BIPOLAR JUNCTION TRANSISTOR

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Transistor current components

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Input & Output characteristics of a transistor in CE configuration

Input & Output characteristics of a transistor in CC configuration

Comparison of a transistor in CB, CE and CC configurations

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Bipolar junction Transistor (BJT) :-

Introduction :

* A Bipolar junction transistor is a three terminal semi conductor device in which the operation depends on the interaction of majority and minority carriers. hence it is named as Bipolar device.

* Transistor means 'Transfer Resistor' ie signals are transfered from low resistance circuit (input) into high resistance (output circuit).

* Basically a third doped element is added to a crystal diode in such a way that two PN junctions are formed. These two junctions give three regions called emitter, base and collector.

* The BJT is analogous to a vaccum triode and is comparatively smaller in size.

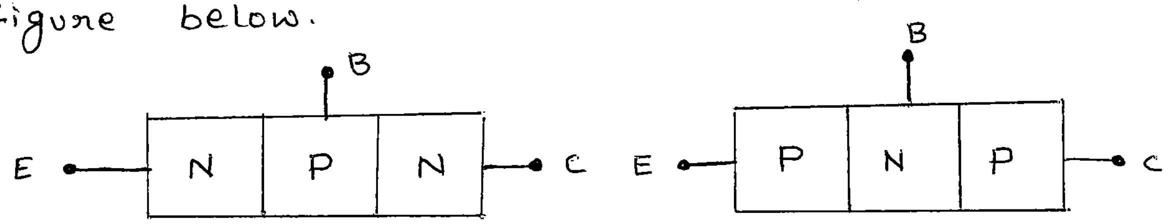
* BJT's are used in amplifier and oscillator circuits and as a switch in digital circutts

BJT construction :-

* The BJT consists of a silicon (Germanium) crystal in which a thin layer of N-type silicon is sandwiched between two layers of P-type silicon. This transistor is referred to as PNP

* Similarly, a layer of P-type material is sandwiched between two layers of N-type material. This transistor is referred to as <u>NPN</u>.

The two types of BJT are represented in figure below.



(a) NPN Transistor (b) PNP Transistor

* The symbolic representation of the two types of the BJT is shown in figure below.

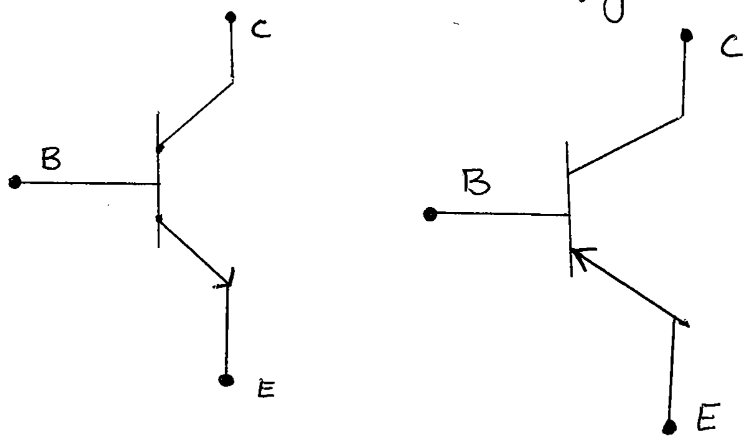


fig (a) Symbol for NPN Transistor

fig(b) Symbol for PNP Transistor.

The three portions of the transistor are Emitter, Base and collector shown as E, B and C respectively. The arrow of the emitter specifies the direction of the current flow when the EB junction is forward biased.

Two junctions are EB → Emitter-base junction

CB → collector-base junction

Emitter: It is more heavily doped than any of the other region because its main function is to supply majority charge carriers to the base.

Base: Base is lightly doped and very thin. It passes most of the injected charge carriers from the emitter in to the collector.

Collector: collector is moderately doped. Its main function is to collect the majority charge carriers coming from the emitter and passing through the base. In most transistors, collector region is made physically larger than the emitter region because it has to dissipate much greater power.

Transistor Biasing:-

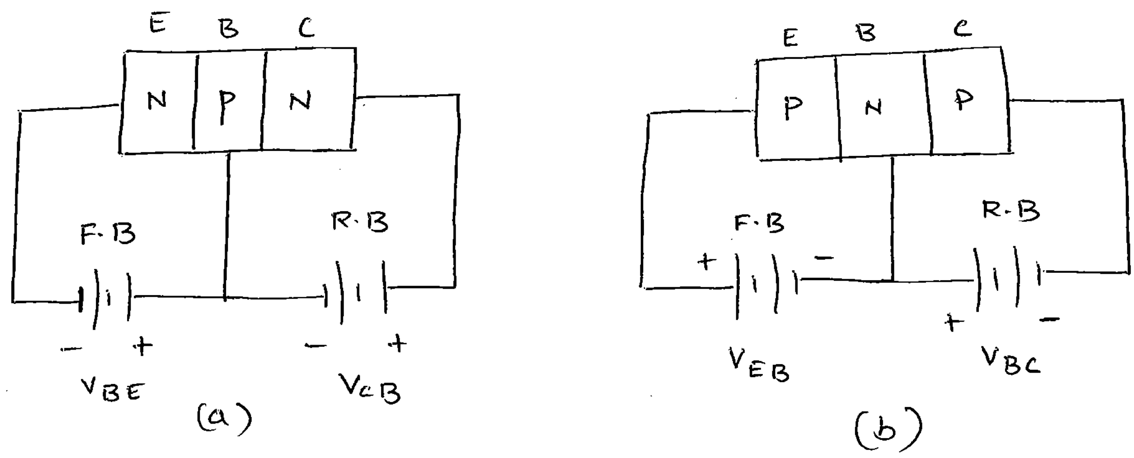
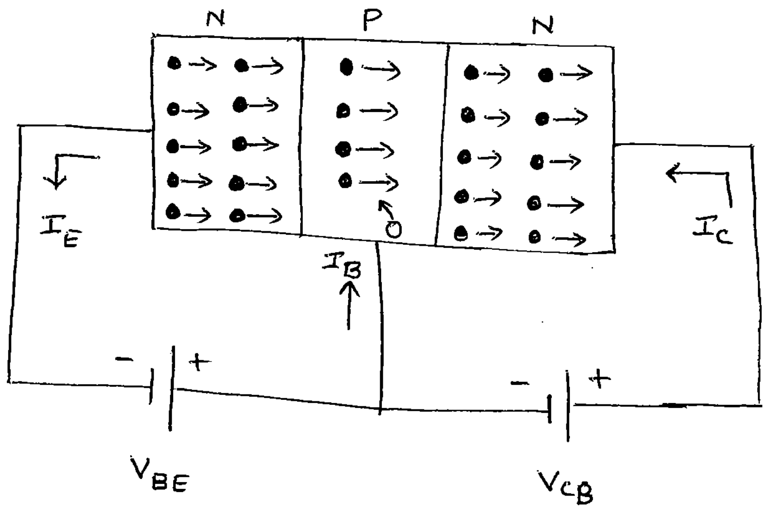


fig: Transistor biasing (a) NPN Transistor and (b) PNP Transistor.

As shown in figure, usually the emitter base junction is forward biased and collector base junction is reverse biased. Due to the forward bias on the emitter base junction, an emitter current flows through the base in to the collector. Though the collector - base junction is reverse biased almost the entire emitter current flows through the collector circuit.

Operation of NPN Transistor :-



As shown in figure, the forward bias is applied to the emitter base junction of an NPN transistor causes a lot of electrons from the emitter region to cross over to the base region.

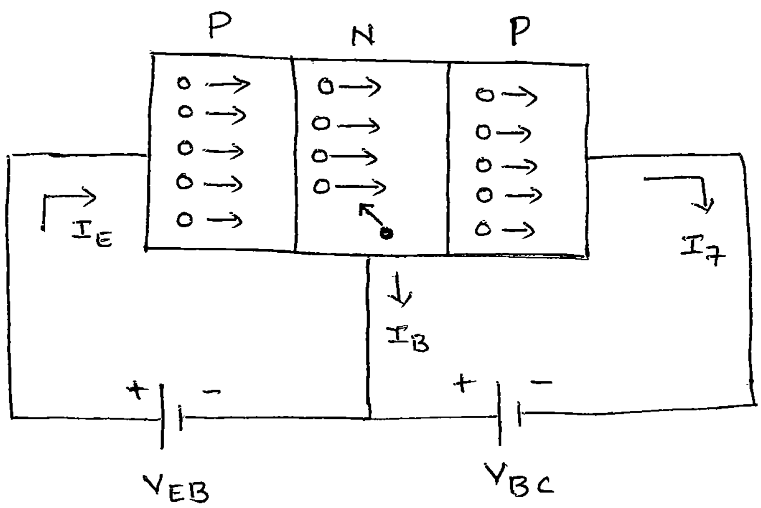
As the base is lightly doped with P-type impurity, the number of holes in the base region is very small and hence the number of electrons that combine with holes in the P-type base region is also very small. Hence a few electrons combine with holes to constitute a base current I_B. The remaining electrons (more than 95%) crossover into the collector region to constitute a collector current (I_C). Thus the base and collector current summed up gives the emitter current. ie

$$I_E = -(I_C + I_B) \quad \left[\because \text{As per KCL} \quad I_C + I_B + I_E = 0 \right]$$

In the external circuit of the NPN bipolar junction transistor, the magnitudes of emitter current I_E, the base current I_B and the collector current I_C are related by

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

Operation of PNP Transistor :-



As shown in figure above, the forward bias applied to the emitter base junction of a PNP transistor causes a lot of holes from the emitter region to crossover to the base region.

As the base is lightly doped with N-type impurity, the number of electrons in the base region are very small and hence the number of holes combined with electrons in the N-type region is also very small. Hence a few holes combined with electrons to constitute a base current I_B. The remaining holes (more than 95%) cross over in to the collector region to constitute a collector current I_C. Thus the collector and base current when summed up gives the emitter current

ie $I_E = -(I_C + I_B)$

In the external circuit of the PNP bipolar junction transistor, the magnitudes of the emitter current I_E, the base current I_B and the collector current I_C are related by

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

<u>Current components in a transistor</u>:

The figure below shows the various current components which flow across the forward biased emitter junction and reverse biased collector junction in P.N.P Transistor.

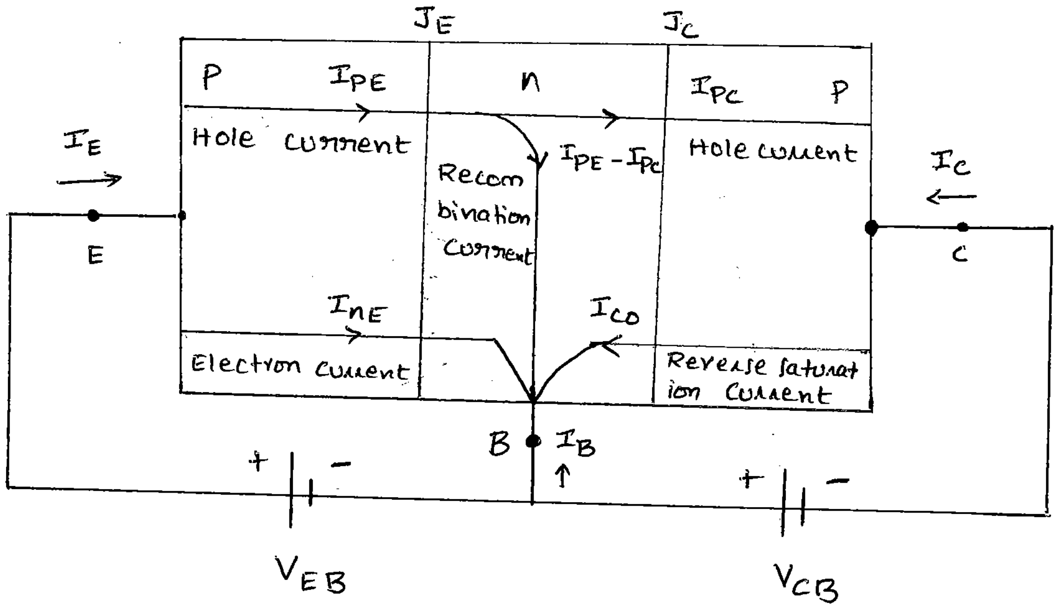


Figure: current components in a transistor with forward biased emitter and reverse biased collector junctions.

The emitter current consists of the following two parts.

1) Hole current I_{PE} constituted by holes (holes crossing from emitter in to base

2) Electron current I_{nE} constituted by electrons (electrons crossing from base in to the emitter)

Therefore total emitter current

$$I_E = I_{PE}\,(\text{majority}) + I_{nE}\,(\text{minority})$$

The holes crossing the emitter base junction J_E reaching the collector base junction J_C constitutes collector current I_{PC}.

Not all the holes crossing the emitter base junction reach collector base junction J_C

because some of them combine with the electrons in the n-type base

Since base width is very small, most of the holes cross the collector base junction J_C and very few recombine, constituting the base current $(I_{PE} - I_{PC})$

When the emitter is open circuited, $I_E = 0$ and hence $I_{PC} = 0$. Under this condition, the base and collector together current I_C equals the reverse saturation current I_{CO}, which consists of the following two parts.

1) I_{PCO} caused by the holes moving across I_C from N region to P region

2) I_{NCO} caused by electrons moving across I_C from P-region to N-region.

$$\therefore I_{CO} = I_{nco} + I_{PCO}$$

In general $I_C = I_{nc} + I_{pc}$

Thus for a PNP Transistor

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

Transistor circuit configurations :

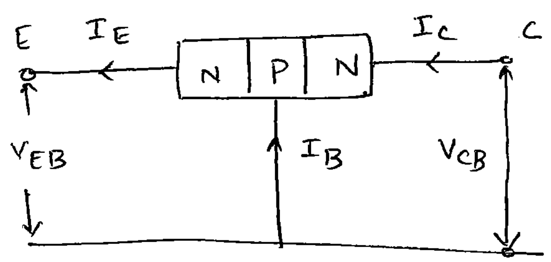
Basically there are three types of circuit connections for operating a transistor.

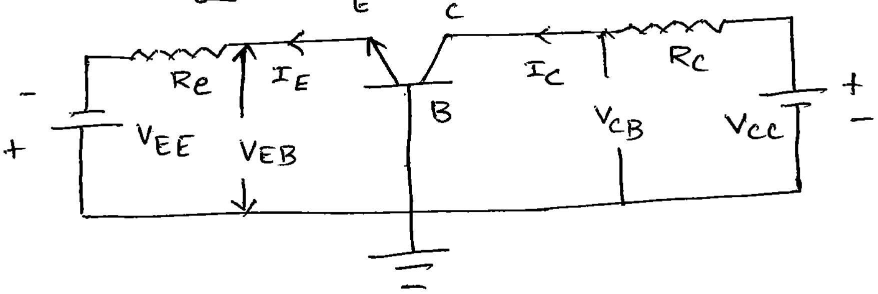
1. Common base configuration (CB)
2. common emitter configuration (CE)
3. common collector configuration (CC)

1. CB configuration :

This is also called grounded base configuration. In this configuration, emitter is the input terminal, collector is the output terminal and base is the common terminal.

The input signal is applied between the emitter and base where as output is taken out from the collector and base, thus emitter current is the input current and collector current is the output current.





The ratio of collector current to emitter current is called <u>dc current gain</u> (α_{dc} or α) of a transistor

$$\alpha = -\frac{I_c}{I_E} \Rightarrow \boxed{I_c = -\alpha I_E}$$

The negative sign indicates that emitter and collector currents flow in opposite direction (ie. the conventional emitter current flows out and collector current enters in to the transistor)

thus α of a transistor is a measure of the quality of a transistor, higher the value of α, better the transistor in the sense that the collector current more closely equal to the emitter current. Its value ranges from 0.98 to ~~0.99~~. 0.985.

For simplicity $I_c = \alpha I_E$

we know that $I_E = I_c + I_B$

$$I_B = I_E - \alpha I_E$$

$$\boxed{I_B = (1-\alpha) I_E}$$

ac current gain $\alpha_{ac} = \frac{-\Delta I_c}{\Delta I_E}$

(It refers to the change in collector current to change in emitter current)

<u>Total collector current</u> :-

The whole emitter current does not reach the collector because a small percentage of electron hole combination occuring in the base area it gives rise to base current. Due to reverse biasing of collector base junction wide depletion region is formed across it, this depletion region helps the minority carriers of base (electrons) to cross the collector base junction, thus more collector current flows in addition to this leakage current (I_{CBO}) therefore total collector current is given by

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

where I_{CBO} = leakage current. Hence it is very small hence it is neglected in circuit calculation.

<u>Characteristics of CB Configuration</u> :-

The circuit diagram for determining the static characteristics of an NPN Transistor in the common base configuration is shown in figure below.

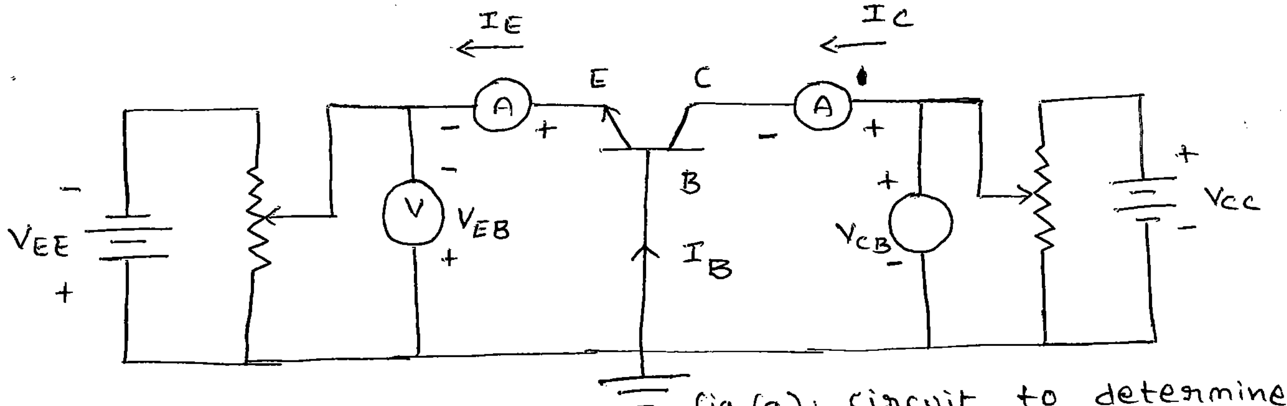


fig (a): circuit to determine CB static characteristics

<u>Input characteristics</u> :-

To determine the input characteristics the collector base voltage V_{CB} is kept constant at zero volt and the emitter current I_E is increased from zero in suitable equal steps by increasing V_{EB}

This is repeated for higher fixed values of V_{CB}. A curve is drawn between emitter current (I_E) and emitter base voltage (V_{EB}) at constant collector base voltage (V_{CB}). The input characteristics thus obtained are shown in figure below.

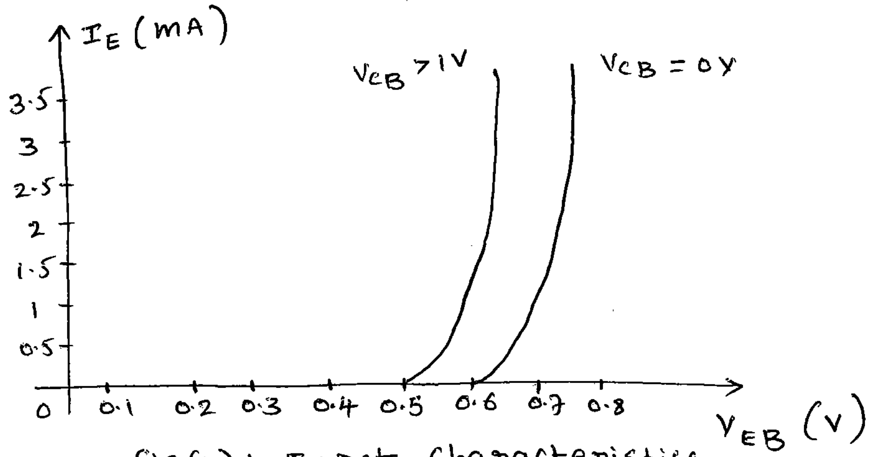


fig (b): Input characteristics

when V_{CB} is equal to zero and the emitter base junction is forward biased as shown in the characteristics, the junction behaves as a forward biased diode so that emitter current (I_E) increases rapidly with small increase in emitter base voltage (V_{EB})

when V_{CB} is increased keeping V_{EB} constant, the width of the base region will decrease. this effect results in an increase of I_E. therefore the curve shift ~~too~~ towards the left as V_{CB} is increased.

<u>output characteristics</u> :- To determine the output characteristics, the emitter current I_E is kept constant at a suitable value by adjusting the

the emitter - base voltage (V_{EB}). Then V_{CB} is increased in suitable equal steps and the collector current I_C is noted for each value of I_E. This is repeated for different fixed values of I_E. Now the curves of I_C versus V_{CB} are plotted for constant values of I_E and the output characteristics thus obtained is shown in figure below.

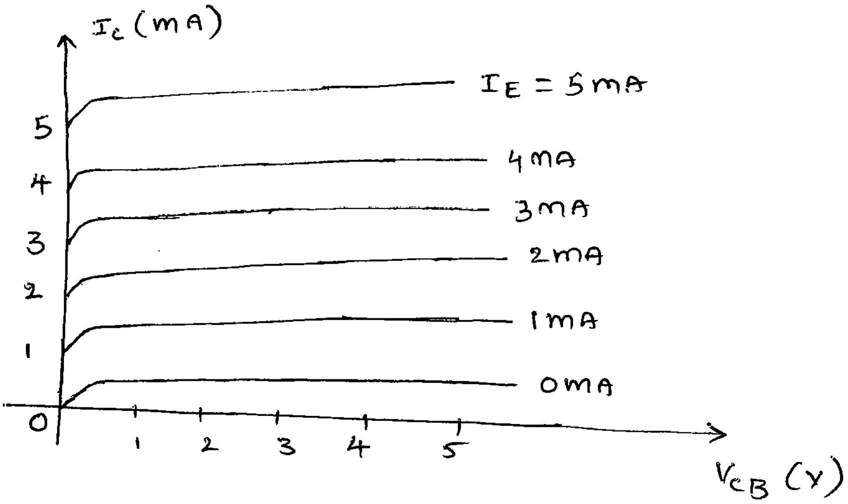


fig:- CB output characteristics

From the characteristics, it is seen that for a constant value of I_E, I_C is independent of V_{CB} and the curves are parallel to the axis of V_{CB}.

I_C flows even when V_{CB} is equal to zero. As the emitter base junction is forward biased, the majority carriers ie electrons, from the emitter are injected in to the base region. Due to the action of the internal potential barrior at the reverse biased collector base junction, they flow to the collector region and gives rise to I_C even when V_{CB} is equal to zero.

Early effect or base-width modulation :-

As the collector voltage V_{CC} is made to increase the reverse bias, the depletion region width between collector and base tends to increase, with the result that the effective width of the base decreases. This dependency of base width on collector to emitter voltage is known as the 'Early Effect'. This decrease in effective base-width has three consequences.

(1) There is a less chance for recombination within the base region. Hence α increases with increasing $|V_{CB}|$

(2) The charge gradient is increased within the base, and consequently, the current of minority carriers injected across the emitter junction increases.

(3) For extremely large voltages, the effective base width may be reduced to zero, causing voltage break down in the transistor. This phenomenon is called the "punch through."

For higher values of V_{CB}, due to Early effect, the value of α increases. for example α changes from 0.98 to 0.985. Hence there is a very small positive slope in the CB output characteristics and hence the output resistance is not zero.

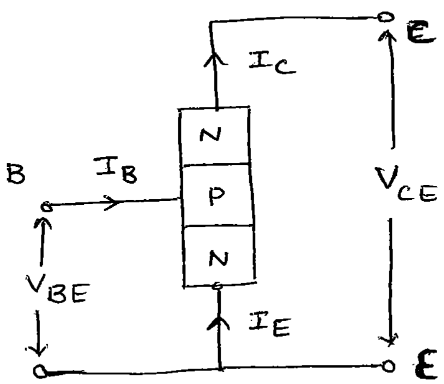
2) Common emitter configuration (CE) :

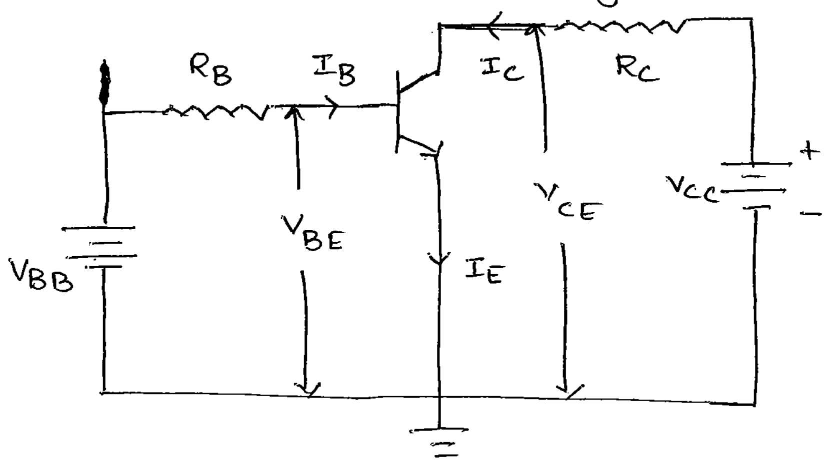
CE configuration means the emitter terminal is common to the input and output. In this case input signal is applied between the base and emitter and output signal is taken out from the collector and emitter terminals.

The ratio of dc collector current (output) to the dc base current (input) is called the dc current gain (β_{dc} or β).

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

The collector current of a transistor is much larger than the base current. Therefore the value of β is much greater than unity.





Relation between α and β :-

$$\beta = \frac{I_C}{I_B} \quad \text{and} \quad \alpha = \frac{I_C}{I_E} \Rightarrow \frac{\beta}{\alpha} = \frac{I_E}{I_B}$$

we know that $I_B = I_E - I_C$

$$\therefore \quad \beta = \frac{I_C}{I_E - I_C} = \frac{\frac{I_C}{I_E}}{1 - \frac{I_C}{I_E}} = \frac{\alpha}{1-\alpha}$$

so $\boxed{\beta = \frac{\alpha}{1-\alpha}}$ from this we can calculate for α

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

<u>Total</u> <u>collector</u> <u>current</u> :-

In CE configuration I_B is the input current and I_C is the output current.

we know that $I_E = I_C + I_B$

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

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

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

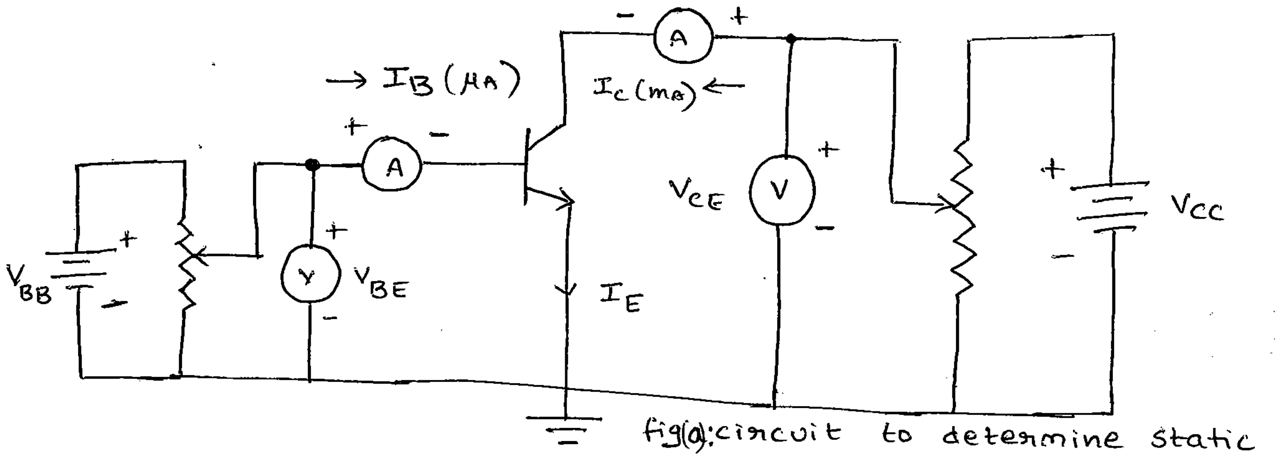
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

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

where $\beta = \frac{\alpha}{1-\alpha}$, I_{CEO} = Leakage current in CE configuration

$$\therefore \quad \boxed{I_C = \beta I_B + I_{CEO}}$$

Common Emitter Configuration (CE) Characteristics :-

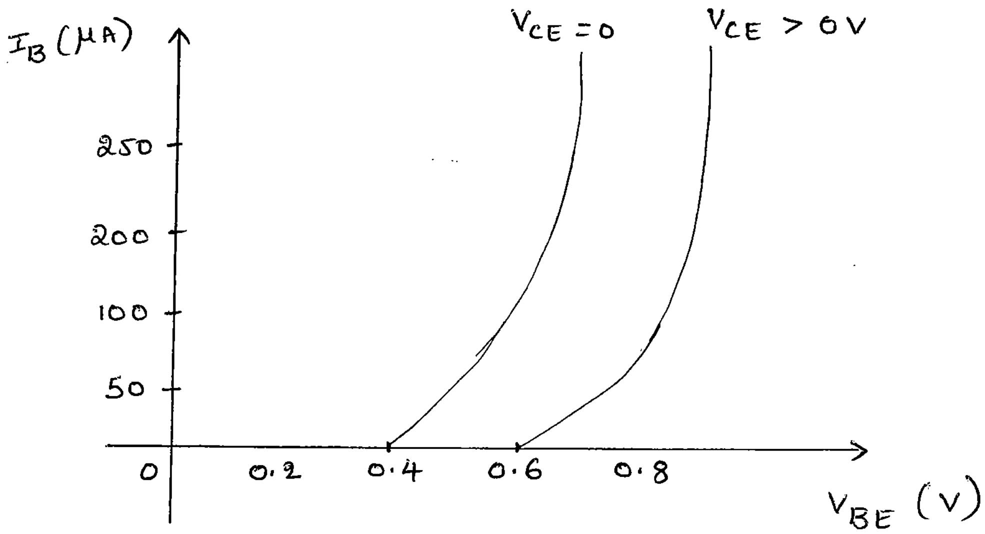


fig(a): circuit to determine static char's in CE configuration

The circuit diagram for determining the static characteristics curves of an NPN transistor in the common Emitter configuration is shown in figure above.

Input characteristics :-

To determine the input characteristics, the collector to emitter voltage is kept constant at zero volt and base current is increased from zero in equal steps by increasing V_{BE} in the circuit shown in fig(a).



fig(b): CE input characteristics.

The value of V_{BE} is noted for each setting of I_B. This procedure is repeated for higher fixed values of V_{CE}, and the curves of I_B Vs V_{BE} are drawn. The input characteristics thus obtained are shown in ~~above~~ fig (b).

When $V_{CE} = 0$, the emitter - base junction is forward biased and the junction behaves as a forward biased diode. Hence the input characteristic for $V_{CE} = 0$ is similar to that of a forward-biased diode.

When V_{CE} is increased, the width of the depletion region at the reverse biased collector - base junction will increase. Hence the effective width of the base will decrease. This effect causes a decrease in the base current (I_B). Hence to get the same value of I_B as that for $V_{CE} = 0$, V_{BE} should be increased. Therefore the curve shifts to the right as V_{CE} increases.

Output Characteristics :-

To determine the output characteristics, the base current I_B is kept constant at a suitable value by adjusting base - emitter voltage V_{BE}.

The magnitude of collector - emitter voltage (V_{CE}) is increased in suitable equal steps from zero and the collector current I_C is noted for each setting of V_{CE}. Now the curves of I_C versus V_{CE} are plotted for different constant values of I_B. The output characteristics thus obtained are shown in fig (c) below

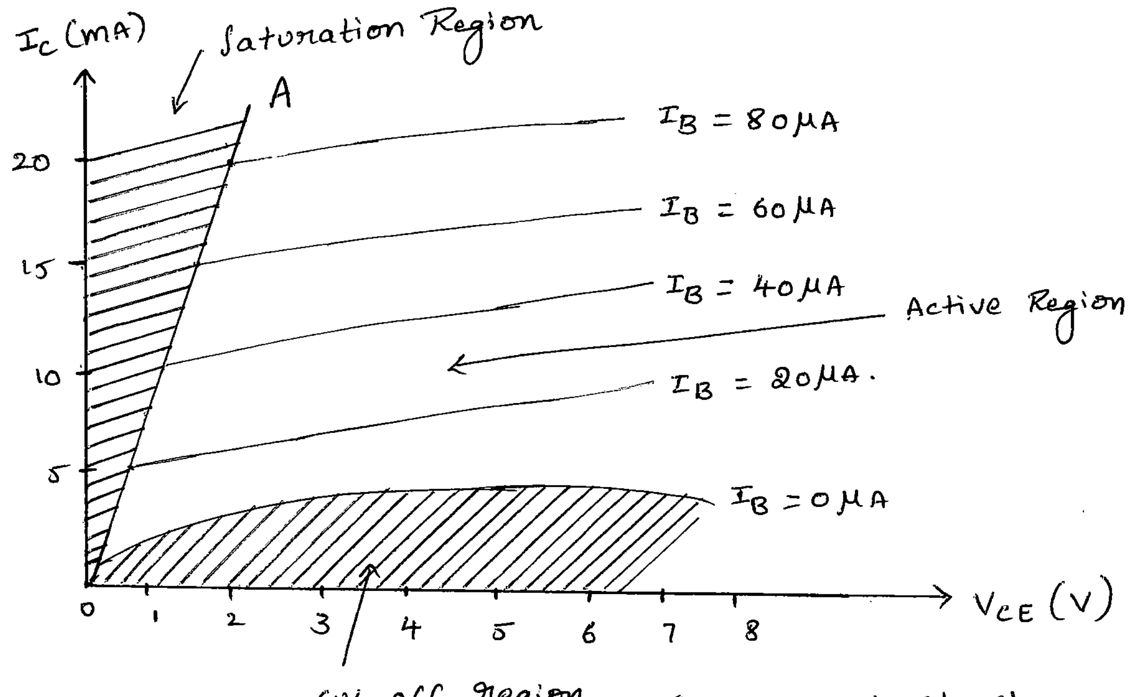


fig c: output characteristics.

we know that $\beta = \dfrac{\alpha}{1-\alpha}$

For larger values of V_{CE}, due to early effect, a very small change in α is reflected in a very large change in β.

For example $\alpha = 0.98$ then $\beta = \dfrac{0.98}{1-0.98} = 49$

If α increases to 0.985, then $\beta = \dfrac{0.985}{1-0.985} = 66$.

Here a slight increase in α by about 0.5% results in an increase in β by about 34%.

Hence the output characteristics of CE configuration show a larger slope when compared with CB configuration.

The output characteristics have three regions

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

① Saturation Region :-

The region of curves to the left of the line OA is called the saturation region (hatched) and the line OA is called the saturation line. In this region both junctions are forward biased and an increase in base current doesn't cause a corresponding large change in I_C. The ratio of $V_{CE(sat)}$ to I_C in this region is called Saturation resistance.

② cut-off region :-

The region below the curve for $I_B = 0$ is called the cut-off region (hatched) In this region both junctions are reverse biased. When the operating point for the transistors enter the cut-off region, the transistor is off. Hence the collector current becomes almost zero and the collector voltage almost equals V_{CC}. The transistor is virtually an open circuit between collector and emitter.

3) Active Region:-

The central region where the curves are uniform in spacing and slope is called the 'active region (un hatched). In this region emitter base junction is forward biased and the collector base junction is reverse biased. If the transistor is to be used ~~operated~~ as a linear amplifier, it should be operated in the active region.

→ If the base current is subsequently driven large and positive, the transistor switches in to the saturation region via the active region.

→ In this ON condition large collector current flows and collector voltage falls to a very low value called $V_{CE\,sat}$, typically around 0.2 V for a Si transistor. The transistor is virtually a short circuit in this state.

Transistor parameters:-

The slope of the CE characteristics will give the following four transistor parameters. Since these parameters have different dimensions they are commonly known as common emitter hybrid parameters or h parameters.

3) common collector configuration (CC) :-

CC configuration means the collector terminal is common to the input and output. In this case input signal is applied between the base and collector and output signal is taken out from the emitter and collector terminals.

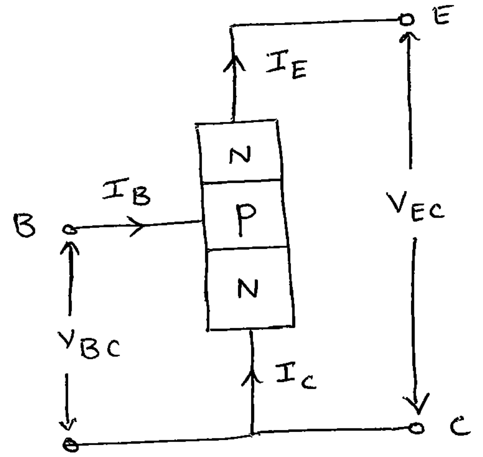
The ratio of emitter current (output) to the base current (input) is called the dc current gain (γ_{dc} or γ) .

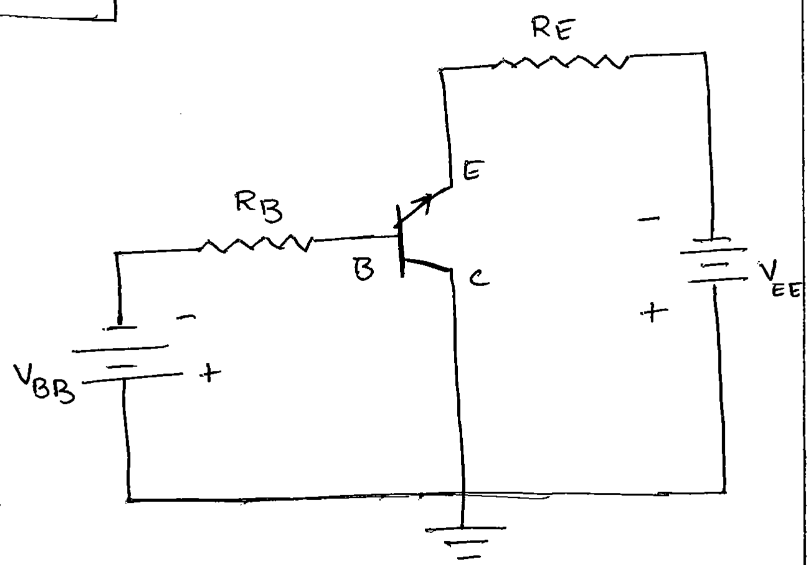
$$\therefore \quad \gamma = \frac{I_E}{I_B}$$

$$\gamma = \frac{I_E}{I_B} = \frac{I_E}{I_C} \frac{I_C}{I_B} = \frac{1}{\alpha} \cdot \beta = \frac{\beta}{\alpha}$$

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

$$\therefore \quad \boxed{\gamma = \frac{1}{1-\alpha} = 1+\beta}$$





Total Emitter current :

We know that $I_C = \alpha I_E + I_{CBO}$

and $I_E = I_C + I_B$

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

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

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

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

Characteristics of CC configuration :-

The circuit diagram for determining the static characteristics of an NPN transistor in the common collector configuration. is shown in figure below.

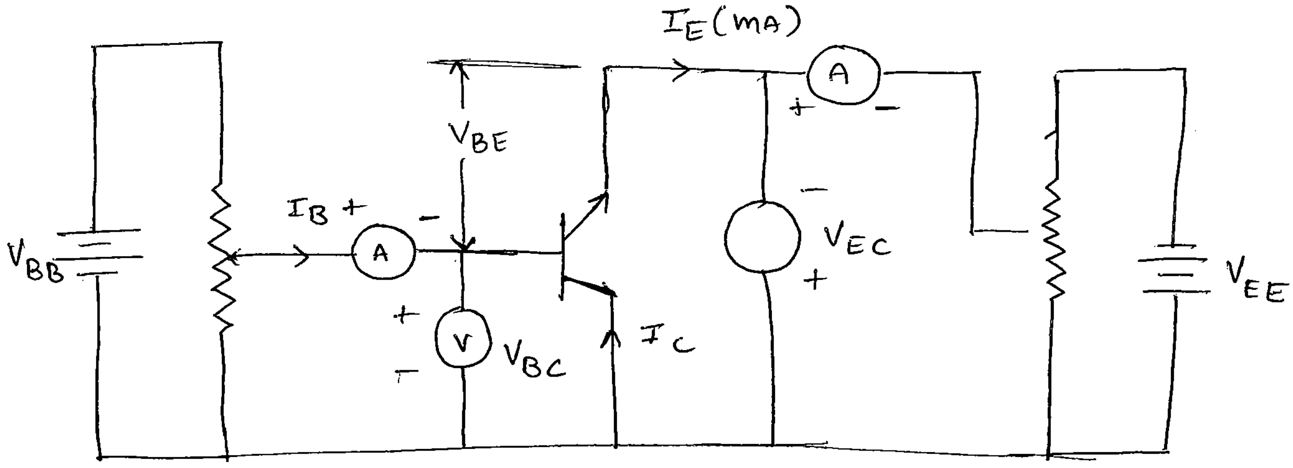
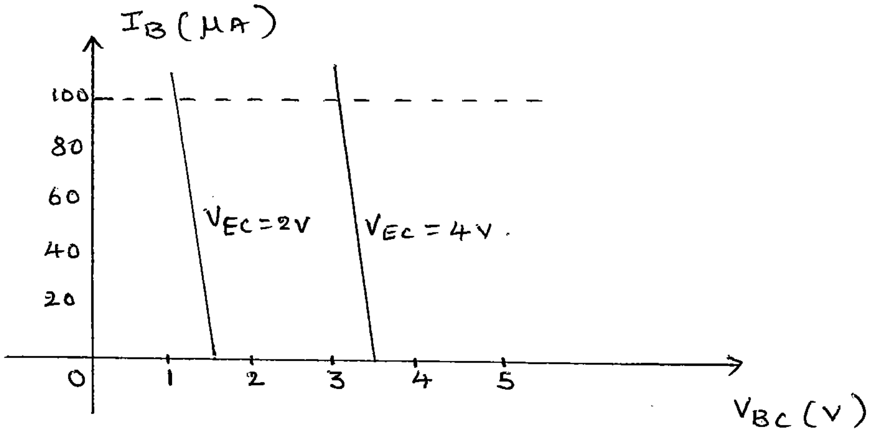


fig (a) circuit to determine CC static char's

Input Characteristics :-

To determine the input characteristics V_{EC} is kept at a suitable fixed value.

then V_{BC} is increased in equal steps and the corresponding increase in I_B is noted. This is repeated for different fixed values of V_{EC}. The input characteristics are plotted below.



fig(b) : CC input characteristics

The common collector input characteristics are different from CB and CE configurations. The diff--erence is due to the fact that V_{BC} is determined by V_{EC}. This is because when the transistor is biased on, V_{BE} remains around 0.7 V, (for Si) and 0.3 for Ge and V_{EC} may be much larger than 0.7V

from fig(a) $V_{EC} = V_{BC} + V_{BE}$

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

If $V_{EC} = 2V$ at $I_B = 100 \mu A$ then

$$V_{BC} = V_{EC} - V_{BE} = 2 - 0.7 = 1.3 V.$$

Suppose V_{EC} is maintained constant at 2V, while the input voltage V_{BC} is increased to 1.5 V then V_{BE} is reduced to 0.5V. Because of V_{BE} is reduced,

I_B is reduced from 100 μA to zero.

Output characteristics :

The CC output characteristics are plotted, I_E versus V_{EC} for several fixed values of I_B.

We know that the CE output characteristics are plotted b/n I_C and V_{CE}. Since I_C is approximately equal to I_E thus CC o/p characteristics is identical to CE output characteristics.

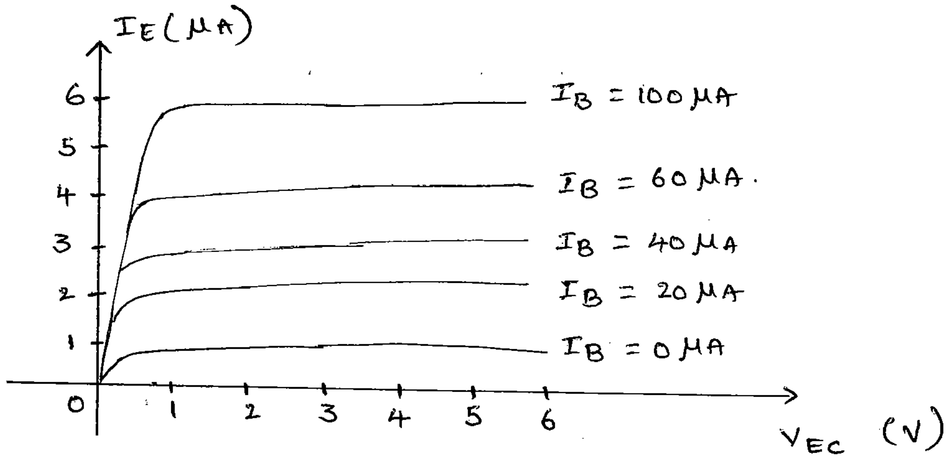


fig (c) : CC output characteristics.

Current Amplification factor :-

In a transistor amplifier with a-c input signal, the ratio of change in output current to the change in input current is known as the current amplification factor.

In the CB configuration the current amplification factor $\alpha = \frac{\Delta I_C}{\Delta I_E}$ $\longrightarrow$ ①

In the CE configuration the current amplification factor $\beta = \frac{\Delta I_C}{\Delta I_B}$ $\longrightarrow$ ②

In the CC configuration the current amplification factor $\gamma = \frac{\Delta I_E}{\Delta I_B} \longrightarrow (3)$

Relationship between α and β

we know that $\Delta I_E = \Delta I_C + \Delta I_B \longrightarrow (4)$

By definition $\Delta I_C = \alpha \Delta I_E$ (from eq (1))

ie $\Delta I_E = \alpha \Delta I_E + \Delta I_B$

$$\Delta I_B = \Delta I_E (1-\alpha) \longrightarrow (5)$$

Dividing both sides by ΔI_C, we get

$$\frac{\Delta I_B}{\Delta I_C} = \frac{\Delta I_E}{\Delta I_C}(1-\alpha)$$

$$\Rightarrow \frac{1}{\beta} = \frac{1}{\alpha}(1-\alpha) \quad \Rightarrow \beta = \frac{\alpha}{1-\alpha}$$

Re arranging we also get $\alpha = \frac{\beta}{1+\beta}$ (or) $\frac{1}{\alpha} - \frac{1}{\beta} = 1$

From this relationship, it is clear that as α approaches unity, β approaches infinity. The CE configuration is used for almost all transistor applications because of its high current gain β.

Relation among α, β and γ :

In the CC transistor amplifier circuit, I_B is the input current and I_E is the output current.

from eq (3) $\gamma = \frac{\Delta I_E}{\Delta I_B}$

Substituting $\Delta I_B = \Delta I_E - \Delta I_C$, we get

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C} \longrightarrow (6)$$

~~Diving~~ ~~&~~ Dividing the numerator and denominator of eq (6) by ΔI_E, we get

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

$$\therefore \quad \gamma = \frac{1}{1-\alpha} \longrightarrow (7)$$

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

$$\therefore \quad \boxed{\gamma = \frac{1}{1-\alpha} = 1+\beta}$$

Comparison of CB, CE and CC configurations

Property	CB	CE	CC
Input resistance	Low (about 100 Ω)	Moderate (about 750 Ω)	High (750)
Output resistance	High (450 KΩ)	Moderate (45 KΩ)	Low (25 Ω)
Current gain	1	High	High
Voltage gain	About 150	About 500.	Less than 1
phase shift b/n i/p and o/p voltages	0 (or) 360°	180°	0 (or) 360°
Applications	For high frequency circuits	for audio frequency ckts	For impedance matching

BJT specifications :-

In different conditions such as active, saturation and cut-off there are different junction voltages. The junction voltages for a typical npn transistor at 25°c are given in the table below.

Type	$V_{CE\,sat}$	$V_{BE\,sat}$	$V_{BE\,active}$	$V_{BE\,cut\,in}$	$V_{BE\,cutoff}$
Si	0.3	0.7	0.7	0.5	0.0
Ge	0.1	0.3	0.3	0.1	-0.1

The junction voltages in the above table are appropriate for an npn transistor. For pnp transistor the signs of all entries should be reversed.

TRANSISTOR AS AN AMPLIFIER

A load resistor R_L is connected in series with the collector supply voltage V_{CC} of CB transistor configuration as shown in Fig. 3.16.

A small change in the input voltage between emitter and base, say ΔV_i, causes a relatively larger change in emitter current, say ΔI_E. A fraction of this change in current is collected and passed through R_L and is denoted by symbol α'. Therefore the corresponding change in voltage across the load resistor R_L due to this current is $\Delta V_o = \alpha' R_L \, \Delta I_E$.

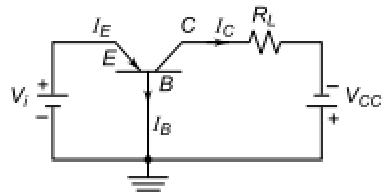


Fig. 3.16 Common Base Transistor Configuration

Here, the voltage amplification $A_v = \dfrac{\Delta V_o}{\Delta V_i}$ is greater than unity and thus the transistor acts as an amplifier.

NEED FOR BIASING

Biasing in amplifiers sets the static dc voltage and current levels on a transistor at a point (called quiescent point or Q-point) where they can be made to vary with an input signal without going into saturation or cut-off.

In order to produce distortion-free output in amplifier circuits, the supply voltages and resistances in the circuit must be suitably chosen. These voltages and resis-

tances establish a set of dc voltage V_{CEQ} and current I_{CQ} to operate the transistor in the active region. These voltages and currents are called *quiescent values* which determine the *operating point* or Q-point for the transistor. The process of giving proper supply voltages and resistances for obtaining the desired Q-point is called *biasing*. The circuits used for getting the desired and proper operating point are known as *biasing circuits*.

The collector current for common-emitter amplifier is expressed by

$$I_C = \beta I_B + I_{CEO} = (1 + \beta) I_{CO}$$

Here the three variables h_{FE} i.e. β, I_B and I_{CO} are found to increase with temperature. For every 10°C rise in temperature, I_{CO} doubles itself. When I_{CO} increases, I_C increases significantly. This causes power dissipation to increase and hence to make I_{CO} increase. This will cause I_C to increase further and the process becomes cumulative which will lead to thermal runaway that will destroy the transistor. In addition, the quiescent operating point can shift due to temperature changes and the transistor can be driven into the region of saturation. The effect of β on the Q-point is shown in Fig. 5.1. One more source of bias instability is to be considered due to the variation of V_{BE} with temperature. V_{BE} is about 0.6 V for a silicon transistor and 0.2 V for a germanium transistor at room temperature. As the temperature increases, $|V_{BE}|$ decreases at the rate of 2.5 mV/°C for both silicon and germanium transistors. The transfer characteristic curve shifts to the left at the rate of 2.5 mV/°C (at constant I_C) for increasing temperature and hence the operating point shifts accordingly. To establish the operating point in the active region, compensation techniques are needed.

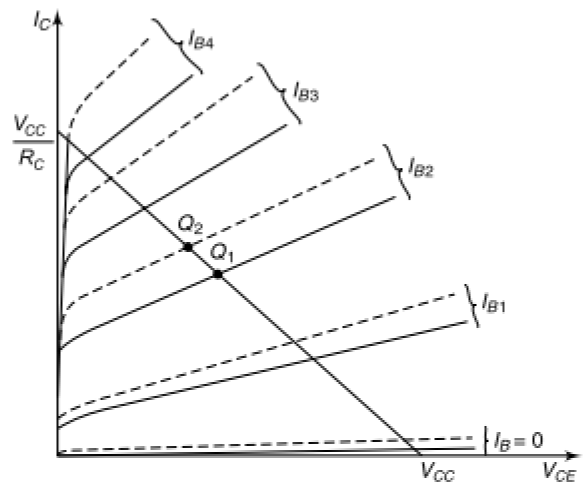


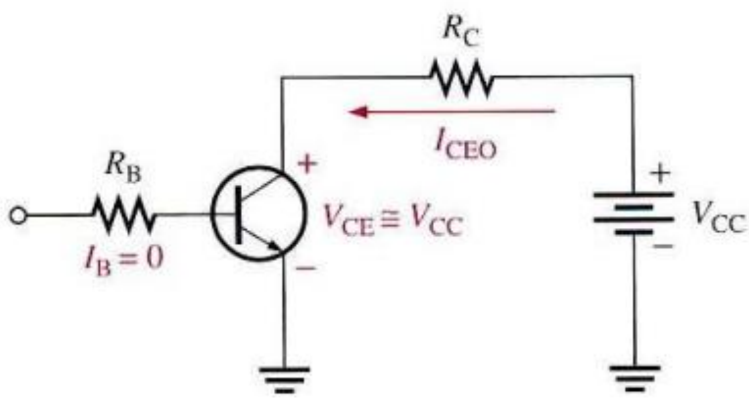
Fig. 5.1

EXPLAIN HOW TRANSISTOR ACTS AS A SWITCH

Cutoff

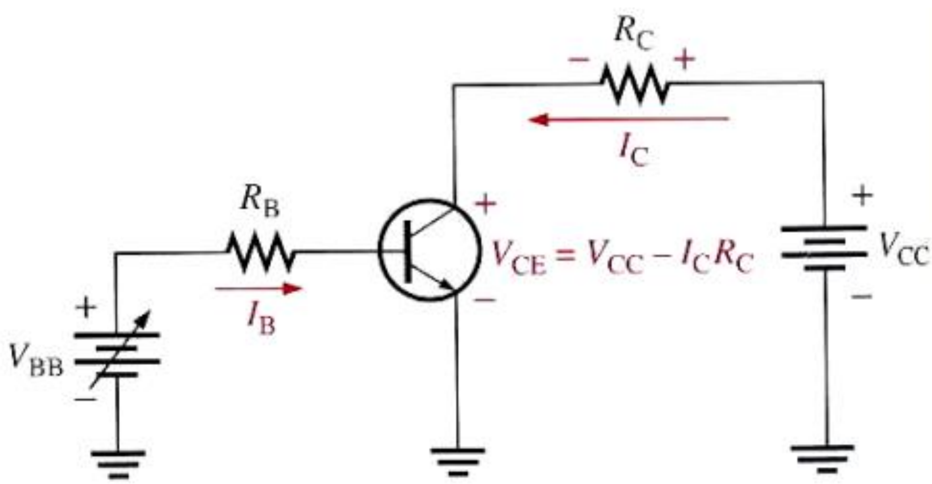
When $I_B = 0$, the transistor is in the cutoff region of its operation. This is shown in Figure with the base lead open, resulting in a base current of zero.

Under this condition, there is very small of collector leakage current, I_{CEO}, due mainly to thermally produced carriers. Because, I_{CEO} is extremely small, it will usually be neglected in circuit analysis so that $V_{CE} = V_{CC}$. Moreover, in cutoff mode, both the base-emitter and the base-collector junction are reverse-biased.

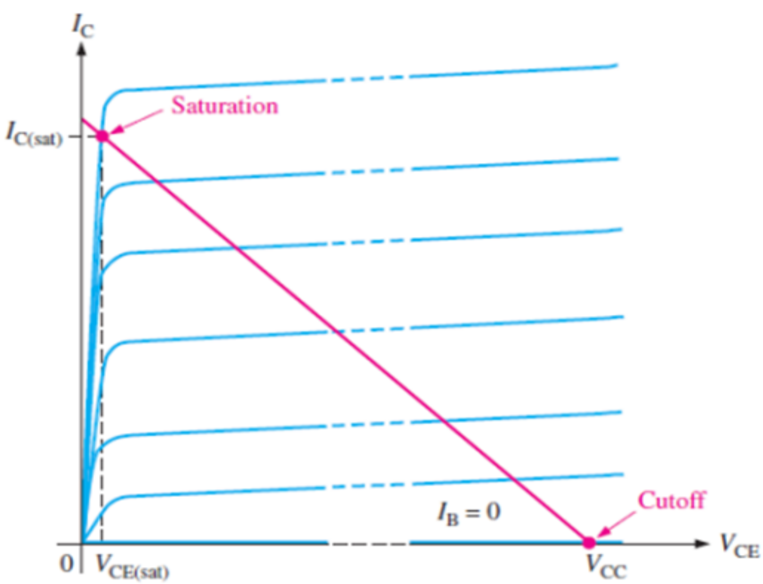


Saturation

When the base-emitter junction becomes forward-biased and the base-current is increased, the collector current also increases and V_{CE} decreases as a result of more drop across the collector resistor ($V_{CE} = V_{CC} - I_C R_C$). This is illustrated in Figure . When V_{CE} reaches its saturation value, $V_{CE(sat)}$, the base-collector junction becomes forward-biased and I_C can increase no further even with a continued increase in I_B. And $V_{CE(sat)}$ is usually only 0.2 – 0.3 V for silicon transistors.



R_C
I_C
R_B
$V_{CE} = V_{CC} - I_C R_C$
V_{CC}
I_B
V_{BB}



I_C
Saturation
$I_{C(sat)}$
Cutoff
$I_B = 0$
V_{CE}
0
$V_{CE(sat)}$
V_{CC}

The Transistor as a Switch

The basic operation as a switching device is illustrated in Figure 4.24. In part (a), the transistor is in the cutoff region because the base-emitter junction is not forward-biased. In this condition, there is, ideally, an open between collector and emitter, as indicated by the switch equivalent. In part (b), the transistor is in the saturation region because the base-emitter junction and the base-collector junction are forward-biased and the base current is made large enough to cause the collector to reach its saturation value.

In this condition, there is, ideally, a short between collector and emitter, as indicated by the switch equivalent. Actually, a voltage drop of up to a few tenths of a volt normally occurs, which is the saturation voltage, $V_{CE(sat)}$.

Conditions in Cutoff:

As mentioned before, a transistor is in the cutoff region when the base-emitter junction it not forward-biased. Neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}. Or $V_{CE(cutoff)} = V_{CC}$

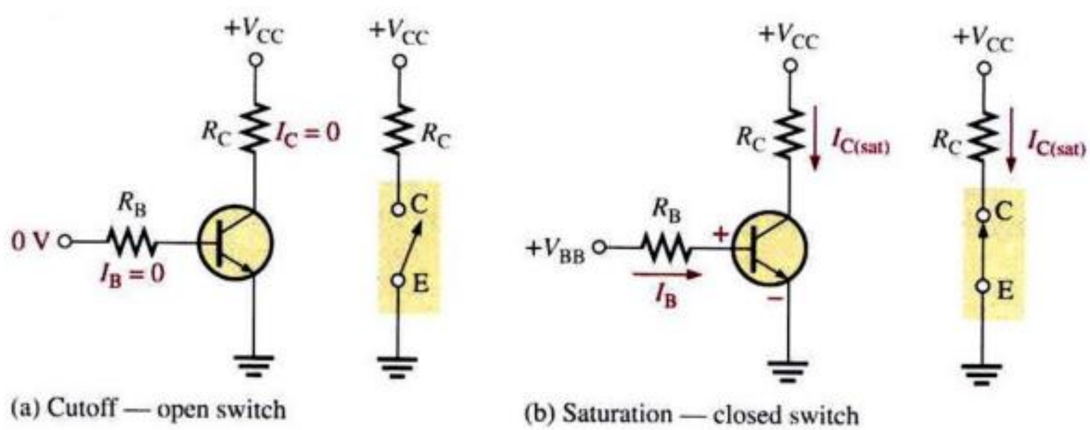


Figure 4.24 Switching action of an ideal transistor. [5]

Conditions in Saturation:

When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

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

since $V_{CE(sat)}$ is very small and can usually be neglected

The minimum value of base current needed to produce saturation is

$$I_{B(\min)} = \frac{I_{C(\text{sat})}}{\beta_{DC}}$$

I_B should be significantly greater than $I_{B(min)}$ to keep the transistor well into saturation.