Bipolar Junction Transistor

By

Mr. Aniket Kumar
Assistant Professor, Department of Electronics & Communication Engineering
Shobhit Institute of Engineering & Technology (Deemed to-be University)
NH-58, Modipuram, Meerut – 250 110, India

Chapter-3
Bipolar Junction Transistor

The transistor is a three-layer semiconductor device consisting of either two n- and one p-type layers of material or two p- and one n-type layers of material. The former is called an npn transistor, while the latter is called a pnp transistor.

The unbiased transistor

A Transistor has three doped regions: an emitter , a base and the collector. A p-n junction exists between the base and the collector; this part of transistor is called the emitter diode. Another p-n junction exists between the base and the collector; this part of the transistor is called the collector diode.

The Biased Transistor

For the normal operation, we forward bias the emitter diode & reverse bias the collector diode . Under these conditions the emitter sends free electrons into the base. Most of these free electrons pass through the base to collector. Because of this, the collector current approximately equal the emitter current. The base current is much smaller ≈ 5% of emitter current.

Transistor Current

The ratio of the collector current to the base current is called the current gain symbolized as β_{dc} or h_{FE}, For low-power transistor, this is typically 100 to 300. The emitter current is the largest of the three currents, the collector current is almost as large and the base current is much smaller.

The CE Configuration

The emitter is grounded or common in CE circuit. The base-emitter part of a transistor acts approximately like ordinary diode. The base-collector part acts like a current source that is equal to β_{dc} times the base current. The transistor has an active region , a saturation region and a breakdown region. The active region is used in linear amplifier, Saturation and cutoff are used in digital circuits (as a switch).

Collector curves

The four distinct operating region, are the active region, the saturating region , the cut off region & the breakdown region . When it is used as an amplifier, the transistor operates in the active region. When it is used in digital circuits, the transistor operates in the saturation & cutoff region. The breakdown region is avoided because the risk of transistor destruction is too high.

The Load line

The dc load line contains all the possible dc operating points of a transistor circuit. The upper end of the load line is called saturation and the lower end is called cutoff. Saturation conditions arises a short b/w collector & emitter and the cutoff condition arises open b/w collector & emitter.

The Operating Point

The operating point of transistor is on the dc line. The exact location of this point is determine by the collector current & the collector-emitter voltage.

Current amplification factor in C-E Mode (β):

The current amplification factor or current gain in C-E mode is defined as the ratio of the change in the collector current (ΔI_C) to the change in base current (ΔI_B) at a constant collector-emitter voltage (V_{CE})

It has a value between 20 to 500.

Current amplification factor in C-B Mode(α):

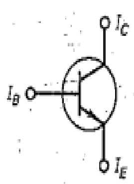
Defined as the ratio of the change in the collector current (ΔI_C) to the change in emitter current (ΔI_E) at a constant base- collector voltage (V_{CB}). The value of **α** in general is slightly lesser then unity.

Base width modulation

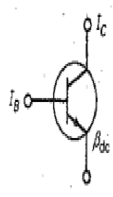
As the collector to emitter voltage V_{CC} is made to increase the reverse bias , the space charge width between collector and base tends to increase, with the result that the effective width or the base decreases. This dependency of base width on collector to emitter voltage is known as the base width modulation or early effect.

Transit time & life time of minority carriers
To have a good p-n-p transistor , we prefer that almost all holes injected by the emitter into the base be collected. Thus n-type base region should be narrow & the hole life time t_p should be long i.e. $W_b << L_p$, where W_b is the length of the neutral n-type material & L_p is the diffusion length.
There is an important difference in the times which electrons & holes spend in the base. The average excess hole spends a time τ_p, defined as the **transit time from emitter to collector.**
Life time of Minority Carriers
Carrier lifetime is defined as the average time it takes for a minority carrier to recombine. Carrier lifetime plays an important role in bipolar transistors and solar cells.
Base emitter resistance
Base Emitter Resistance is a resistance that provides the required amount of automatic biasing needed for a common emitter amplifier
Base spreading resistance
Resistance which is found in the base of any transistor and acts in series with it, generally a few ohms in value known as base spreading resistance
Diffusion Capacitance
When the p-n junction diode is forward biased, a capacitance which is much larger then the transient capacitance is known as diffusion capacitance (C_D) or storage capacitance.

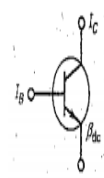
Derivations :
Emitter current **Collector Current** **Base Current**



$I_E=I_C+I_B$

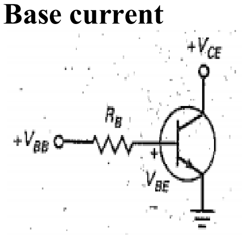


$I_C= \beta I_B$

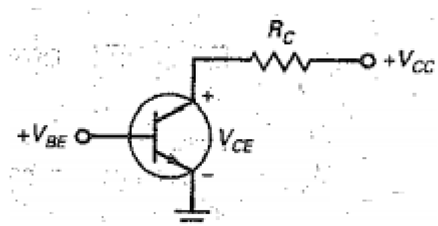


$I_B= I_C/ \ \beta_{dc}$

Base current **Collector- emitter Voltage**

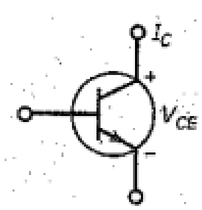


$I_B=(V_{BB}-V_{BE})/ R_B$

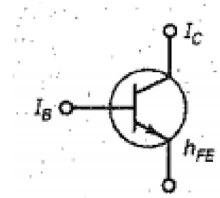


$V_{CE}=V_{CC} -I_CR_C$

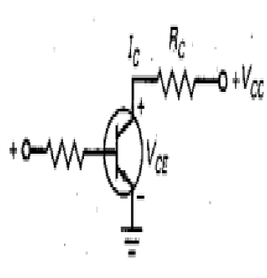
CE power dissipation **Current gain**



$P_D=V_{CE}\ I_C$

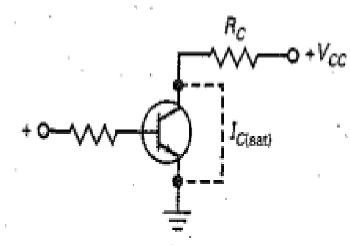


$\beta_{dc}=h_{FE}$

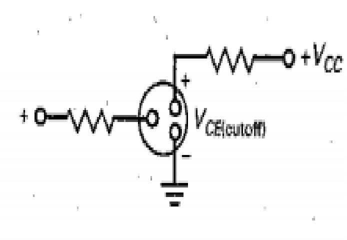


Load line analysis **Saturation Current**

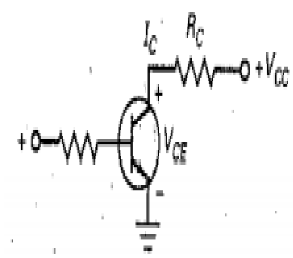
$I_C=(V_{CC}-V_{CE})/\ R_C I_{C(sat)}$
$I_C(sat)= V_{CC}/R_C$



Cutoff Voltage (base bias) **Emitter voltage**



$V_{CE(cutoff)}=V_{CC}$



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

Long & Short Questions

Q.1. Define BJT , Why BJT is called bipolar? Describe its operating regions.

Transistor

A transistor is a three terminal solid state device, whose operation depends upon the flow of charge carrier with in solid. BJT is formed by sandwiching one type of semiconductor (p-type or n-type) between two layers of other types , creating three terminals

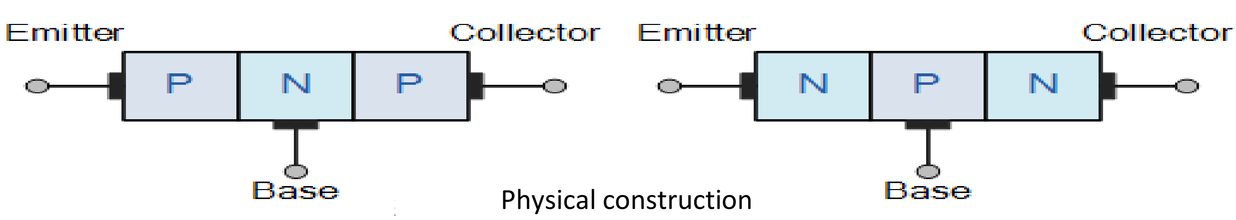
The three terminals are Emitter (E) , Base(B) & Collector(C)

Emitter: It is a terminal through which charge carriers enters in base . It is quite large in compare to base

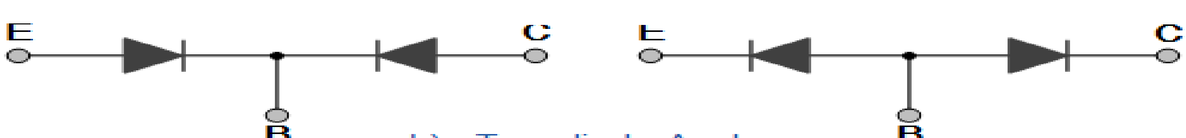
Base : It is a terminal through which charge carriers(electrons or holes) enters in collector, it is very small.

Collector : It is the largest terminal charge carriers coming from base collect here, therefore to reduce energy dissipation it is made so large.

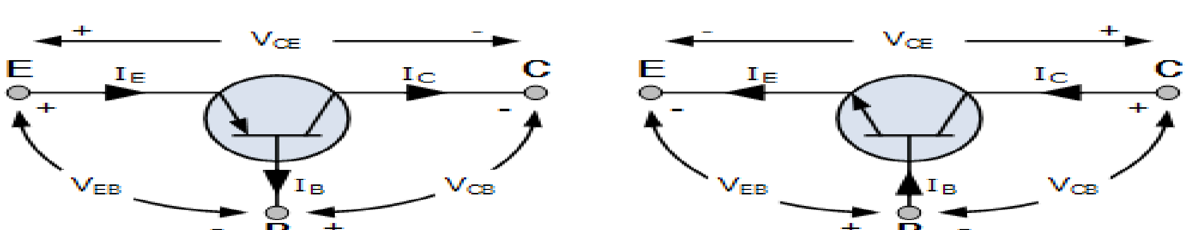
Transistor has two types of physical construction , two diode analogy & circuits symbols are as shown in fig. below :



Physical construction



b). Two-diode Analogy



c). Circuit Symbols

In order to distinguish the emitter & collector an arrow is included in the emitter. The direction of arrow depends on the flow of conventional current, when the emitter base junction is forward bias.

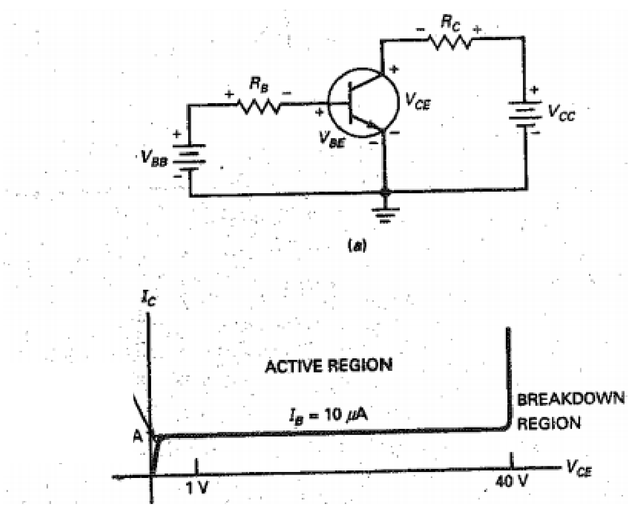
Bipolar

Transistor operation is carried out by two types of charge carrier i.e. electrons & holes, because of this the transistor is known bipolar .

BJT operating regions

The transistor can operate in different regions as Active, Breakdown & Saturation

Active region : It is a region (collector voltage have no effe(i.e. collector current acts as a current source. It occurs when emitter base junction is forward bias & Collector base junction is reversed bias.



Circuit Symbols

Breakdown region : It is a region in which current through the BJT is ≈ zero i.e. off state of diode.

It occurs when emitter base junction is reverse bias & Collector base junction is reversed bias.

Saturation region :When emitter base junction & Collector base junction both are made forward bias,

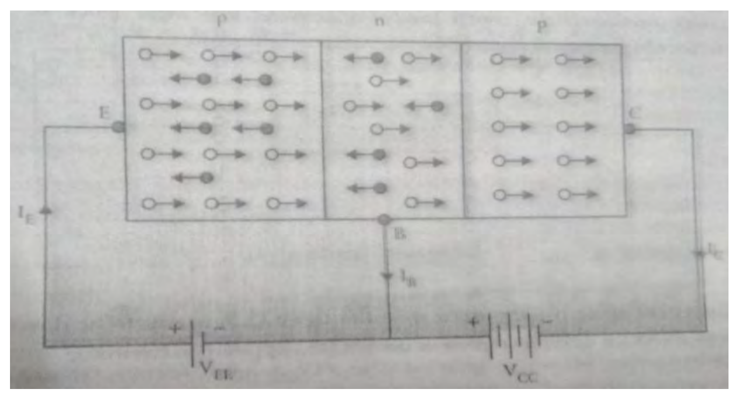
BJT enters into region known as Saturation region. In this region V_{CE} is between 0V to 0.3 V.

Q.2. Explain the mechanism of current flow in NPN & PNP transistors.

Mechanism of current flow in NPN transistor

The operation of n-p-n transistor is shown in fig. Forward bias is provided to emitter base junction & reverse bias is provided to base-collector junction.

- Under the forward biasing of B-E junctions the electrons of emitter (n-region) moves toward base(p-region) and holes of the p-region moves towards emitter.

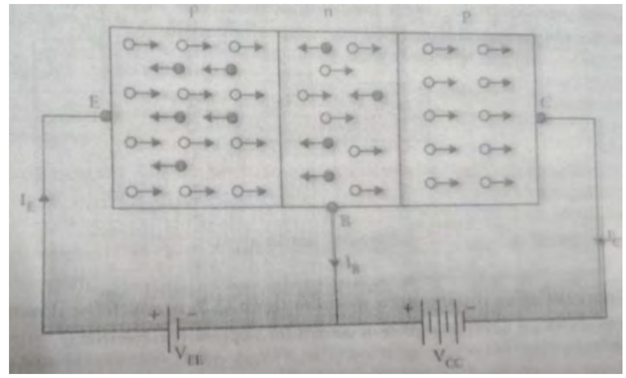


- As the base is very thin , nearly 95% to 98% electrons crosses the base and enters in to collectors region while remaining recombines with holes in p-region.
- Electrons entering the collectors region under the influence of reverse bias , are attracted towards the collector terminal.
- As the electron reach the terminal C, enters the +ve terminal of battery V_{CC} , an electron from the –ve terminal of battery V_{EE} enters the emitter which compensate the loop of electron.
- Thus for a transistor , we can say that , $I_E = I_B + I_C$, where I_E , I_B, &I_C are emitter current , base current & collector current respectively.

Mechanism of current flow in PNP transistor

The operation of p-n-p transistor is shown in fig. As the small forward bias is provided to emitter- base(p-n) junction and reverse bias to base-collector(n-p) junction.

- Under the forward biasing of B-E junctions the holes (+vely charged) in the emitter(p-region) move towards the base, while electrons(-vely charged) in the base(n-region) move toward emitter.
- As the base is very thin, 95% to 98% entering it passes on to the collector, & remaining combines with the electrons present in the base.
- Holes entering the collector move under the reverse bias voltage which helps them to pull towards the collector terminal C.



- As the hole reach the terminal C, they combine with the electrons coming from the –ve terminal of battery V_{CC} and both electron & holes neutralized each other.
- Thus $I_E = I_B + I_C$, where I_E , I_B, & I_C are emitter current , base current & collector current respectively.

Q.3. Define α & β and derive the relationship between them.

Current amplification factor in C-B Mode(α):

Defined as the ratio of the change in the collector current (ΔI_C) to the change in emitter current (ΔI_E) at a constant base- collector voltage (V_{CB}).

$\therefore \boldsymbol{\alpha} = \Delta I_C / \Delta I_E$ at V_{CB}= constant

The value of **α** in general is slightly lesser then unity.

Current amplification factor in C-E Mode (β):

The current amplification factor or current gain in C-E mode is defined as the ratio of the change in the collector current (ΔI_C) to the change in base current (ΔI_B) at a constant collector-emitter voltage (V_{CE})

$\therefore \beta = \Delta I_C / \Delta I_B$ at V_{CE}= constant

It has a value between 20 to 500.

Relationship between α & β

$\because I_E = I_B + I_C$

Dividing throughout by I_C

We have $I_E / I_C = I_B / I_C + 1$

$\Delta I_E / \Delta I_C = \Delta I_B / \Delta I_C + 1$

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

Q.4. Define the term reverse saturation current & its relation.

The collector current I_C of the common base configuration is given by

$I_C = I_{C(INJ)} + I_{CBO}$

$\mathbf{I_{C(INJ)}}$ **:** It is called as the injected collector current & due to the no. of electrons crossing the collector base junction. $I_{C(INJ)} = \alpha . I_E$

$\mathbf{I_{CBO}}$: This is reverse saturation current flowing due to minority carriers between collector & base when emitter is open. $\mathbf{I_{CBO}}$ is negligible as compare to $I_{C(INJ)}$.

Q.4. Derive the relation $\mathbf{I_C = \beta I_B + (1+\beta) I_{CO}}$

For the CE configuration we have $I_E = I_B + I_C$ Where $I_C = \alpha . I_E + I_{CBO}$

Rearranging the above equations we have

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

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

$\Rightarrow I_C = I_B\left(\frac{\alpha}{1-\alpha}\right) + I_{CBO}\left(\frac{1}{1-\alpha}\right)$

$\Rightarrow I_C = I_B.\beta + I_{CBO}\left(\frac{1}{1-\alpha}\right)$ $\quad \{\because \beta = \frac{\alpha}{1-\alpha}\}$

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

Adding both side 1 , we have

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

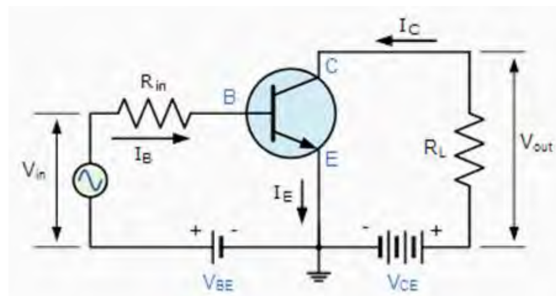
$\therefore\ \ I_C = I_B.\beta + I_{CBO}(\frac{1}{1-\alpha})$

$I_C = I_B.\beta + I_{CBO}(\beta+1)$ Hence Proved

Q.5. Draw circuit diagram of common emitter transistor amplifier & explain its working .

Or

Draw a circuit diagram & explain the method of obtaining the characteristics curves of a n-p-n transistor in common emitter configuration and obtain the relation between between current gain for common base & common emitter configuration in a transistor.



Common emitter transistor

The input signal is applied across the base and emitter terminal while output is taken across collector & emitter with the help of load resistance R_L.

This is the most flexible & efficient configuration in compare to other configuration. In this configuration the collector current is controlled by base current only.

Characteristics curves of transistor in C-E Mode:

A n-p-n common emitter configuration is shown in fig. This configuration is most widely used because of high amplification .

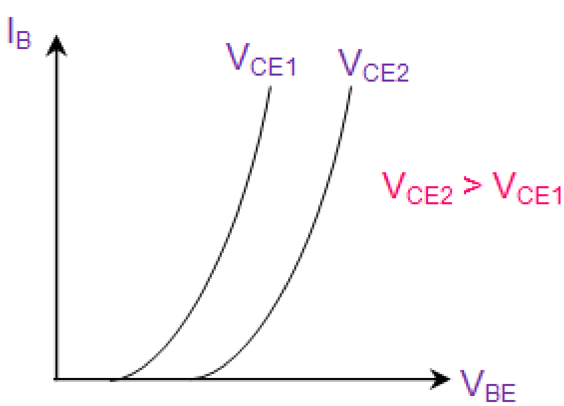


Fig. (a) Input Characteristics

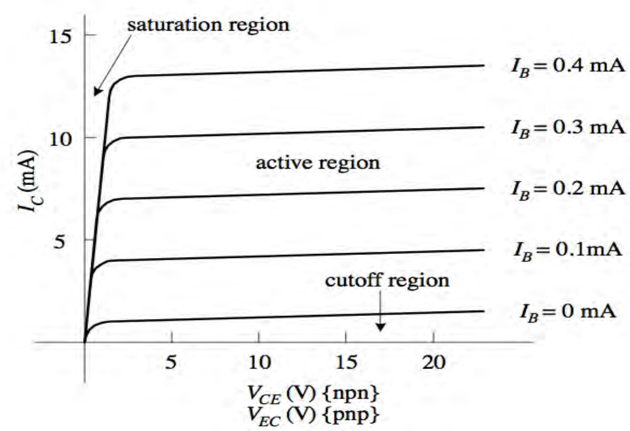


Fig. (b) Output Characteristics

Input Characteristics

In order to obtain the input characteristics of C-E Mode as shown in fig., for the collector – emitter voltage V_{CE} at V_{CE1} and increase in voltage V_{BE} leads to increase in base current (I_B).The process is repeated for different values of $V_{CE,}$ then I_B is plotted as a function of V_{BE}. This is known as input characteristics.

Output Characteristics

To obtain the output characteristics of a n-p-n transistor in CE mode , keeping V_{BE} & I_B constant , V_{CE} is increased & I_C is obtained . The plot between I_C & V_{CE} for the given V_{BE} & I_B known as Output Characteristics as shown in fig. (b).
In this characteristics there are three regions of operations i.e. Active, Saturation & Cutoff region.

Current amplification factor in C-E Mode (β):

The current amplification factor or current gain in C-E mode is defined as the ratio of the change in the collector current (ΔI_C) to the change in base current (ΔI_B) at a constant collector-emitter voltage (V_{CE})

$\therefore\ \beta = \Delta I_C / \Delta I_B$ at V_{CE}= constant

It has a value between 20 to 500.

Current amplification factor in C-B Mode(α):

Defined as the ratio of the change in the collector current (ΔI_C) to the change in emitter current (ΔI_E) at a constant base- collector voltage (V_{CB}).

$\therefore\ \boldsymbol{\alpha} = \Delta I_C / \Delta I_E$ at V_{CB}= constant

The value of **α** in general is slightly lesser then unity.

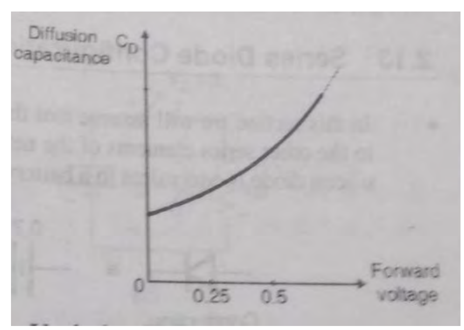
Q.6. Explain why silicon transistor are preferably used.

Silicon is preferred over germanium due to few reasons that are mentioned as below

- At room temperature, silicon crystal has fewer free electrons than germanium crystal due to which silicon has smaller collector cut off current than germanium.
- The variation of collector cut off current with temp. is less in silicon compared to germanium.
- The structure of germanium crystals will be destroyed at higher temperature. However, Silicon crystals are not easily damaged by excess heat.
- Peak Inverse Voltage rating of silicon diodes is greater than germanium diodes.
- Silicon is less expensive due to its abundance.

Q.7. Explain diffusion capacitance in transistor.

When the p-n junction diode is forward biased, a capacitance which is significant is known as **diffusion capacitance** (C_D) or storage capacitance.



- The diffusion capacitance (C_D) is given by ,

  $$C_D = \frac{dQ}{dV} = \frac{dI(V)}{dV} T_F \quad , \quad \text{where}$$

  $T_F = transist\ time$
- The variation of diffusion capacitance with the change in forward voltage is shown in fig.
- In the forward biased state, C_D increases with the increase in forward bias .

Q.8. Draw the circuit diagram, explain the action of an n-p-n transistor in the common emitter configuration and obtain the expression for current gain given by β=α/(1-α).

Refer to Q.2 ,Q.3 & Q.9

Q.9. Draw the circuit diagram of a p-n-p transistor in the common bias configuration. Draw the characteristics curves and write its important features.

Refer to Q.2 & Q.3

Q.10. What do you mean by different current gains α, β &γ of a transistor ? Establish relation in them.

α is known as Current amplification factor in C-B Mode , defined as the ratio of the change in the collector current (ΔI_C) to the change in emitter current (ΔI_E) at a constant base- collector voltage (V_{CB}).

$\therefore \alpha = \Delta I_C / \Delta I_E$ at V_{CB}= constant

β is known as Current amplification factor in C-E Mode . It is the ratio of the change in the collector current (ΔI_C) to the change in base current (ΔI_B) at a constant collector-emitter voltage (V_{CE})

$\therefore \beta = \Delta I_C / \Delta I_B$ at V_{CE}= constant

γ is known as Current amplification factor in C-C Mode . It is the ratio of the change in the emitter current (ΔI_E) to the change in base current (ΔI_B) at a constant collector-emitter voltage (V_{CE})

$\therefore \gamma = \Delta I_E / \Delta I_B$ at V_{CE}= constant

Relation b/w α , β & γ

$\because I_E = I_B + I_C$

Dividing throughout by I_C , We have

$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + 1$$

$$\Longrightarrow 1/\frac{I_E}{I_C} = 1/\frac{I_B}{I_C} + 1$$

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

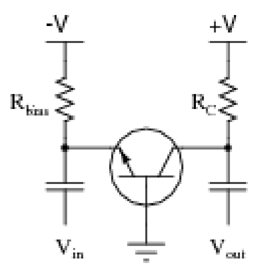
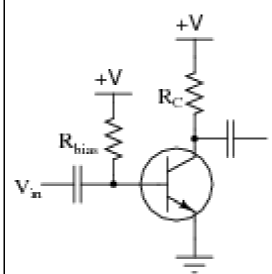
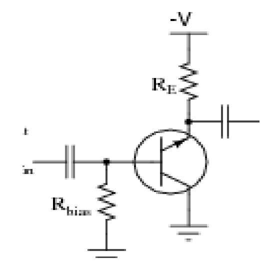
$$\therefore \alpha = \beta / (\beta + 1)$$

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

$$\gamma = \frac{\Delta I_E}{\Delta I_B} = \frac{\Delta I_C + \Delta I_B}{\Delta I_B} = \frac{\Delta I_C}{\Delta I_B} + 1 = \beta + 1$$

Also $\gamma = \alpha / (1 - \alpha) + 1 = 1/(1 - \alpha)$ $\{\because \beta = \alpha / (1 - \alpha)\}$

Q.11. Compare the different characteristics of BJT configurations .

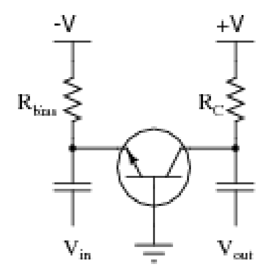
S. No.	Characteristics	CB Mode	CE Mode	CC Mode
1	Input resistance	Vary low≈100Ω	Low≈800Ω	Very High ≈800KΩ
2.	Output Resistance	Very High ≈550KΩ	High≈75Ω	Very low ≈50Ω
3	Current Gain	Less than 1	High 50 to 500	High ≈100
4.	Voltage gain	≈150	≈550	Less than 1
5.	Power gain	≈147	≈50,000	≈98
6.	Signal phase	As input	Opposite	Same as input
7.	Circuit			
8.	Application	In high frequency apparaatus	In audio frequency applications	In impedance matching

Q.12. Explain current gain & voltage gain of a transistor in different configurations .

Common Base Configuration

Current Gain : It is the ratio of change in collector current to the change in emitter current, denoted by α , its value is near to unity. It is also defined as the ac current gain.

$$\alpha = \frac{\Delta i_c}{\Delta i_e}$$



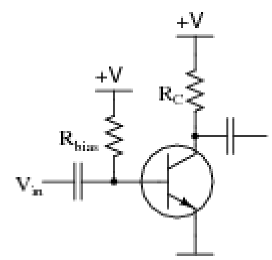
Voltage Gain

It is the ratio of change in output voltage to change in input voltage, denoted by A.

$$A = \frac{\Delta V_{out}}{\Delta V_{input}} = \frac{\Delta i_c}{\Delta i_e}\frac{R_L}{R_i} = \alpha\frac{R_L}{R_i}$$

Common Emitter Configuration

Current Gain: The ratio of change in collector current to the change in base current, denoted by β, $\beta = \frac{\Delta I_C}{\Delta I_B}$



Voltage gain

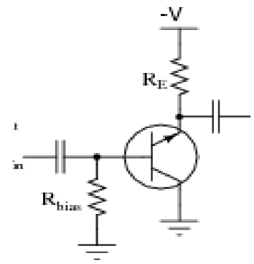
It is the ratio of change in output current to change in input current, denoted by A.

$$A = \frac{\Delta V_{out}}{\Delta V_{input}} = \frac{\Delta i_c}{\Delta i_B}\frac{R_L}{R_i} = \beta\frac{R_L}{R_i}$$

Common Collector Configuration

Current Gain: The ratio of change in emitter current to the change in base current, denoted by γ,

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



$$\text{Further } \gamma = \frac{\Delta I_E}{\Delta I_B} = \frac{\Delta I_E}{\Delta I_E - \Delta I_C} = \frac{\frac{\Delta I_E}{\Delta I_C}}{\frac{\Delta I_E}{\Delta I_C}-1} = \frac{\frac{1}{\alpha}}{\frac{1}{\alpha}-1} = \frac{1}{1-\alpha} = \beta+1$$

Voltage gain

It is the ratio of change in output current to change in input current, denoted by A which value is lesser then unity.

Q.13. What do you mean by transistor load line ? How will you obtain a d.c. load line for a transistor ? What is its utility.

Or

Define load line & operating point.

The load line is defined as a line that contains every possible operating point for the circuit. To understand the concept of dc load line consider the common emitter configuration & the output circuit as shown in fig (a) & fig. (b) resp.

Procedure to obtain the DC load line :

- Refer to the collector circuit of the CE configuration & apply KVL to this circuit, we have $V_{CC} - V_{CE} - I_C R_C = 0$
- Rearranging the equation , We have
  $I_C = V_{CE}(-1/R_E) + V_{CC} / R_C$

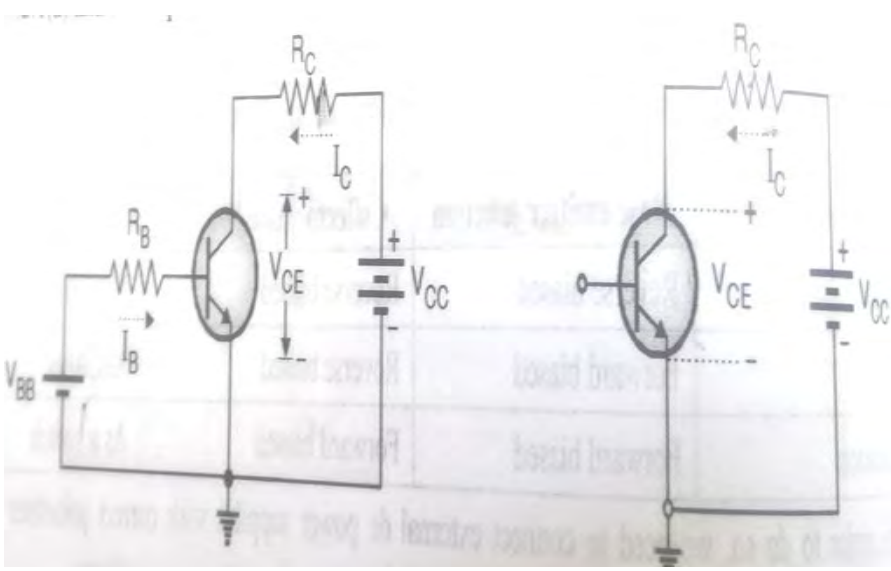


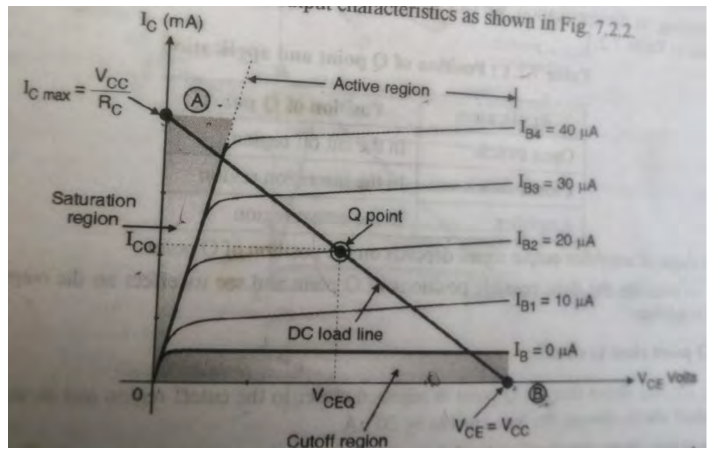
Fig. (a) Fig. (b)

- The above equation is the equation of a straight line ($y = mx + c$) with slope $-1/R_E$ & intercept V_{CC} / R_C.

- This straight line equivalency is known as dc load line.
- DC indicates that this line is drawn under dc operating conditions without ac signal at input

The Operating Point or Quiescent Point(Q-Point)

- It is a point on the load line which represents the dc current through a transistor (I_{CQ}) and the voltage across it (V_{CQ}), when no ac signal is applied. In short it represents the dc bias condition. The term Quiescent Point means quiet, still or inactive. The Q-point is also known as "Operating point" or "bias point".
- The position of operating point on load line is dependent on the application of the transistor. If the transistor is being used in for amplification purpose the Q-point should be exactly at the centre of load line
- Any point on the dc load line can be used as Q point.



Utility of transistor load line

- In absence of characteristics curve , the load line acts as a substitute , as it gives locus of all points of a curve where the device can be operated and a corresponding output can be obtained.

Q.14. Why common emitter amplifier is preferred to common bas amplifier ?

Or

Explain why the common emitter configuration is preferred for a transistor.

Out of the three configuration CE configuration is the most popular & widely used configuration , due to following reasons

- It has high voltage gain as well as high current gain
- As voltage gain as well as current gain is high , it has a very high power gain, as power gain is product of current gain & voltage gain.
- The CE configuration has moderate values of R_i & R_o, therefore many such stages can be coupled to each other without using any additional impedance matching circuits . Because of this property maximum power transfer takes place from one stage to other.
- Further ref. to Q. 11.

Q.15. Explain the term base width modulation in transistor.

The modulation of effective base width due to collector voltage (V_{CC}) is known as **width modulation** or **Early effect.**

As the collector to emitter voltage V_{CC} is made to increase the reverse bias , the space charge width between collector and base tends to increase, with the result that the effective width or the base decreases. This dependency of base width on collector to emitter voltage is known as the base width modulation or early effect.

- Recombination chances decreased within the base region. Hence α(common base current amplification) increases with increasing V_{CC} . β also increases for CE configuration.
- The current of minority carriers injected across the emitter junction increases.
- Very large reverse bias may cause voltage breakdown in the transistor. This is due to reduction of effective base width to zero.

Q.16. Define & discuss base spreading resistance

Base is lightly doped thin region, that becomes thinner due to spread of the two depletion regions . It offers a resistance to the passing currents, that is known as base spreading resistance. The value of this base spreading resistance r_v is of the order of hundred volts.

- Base spreading resistance is contributed by three factors i.e. the base is narrow, it is a very thin slice and doping is low .
- Base Emitter Resistance is a resistance that provides the required amount of automatic biasing needed for a common emitter amplifier

Q.17. Explain transit time for minority carriers. Derive an expression for it.

There are two dominant features of p-n junctions, the injection of minority carrier with forward bias & the variation of depletion width W with reverse bias.

- To have a good p-n-p transistor , we prefer that almost all holes injected by the emitter into the base be collected.
- Thus n-type base region should be narrow & the hole life time t_p should be long i.e. $W_b << L_p$, where W_b is the length of the neutral n-type material & L_p is the diffusion length.
- There is an important difference in the times which electrons & holes spend in the base. The average excess hole spends a time τ_p, defined as the **transit time from emitter to collector.**
- Since the base width W_b is made smaller then length L_p , the transit time is much less than the average hole life time τ_p in the base.
- On the other hand an average excess electron supplied from the base contact spend τ_p second in the base supplying space charge neutrality during the life time of an average excess hole.
- While the average electron waits τ_p seconds for recombination , many individual holes can enter and leave the base region , each with an average transit time τ_t .
- The ratio of τ_p & τ_t is β i.e. $\beta = {}^{\tau_p}/_{\tau_t} = {}^{i_c}/_{i_b}$

Calculation of transit time: Consider that the diffusing holes seem to have an average velocity $v(x_n)$.

The transit time is

$$\tau_t = \int_0^{w_b} \frac{dx_n}{v(x_n)} = \int_0^{w_b} \frac{qAp\,(x_n)}{i_p\,(x_n)}\, dx_n$$

For the triangular distribution, the diffusion current is almost constant at

$i_p = qAD_p \frac{\Delta p_E}{w_b}$ & τ_t becomes

$$\tau_t = \frac{qA\Delta p_E \, {w_b}/2}{qAD_p \Delta p_E / w_b} = \frac{w_b^2}{2D_p}$$

Q.16. Explain Life time of minority carrier .

Carrier lifetime is defined as the average time it takes for a minority carrier to recombine. The process through which this is done is typically known as minority carrier recombination.

- Carrier lifetime plays an important role in bipolar transistors and solar cells.
- In indirect band gap semiconductors, the carrier lifetime strongly depends on the concentration of recombination centers.
- Gold atoms act as highly efficient recombination centers
- Silicon for some high switching speed diodes and transistors is therefore alloyed with a small amount of gold. Many other atoms, e.g. iron or nickel, have similar effect.

Numerical

Q.1. Current amplification factor of a common base configuration is 0.88. Find the value of base current when the emitter current is 1mA.

Exp: Given Current amplification factor (α) = 0.88, I_E= 1mA

For CB configuration $\alpha = I_C / I_E$

$\because I_E = I_B + I_C$

$\therefore I_E = I_B + \alpha I_E$

$\Rightarrow I_B = I_E * (1 - \alpha)$

$= 1mA * (1-0.88) = 0.12mA$ Ans

Q.2. The constant α of a transistor is 0.95. What would be the change in the collector current corresponding to a change of 0.4mA in the base current in the common emitter configuration.

Exp: Given α= 0.95, ΔI_B= 0.4mA, ΔI_C= ?

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

$\therefore \beta = 0.95/(1-0.95) = 19$

Also $\beta = \Delta I_C / \Delta I_B \Rightarrow \Delta I_C = \beta * \Delta I_B$

$\therefore \Delta I_C = 19*0.4mA = 7.6$ mA Ans

Q.3. The load resistance of the output circuit in a common emitter amplifier is 400 kΩ and the input resistance is 300Ω. If current gain is common base configuration is 0.95, then find the voltage amplification.

Exp: Given Load resistance(R_L)= 400kΩ, Input resistance(R_{in})= 300Ω, α= 0.95

$\because \beta = \alpha / (1 - \alpha) \Rightarrow \beta = 0.95/(1-0.95) = 19$

$\because$ Voltage amplification = Voltage gain

and Voltage gain = Output voltage/ Input voltage

For CE configuration output voltage= $\Delta I_C R_L$

Input Voltage= $\Delta I_B R_{in}$

$\therefore$ Voltage gain = $\Delta I_C R_L / \Delta I_B R_{in} = (\Delta I_C/\Delta I_B)*(R_L/R_{in}) = \beta*(R_L/R_{in})$
$= 19*(400\ k\Omega/\mathbf{300\Omega}) = 25.33 \times 10^3$ Ans

Q.4. In the CE configuration, the voltage drop across a resistance of 6kΩ connected in the collector circuit is 6volts. If the current gain in the CB configuration of the transistor is 0.995, then find the base current I_b.

Exp: Given $R_L = 6k\Omega$, $V_0 = 6V$, $\alpha = 0.995$

$\because \beta = \alpha / (1-\alpha) \Rightarrow \beta = 0.995/(1-0.995) = 199$

Also $\beta = I_C/I_B = (V_0/R_L)/I_B$

$\Rightarrow 199 = (6V/6k\Omega)/I_B$

$\Rightarrow I_B = (6V/6k\Omega)/199 = 5.025\mu A$ Ans

Q.5. The reverse Saturation current in a an NPN transistor in CB configuration is 12.5µA. For an emitter current of 2mA, the collector current is 1.97mA. Determine current gain & base current.

Exp: Given ,Reverse Saturation current (I_{CBO})= 12.5×10^{-3}mA, I_E=2mA , I_C= 1.97mA , I_B= ?,

$\alpha = ?$

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

$\therefore \alpha = (I_C - I_{CBO})/I_E$

$\alpha = (1.97mA - 12.5 \times 10^{-3} mA)/2mA = 0.978$ Ans

Also $I_E = I_B + I_C \Rightarrow I_B = I_E - I_C$

$\therefore I_B = 2mA - 1.97mA = 0.03mA$

Q.6. In a transistor circuit when the base current is increased by 50µA keeping collector voltage fixed at 2 volts, the collector current increases by 1mA. Calculate the current amplification factor α and β of the transistor.

Exp: Given $\Delta I_B = 50\mu A$, $V_C = 2$Volt , $\Delta I_C = 1mA$, α and β =?

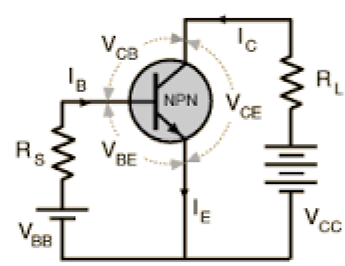
$\because \beta = \Delta I_C / \Delta I_B \Rightarrow \beta = 1mA/50\mu A = 10^{-3}/50*10^{-6} = 20$ Ans

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

$\therefore \alpha = 20/21 = 0.952$ Ans

Q.7. A silicon NPN transistor (β=100) I_{CO}= 22nA is operated in CE configuration as shown in fig. Determine the collector current if the transistor is in active region, V_{BE}=0.7v. Here V_{BB}= 5V , R_S= 220kΩ , R_L= 3.3kΩ & V_{CC}= 12V.

Exp: Given I_{CO}= 22nA , β=100, V_{BE}=0.7v,
V_{BB}= 5V , R_S= 220kΩ , R_L= 3.3kΩ & V_{CC}= 12V
I_C =?



Applying KVL to input side of CE configuration given

We have $-V_{BB} + I_B R_S + 0.7 = 0$

$I_B = (V_{BB} - 0.7)/R_S$

I_B=(5-0.7) / 220kΩ = 1.95x 10^{-5}A

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

$\therefore I_C$= 100* 1.95x 10^{-5}+ (1+100) 22x 10^{-9}

= 195x 10^{-5}+ 101x22x 10^{-9}

= 195.22 x 10^{-5} A Ans

Q.8. In a CB configuration , current amplification factor is 0.9. If the emitter current is 1mA, determine the value of base current.

Exp: Given α = 0.9 , I_E= 1mA , I_B= ?

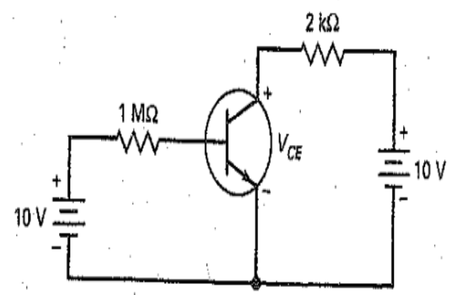
$\because \alpha = I_C / I_E$

$\therefore I_C = \alpha * I_E$ = 0.9x 1mA = 0.9mA

$\because I_E = I_B + I_C$

$\therefore I_B = I_E - I_C \Rightarrow I_B$= 1mA- 0.9mA = 0.1mA Ans

Q.9. The transistor of fig. has β_{dc}=300, Calculate I_B, I_C, V_{CE} and P_D.



Exp: Given β_{dc}=300 ,

For base current , I_B

Applying KVL at the input side we have

-10V+ 1MΩ . I_B+ 0.7 =0

$\Rightarrow$ **I_B**= (10-0.7) / 10^6= 9.3μA

For collector current

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

$\therefore I_C$= 300x9.3μA=2.79mA

For Collector- emitter voltage

Applying KVL at the output side we have

-10+ 2kΩ.I_C +V_{CE}=0

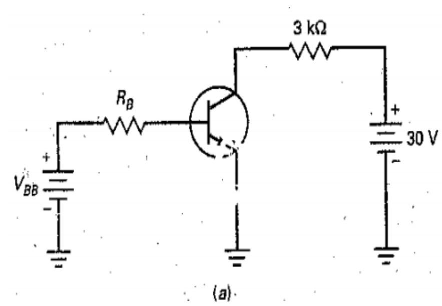
V_{CE}= 10-2x 10^3 x 2.79 x 10^{-3}

= 4.42 V

For Collector power dissipation i.e. P_D

$P_D = V_{CE} I_C$= (4.42V)(2.79mA)= 12.3 mW Ans

Q.10. What are the saturation current and the cutoff voltage in fig.



Exp: During Saturation V_{CE}=0 V

$\therefore$ Applying KVL at the output side, we have

-30+ 3KΩ. I_C- V_{CE} =0

$\Rightarrow$ -30+ 3KΩ. I_C - 0 =0 {$\because$ }

$\therefore I_C$= 30/(3 x 10^3)= 10mA

During Cutoff Collector to emitter terminal is open

$\therefore V_{CE}$= 30V Ans