voltage gain.





Common base configuration:

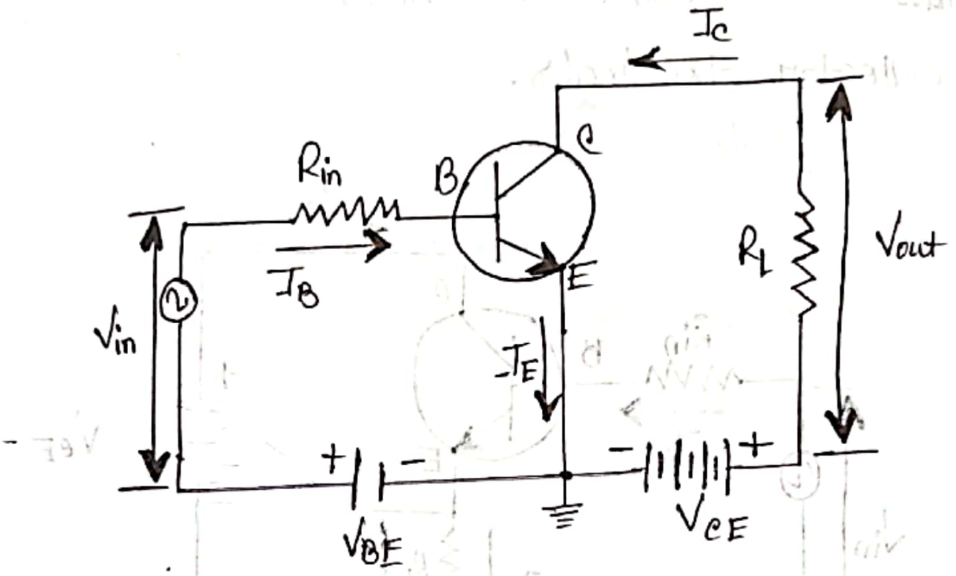
- In this configuration base terminal is connected as a common terminal.
- The input is ~~imp~~ applied between ~~a~~ the emitter and base terminals. The output is taken between the collector and base terminals.



In the common base or grounded base configuration, the base connection is common to both the input signal and the output signal with the input signal being applied between the base and the emitter terminals. The corresponding output signal is taken from between the base and collector terminals as shown with the base terminal grounded or connected to a fixed reference voltage point. The input current ~~point~~ flowing into the emitter is quite large as it's the sum of both the base current and collector current respectively therefore, the collector current output is less than the emitter current input current gain. The common base configuration 'attenuates' the input signal.

Common Emitter configuration:

- Emitter terminal is connected as a common terminal.
- The input is applied between the base and emitter terminals. Output is taken between the collector and base terminals.

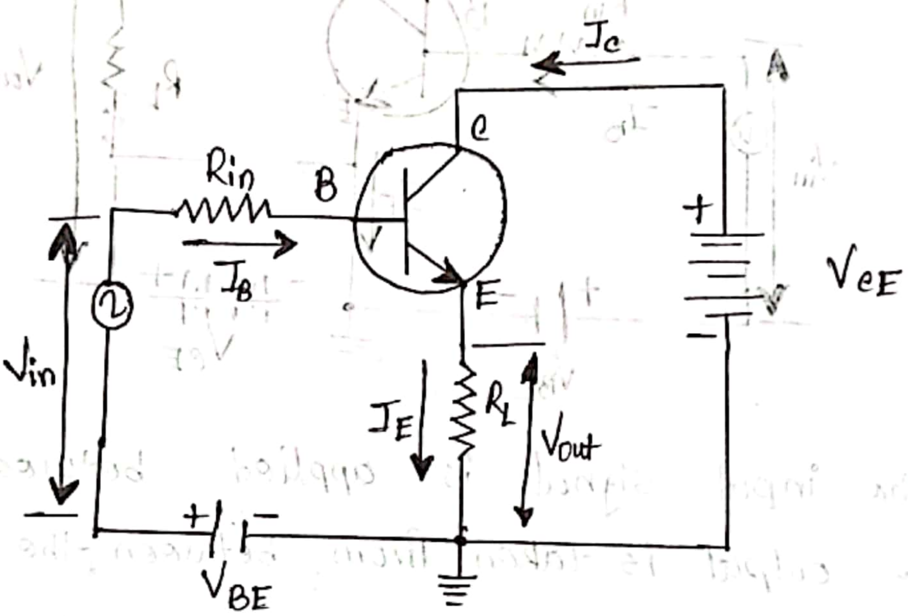


Here, the input signal is applied between the base, while the output is taken from between the collector and the emitter as shown. This type of configuration is the most commonly used circuit for transistor based amplifiers. The common emitter amplifier configuration produces the highest current and power gain of all the three bipolar transistor configurations.

$$I_E = I_C + I_B$$

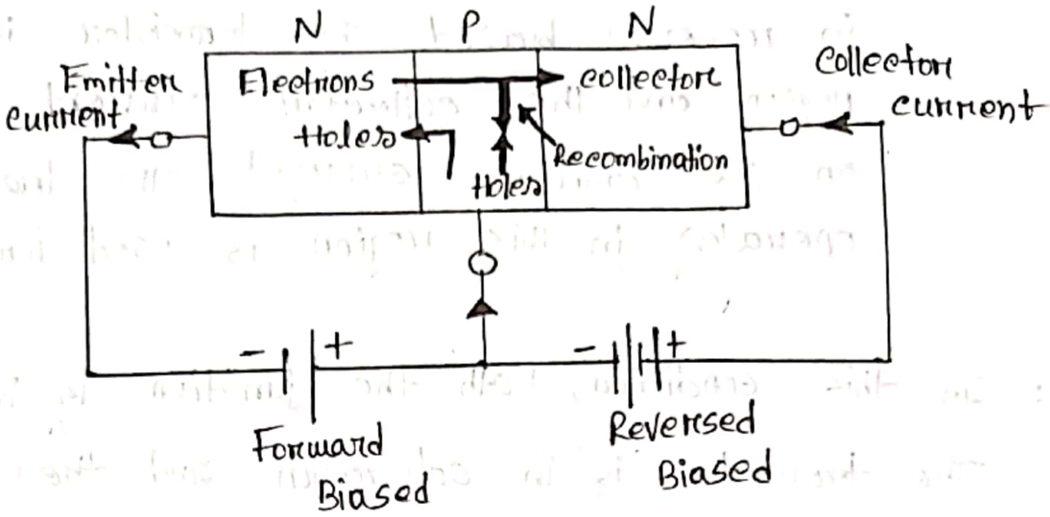
Common collector configuration:

- Collector terminal is connected as a common terminal.
- The input is applied between the base and collector terminals. The output is taken between the emitter and collector terminals.



The collector is now common through the supply. The input signal is connected directly to the base, while the output is ~~to~~ taken from the emitter load as shown. It is commonly known as a voltage follower or emitter follower circuit.

Working on transistor:



Transistor operating conditions: When the emitter junction is in forward bias and the collector junction is in reverse bias then it is said to be in the active region.

The transistor has two junction which can be biased in different ways.

Condition	Emitter junction (EB)	collector junction (CB)	Region of operation
FR	Forward biased	Reverse Biased	Active
FF	Forward biased	Forward biased	Saturation
RR	Reversed biased	Reverse biased	cut off
RF	Reversed biased	Forward biased	Inverted

FR: The emitter base junction is connected in forward biased and the collector base junction in connected in reverse biased. The transistor is in the active region and the collector current is depend on the emitter current. The transistor which operates in this region is used for amplification.

FF: In this condition, both the junction is in forward biased. The transistor is in saturation and the collector current becomes independent of the base current. The transistor act like a closed switch.

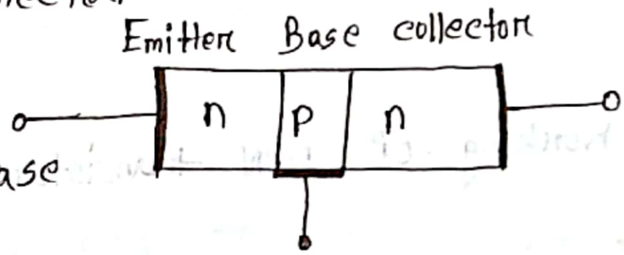
RR: Both the current are in reverse biased. The emitter does not supply the majority charge carrier to the base and carriers current are not collected by the collector. Thus the transistor act like a closed switch.

RF: The emitter base junction is in reverse bias and the collector base junction is kept in forward biased. As the collector is lightly doped as compared to the emitter junction it does not supply the majority charge carrier to the base. Hence poor transistor action is achieved.

NPN transistor: The transistor in which one p-type material is placed between two n-type materials is known as NPN transistor. This transistor amplifies the weak signal. In NPN transistor the direction of movement of an electron is from the emitter to collector region due to which the current constitutes in the transistor.

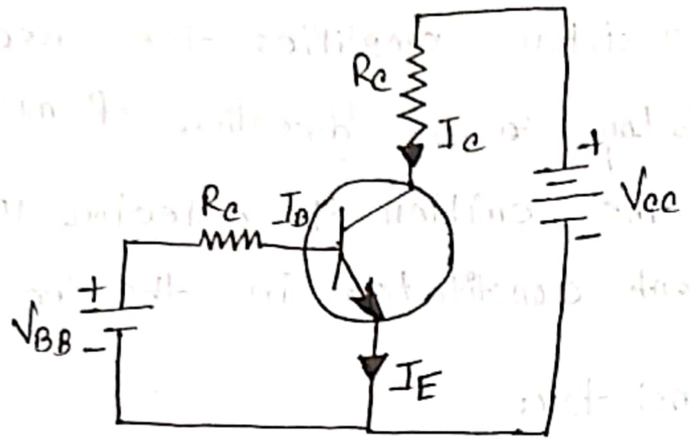
Construction of NPN transistor:

The NPN has two diodes connected back to back. Left side diode is called an emitter-base diode and right side diode is called an collector base diode.

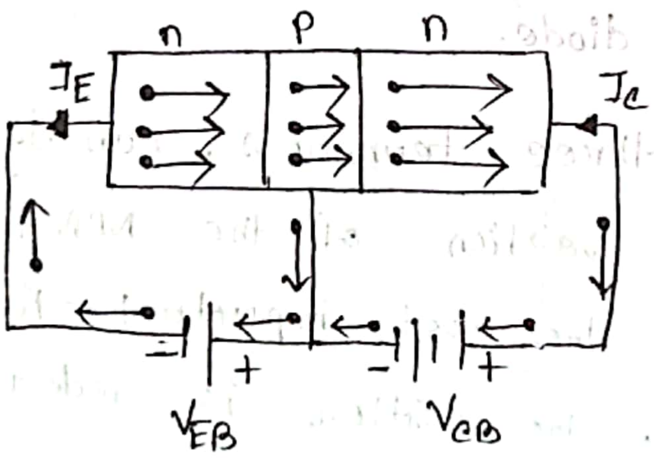


The NPN transistor has three terminals, namely emitter collector and base. Middle section of the NPN transistor is lightly doped And it is the most important factor of the working on transistor. The emitter is moderatly doped and the collector is heavily doped.

Circuit diagram of NPN transistor:



Working of NPN transistor:



Current Amplification Factor (α): It is the ratio of output current to input current. In a common base connection, the input current is the emitter current I_E and output current is the collector current I_C.

The ration of change in collector current to the change in emitter current at constant collector base voltage V_{CB} is known as current amplification factor.

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at constant } V_{CB}.$$

Base current Amplification factor (β): In common emitter connection input current is I_B and output current is I_C.

The ratio of change in collector current (ΔI_C) to the change in basic current (ΔI_B) is known as base current amplification factor.

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

Relation between α and β:

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{--- ①}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{--- ②}$$

Now, $I_E = I_B + I_C$

$$\Rightarrow \Delta I_E = \Delta I_B + \Delta I_C$$

$$\Rightarrow \Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of ΔI_B in eq① we get,

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} \quad \text{--- ③}$$

Dividing the numerator and denominator of R.H.S of eq ③ by ΔI_E we get,

$$\beta = \frac{\frac{\Delta I_C}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} \qquad \left[\alpha = \frac{\Delta I_C}{\Delta I_E}\right]$$

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

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

Current Amplification factor (γ): In common collector circuit input current is the base current I_B and output current is the emitter current I_E.

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

Relation between γ and α:

$$\gamma = \frac{\Delta I_E}{\Delta I_B} \quad \text{--- (1)}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{--- (2)}$$

Now, $I_E = I_B + I_C$

$$\Rightarrow \Delta I_E = \Delta I_B + \Delta I_C$$

$$\Rightarrow \Delta I_B = \Delta I_E - \Delta I_C$$

$$\therefore \gamma = \frac{\Delta I_E}{\Delta I_B}$$

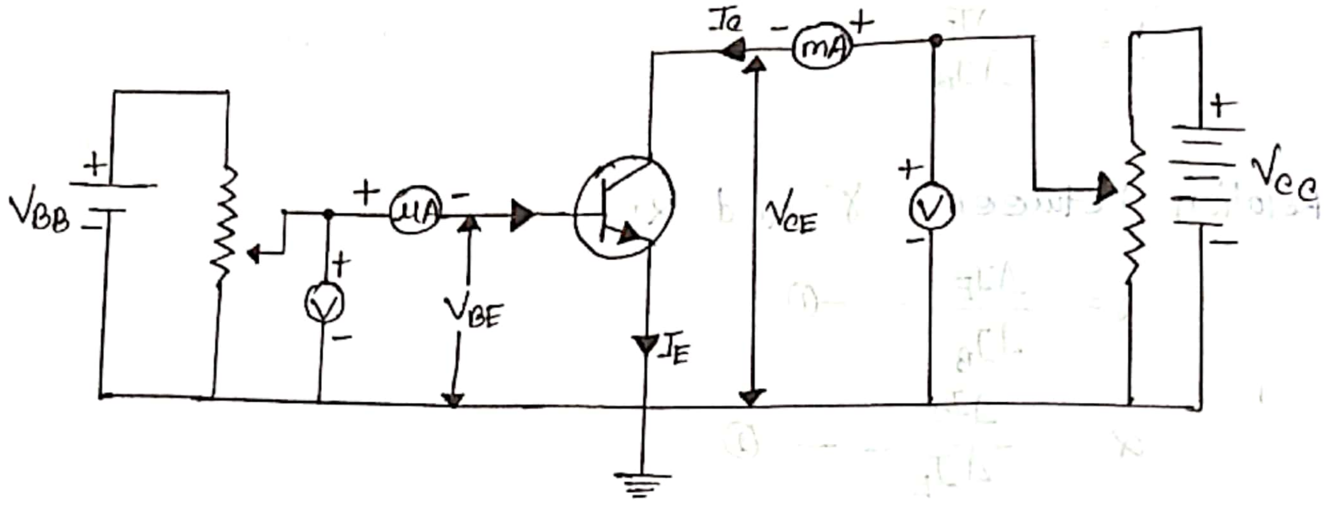
$$= \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

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

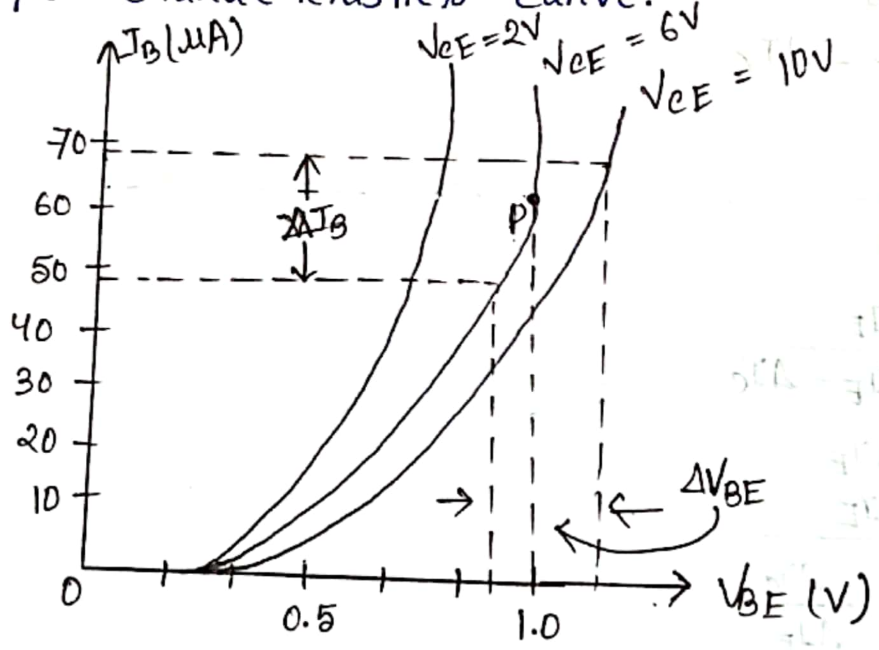
$$= \frac{1}{1-\alpha}$$

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

Characteristics of common emitter (CE) configuration:

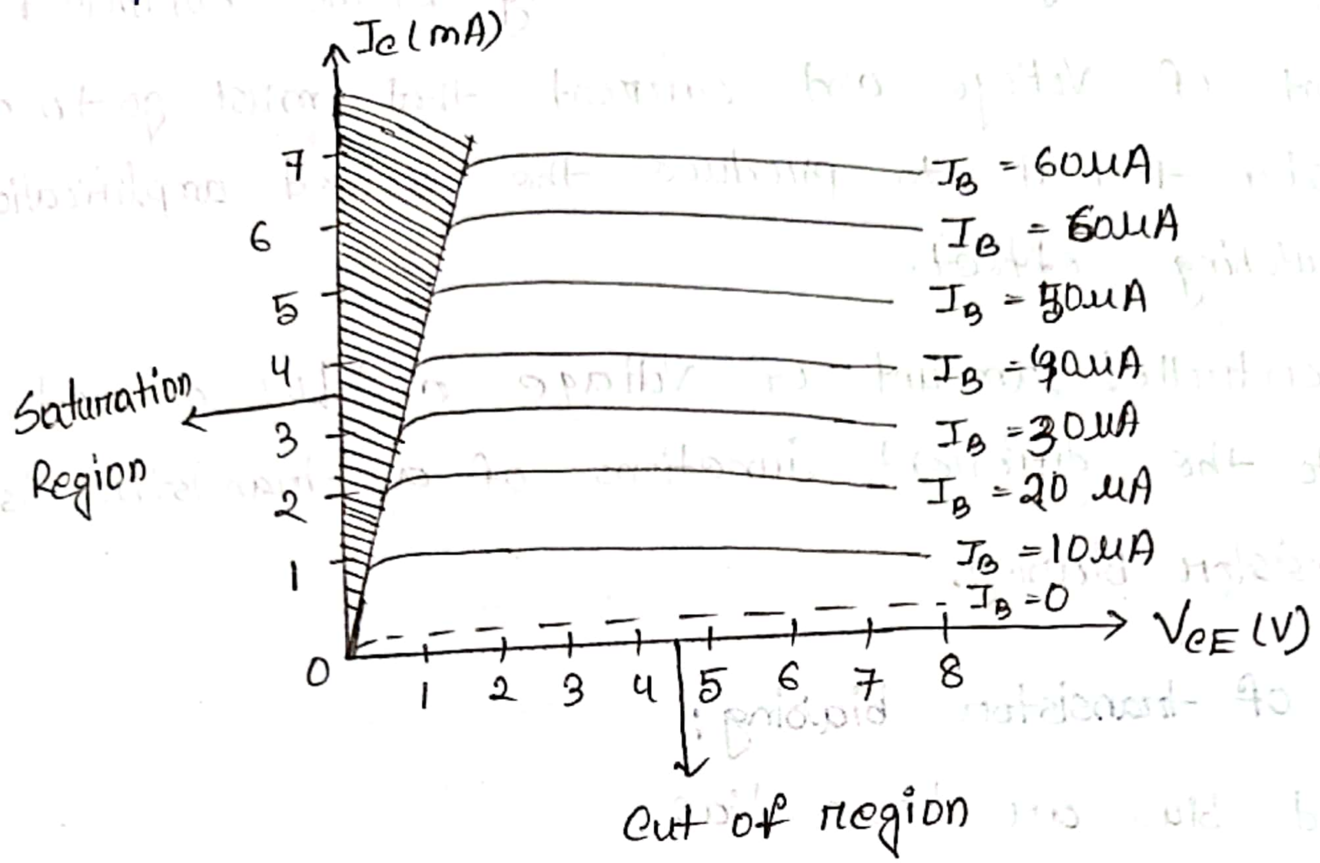


Input characteristics curve:



Input Resistance: $h_i = \frac{\Delta V_{BE}}{\Delta I_B}$ at constant V_{CE}.

output ~~resist~~ characteristic curve:



Output resistance: $h_o = \dfrac{\Delta V_{CE}}{\Delta I_C}$ at constant I_B

Transistor Biasing:

Transistor Biasing is the controlled amount of Voltage and current that must go to a transistor for it to produce the desired amplification or switching effect.

The controlled amount of Voltage and / or currents fed to the different junctions of a transistor is a transistor biasing.

Method of transistor biasing:

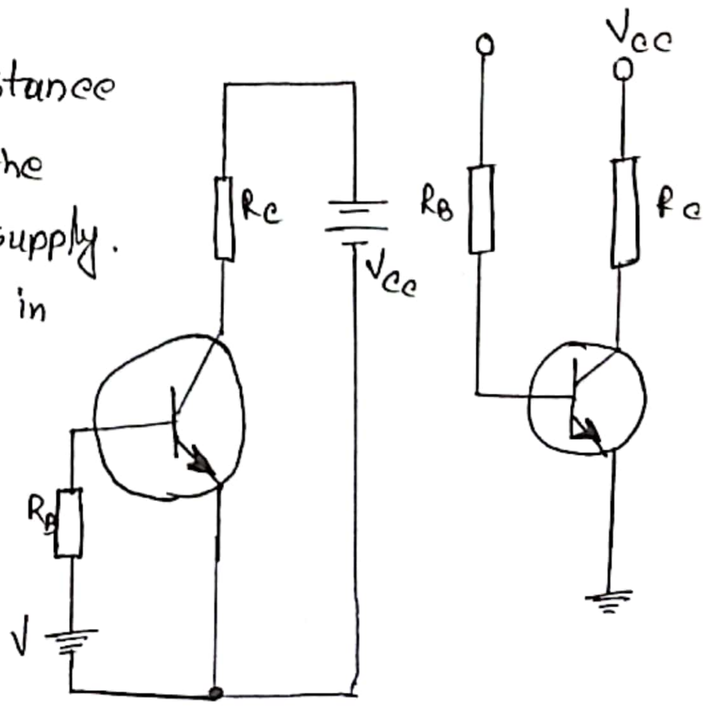
(i) Fixed bias or base bias

(ii) collector ~~bias~~ to base bias

(iii) Emitter bias or self bias

(iv) Voltage divider bias.

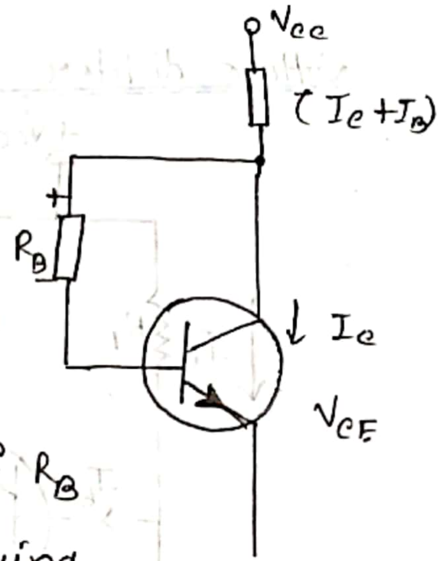
Fixed bias:



In this method a high resistance R_B is connected between the base and positive end of supply. A NPN transistor connected in C_{EE} mode.

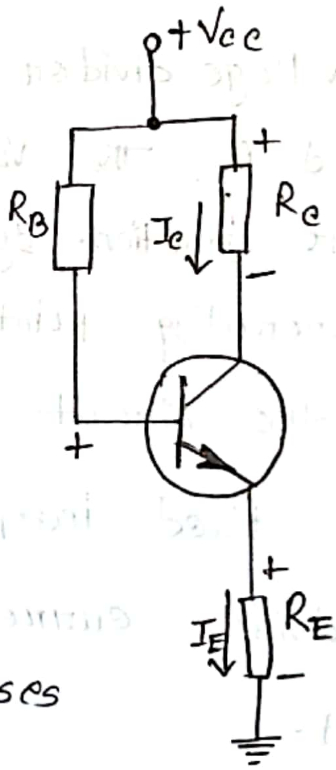
It makes base positive with respect to emitter junction is to forward bias.

Collector to base bias:



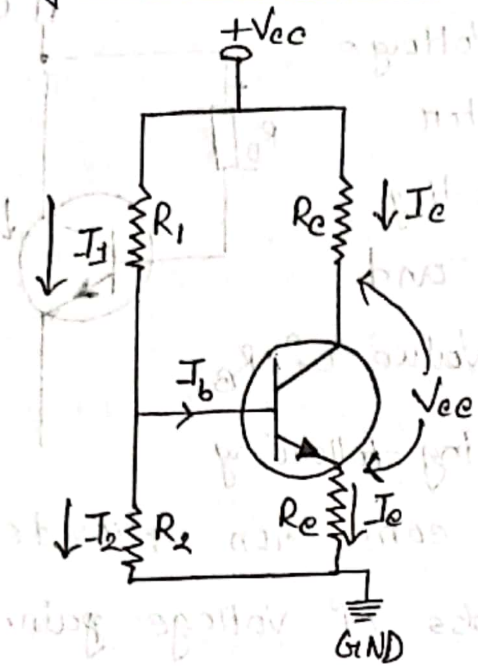
In this method, the bias voltage is obtained from the collector of the transistor by connecting Resistance R_B betwee base and collector as shown. The value of R_B can be calculated by using following relation. R_B = this types of connection provides good feedback but suffers a loss of voltage gain.

Emitter to self bias:



The type of connection is used where R_c is very small.
The R_E Provides negative feed back and causes for stability.
But R_E should be high or R_B is very low and results further losses and complications. Hence this type of connection is not in use

Voltage divider bias:



The most commonly used biasing method. It gives a stable operating point. R_1 and R_2 Voltage dividers, R_c Load resistance, R_E stabilization.

The voltage divider is formed using external resistors R_1 and R_2. The voltage across R_2 forward biases the emitter junction. By proper selection of resistors R_1 and R_2 the operating point transistor can be made independent of β. In this circuit the voltage divider holds the base voltage fixed independent of base current provided the divider current is large compared to the base current.

This is the most widely used in linear circuit. The name voltage divider comes from the voltage divider formed by R_1 and R_2

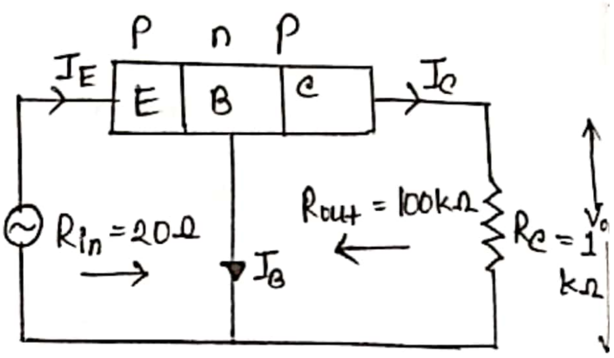
8.1 A common base transistor amplifier has an input resistance of 20Ω and output resistance of $100k\Omega$. The collector load is $1k\Omega$ if a signal of $500mV$ is applied between emitter and base, find the voltage amplification. Assume α_{ac} to be nearly one.

Solution:

Input current, $I_E = \frac{\text{signal}}{R_{in}}$

$= \frac{500}{20}$

$= 25mA$



Since, α_{ac} is nearly 1,

Output current, $I_c = I_E = 25\,mA$

output voltage, $V_{out} = I_c R_c$

$= 25 \times 1k\Omega$

$= 25V$

Voltage amplification, $A_v = \frac{V_{out}}{\text{signal}} = \frac{25V}{500mV} = 50$

(Ans)

8.2 In a common base connection, $I_E = 1\,mA$, $I_c = 0.95\,mA$. calculate the value of I_B.

Solution:

$I_E = I_B + I_c$

$\Rightarrow 1 = I_B + 0.95$

$\Rightarrow I_B = 1 - 0.95$

$= 0.05\,mA$ (Ans)

$I_E = 1\,mA$

$I_c = 0.95\,mA$

CamScanner

8.3 In a common base connection, current amplification factor is 0.9. If the emitter current is 1mA. determine the value of base current.

Solution: Here, ~~Am~~ current amplification factor, $\alpha = 0.9$

$$I_E = 1mA$$

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

$$\Rightarrow I_C = \alpha I_E = (0.9 \times 1) = 0.9 \, mA$$

$$\therefore I_E = I_B + I_C$$

$$\Rightarrow I_B = I_E - I_C = (1 - 0.9) = 0.1 \, mA$$

(Ans)

8.4 In a common base connection $I_C = 0.95$ mA and $I_B = 0.05$ mA. Find the value of α.

Solution: $I_E = I_B + I_C = (0.05 + 0.95) = 1 \, mA$

$\therefore$ current amplification factor, $\alpha = \frac{I_C}{I_E} = \frac{0.95}{1}$

$$= 0.95.$$

8.5 In a common base connection, the emitter current is 1mA. If the emitter circuit is open, the collector current is 50 μA. Find the total collector current. Given that, $\alpha = 0.92$.

Solution: Here, $I_E = 1mA$

$\alpha = 0.92$

$I_{CBO} = 50 \mu A$

Total collector current, $I_C = \alpha I_E + I_{CBO}$

$= 0.92 \times 1 + 50 \times 10^{-3}$

$= 0.97 mA$

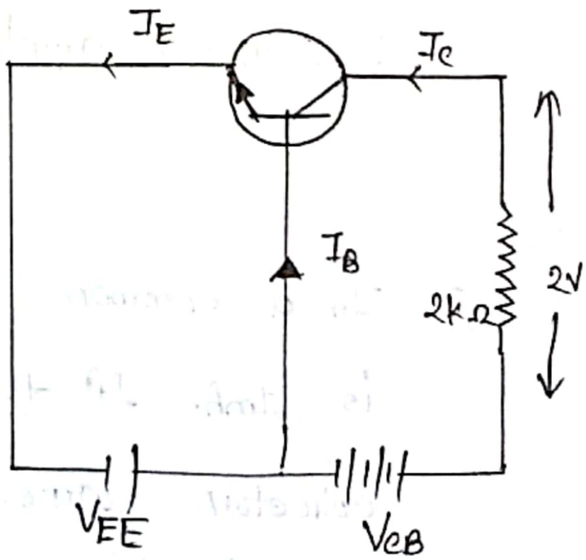
(Ans)

8.6 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.

Solution:

The Voltage drop across $R_C = (2k\Omega)$ is 2V

$I_C = 2V / 2k\Omega = 1mA$



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

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

$= \frac{1}{0.95}$

$= 1.05 mA$

Using the relation, $I_E = I_B + I_C$

$\Rightarrow I_B = I_E - I_C$

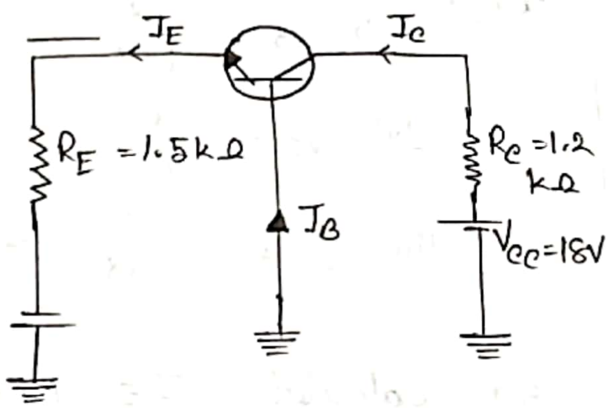
$= 1.05 - 1$

$= 0.05 mA$

(Ans)

8.7 For the common base circuit shown in Figure determine I_C and V_{CB}. Assume the transistor to be of silicon.

Solution:



Since the transistor is of silicon,

$V_{BE} = 0.7V$

Applying kirchoff's voltage law to the emitter-side loop, we get,

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

$$\Rightarrow I_E R_E = V_{EE} - V_{BE}$$

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

$$= \frac{8V - 0.7V}{1.5 k\Omega}$$

$$= 4.87 mA$$

$$\therefore I_C \simeq I_E = 4.87 mA$$

Applying kirchoff's voltage law to the collector-side loop, we have, $V_{CC} = I_C R_C + V_{CB}$

$$\Rightarrow V_{CB} = V_{CC} - I_C R_C$$

$$= 18 - 4.87 \times 1.2 k\Omega$$

$$= 12.16 V$$

(Ans)

8.8 Find the value of β if (i) $\alpha = 0.9$ (ii) $\alpha = 0.98$ (iii) 0.99

Solution:

(i) $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.9}{1-0.9} = 9$

(ii) $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.98}{1-0.98} = 49$

(iii) $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.99}{1-0.99} = 99$

8.9 Calculate I_E in a transistor for which $\beta = 50$ and $I_B = 20\,\mu A$

Solution: Here, $\beta = 50$,

$I_B = 20\,\mu A = 0.02\,mA$

$\therefore \beta = \dfrac{I_C}{I_B}$

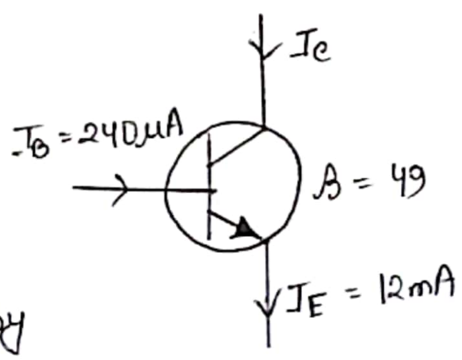
$\Rightarrow I_C = \beta I_B = 50 \times 0.02 = 1\,mA$

5 Using the relation, $I_E = I_B + I_C = 0.02 + 1 = 1.02\,mA$

(Ans)

8.10 Find the α rating of the transistor shown in Figure. Hence determine the value of I_C using both α and β rating of the transistor.

Solution:



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

$= \dfrac{49}{1+49} = 0.98$

The value of I_C can be found by using either α or β rating as under:

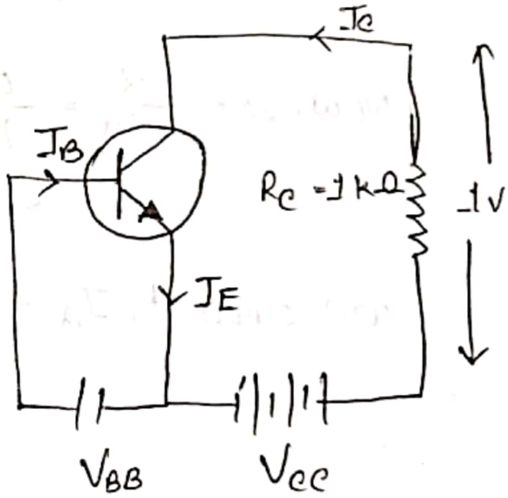
$I_C = \alpha I_E = 0.98\ (12\,mA) = 11.76\,mA$

$I_C = \beta I_B = 49\ (240\,\mu A) = 11.76\,mA$ (Ans)

8.11 For a transistor, $\beta = 45$ and voltage drop across $1\,k\Omega$ which is connected in the collector circuit is 1 Volt. Find the base current for common emitter connection.

Solution: The voltage drop across $R_C = (1\,k\Omega)$ is 1 Volt

$$I_C = \frac{1V}{1\,k\Omega} = 1\,mA$$



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

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

$$= \frac{1}{45}$$

$$= 0.022\,mA \text{ (Ans)}$$

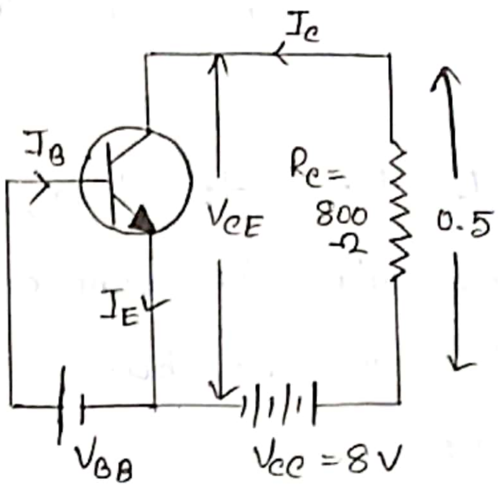
8.12 A transistor is connected in common emitter (CE) configuration in which collector supply is 8V and the voltage drop across resistance R_C connected in the collector circuit is 0.5V. The value of $R_C = 800\,\Omega$ if $\alpha = 0.96$ determine: (i) collector-emitter voltage

(ii) base current.

Solution:

(i) collector emitter voltage,

$$V_{CE} = V_{CC} - 0.5$$
$$= 8 - 0.5$$
$$= 7.5\,V$$



(ii) The voltage drop across R_C ($= 800\Omega$) is 0.5 V

$$\therefore I_C = \frac{0.5\,V}{800\Omega} = \frac{5}{8}\,mA$$
$$= 0.625\,mA$$

$$\text{Now, } \beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96}$$
$$= 24$$

$$\text{Base current, } I_B = \frac{I_C}{\beta}$$
$$= \frac{0.625}{24} = 0.026\,mA$$

(Ans)

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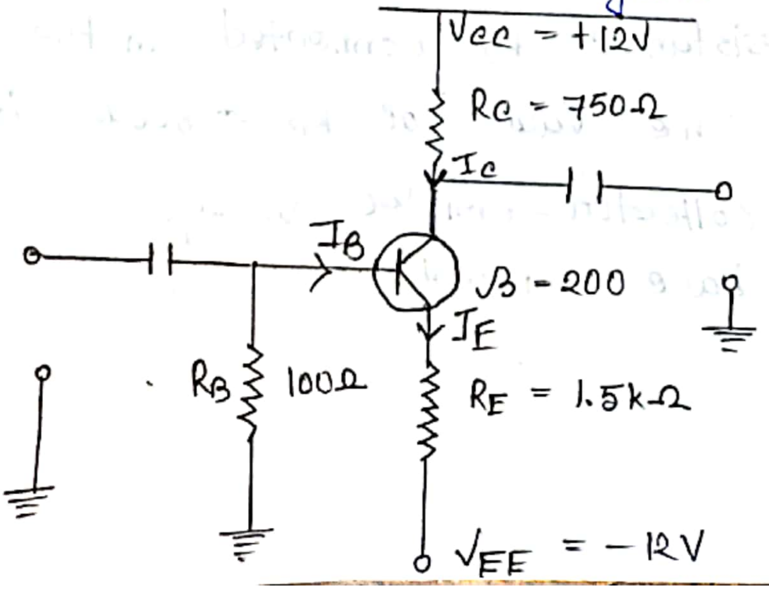
8.32 Determine the values of $V_{CE(off)}$ and $I_{C(sat)}$ for the circuit shown in figure.



Solution: Applying kirchhoff's Voltage law to the collector side of the circuit in Figure, we have,

$$V_{CC} - I_C R_C - V_{CE} - {}^{*} I_C R_E + V_{EE} = 0$$

$$V_{CE} = V_{CC} + V_{EE} - I_C (R_C + R_E) \quad \text{—} (1)$$

* Voltage across $R_E = I_E R_E$ since $I_E \simeq I_C$ Voltage across $R_E = I_C R_E$

$V_{CE(off)}$ when $I_C = 0$,

Therefore, putting $I_C = 0$ in equation (1) we have,

$$V_{CE(off)} = V_{CC} + V_{EE}$$
$$= 12 + 12$$
$$= 24\,V$$

we have, $I_{C(sat)}$ when $V_{CE} = 0$

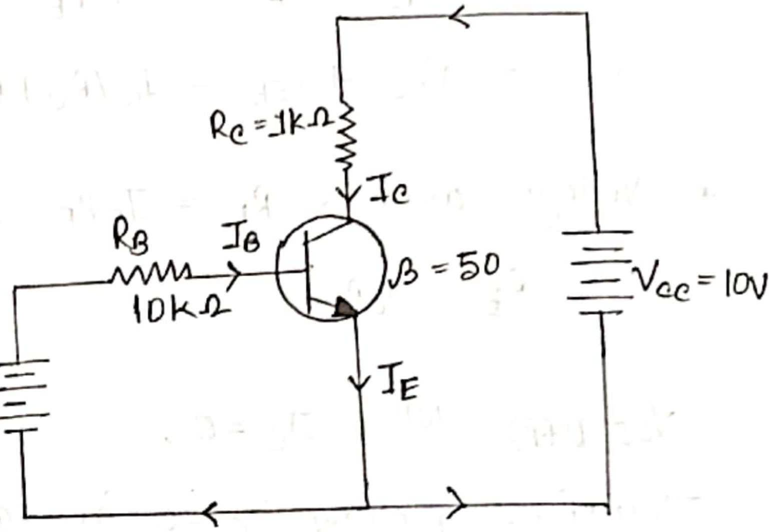
$$I_{C(sat)} = \frac{V_{CC} + V_{EE}}{R_C + R_E}$$

$$= \frac{(12+12)\,V}{(750+1500)\,\Omega}$$

$$= 10.67\,mA.$$

(Ans)

8.33 Determine whether or not the transistor in figure is in Saturation. Assume $V_{knee} = 0.2V$.



Solution:

$$I_{C(sat)} = \frac{V_{CC} - V_{knee}}{R_C}$$

$$= \frac{10V - 0.2V}{1\ k\Omega} = \frac{9.8V}{1k\Omega}$$

$$= 9.8\,mA$$

Now, we shall see if I_B is large enough to produce $I_{C(sat)}$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$= \frac{3V - 0.7V}{10k\Omega}$$

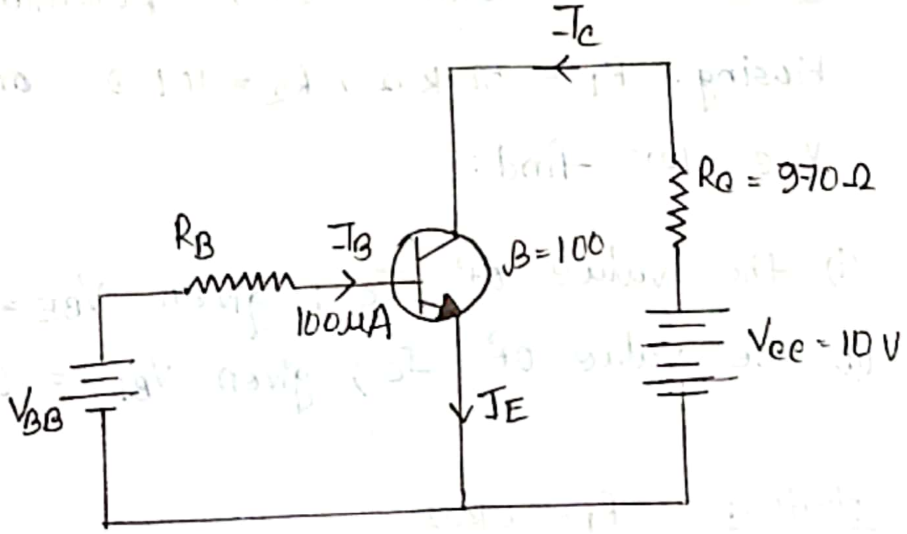
$$= \frac{2.3V}{10k\Omega} = 0.23\,mA$$

$$I_C = \beta I_B = 50 \times 0.23$$

$$= 11.5\,mA.$$

This show that with specified β this base current (= 0.23 mA) is capable of producing I_C greater than $I_{C(sat)}$. Therefore the transistor is saturated. In fact, the collector current value of 11.5 mA is never reached. In the base current value correspo -to $I_{C(sat)}$ is increased the collector current remains at the saturated value (= 9.8 mA).

8.34 In the transistor in figure operating in saturated state?



$I_C = \beta I_B$
$= (100) \times (100\mu A)$
$= 10 mA$

$V_{CE} = V_{CC} - I_C R_C$
$= 10V - (10mA)(970)$
$= 0.3V$

The value of V_{BE} is 0.95V and the value of $V_{CE} = 0.3V$. This leaves V_{CB} of 0.65V (Note that $V_{CE} = V_{CB} + V_{BE}$).

In this case collector - base junction (i.e, collector diode) is forward biased as is the emitter - base junction (i.e, emitter diode). Therefore the transistor is operating in the saturation region.

9.21 A transistor uses potential divider method of biasing. $R_1 = 50\,k\Omega$, $R_2 = 10\,k\Omega$ and $R_E = 1\,k\Omega$ if $V_{CC} = 12V$ find:

(i) the value of I_C; given $V_{BE} = 0.1\,V$

(ii) the value of I_C; given $V_{BE} = 0.3\,V$

Solution:

$R_1 = 50\,k\Omega$

$R_2 = 10\,k\Omega$

$R_E = 1\,k\Omega$

$V_{CC} = 12V$

(i) When, $V_{BE} = 0.1\,V$

Voltage across, R_2, $V_2 = \dfrac{R_2}{R_1+R_2} V_{CC}$

$$= \frac{10}{50+10} \times 12$$

$$= 2V$$

Collector current, $I_C = \dfrac{V_2 - V_{BE}}{R_E}$

$$= \frac{2-0.1}{1\,k\Omega}$$

$$= 1.9\,mA$$

(ii) When, $V_{BE} = 0.3V$

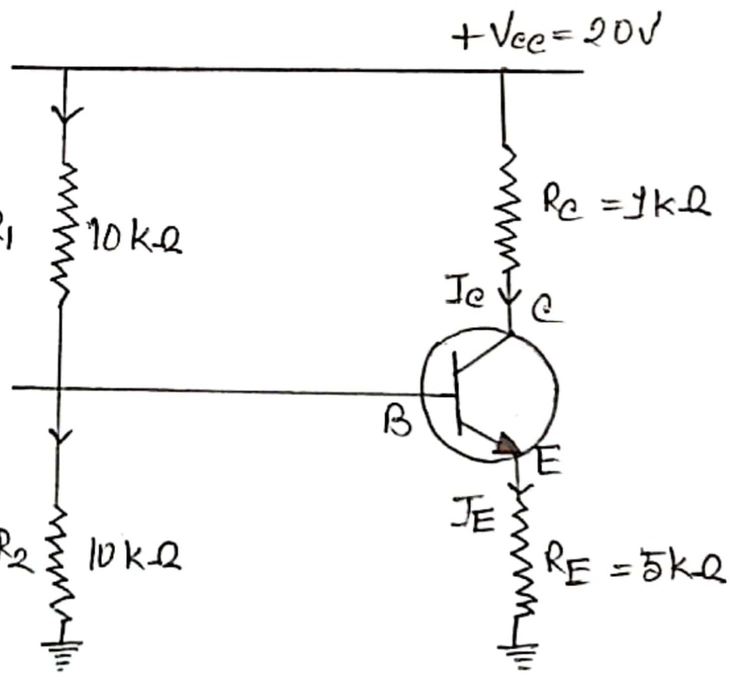
collector current, $I_C = \frac{V_2 - V_{BE}}{R_E}$

$= \frac{2 - 0.3}{1k\Omega}$

$= 1.7 mA$

(Ans)

9.22 Calculate the emitter current in the voltage divider circuit shown in figure. Also find the value of V_{CE} and collector potential V_C.



Solution:

Voltage across R_2,

$V_2 = \left(\frac{V_{CC}}{R_1+R_2}\right) R_2$

$= \left(\frac{20}{10+10}\right) 10$

$= 10V$

Now, $V_2 = V_{BE} + I_E R_E$

As V_{BE} is generally small, therefore, it can be neglected

$I_E = \frac{V_2}{R_E}$

$= \frac{10V}{5k\Omega}$

$= 2mA$

Now, $I_C \simeq I_E = 2\,mA$

$$\therefore V_{CE} = V_{CC} - I_C (R_C + R_E)$$

$$= 20 - 12$$

$$= 8V$$

collector potential, $V_C = V_{CC} - I_C R_C$

$$= 20 - 2 \times 1$$

$$= 20 - 2$$

$$= 18V \quad \text{(Ans)}$$

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