
LAGOS

ELECTRONICS II

PHY 306/316

BY

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Bipolar Junction Transistors

A Bipolar Junction Transistor (BJT) is a three-terminal device which consists of two pn-junctions formed by sandwiching either p-type or n-type semiconductor material between a pair of opposite type semiconductors.
That is two n- and one p- type layers of material or two p- and one n-type layers of material.
The primary function of BJT is to increase the strength of a weak signal, i.e., it acts as an amplifier. A BJT can also be used as a solid state switch in electronic circuits.

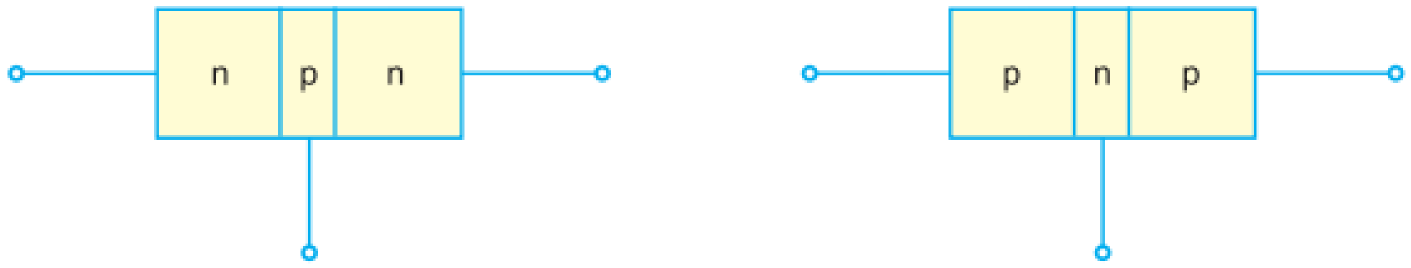
Types of BJT

- There are two types of BJTs –

  i) pnp transistor

  ii) npn transistor

Bipolar Junction Transistors



In each transistor following points to be noted-

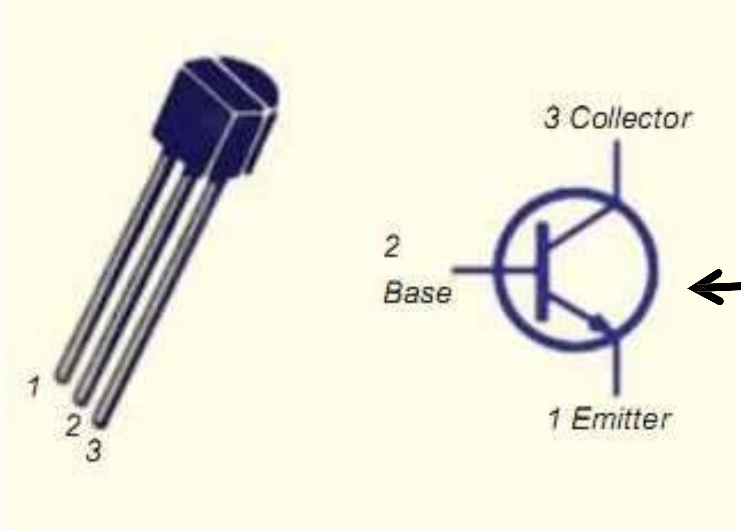
i) There are two junction, so transistor can be considered as two diode connected back to back.

ii) There are three terminals.

iii)The middle section is thin than other.

Naming of Transistor Terminals

- Transistor has three section of doped semiconductor.
- The section one side is called “emitter” and the opposite side is called “collector”.
- The middle section is called “base”.



Transistor symbol

Naming of Transistor Terminals

1) ***Emitter:***

→ The section of one side that supplies carriers is called emitter.

→ Emitter is always forward biased wr to base so it can supply carrier.

→ For “npn transistor” emitter supply holes to its junction.

→ For “pnp transistor” emitter supply electrons to its junction.

Naming of Transistor Terminals

2) Collector:

→The section on the other side that collects carrier is called collector.

→ The collector is always reversed biased wr to base.

→For “npn transistor” collector receives holes to its junction.

→ For “pnp transistor” collector receives electrons to its junction.

Naming of Transistor Terminals

3) Base:

→The middle section which forms two pn junction between emitter and collector is called Base.

Some important factors to be remembered-

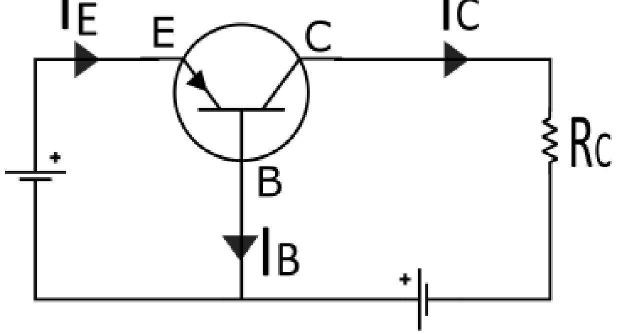
- The transistor has three region named emitter, base and collector.
- The Base is much thinner than other region.
- Emitter is heavily doped so it can inject large amount of carriers into the base.
- Base is lightly doped so it can pass most of the carrier to the collector.
- Collector is moderately doped.

Some important factors to be remembered-

- The junction between emitter and base is called emitter-base junction(emitter diode) and junction between base and collector is called collector-base junction(collector diode).
- The emitter diode is always forward biased and collector diode is reverse biased.
- The resistance of emitter diode is very small(forward) and resistance of collector diode is high(reverse).

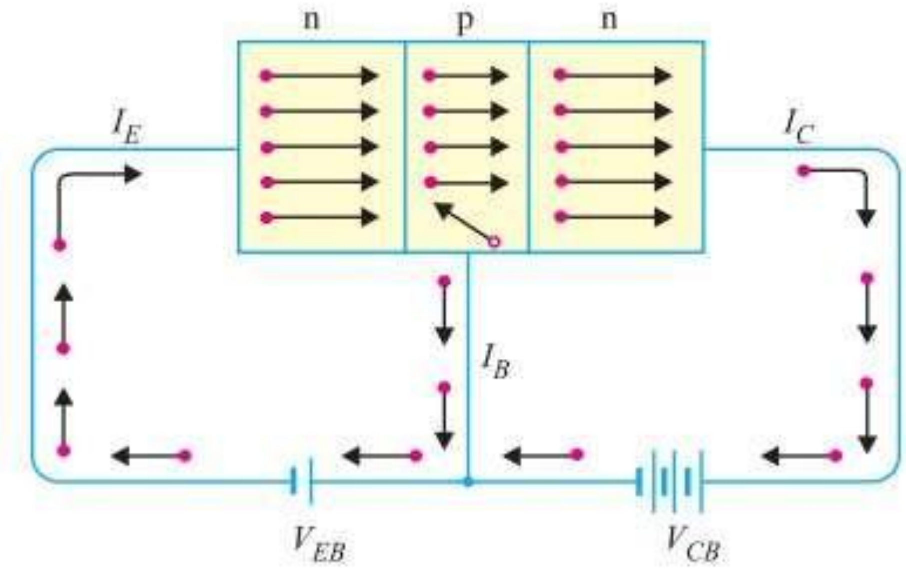
BJT Biasing

- A BJT has two pn-junctions *viz*. emitter-base junction and collector-base junction. Application of proper DC voltage at the two junctions of the BJT is known as BJT or Transistor Biasing.



Transistor Operation

1) Working of npn transistor:



✓Forward bias Is applied to emitter-base junction and reverse bias is applied to collector-base junction.

✓The forward bias in the emitter-base junction causes electrons to move toward base. This constitute emitter current, I_E

Transistor Operation

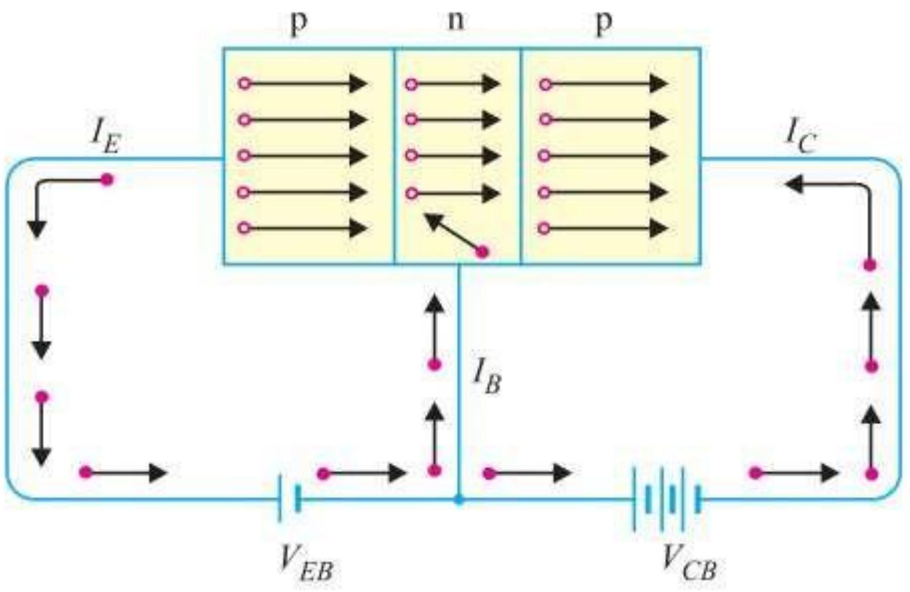
1) Working of npn transistor:

- ✓ As this electrons flow toward p-type base, they try to recombine with holes. As base is lightly doped only few electrons recombine with holes within the base.
- ✓ These recombined electrons constitute small base current.
- ✓ The remainder electrons crosses base and constitute collector current.

$$I_E = I_B + I_C$$

Transistor Operation

2) Working of pnp transistor:



✓Forward bias is applied to emitter-base junction and reverse bias is applied to collector-base junction.

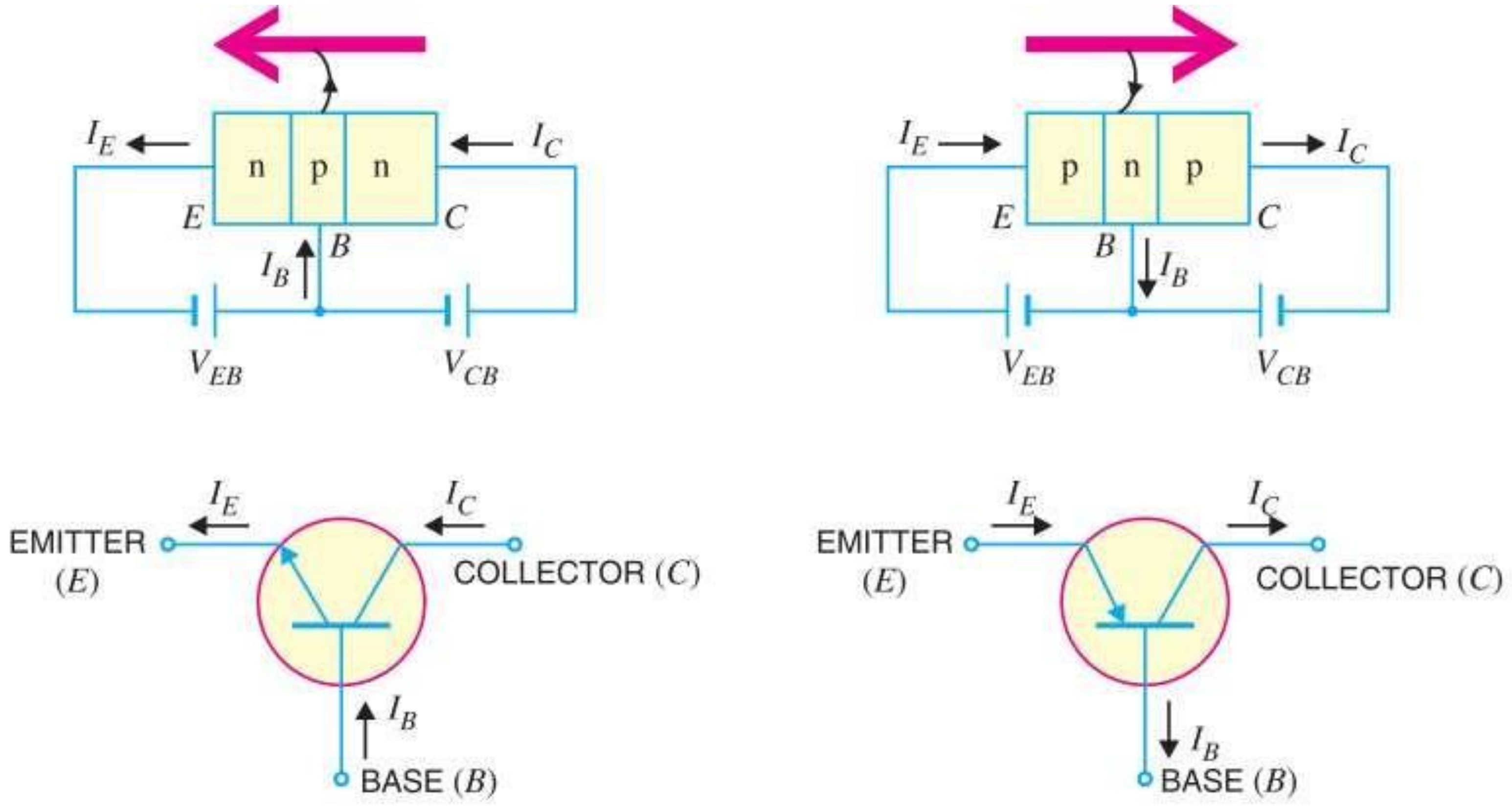
✓The forward bias in the emitter-base junction causes holes to move toward base. This constitute emitter current, I_E

Transistor Operation

2) Working of pnp transistor:

- ✓ As this holes flow toward n-type base, they try to recombine with electrons. As base is lightly doped only few holes recombine with electrons within the base.
- ✓ These recombined holes constitute small base current.
- ✓ The remainder holes crosses base and constitute collector current.

Transistor Symbol



(i)

(ii)

Transistor Operating Modes

- Active Mode

  → Base- Emitter junction is forward and Base-Collector junction is reverse biased.

- Saturation Mode

  → Base- Emitter junction is forward and Base-Collector junction is forward biased.

- Cut-off Mode

  → Both junctions are reverse biased.

Transistor Operating Modes

- When a transistor used as an amplifier, the emitter-base junction is forward biased and collector-base junction is reverse biased. If the transistor is operated under this bias condition then it is said to be operating in the **active region**.
- When both the junctions are forward biased then the transistor is said to be operating in the **saturation region**. The transistor operated in saturation region acts like a closed switch and the collector current becomes maximum.
- When both the junctions are reverse biased, the transistor is said to be operating in the **cut off region**. The BJT operated in cut off region acts as an open switch and a very small collector current (in **μA**) flows from emitter to collector. This current is called reverse leakage current and is due to minority charge carriers (electrons in p-region and holes in n-region).

Emitter-Base Junction	Collector-Base Junction	Operating Region
Forward Biased	Reverse Biased	Active Region
Forward Biased	Forward Biased	Saturation Region
Reverse Biased	Reverse Biased	Reverse Biased

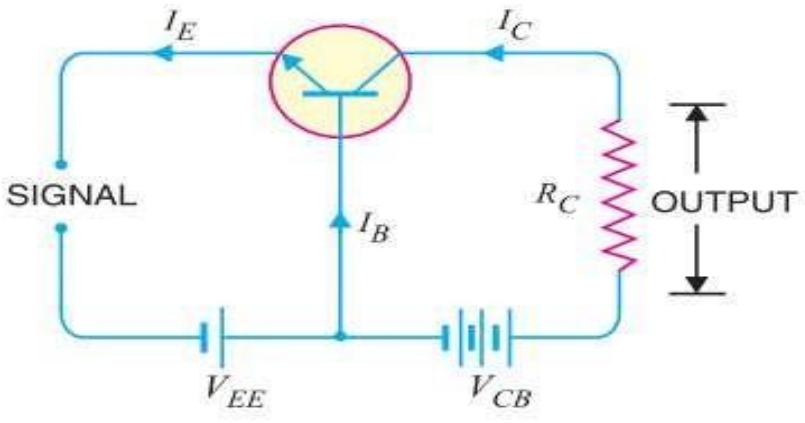
Transistor Connection

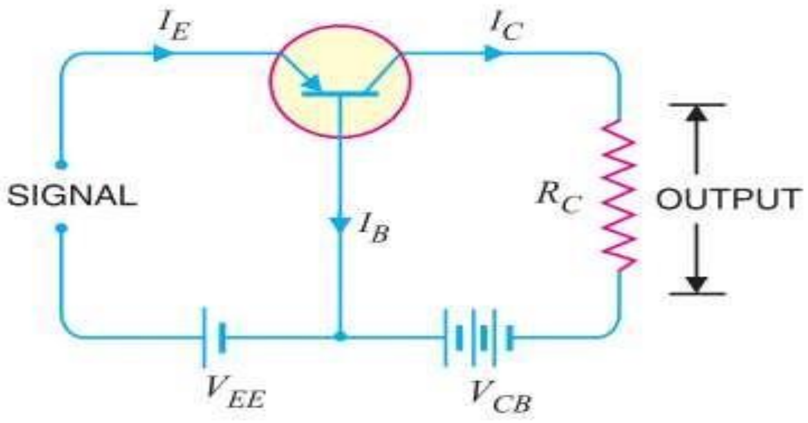
- Transistor can be connected in a circuit in following three ways-

1) Common Base
2) Common Emitter
3) Common Collector

Common Base Connection

- The common-base terminology is derived from the fact that the base is common to both the input and output sides of the configuration.





- First Figure shows common base npn configuration and second figure shows common base pnp configuration.

Common Base Connection

- <u>Current amplification factor (α) :</u>

  The ratio of change in collector current to the change in emitter current at constant V_{CB} is known as current amplification factor, α.

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \ \ at \text{ constant} \mathrm{V}_{CB}$$

→ Practical value of α is less than unity, but in the range of 0.9 to 0.99

Expression for Collector Current

→Total emitter current does not reach the collector terminal, because a small portion of it constitute base current. So,

$$I_E = I_C + I_B$$

→Also, collector diode is reverse biased, so very few minority carrier passes the collector-base junction which actually constitute leakage current, I_{CBO}.

→ So, collector current constitute of portion of emitter current αI_E and leakage current I_{CBO}.

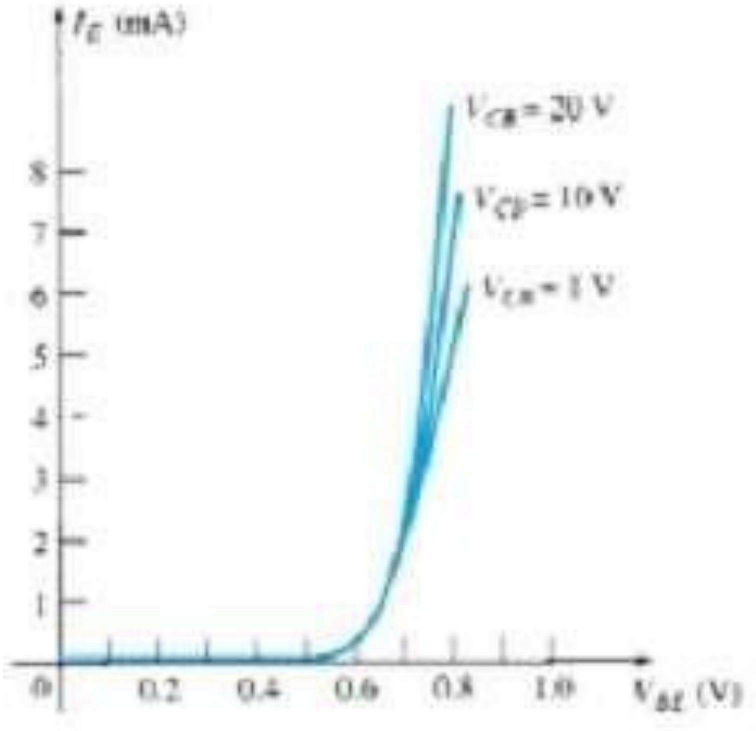
$$I_C = \alpha I_E + I_{CB0}$$

Expression for Collector Current

$$
\begin{aligned}
I_C &= \alpha\,(I_C + I_B) + I_{CBO} \\
I_C\,(1-\alpha) &= \alpha\, I_B + I_{CBO} \\
I_C &= \frac{\alpha}{1-\alpha}\, I_B + \frac{I_{CBO}}{1-\alpha}
\end{aligned}
$$

Characteristics of common base configuration

- <u>Input Characteristics:</u>



→V_{BE} vs I_E characteristics is called input characteristics.

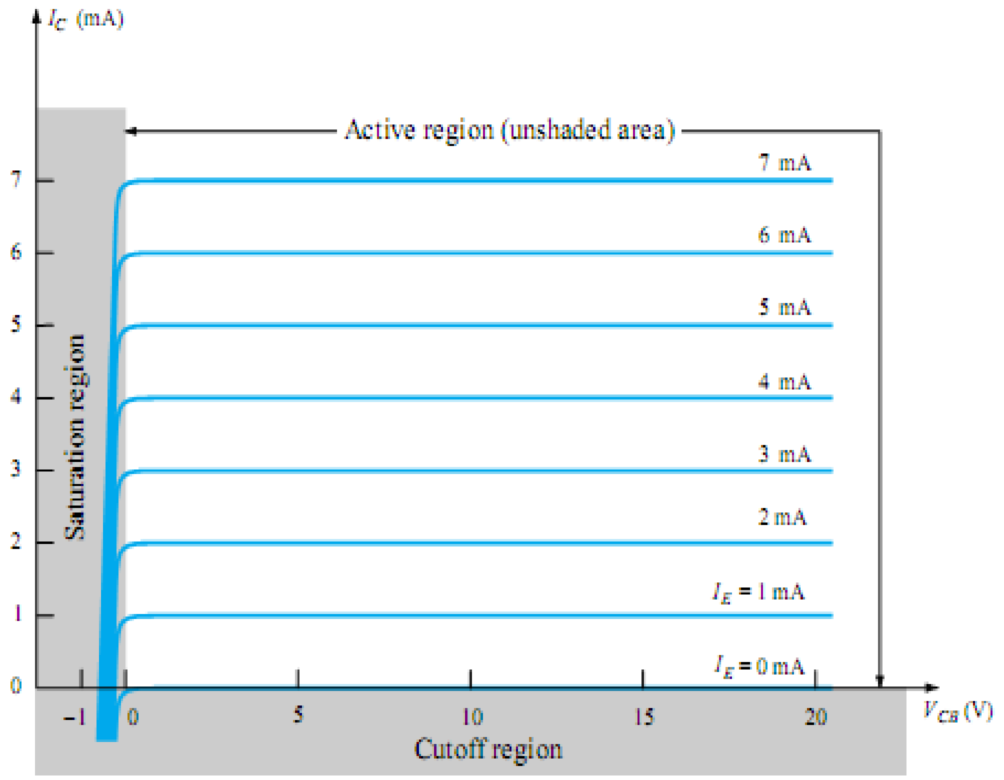
→ I_E increases rapidly with V_{BE}. It means input resistance is very small.

→ I_E almost independent of V_{CB}.

Characteristics of common base configuration

- →V_{Bc} vs I_c characteristics is called output characteristics.
- → I_C varies linearly with V_{Bc} ,only when V_{Bc} is very small.
- → As, V_{Bc} increases, I_C becomes constant.

<u>Output Characteristics:</u>



Input and Output Resistance of common base conf.

- <u>Input Resistance:</u> The ratio of change in emitter-base voltage to the change in emitter current is called Input Resistance.

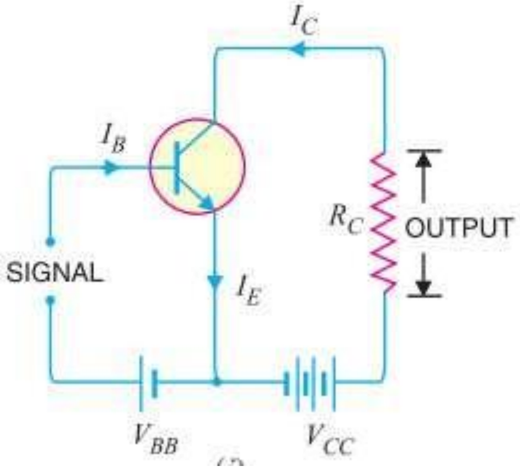
$$r_i = \frac{\Delta V_{BE}}{\Delta I_E}$$

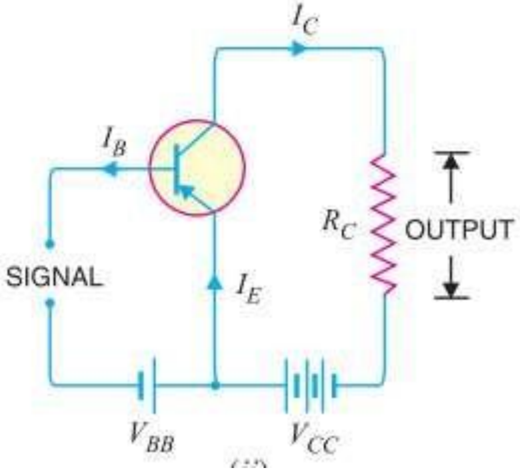
- <u>Output Resistance:</u> The ratio of change in collector-base voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta V_{BC}}{\Delta I_C}$$

Common Emitter Connection

- The common-emitter terminology is derived from the fact that the emitter is common to both the input and output sides of the configuration.





- First Figure shows common emitter npn configuration and second figure shows common emitter pnp configuration.

Common Emitter Connection

- Base Current amplification factor (β) :
- In common emitter connection input current is base current and output current is collector current.
- The ratio of change in collector current to the change in base current is known as base current amplification factor, β.

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

- Normally only 5% of emitter current flows to base, so amplification factor is greater than 20. Usually this range varies from 20 to 500.

Relation Between β and α

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

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

$$I_E = I_B + I_C$$

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

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

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

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

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

Expression for Collector Current

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

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

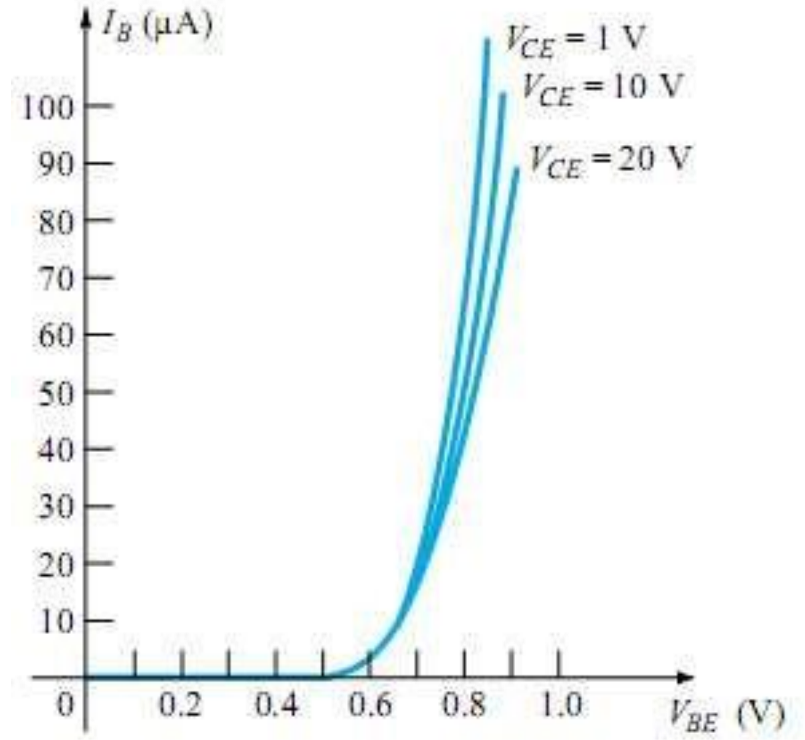
$$I_E (1 - \alpha) = I_B + I_{CBO}$$

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

$$I_C \; ; \; I_E = {}^{*}(\beta + 1) I_B + (\beta + 1) I_{CBO}$$

Characteristics of common emitter configuration

- <u>Input Characteristics:</u>



→V_{BE} vs I_B characteristics is called input characteristics.

→ I_B increases rapidly with V_{BE} . It means input resistance is very small.

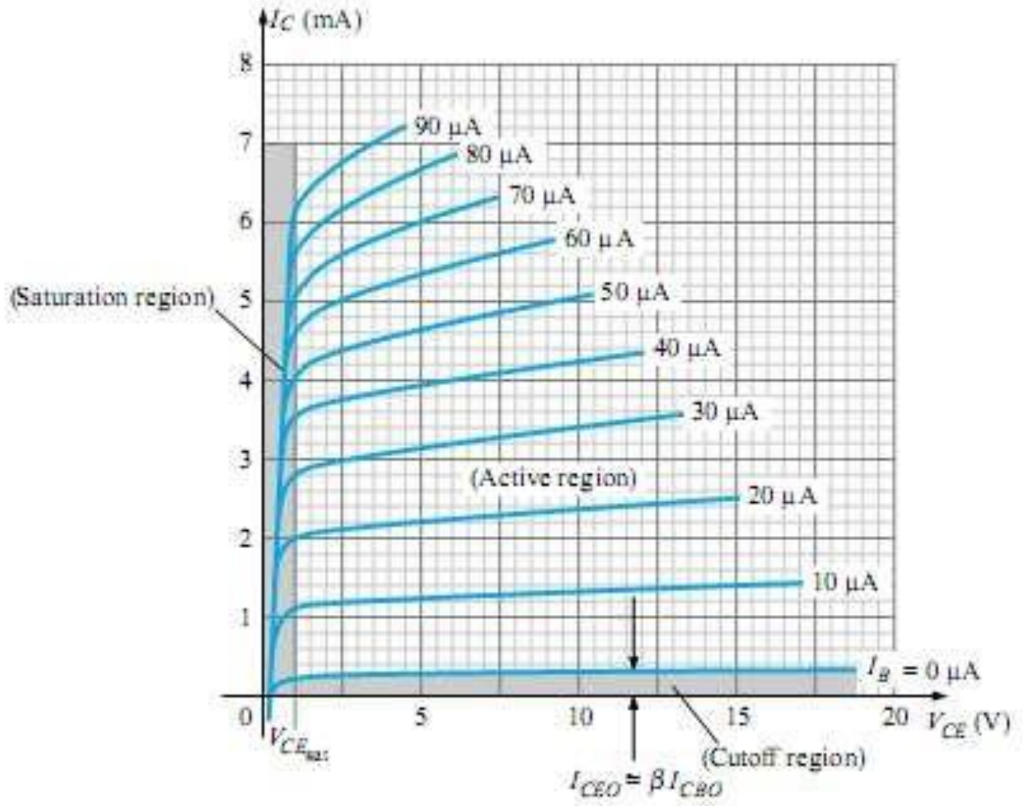
→ I_E almost independent of V_{CE}.

→I_B is of the range of micro amps.

Characteristics of common emitter configuration

- → V_{CE} vs I_c characteristics is called output characteristics.
- → I_C varies linearly with V_{CE} ,only when V_{CE} is very small.
- → As, V_{CE} increases, I_C becomes constant.

- <u>Output Characteristics:</u>



Input and Output Resistance of common emitter conf.

- <u>Input Resistance:</u> The ratio of change in emitter-base voltage to the change in base current is called Input Resistance.

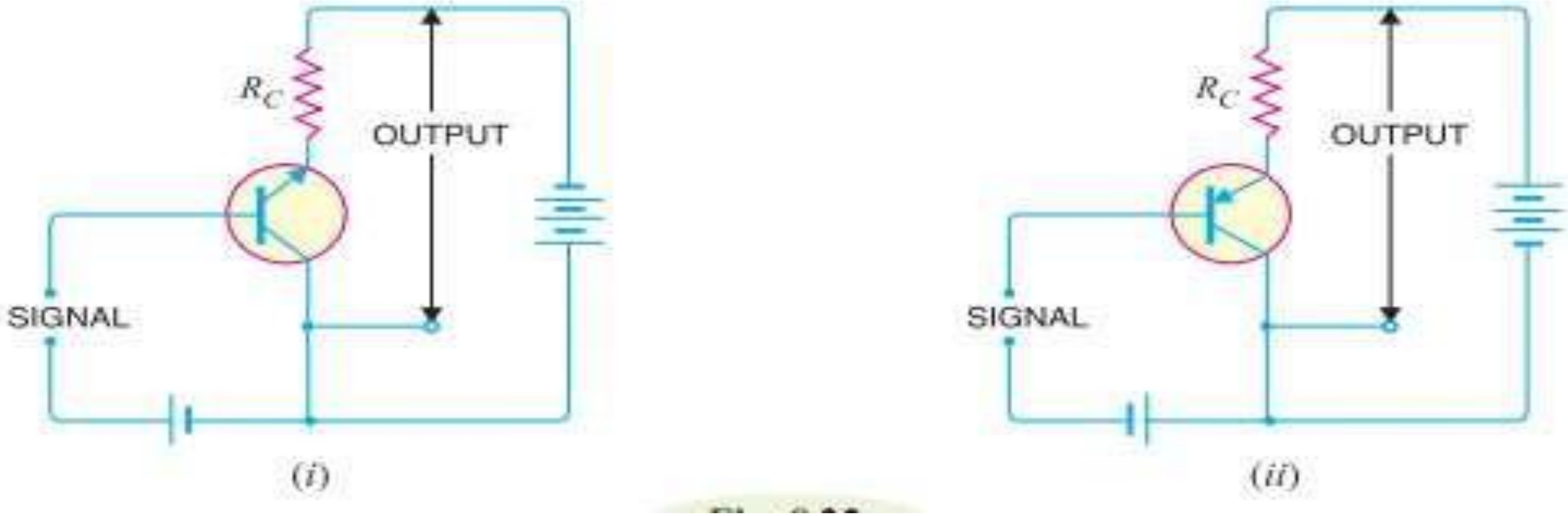
$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

- <u>Output Resistance:</u> The ratio of change in collector-emitter voltage to the change in collector current is called Output Resistance.

$$r_0 = \frac{\Delta V_{CE}}{\Delta I_C}$$

Common Collector Configuration

- The common-collector terminology is derived from the fact that the collector is common to both the input and output sides of the configuration.



- First Figure shows common collector npn configuration and second figure shows common collector pnp configuration.

Common Collector Configuration

- Current amplification factor (γ) :
- In common emitter connection input current is base current and output current is emitter current.
- The ratio of change in emitter current to the change in base current is known as current amplification

factor in common collector configuration.

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

- This circuit provides same gain as CE configuration as,

$$\Delta I_E \approx \Delta I_C$$

Relation Between and α

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

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

$$I_E = I_B + I_C$$

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

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

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

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

Expression for Collector Current

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

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

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

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

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

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

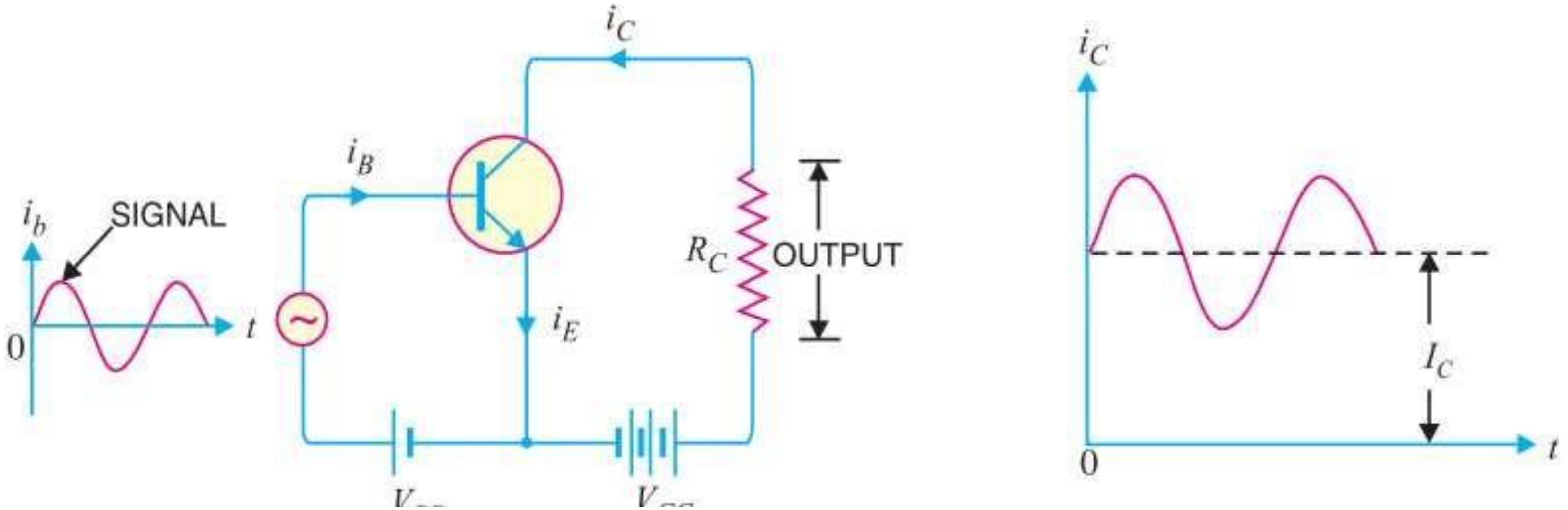
Comparison of Transistor Connection

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

LECTURE 2

BJT as an Amplifier and as a Switch

Transistor as an amplifier in CE conf.



- Figure shows CE amplifier for npn transistor.
- Battery V_{BB} is connected with base in-order to make base forward biased, regardless of input ac polarity.
- Output is taken across Load R

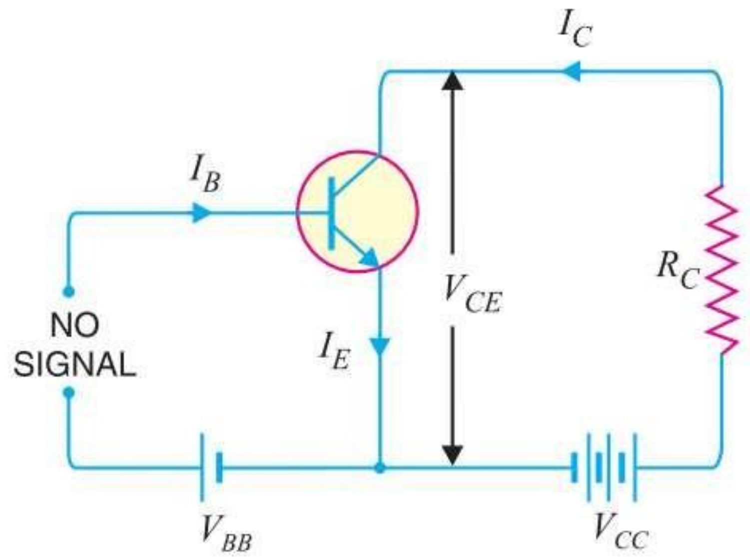
Transistor as an amplifier in CE conf.

- During positive half cycle input ac will keep the emitter-base junction more forward biased. So, more carrier will be emitted by emitter, this huge current will flow through load and we will find output amplified signal.
- During negative half cycle input ac will keep the emitter-base junction less forward biased. So, less carrier will be emitted by emitter. Hence collector current decreases.
- This results in decreased output voltage (In opposite direction).

Transistor Load line analysis

- In transistor circuit analysis it is necessary to determine collector current for various V_{CE} voltage.
- One method is we can determine the collector current at any desired V_{CE} voltage, from the output characteristics.
- More conveniently we can use load line analysis to determine operating point.

Transistor Load line analysis



→Consider common emitter npn transistor ckt shown in figure.

→There is no input signal.

→ Apply KVL in the output ckt-

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

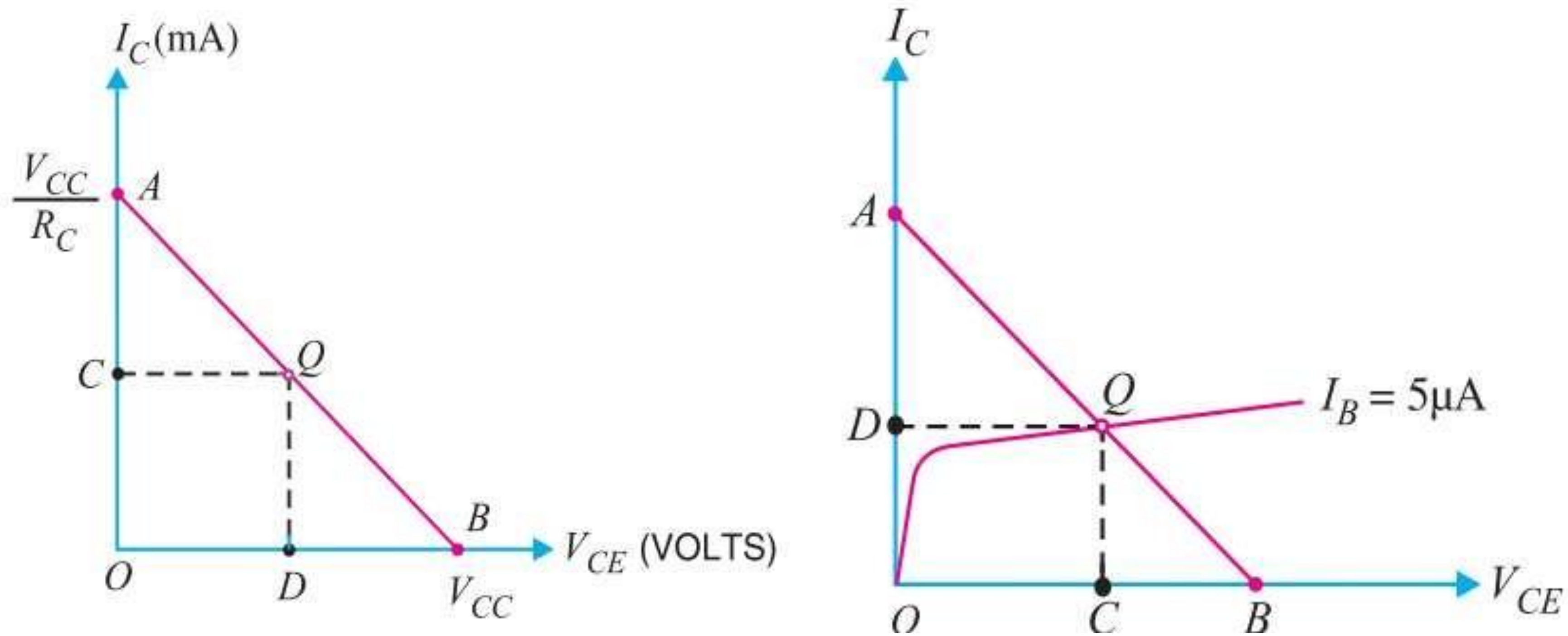
(*i*) When the collector current $I_C = 0$, then collector-emitter voltage is maximum and is equal to V_{CC} i.e.

$$\text{Max. } V_{CE} = V_{CC} - I_C R_C$$
$$= V_{CC} \qquad (\because I_C = 0)$$

When collector-emitter voltage $V_{CE} = 0$,

$$V_{CE} = V_{CC} - I_C R_C$$
$$0 = V_{CC} - I_C R_C$$
$$\text{Max. } I_C = V_{CC}/R_C$$

Transistor Load line analysis

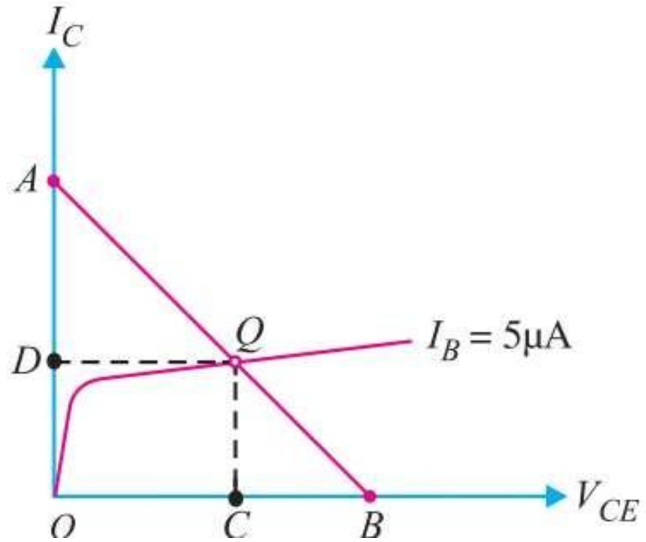


Operating Point

The zero signal values of I_C and V_{CE} are known as the **operating point.**

→It is called operating point because variation of I_C takes place about this point.

→ It is also called quiescent point or Q-point.

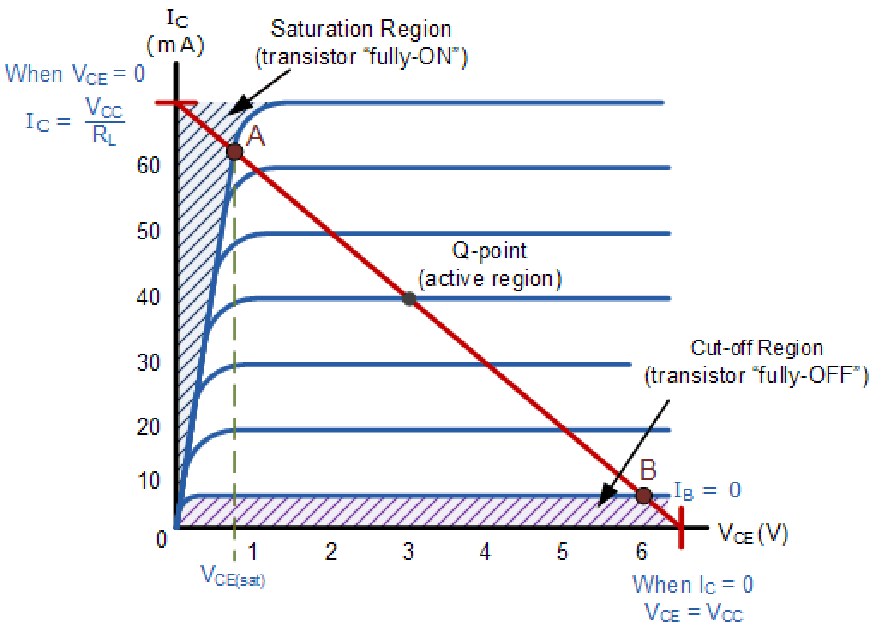


Transistor as a Switch

- When used as an AC signal amplifier, the transistors Base biasing voltage is applied in such a way that it always operates within its “active” region, that is the linear part of the output characteristics curves are used. However, both the NPN & PNP type bipolar transistors can be made to operate as “ON/OFF” type solid state switches by biasing the transistors base differently to that of a signal amplifier.

- Transistor switch operating region
- NPN Transistor and PNP Transistor

V-I Characteristics curves have seen in figure.



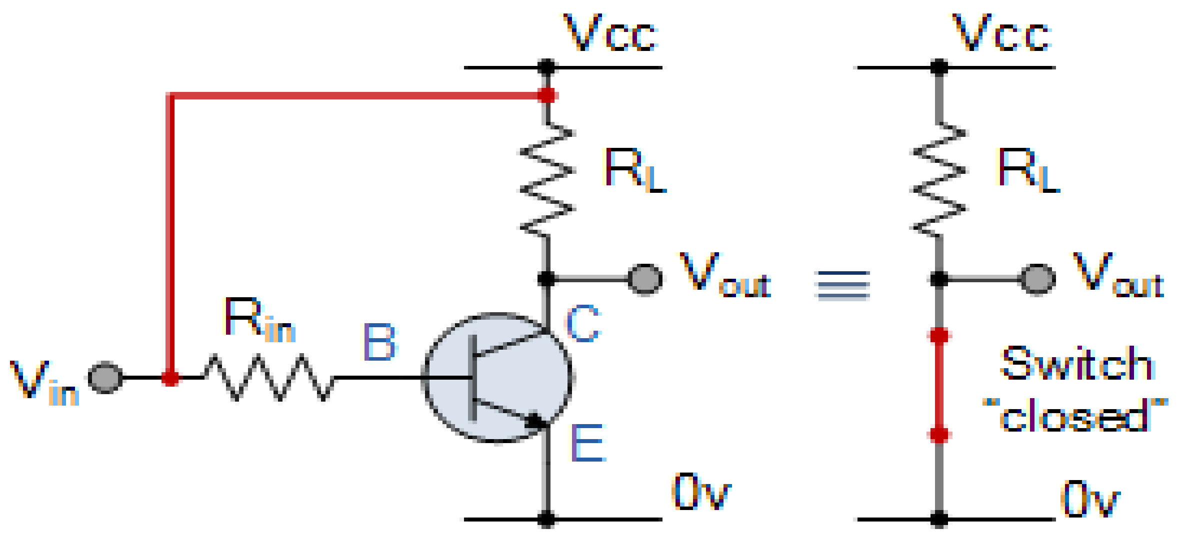
- The areas of operation for a Transistor Switch are known as the Saturation Region and the Cut-off Region. This means then that we can ignore the operating Q-point biasing and voltage divider circuitry required for amplification, and use the transistor as a switch by driving it back and forth between its “fully-OFF” (cut-off) and “fully-ON” (saturation) regions as shown in figure.
- The pink shaded area at the bottom of the curves represents the “Cut-off” region while the blue area to the left represents the “Saturation” region of the transistor. Both these transistor regions are defined as:

1. Cut-off Region

- Then we can define the “cut-off region” or “OFF mode” when using a bipolar transistor as a switch as being, both junctions reverse biased, VB < 0.7v and IC = 0. For a PNP transistor, the Emitter potential must be negative with respect to the Base.

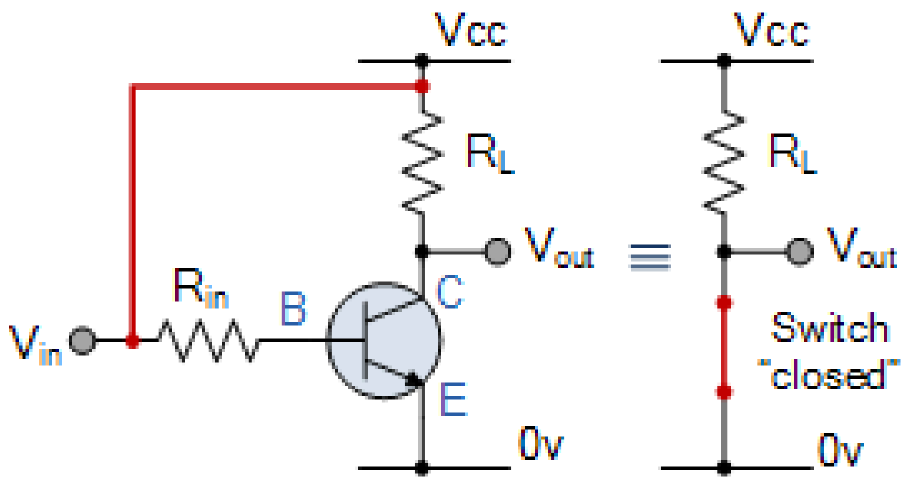
- Here the operating conditions of the transistor are zero input base current (IB), zero output collector current (IC) and maximum collector voltage (VCE) which results in a large depletion layer and no current
flowing through the device. Therefore the transistor is switched “Fully-OFF”.

- transistor switch in cut-off



2. Saturation Region

- Here the transistor will be biased so that the maximum amount of base current is applied, resulting in maximum collector current resulting in the minimum collector emitter voltage drop which results in the depletion layer being as small as possible and maximum current flowing through the transistor. Therefore the transistor is switched “Fully-ON”.
- Saturation Characteristics
- transistor switch in saturation



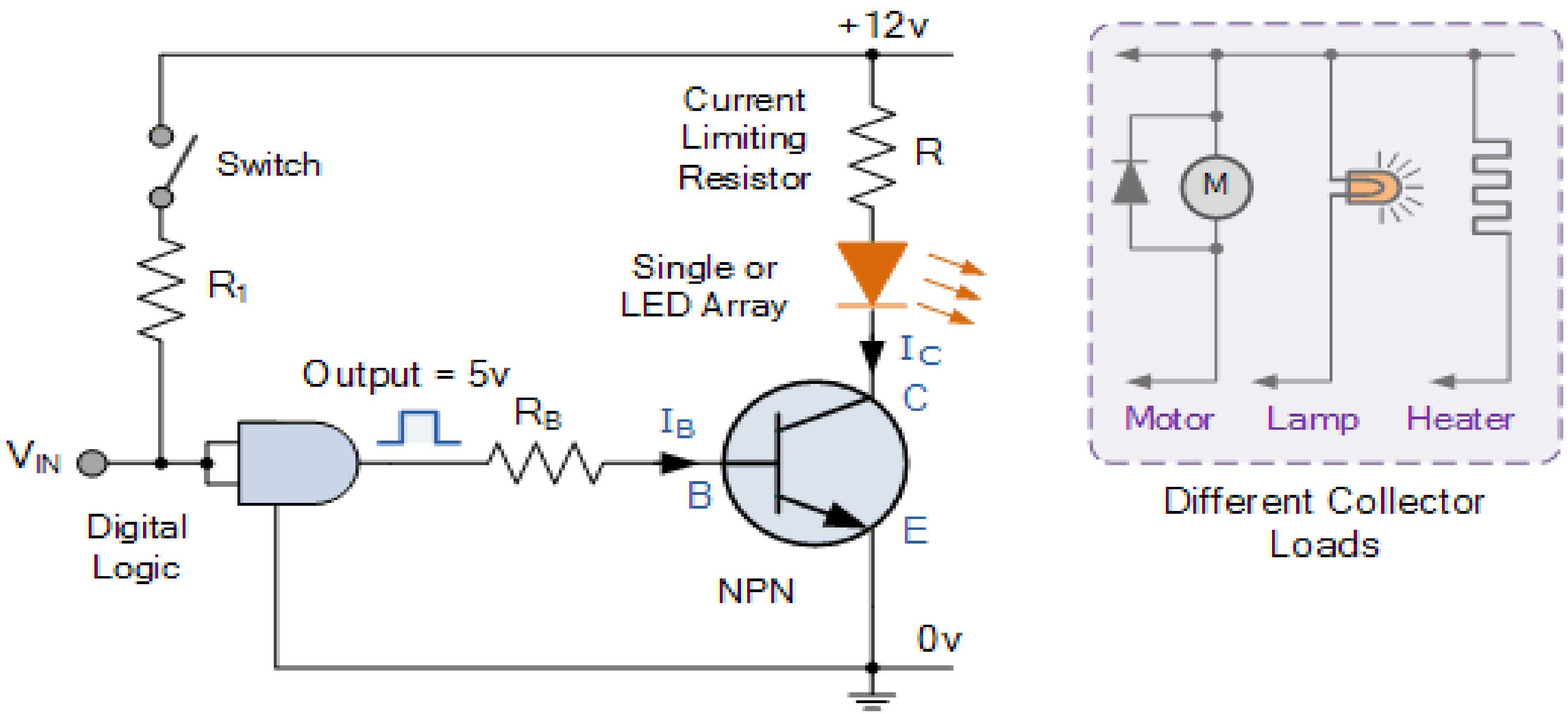
- Then we can define the "saturation region" or "ON mode" when using a bipolar transistor as a switch as being, both junctions forward biased, VB > 0.7v and IC = Maximum. For a PNP transistor, the Emitter potential must be positive with respect to the Base.

Digital Logic Transistor Switch

- Transistor switches are used for a wide variety of applications such as interfacing large current or high voltage devices like motors, relays or lamps to low voltage digital logic IC's or gates like AND gates or OR gates.

  Here, the output from a digital logic gate is only +5v but the device to be controlled may require a 12 or even 24 volts supply. Or the load such as a DC Motor may need to have its speed controlled using a series of pulses (Pulse Width Modulation).
  transistor switches will allow us to do this faster and more easily than with conventional mechanical switches.

Digital Logic Transistor Switch



A Switch Example

- Using the transistor values from the previous tutorials of: $\beta = 200$, $I_c = 4mA$ and $I_b = 20uA$, find the value of the Base resistor (Rb) required to switch the load fully "ON" when the input terminal voltage exceeds 2.5v.

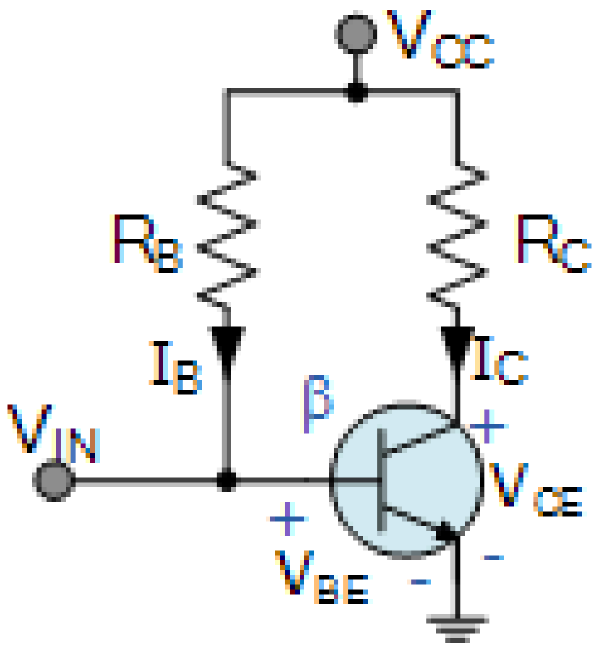
- Transistor Switch Base Resistance

$$R_B = \frac{V_{in} - V_{BE}}{I_B} = \frac{2.5v - 0.7v}{20x10^{-6}} = 90k\Omega$$

LECTURE 3

Transistor Biasing

- Transistor Biasing is the process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor. the most commonly used methods of obtaining transistor biasing from one source of supply (*i.e.* V_{CC}) : **(*i*)** Base resistor method **(*ii*)** Emitter bias method **(*iii*)** Biasing with collector-feedback resistor **(*iv*)** Voltage-divider bias

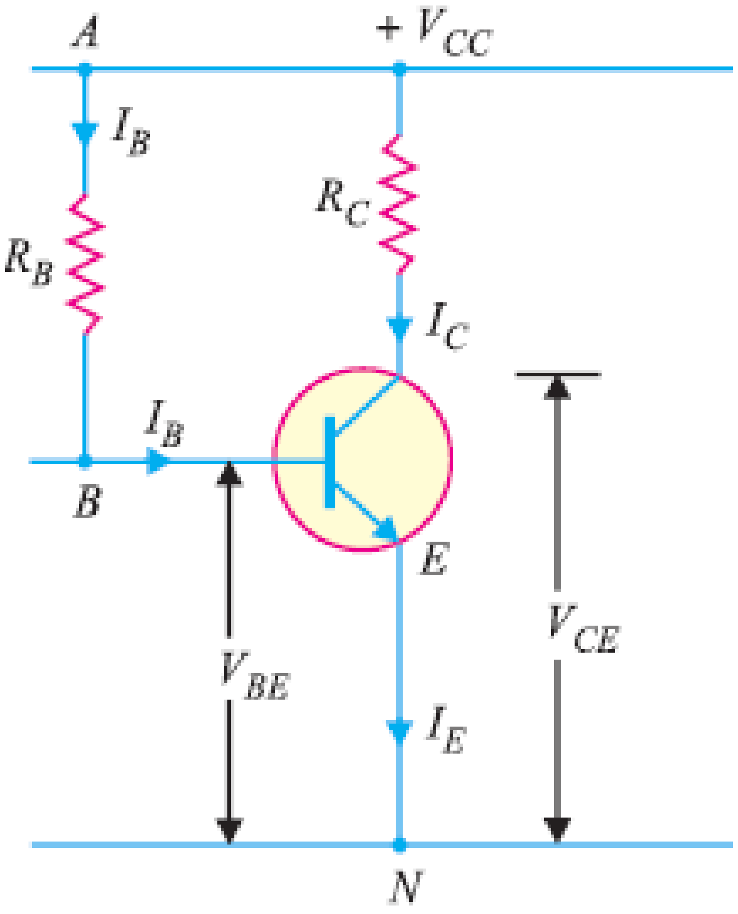


The steady state operation of a bipolar transistor depends a great deal on its base current, collector voltage, and collector current values. Therefore, if the transistor is to operate correctly as a linear amplifier, it must be properly biased around its operating point as improper transistor biasing will result in a distorted output.

The correct biasing point for a bipolar transistor, either NPN or PNP, generally lies somewhere between the two extremes of operation with respect to it being either "fully-ON" or "fully-OFF" along its DC load line. This central operating point is called the "Quiescent Operating Point", or **Q-point** for short.

Base Resistor Method

- In this method, a high resistance R_B (several hundred kohms) is
- connected between the base and +ve end of supply for *npn*
- transistor and between base and negative end
- of supply for *pnp* transistor. Here, the required zero signal
- base current is provided by V_{CC} and it flows through R_B. To
- Find R_B Considering the closed circuit *ABENA* and applying
- Kirchhoff 's voltage law, we get,



$$V_{CC} = I_B R_B + V_{BE}$$
$$I_B R_B = V_{CC} - V_{BE}$$
$$R_B = \frac{V_{CC} - V_{BE}}{I_B}$$

As V_{CC} and I_B are known and V_{BE} can be seen from the transistor manual, therefore, value of R_B can be readily found from the equation above. V_{BE} is 0.7V for silicon and 0.3 V Ge

Transistor Regions of Operation

- The DC supply is provided for the operation of a transistor. This DC supply is given to the two PN junctions of a transistor which influences the actions of majority carriers in these emitter and collector junctions.

- The junctions are forward biased and reverse biased based on our requirement. Forward biased is the condition where a positive voltage is applied to the p-type and negative voltage is applied to the n-type material. Reverse biased is the condition where a positive voltage is applied to the n-type and negative voltage is applied to the p-type material.

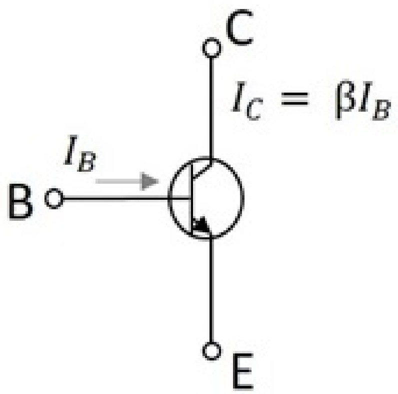
- Transistor Biasing
- The supply of suitable external dc voltage is called as **biasing**. Either forward or reverse biasing is done to the emitter and collector junctions of the transistor.
- These biasing methods make the transistor circuit to work in four kinds of regions such as **Active region, Saturation region, Cutoff region** and **Inverse active region** (seldom used). This is understood by having a look at the following table.

Emitter Junction	Collector Junction	Region of Operation
Forward biased	Forward biased	Saturation region
Forward biased	Reverse biased	Active region
Reverse biased	Forward biased	Inverse active region
Reverse biased	Reverse biased	Cut off region

- Among these regions, Inverse active region, which is just the inverse of active region, is not suitable for any applications and hence not used.

Active Region

- This is the region in which transistors have many applications. This is also called as **linear region**. A transistor while in this region, acts better as an **Amplifier**.
- The following circuit diagram shows a transistor working in active region.



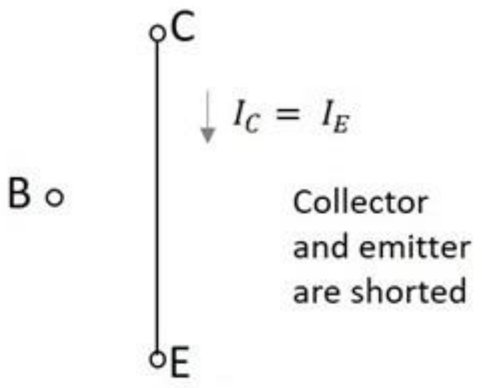
- This region lies between saturation and cutoff. The transistor operates in active region when the emitter junction is forward biased and collector junction is reverse biased.
- In the active state, collector current is β times the base current, i.e.

$$I_C = \beta I_B$$

Where I_C = collector current, β = current amplification factor, and I_B = base current.

Saturation Region

- This is the region in which transistor tends to behave as a closed switch. The transistor has the effect of its collector and emitter being shorted. The collector and emitter currents are maximum in this mode of operation.
- The following figure shows a transistor working in saturation region.



The transistor operates in saturation region when both the emitter and collector junctions are forward biased.

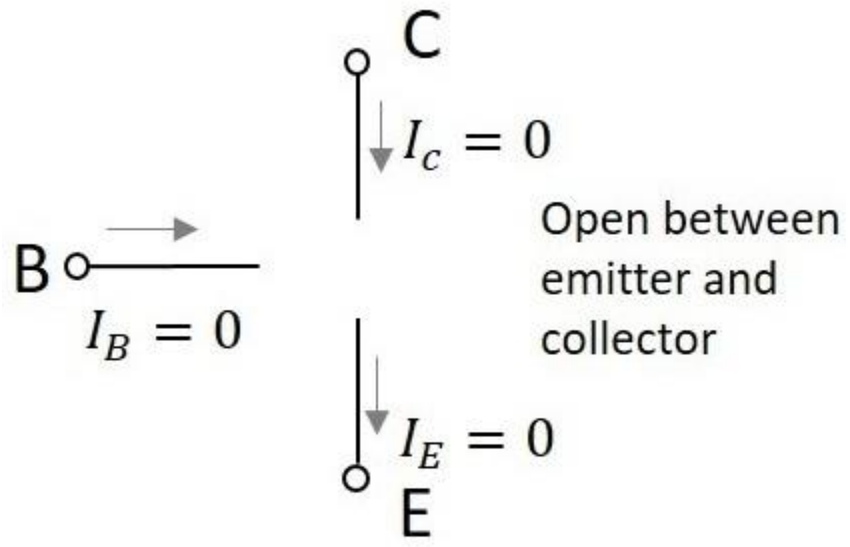
In saturation mode, $\beta < \frac{I_C}{I_B}$

As in the saturation region the transistor tends to behave as a closed switch, $I_C = I_E$

Where I_C = collector current and I_E = emitter current.

Cutoff Region

- This is the region in which transistor tends to behave as an open switch. The transistor has the effect of its collector and base being opened. The collector, emitter and base currents are all zero in this mode of operation.
- The figure below shows a transistor working in cutoff region.



The transistor operates in cutoff region when both the emitter and collector junctions are reverse biased.

As in cutoff region, the collector current, emitter current and base currents are nil, we can write as

$$I_C = I_E = I_B = 0$$

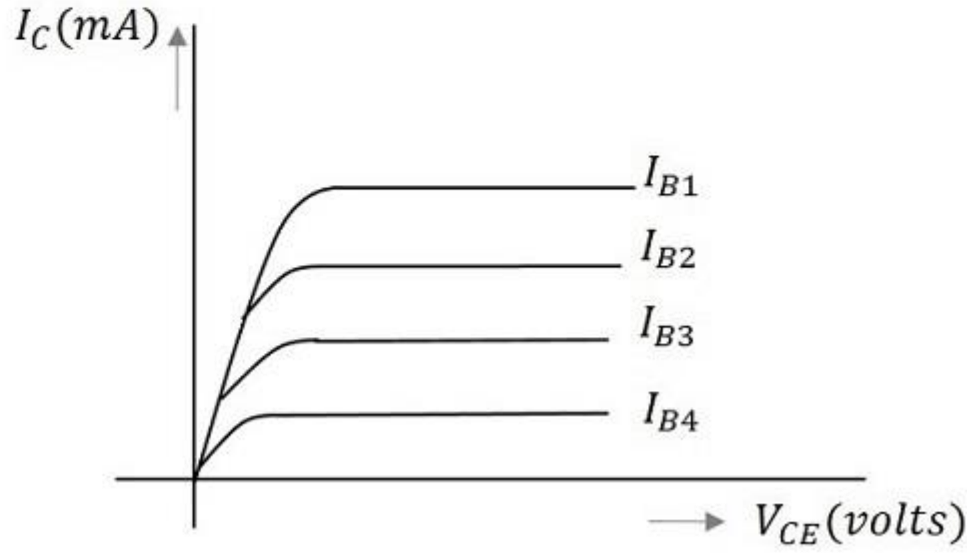
Where I_C = collector current, I_E = emitter current, and I_B = base current.

Transistor Load Line Analysis

- Till now we have discussed different regions of operation for a transistor. But among all these regions, we have found that the transistor operates well in active region and hence it is also called as linear region. The outputs of the transistor are the collector current and collector voltages.

<u>Output Characteristics</u>

- When the output characteristics of a transistor are considered, the curve looks as below for different input values.



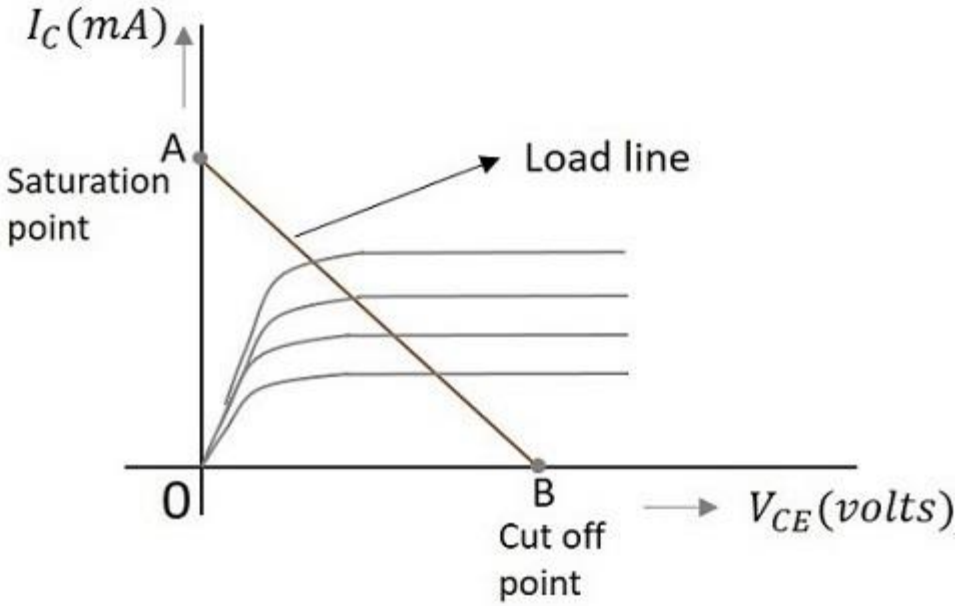
In the above figure, the output characteristics are drawn between collector current $\mathbf{I_C}$ and collector voltage $\mathbf{V_{CE}}$ for different values of base current $\mathbf{I_B}$. These are considered here for different input values to obtain different output curves.

Load Line

- When a value for the maximum possible collector current is considered, that point will be present on the Y-axis, which is nothing but the **Saturation point**. As well, when a value for the maximum possible collector emitter voltage is considered, that point will be present on the X-axis, which is the **Cutoff point**.
- When a line is drawn joining these two points, such a line can be called as **Load line**. This is called so as it symbolizes the output at the load. This line, when drawn over the output characteristic curve, makes contact at a point called as **Operating point** or **quiescent point** or simply **Q-point**.
- The concept of load line can be understood from the following graph.

The load line is drawn by joining the saturation and cut off points. The region that lies between these two is the linear region. A transistor acts as a good amplifier in this linear region.

If this load line is drawn only when DC biasing is given to the transistor, but no input signal is applied, then such a load line is called as DC load line. Whereas the load line drawn under the conditions when an input signal along with the DC voltages are applied, such a line is called as an AC load line.



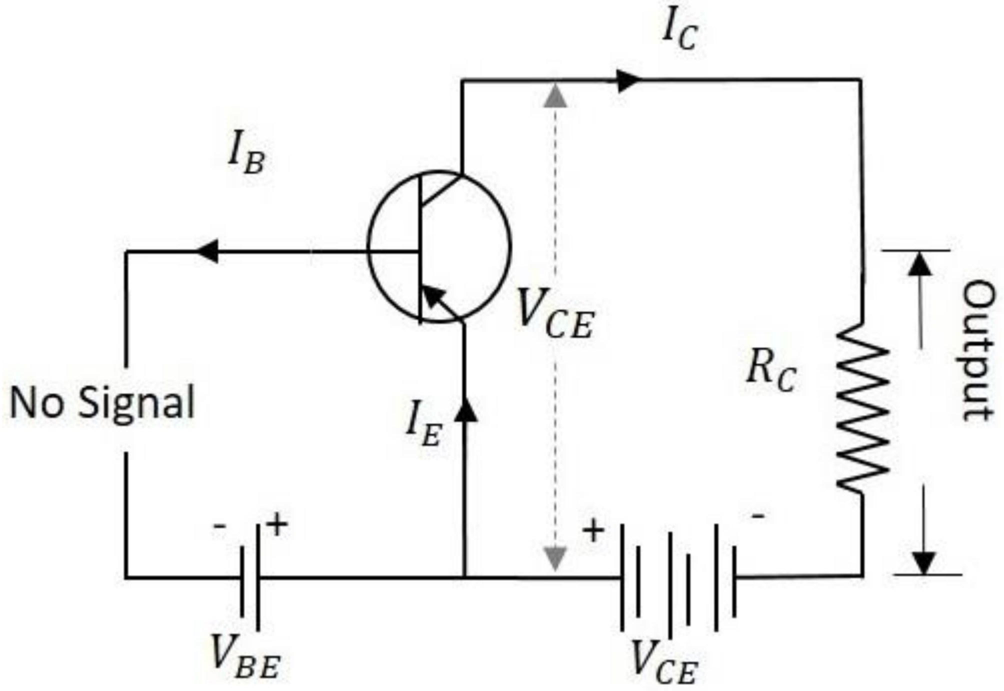
DC Load Line

- When the transistor is given the bias and no signal is applied at its input, the load line drawn under such conditions, can be understood as **DC** condition. Here there will be no amplification as the **signal is absent**. The circuit will be as shown below.

The value of collector emitter voltage at any given time will be

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

As V_{CC} and R_C are fixed values, the above one is a first degree equation and hence will be a straight line on the output characteristics. This line is called as **D.C. Load line**. The figure below shows the DC load line.



To obtain the load line, the two end points of the straight line are to be determined. Let those two points be A and B.

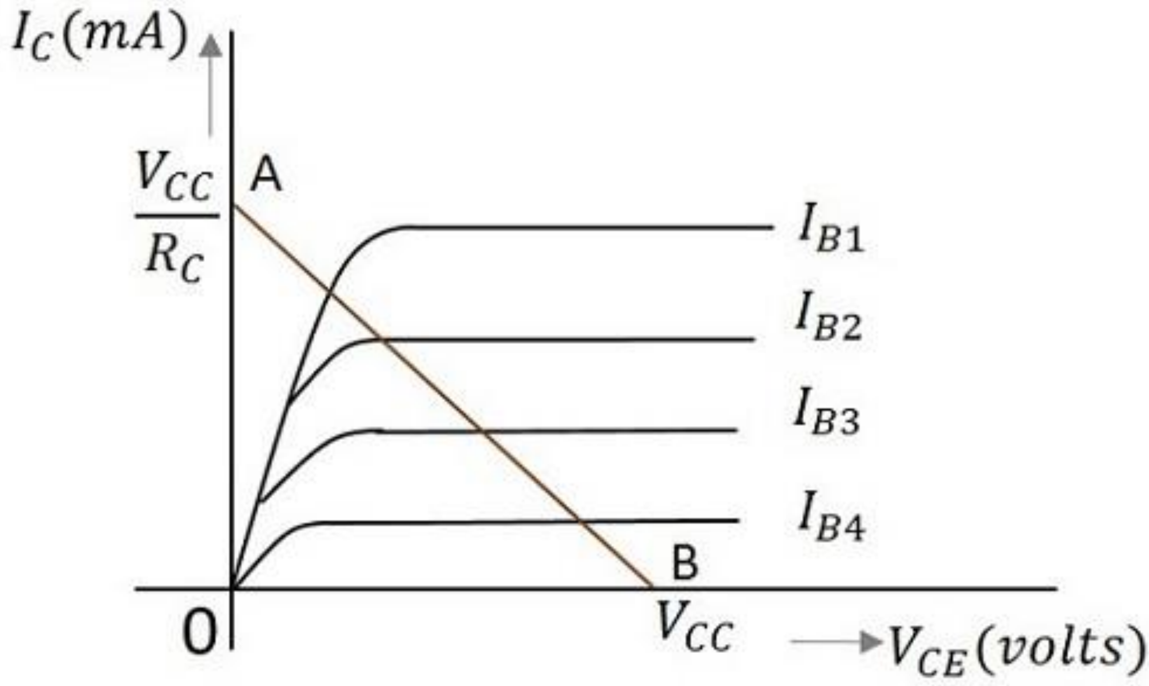
To obtain A

When collector emitter voltage $V_{CE} = 0$, the collector current is maximum and is equal to V_{CC}/R_C. This gives the maximum value of V_{CE}. This is shown as

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

$$0 = V_{CC} - I_C R_C$$

$$I_C = \frac{V_{CC}}{R_C}$$



This gives the point A ($OA = V_{CC}/R_C$) on collector current axis, shown in the above figure.

- To obtain B
- When the collector current $I_C = 0$, then collector emitter voltage is maximum and will be equal to the V_{CC}. This gives the maximum value of I_C. This is shown as

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

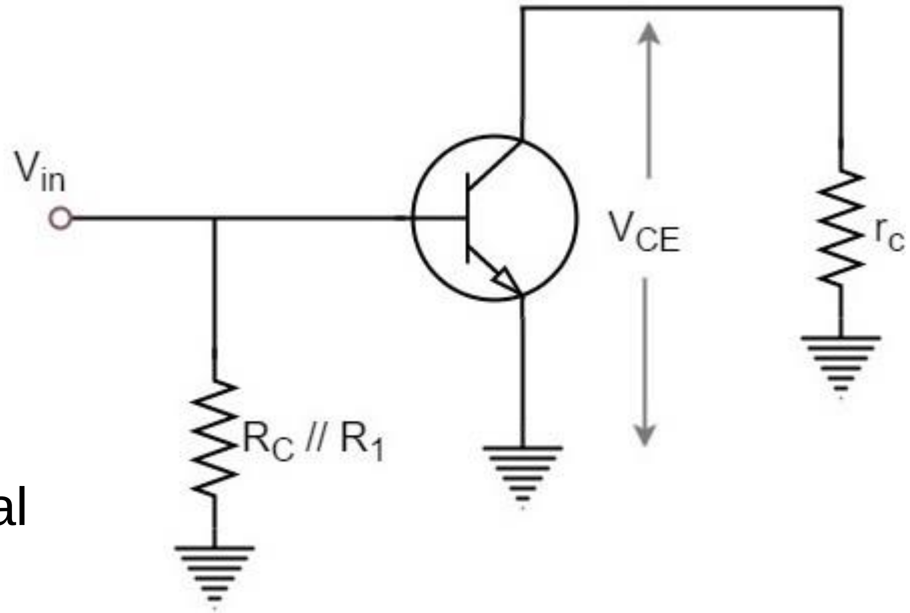
$$V_{CE} = V_{CC}, \ \text{since } I_C = 0$$

This gives the point B, which means (OB = V_{CC}) on the collector emitter voltage axis shown in the above figure.

Hence we got both the saturation and cutoff point determined and learnt that the load line is a straight line. So, a DC load line can be drawn.

- AC Load Line

- The DC load line discussed previously, analyzes the variation of collector currents and voltages, when no AC voltage is applied. Whereas the AC load line gives the peak-to-peak voltage, or the maximum possible output swing for a given amplifier.
- We shall consider an AC equivalent circuit of a CE amplifier for our understanding.



From the above figure,

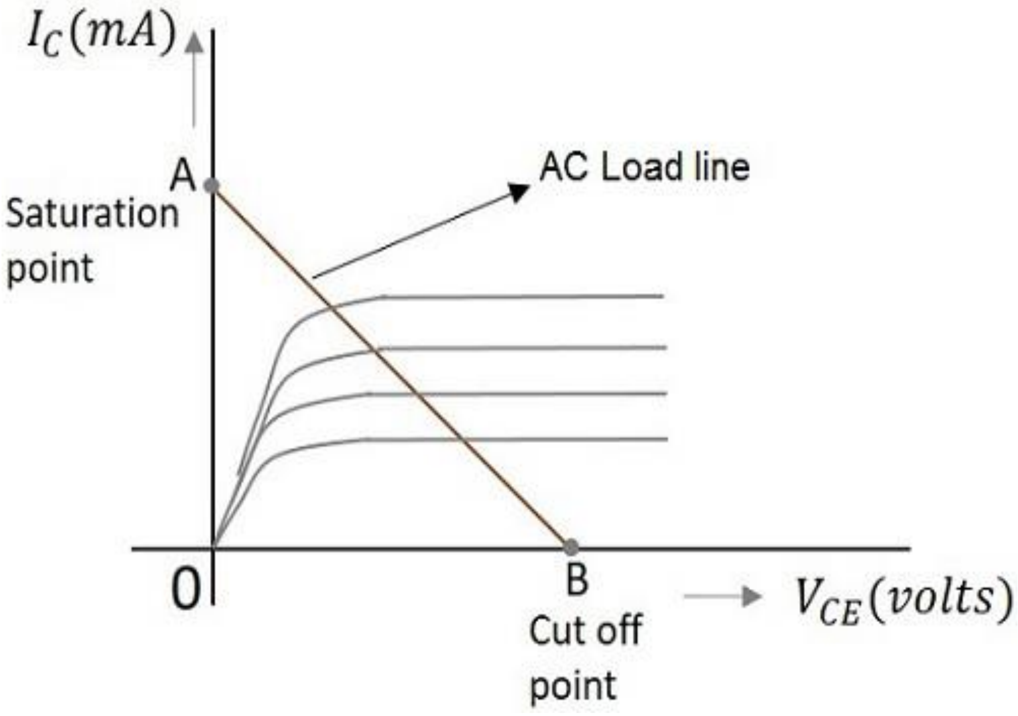
$$V_{CE} = (\mathrm{R}_C // \mathrm{R}_1) \times \mathrm{I}_C$$
$$r_C = R_C // R_1$$

For a transistor to operate as an amplifier, it should stay in active region. The quiescent point is so chosen in such a way that the maximum input signal excursion is symmetrical on both negative and positive half cycles.

Hence, $V_{max} = V_{CEQ}$ and $V_{min} = -V_{CEQ}$

Where V_{CEQ} is the emitter-collector voltage at quiescent point

- The following graph represents the AC load line which is drawn between saturation and cut off points.



From the graph above, the current IC at the saturation point is

$$I_{C(sat)} = I_{CQ} + (V_{CEQ}/r_C)$$

The voltage V_{CE} at the cutoff point is

$$V_{CE(off)} = V_{CEQ} + I_{CQ} r_C$$

Hence the maximum current for that corresponding $V_{CEQ} = V_{CEQ} / (R_C // R_1)$ is

$$I_{CQ} = I_{CQ} * (R_C//R_1)$$

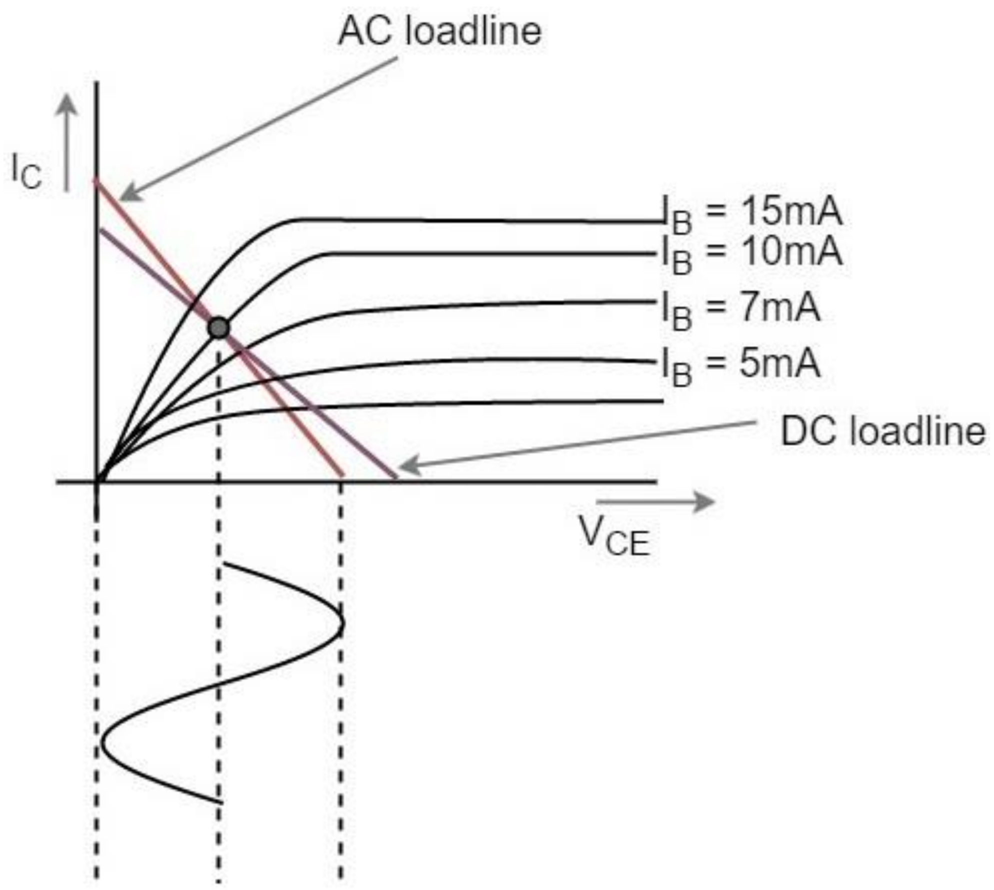
Hence by adding quiescent currents the end points of AC load line are

$$I_{C(sat)} = I_{CQ} + V_{CEQ}/(R_C//R_1)$$

$$V_{CE(off)} = V_{CEQ} + I_{CQ} * (R_C//R_1)$$

- AC and DC Load Line
- When AC and DC Load lines are represented in a graph, it can be understood that they are not identical. Both of these lines intersect at the **Q-point** or **quiescent point**. The endpoints of AC load line are saturation and cut off points. This is understood from the figure below.

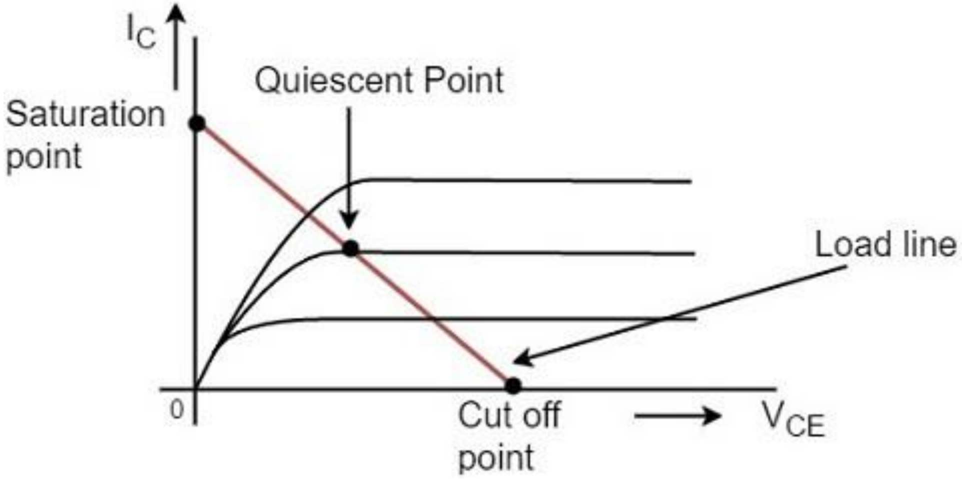
From the above figure, it is understood that the quiescent point (the dark dot) is obtained when the value of base current I_B is 10mA. This is the point where both the AC and DC load lines intersect.



Operating Point

- When a line is drawn joining the saturation and cut off points, such a line can be called as **Load line**. This line, when drawn over the output characteristic curve, makes contact at a point called as **Operating point**.
- This operating point is also called as **quiescent point** or simply **Q-point**. There can be many such intersecting points, but the Q-point is selected in such a way that irrespective of AC signal swing, the transistor remains in the active region.
- The following graph shows how to represent the operating point.

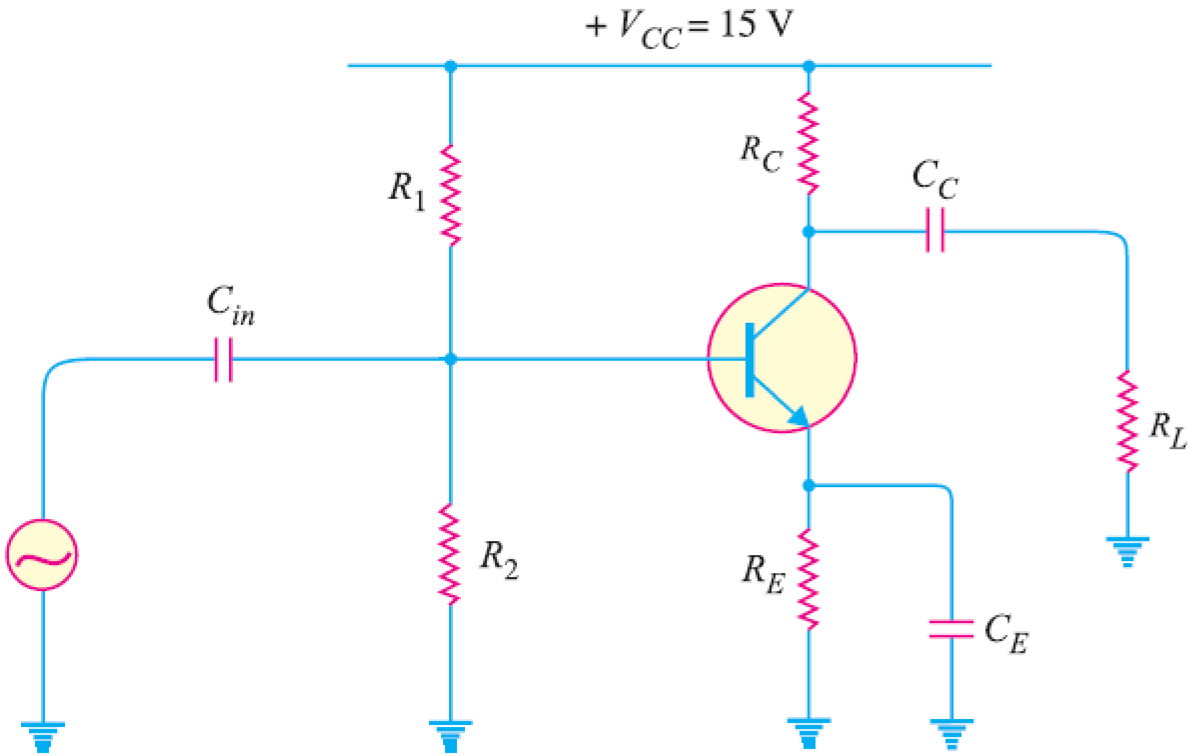
The operating point should not get disturbed as it should remain stable to achieve faithful amplification. Hence the quiescent point or Q-point is the value where the Faithful Amplification is achieved.



The process of increasing the signal strength is called as **Amplification**. This amplification when done without any loss in the components of the signal, is called as **Faithful amplification**.
Faithful amplification is the process of obtaining complete portions of input signal by increasing the signal strength. This is done when AC signal is applied at its input.

Example

- *For the transistor amplifier shown in Figure below, R_1 = 10 kΩ, R_2 = 5 kΩ, R_C =1 kΩ, R_E = 2 kΩ and R_L = 1 kΩ.(i) Draw d.c. load line (ii) Determine the operating point (iii) Draw a.c. load line. Assume VBE = 0.7 V.*



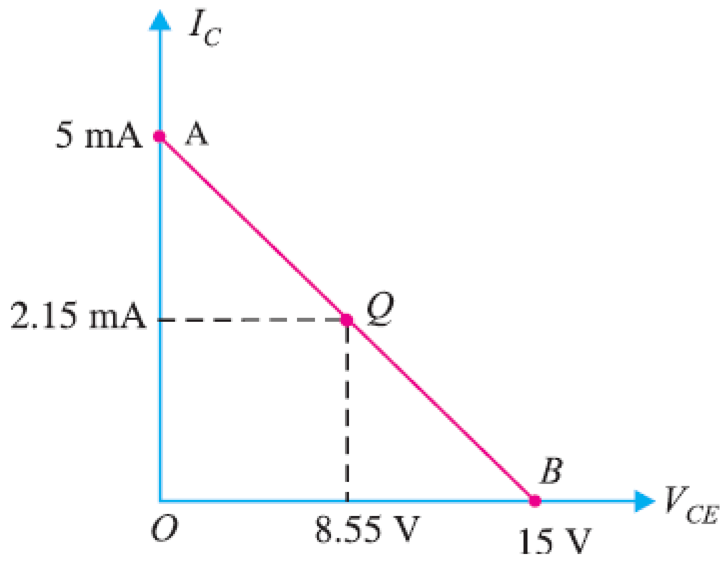
- <u>SOLUTION</u>
- (i) d.c. load line : To draw d.c. load line, we require two end points *viz* maximum V_{CE} point and maximum I_C point.

$$V_{CE} = V_{CC} - I_C\,(R_C + R_E) \qquad (1)$$

- The value of V_{CE} will be maximum when $I_C = 0$. Therefore, by putting $I_C = 0$ in equ. (*i*), we get, Max. $V_{CE} = V_{CC}$

$$\text{Maximum } I_C = \frac{V_{CC}}{R_C + R_E} = \frac{15\,V}{(1+2)\,\text{k}\Omega} = 5\text{ mA}$$

This locates the point *A* (*OA* = 5 mA) of the d.c. load line. Figure below (*i*) shows the d.c. load line *AB*.



(*ii*) Operating point Q. The voltage across R_2 (= 5 kΩ) is *5 V *i.e.* $V_2 = 5$ V.

$$\text{Now} \quad V_2 = V_{BE} + I_E R_E$$

$$\therefore \quad I_E = \frac{V_2 - V_{BE}}{R_E} = \frac{(5 - 0.7)\,V}{2\text{ k}\Omega} = 2.15 \text{ mA}$$

$$\therefore \quad I_C = I_E = 2.15 \text{ mA}$$

$$\text{Now} \quad V_{CE} = V_{CC} - I_C(R_C + R_E) = 15 - 2.15 \text{ mA} \times 3 \text{ k}\Omega$$

$$= 8.55 \text{ V}$$

∴ Operating point *Q* is **8.55 V, 2.15 mA.** This is shown on the d.c. load line.

(iii) a.c. load line. To draw a.c. load line, we require two end points *viz.* maximum collector-emitter voltage point and maximum collector current point when signal is applied.

$$\text{a.c. load, } R_{AC} = R_C \parallel R_L = \frac{1\times1}{1+1} = 0.5\ \text{k}\Omega$$

∴ Maximum collector-emitter voltage

$$= V_{CE} + I_C R_{AC} \qquad \text{[See example 10.4]}$$

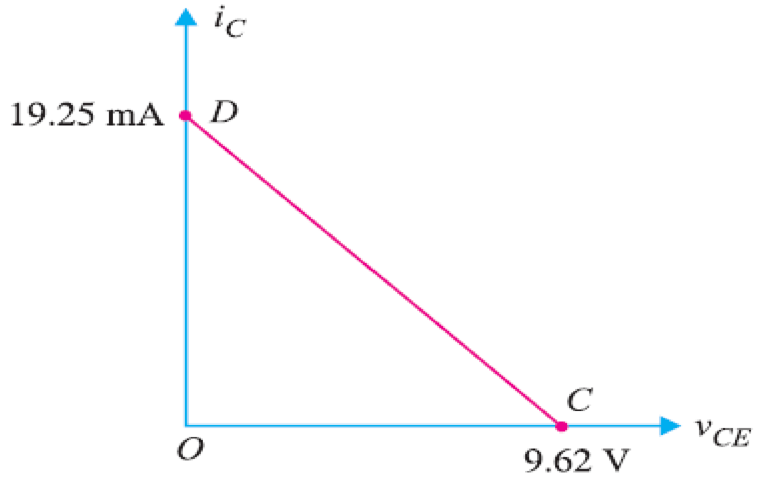
$$= 8.55 + 2.15\ \text{mA} \times 0.5\ \text{k}\Omega = 9.62\ \text{volts}$$

This locates the point C ($OC = 9.62$ V) on the v_{CE} axis.

$$\text{Maximum collector current} = I_C + V_{CE}/R_{AC}$$

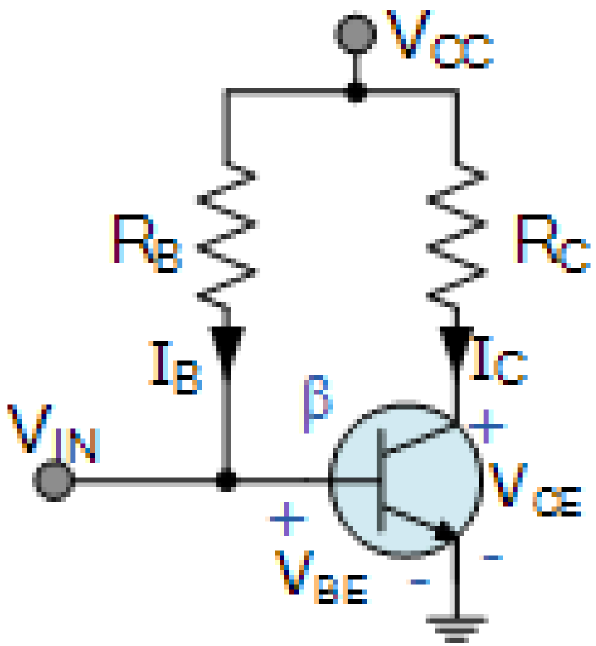
$$= 2.15 + (8.55\ \text{V}/0.5\ \text{k}\Omega) = 19.25\ \text{mA}$$

This locates the point *D* (*OD* = 19.25mA) on the i_C axis. By joining points *C* and *D*, a.c. load line *CD* is constructed



Transistor Biasing

- Transistor Biasing is the process of setting a transistors DC operating voltage or current conditions to the correct level so that any AC input signal can be amplified correctly by the transistor. the most commonly used methods of obtaining transistor biasing from one source of supply (*i.e.* V_{CC}) : **(*i*)** Base resistor method **(*ii*)** Emitter bias method **(*iii*)** Biasing with collector-feedback resistor **(*iv*)** Voltage-divider bias



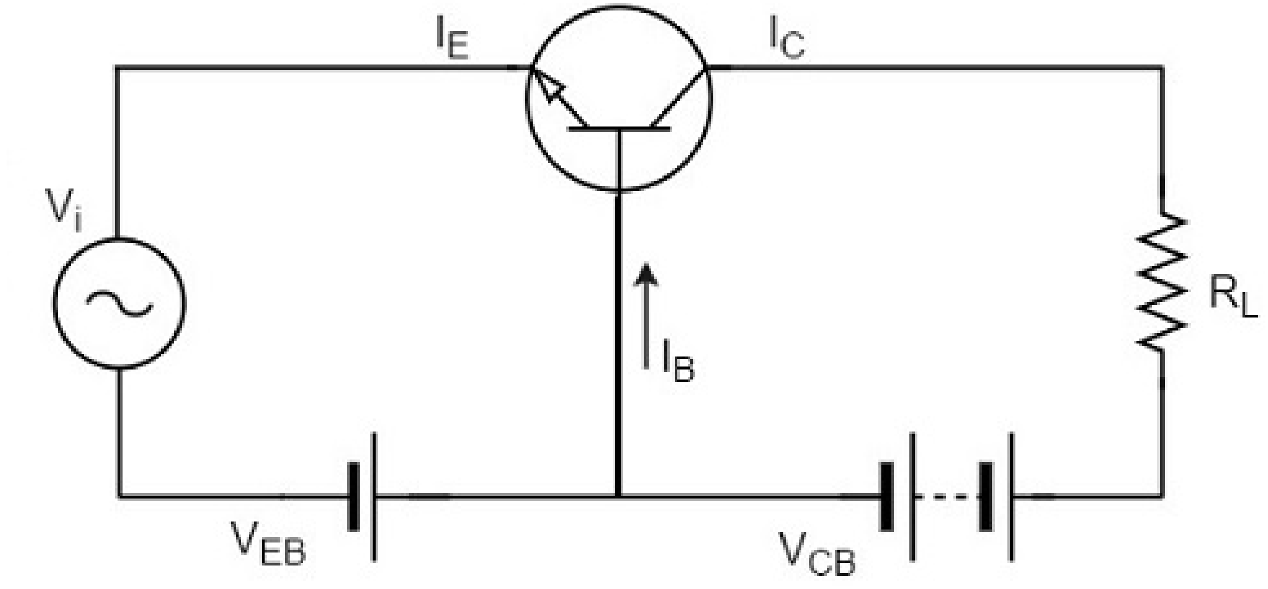
The steady state operation of a bipolar transistor depends a great deal on its base current, collector voltage, and collector current values. Therefore, if the transistor is to operate correctly as a linear amplifier, it must be properly biased around its operating point as improper transistor biasing will result in a distorted output.

The correct biasing point for a bipolar transistor, either NPN or PNP, generally lies somewhere between the two extremes of operation with respect to it being either “fully-ON” or “fully-OFF” along its DC load line. This central operating point is called the “Quiescent Operating Point”, or **Q-point** for short.

Transistor Biasing

- If a signal of very small voltage is given to the input of BJT, it cannot be amplified. Because, for a BJT, to amplify a signal, two conditions have to be met.
- The input voltage should exceed **cut-in voltage** for the transistor to be **ON**.
- The BJT should be in the **active region**, to be operated as an **amplifier**.
- If appropriate DC voltages and currents are given through BJT by external sources, so that BJT operates in active region and superimpose the AC signals to be amplified, then this problem can be avoided. The given DC voltage and currents are so chosen that the transistor remains in active region for entire input AC cycle. Hence DC biasing is needed.

- The below figure shows a transistor amplifier that is provided with DC biasing on both input and output circuits.



For a transistor to be operated as a faithful amplifier, the operating point should be stabilized. Let us have a look at the factors that affect the stabilization of operating point.

- Factors affecting the operating point
- The main factor that affect the operating point is the temperature. The operating point shifts due to change in temperature.
- As temperature increases, the values of I_{CE}, β, V_{BE} gets affected.
- I_{CBO} gets doubled (for every 10^{o} rise)
- V_{BE} decreases by 2.5mv (for every 1^{o} rise)
- So the main problem which affects the operating point is temperature. Hence operating point should be made independent of the temperature so as to achieve stability. To achieve this, biasing circuits are introduced.

Stabilization

- The process of making the operating point independent of temperature changes or variations in transistor parameters is known as **Stabilization**.
- Once the stabilization is achieved, the values of I_C and V_{CE} become independent of temperature variations or replacement of transistor. A good biasing circuit helps in the stabilization of operating point.
- <u>Need for Stabilization</u>
- Stabilization of the operating point has to be achieved due to the following reasons.
- Temperature dependence of I_C
- Individual variations
- Thermal runaway

Stability Factor

- It is understood that I_C should be kept constant in spite of variations of I_{CBO} or I_{CO}. The extent to which a biasing circuit is successful in maintaining this is measured by **Stability factor**. It denoted by **S**.
- By definition, the rate of change of collector current I_C with respect to the collector leakage current I_{CO} at constant β and I_B is called **Stability factor**.

$$S = \frac{dI_C}{dI_{CO}} \quad \text{at constant } I_B \text{ and } \beta$$

Hence we can understand that any change in collector leakage current changes the collector current to a great extent. The stability factor should be as low as possible so that the collector current doesn't get affected. S=1 is the ideal value.

The general expression of stability factor for a CE configuration can be obtained as under.

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

Differentiating above expression with respect to I_C, we get

$$1 = \beta \frac{dI_B}{dI_C} + (\beta+1)\frac{dI_{CO}}{dI_C}$$

Since $\frac{dI_{CO}}{dI_C} = \frac{1}{S}$

$$1 = \beta \frac{dI_B}{dI_C} + \frac{(\beta+1)}{S}$$

$$S = \frac{\beta+1}{1-\beta\left(\frac{dI_B}{dI_C}\right)}$$

Hence the stability factor S depends on β, I_B and I_C.

- The commonly used methods of transistor biasing are

- Base Resistor method
- Collector to Base bias
- Biasing with Collector feedback resistor
- Voltage-divider bias
- All of these methods have the same basic principle of obtaining the required value of I_B and I_C from V_{CC} in the zero signal conditions.

Base Resistor Method

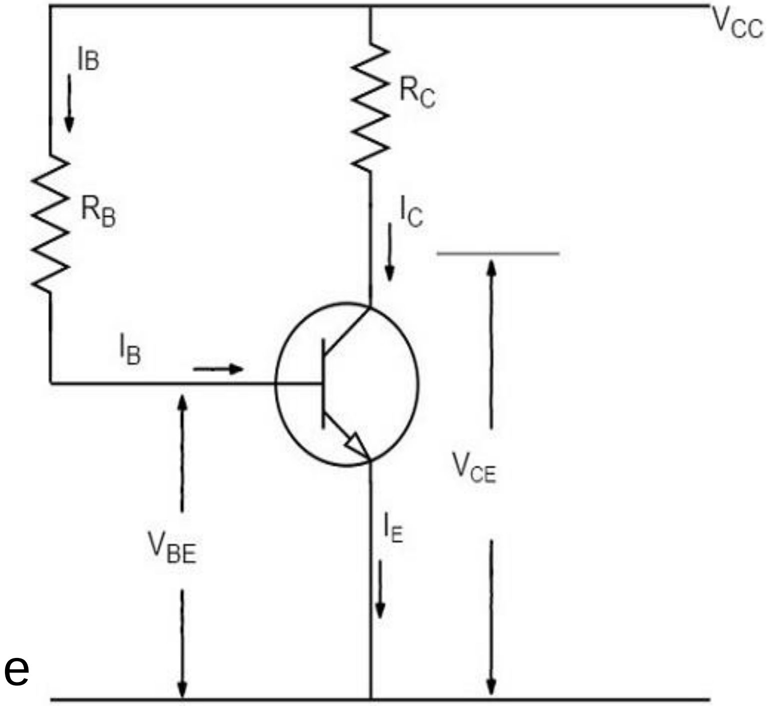
- In this method, a resistor R_B of high resistance is connected in base, as the name implies. The required zero signal base current is provided by V_{CC} which flows through R_B. The base emitter junction is forward biased, as base is positive with respect to emitter.
- The required value of zero signal base current and hence the collector current (as $I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor R_B. Hence the value of R_B is to be known. The figure below shows how a base resistor method of biasing circuit looks like.
- Let I_C be the required zero signal collector current.

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

- Considering the closed circuit from V_{CC}, base, emitter and ground,

while applying the Kirchhoff's voltage law, we get, $$V_{CC} = I_B R_B + V_{BE}$$

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



Since V_{BE} is generally quite small as compared to V_{CC}, the former can be neglected with little error. Then, $$R_B = \frac{V_{CC}}{I_B}$$

We know that V_{CC} is a fixed known quantity and I_B is chosen at some suitable value. As R_B can be found directly, this method is called as **fixed bias method**.

- The Stability factor for Base Resistor Method

$$S = \frac{\beta + 1}{1 - \beta\left(\frac{dI_B}{dI_C}\right)}$$

In fixed-bias method of biasing, I_B is independent of I_C so that, $\frac{dI_B}{dI_C} = 0$

Substituting the above value in the previous equation, Stability factor, $S=\beta+1$

Thus the stability factor in a fixed bias is (β+1) which means that I_C changes (β+1) times as much as any change in I_{CO}. For instance, if β = 100, then $S = 101$ which means that I_C increases 101 times faster than I_{CO}. Due to the large value of S in a fixed bias, it has poor thermal stability.

Advantages

- The circuit is simple.
- Only one resistor R_B is required.
- Biasing conditions are set easily.
- No loading effect as no resistor is present at base-emitter junction.

Disadvantages

- The stabilization is poor as heat development can't be stopped.
- The stability factor is very high. So, there are strong chances of thermal run away.

Hence, this method is rarely employed.

BASE BIAS WITH EMITTER FEEDBACK

$$-I_BR_B - V_{BE} - I_ER_E + V_{CC} = 0$$

$$V_{CC} = I_BR_B + V_{BE} + I_ER_E$$

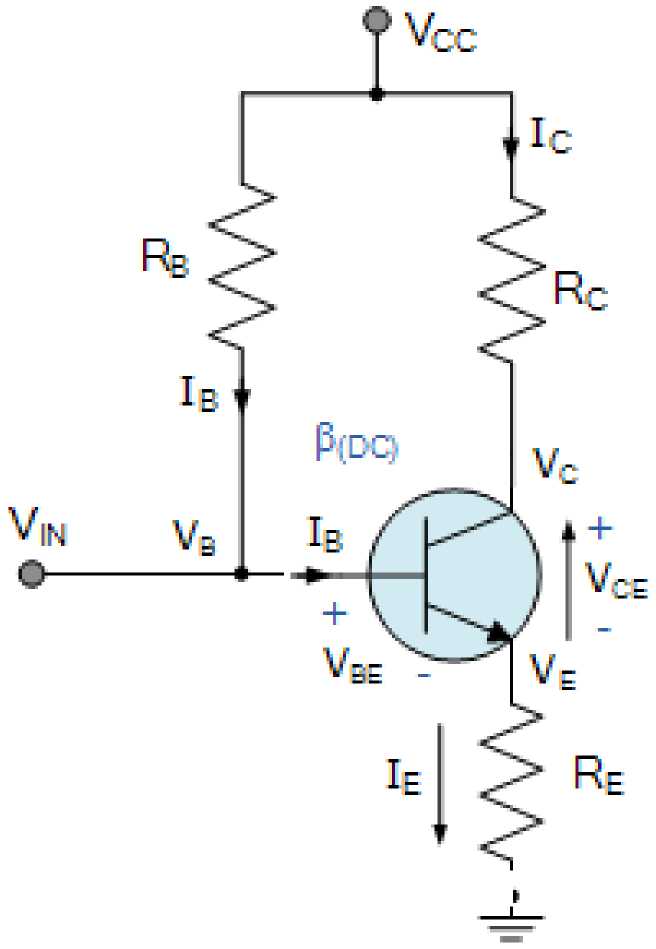
Where $I_B = I_C/\beta$ and $I_E = I_C$

$$I_C = V_{CC} - V_{BE}/ R_E + R_B/\beta$$

collector to ground voltage $V_C = V_{CC} - I_CR_L$

emitter to ground voltage $V_E = I_ER_E = I_CR_E$

$$V_{CE} = V_C - V_E$$



- Collector to Base Bias
- The collector to base bias circuit is same as base bias circuit except that the base resistor R_B is returned to collector, rather than to V_{CC} supply as shown in the figure below.

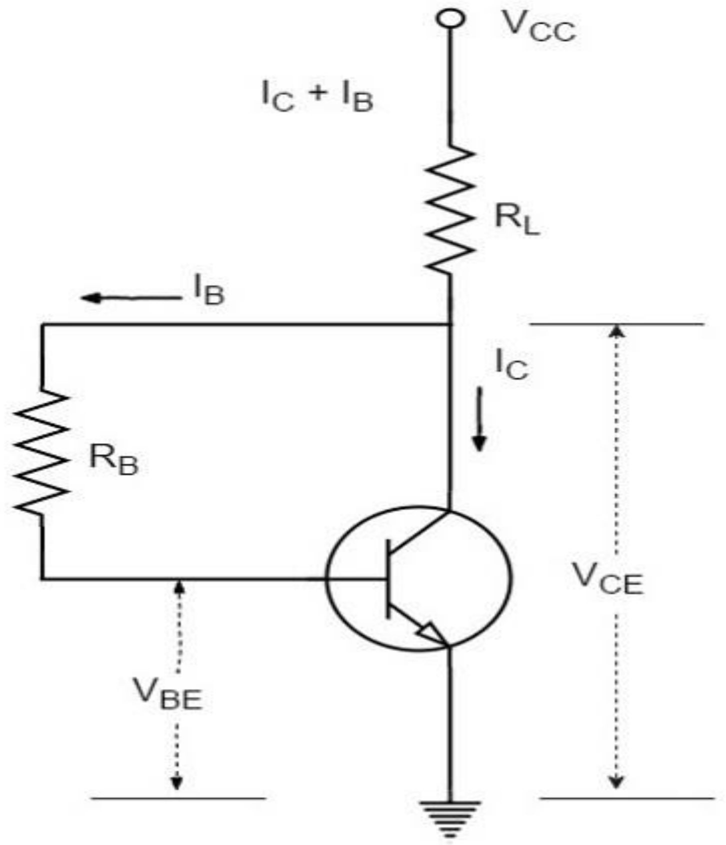
This circuit helps in improving the stability considerably. If the value of I_C increases, the voltage across R_L increases and hence the V_{CE} also increases. This in turn reduces the base current I_B. This action somewhat compensates the original increase.

The required value of R_B needed to give the zero signal collector current I_C can be calculated as follows.

Voltage drop across R_L will be $$R_L = (I_C + I_B)R_L \cong I_C R_L$$

From the figure, $$I_C R_L + I_B R_B + V_{BE} = V_{CC}$$

$$I_B R_B = V_{CC} - V_{BE} - I_C R_L$$



$$R_B = \frac{V_{CC} - V_{BE} - I_C R_L}{I_B} \qquad \beta = \frac{I_C}{I_B} \qquad R_B = \frac{(V_{CC} - V_{BE} - I_C R_L)\beta}{I_C}$$

Applying KVL we have $(I_B + I_C)R_L + I_B R_B + V_{BE} = V_{CC}$ Or $I_B(R_L + R_B) + I_C R_L + V_{BE} = V_{CC}$

$$I_B = \frac{V_{CC} - V_{BE} - I_C R_L}{R_L + R_B}$$

Since V_{BE} is almost independent of collector current, we get

$$\frac{dI_B}{dI_C} = -\frac{R_L}{R_L + R_B}$$

We know that

$$S = \frac{1+\beta}{1-\beta(dI_B/dI_C)}$$

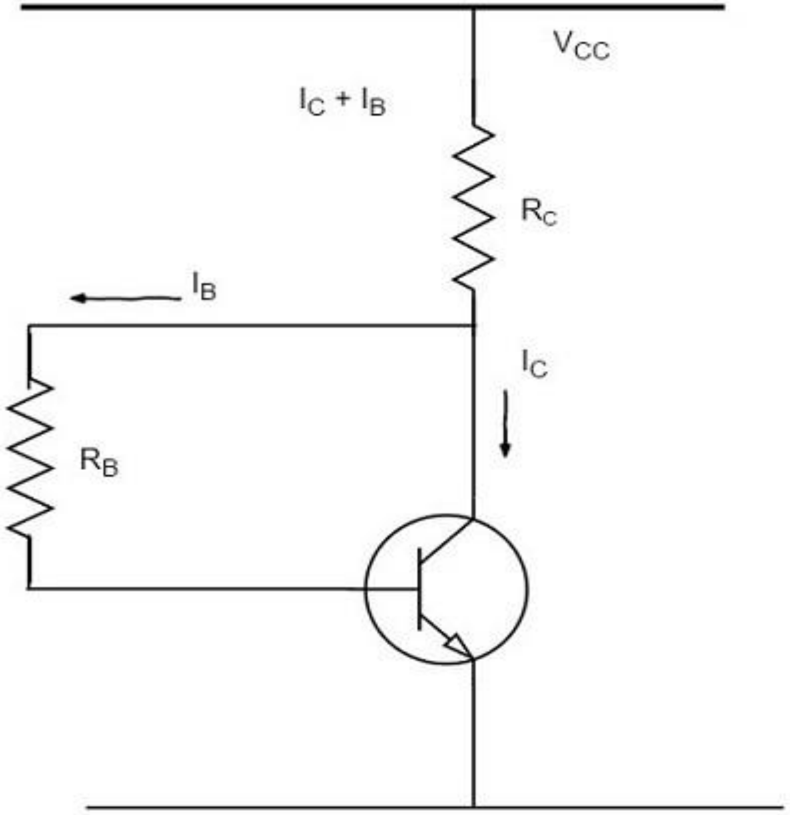
Therefore

$$S = \frac{1+\beta}{1+\beta\left(\frac{R_L}{R_L+R_B}\right)}$$

This value is smaller than (1+β) which is obtained for fixed bias circuit. Thus there is an improvement in the stability.

This circuit provides a negative feedback which reduces the gain of the amplifier. So the increased stability of the collector to base bias circuit is obtained at the cost of AC voltage gain.

- <u>Biasing with Collector Feedback resistor</u>
- In this method, the base resistor R_B has its one end connected to base and the other to the collector as its name implies. In this circuit, the zero signal base current is determined by V_{CB} but not by V_{CC}.
- It is clear that V_{CB} forward biases the base-emitter junction and hence base current I_B flows through R_B. This causes the zero signal collector current to flow in the circuit. The below figure shows the biasing with collector feedback resistor circuit.



The required value of R_B needed to give the zero signal current I_C can be determined as follows.

$$V_{CC} = I_C R_C + I_B R_B + V_{BE}$$

$$R_B = \frac{V_{CC} - V_{BE} - I_C R_C}{I_B} = \frac{V_{CC} - V_{BE} - \beta I_B R_C}{I_B}$$

$I_C = \beta I_B$ **Alternatively,** $V_{CE} = V_{BE} + V_{CB}$ **Or** $V_{CB} = V_{CE} - V_{BE}$

Since $$R_B = \frac{V_{CB}}{I_B} = \frac{V_{CE} - V_{BE}}{I_B}$$

- Mathematically, Stability factor, $S < (\beta + 1)$
- Therefore, this method provides better thermal stability than the fixed bias.
- The Q-point values for the circuit are shown as $I_C = \dfrac{V_{CC} - V_{BE}}{R_B/\beta + R_C}$

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

Advantages

•The circuit is simple as it needs only one resistor.

•This circuit provides some stabilization, for lesser changes.

Disadvantages

•The circuit doesn’t provide good stabilization.

•The circuit provides negative feedback.

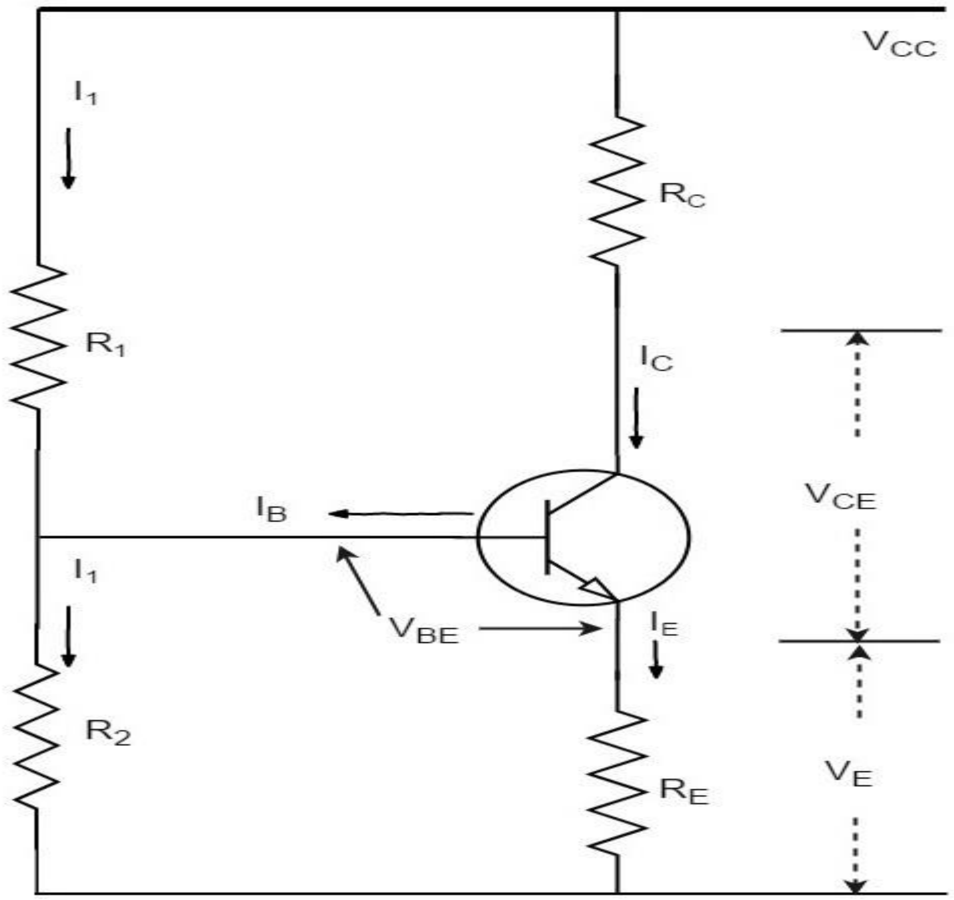
- <u>Voltage Divider Bias Method</u>
- Among all the methods of providing biasing and stabilization, the **voltage divider bias method** is the most prominent one. Here, two resistors R_1 and R_2 are employed, which are connected to V_{CC} and provide biasing. The resistor R_E employed in the emitter provides stabilization.
- The name voltage divider comes from the voltage divider formed by R_1 and R_2. The voltage drop across R_2 forward biases the base-emitter junction. This causes the base current and hence collector current flow in the zero signal conditions. The figure below shows the circuit of voltage divider bias method.

Suppose that the current flowing through resistance R_1 is I_1. As base current I_B is very small, therefore, it can be assumed with reasonable accuracy that current flowing through R_2 is also I_1.
Now let us try to derive the expressions for collector current and collector voltage.
Collector Current, I_C
From the circuit, it is evident that,

$$I_1 = \frac{V_{CC}}{R_1 + R_2}$$

Therefore, the voltage across resistance R_2 is

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



- Applying Kirchhoff's voltage law to the base circuit,

$$V_2 = V_{BE} + V_E$$

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

$$I_E = \frac{V_2 - V_{BE}}{R_E} \quad \text{since } I_E \approx I_C$$

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

From the above expression, it is evident that I_C doesn't depend upon β. V_{BE} is very small that I_C doesn't get affected by V_{BE} at all. Thus I_C in this circuit is almost independent of transistor parameters and hence good stabilization is achieved.

- Collector-Emitter Voltage, V_{CE}
- Applying Kirchhoff's voltage law to the collector side,

$$V_{CC} = I_C R_C + V_{CE} + I_E R_E \qquad \text{since } I_E \approx I_C$$

$$= I_C R_C + V_{CE} + I_C R_E = I_C \left(R_C + R_E \right) + V_{CE}$$

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

R_E *provides excellent stabilization in this circuit.*

$$V_2 = V_{BE} + I_C R_E$$

Suppose there is a rise in temperature, then the collector current I_C decreases, which causes the voltage drop across R_E to increase. As the voltage drop across R_2 is V_2, which is independent of I_C, the value of V_{BE} decreases. The reduced value of I_B tends to restore I_C to the original value.

- Stability Factor
- The equation for **Stability factor** of this circuit is obtained as

$$\text{Stability Factor} = \quad S = \frac{(\beta+1)(R_0+R_3)}{R_0+R_E+\beta R_E} \qquad = (\beta+1) \times \frac{1+\frac{R_0}{R_E}}{\beta+1+\frac{R_0}{R_E}}$$

Where,

$$R_0 = \frac{R_1 R_2}{R_1 + R_2}$$

If the ratio R_0/R_E is very small, then R_0/R_E can be neglected as compared to 1 and the stability factor becomes

$$\text{Stability Factor} = \quad S = (\beta+1) \times \frac{1}{\beta+1} = 1$$

This is the smallest possible value of S and leads to the maximum possible thermal stability.

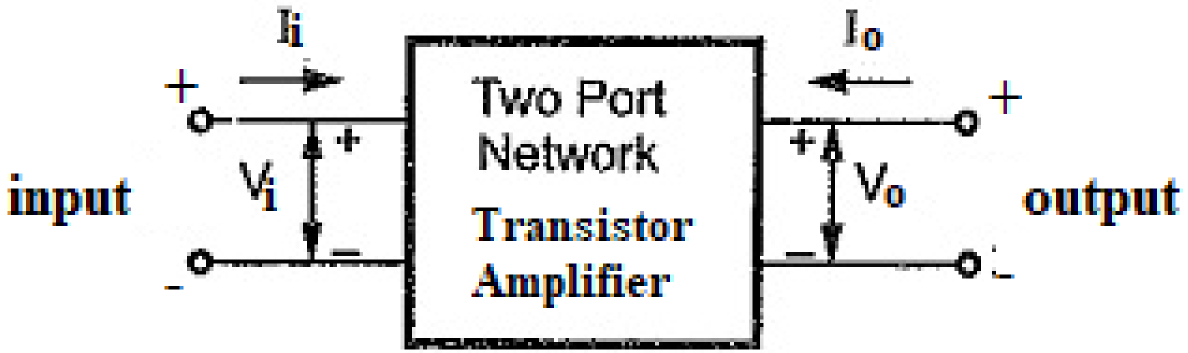
BJT H- PARAMETERS OF A TRANSISTOR

- BJT AMPLIFIERS
- BJT h-parameter Model
- Analysis of transistor amplifier Using h-parameter model
- CB, CE and CC amplifiers
- Comparison of CB, CE and CC configurations
- Simplified h-parameter model

BJT H- PARAMETERS OF A TRANSISTOR

H-Parameter representation of a Transistor

- A transistor can be treated as a two-port network



here
I_i = Input current to the amplifier
V_i = Input voltage to the amplifier
I_o = output current of the amplifier
V_o = output voltage of the amplifier

Transistor is a current operated/controlled device.
Here input voltage V_i and output current I_o are the dependent variables.
input current I_i and output voltage V_o are independent variables .

$$V_i = f(I_i, V_o)$$
$$I_o = f(I_i, V_o)$$

This can be written in the equation form as follows

$$V_i = h_{11} I_i + h_{12} V_o$$
$$I_o = h_{21} I_i + h_{22} V_o$$

- the above equation can also be written using alphabetical notations

$$V_i = h_{11} I_i + h_{12} V_o = h_i I_i + h_r V_o$$
$$I_o = h_{21} I_i + h_{22} V_o = h_f I_i + h_o V_o$$

Definitions of h-parameter:
The parameters in the above equation are defined as follows:

$$h_{11} = \frac{V_i}{I_i} \bigg|_{V_o = 0} \qquad h_{12} = \frac{V_i}{V_o} \bigg|_{I_i = 0}$$

$$h_{21} = \frac{I_o}{I_i} \bigg|_{V_o = 0} \qquad h_{22} = \frac{I_o}{V_o} \bigg|_{I_i = 0}$$

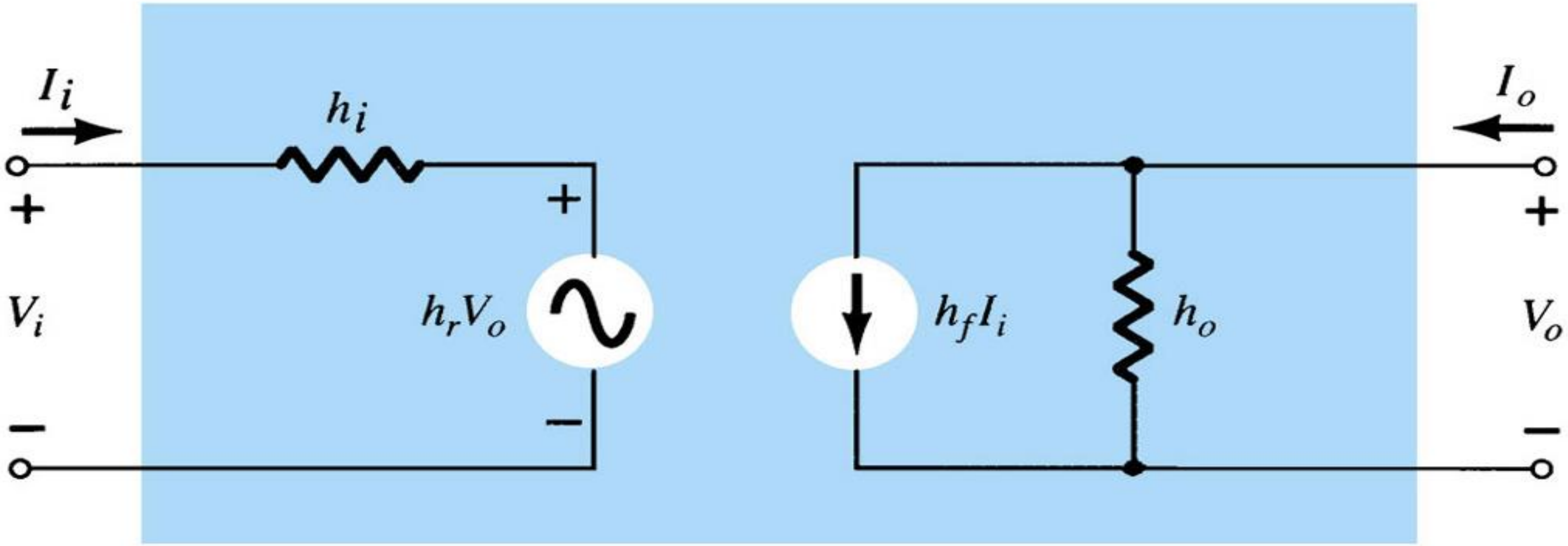
$h_{11} = h_i$ = Input Resistance with output short circuited
$h_{12} = h_r$ = Reverse Transfer Voltage Ratio with input open circuited
$h_{21} = h_f$ = Forward Transfer Current Ratio/gain with output short circuited
$h_{22} = h_o$ = Output Admittance with input open circuited

- Based on the definition of h-parameter the mathematical model for two port networks known as h-parameter model can be developed.
- The two equations of a transistor is given by

$$V_i = h_i I_i + h_r V_o$$

$$I_o = h_f I_i + h_o V_o$$

- Based on above two equations of the equivalent circuit the hybrid model for transistor can be drawn



- **<u>Advantages of h-parameter:</u>**
- 1. Easy to measure
- 2. Convenient to use in circuit analysis and design
- 3. Real numbers at audio frequencies
- 4. Can be obtained from the transistor static characteristics curves
- 5. Most of the transistor manufacturers specify the h-parameter
- 6. Easily convertible from one configuration to another

Disadvantages of h-parameter

The h-parameter, or hybrid parameter, model is a small-signal model commonly used to represent the behavior of a transistor in electronic circuits. While the h-parameter model is widely used and provides a valuable simplification for small-signal analysis, it also has certain disadvantages. Despite these disadvantages, the h-parameter model remains a valuable tool for small-signal analysis, especially in amplifier design and other applications where linear behavior predominates.

Here are some of the disadvantages of the h-parameter transistor model:

1. **Limited Frequency Range:** The h-parameter model is primarily suitable for low-frequency or small-signal analysis. It becomes less accurate at higher frequencies, where other transistor models such as the y-parameter or s-parameter models may be more appropriate.

2. **Temperature Sensitivity:** The h-parameters are temperature-dependent, and variations in temperature can affect the accuracy of the model. This sensitivity to temperature changes may pose challenges in environments with temperature fluctuations.

3. **Limited for Nonlinear Analysis:** The h-parameter model is designed for linear or small-signal analysis. It is not well-suited for accurately predicting the behavior of transistors under large-signal or nonlinear conditions.

4. **Dependence on Biasing Conditions:** The h-parameters are dependent on the biasing conditions of the transistor. Changes in the operating point can impact the values of h-parameters, making it necessary to recompute or adjust the model for different biasing points.

Disadvantages of h-parameter

5. Limited for Power Amplifier Design: The h-parameter model is less suitable for designing power amplifiers, where large-signal performance is crucial. Power amplifiers typically require models that can accurately represent nonlinear effects, which the h-parameter model does not capture effectively.

6. Does Not Consider Parasitic Elements: The h-parameter model simplifies the transistor by not considering parasitic elements such as capacitances and inductances associated with the transistor's structure. In high-frequency applications, these parasitic elements become significant and need to be considered for accurate modeling.

7. Not Ideal for High-Frequency Applications: At high frequencies, the h-parameter model may not accurately represent the transistor's behavior. For RF (radio frequency) and microwave applications, other models like the y-parameter or s-parameter models are more appropriate.

8. Not Suitable for Large-Signal Transient Analysis: The h-parameter model is not well-suited for analyzing the transient response of a transistor under large-signal conditions. It lacks the necessary details to predict the dynamic behavior of the transistor during large-signal transitions.

Hybrid Equivalent of Transistor

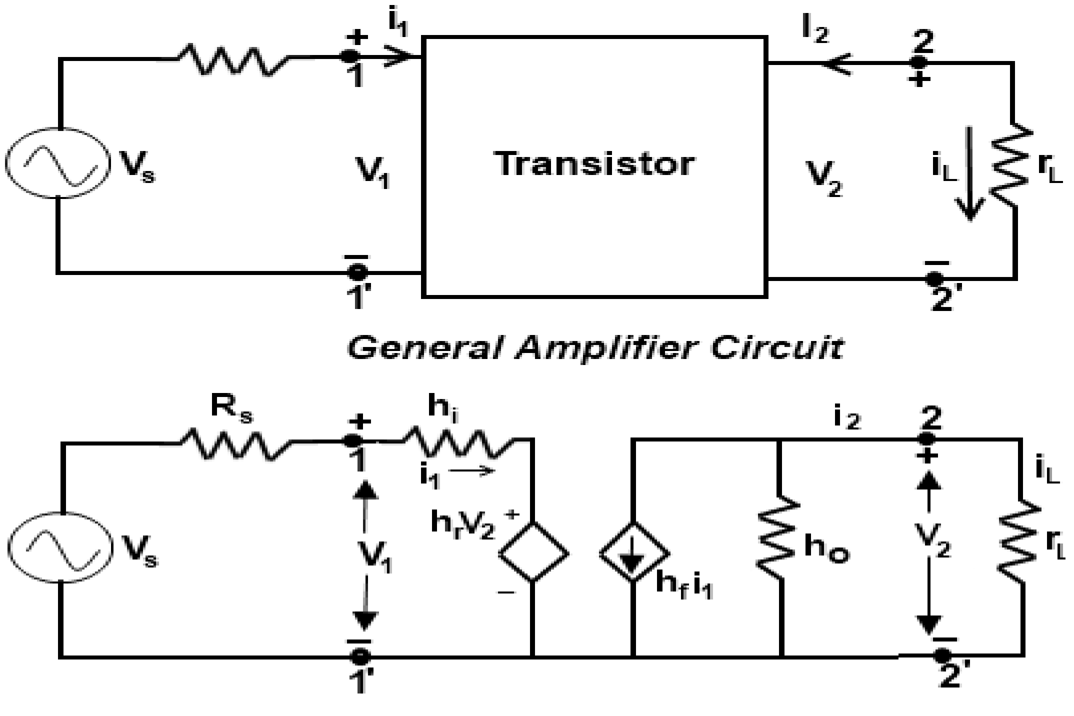
Figure(a) shows a transistor amplifier circuit. Such circuit can be connected in any one of the three configuration called common emitter, common base or common collector to a voltage source (V_s) and load resistance (r_i). The voltages source has an internal resistance (R_s) as shown in figure. The load resistance (r_L)) is the effective or A.C load resistance seen by the transistor at its output. Figure (a) shows the hybrid formulas for input resistance, output resistance, current gain and voltage gain of a transistor.

$V_i = h_1.i_1 + h_r.V_2$ ----------------(1)

$i_2 = h_f.i_1 + h_o.V_2$ -----------------(2)

The voltage drop across load resistance (r_L) is equal to the voltage across the output terminals of a transistor.

$V_2 = i_L.r_L = -i_2.r_L$ (Since $i_2 = -i_L$)



General Amplifier Circuit

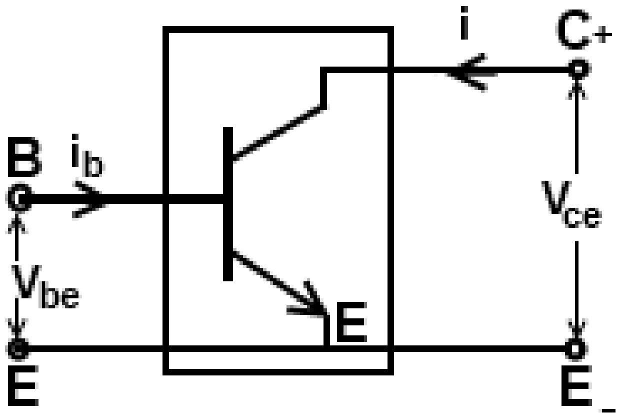
Hybrid equivalent circuit

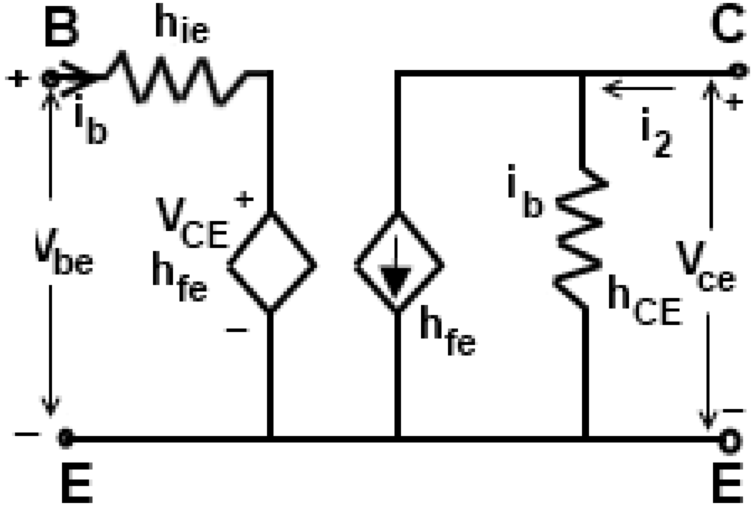
Figure (a)

Hybrid Equivalent For CE Transistor

- The figure shows the transistor connected in common emitter configuration and the figure also shows the hybrid equivalent circuit of such a transistor.
- In common emitter transistor configuration, the input signal is applied between the base and emitter terminals of the transistor and output appears between the collector and emitter terminals. The variables i_b, v_b, v_c and i_c represents total instantaneous currents and voltages. The input voltage (V_{be}) and the output current (i_c) are given by the following equations:

$$\mathbf{V_{be} = h_{ie}.i_b + h_{re}.V_c}$$
$$\mathbf{i_e = h_{fe}.i_b + h_{oe}.V_c}$$





Characteristics of Common Emitter Amplifier

- The voltage gain of a common emitter amplifier is medium
- The power gain is high in the common emitter amplifier
- There is a phase relationship of 180 degrees in input and output
- In the common emitter amplifier, the input and output resistors are medium.

Some common applications of the common emitter amplifier:

- **Audio Amplifiers:** Common emitter amplifiers are frequently employed in audio amplifier circuits. They can amplify weak audio signals from sources such as microphones, musical instruments, or electronic devices, providing the necessary gain for driving speakers or headphones.
- **RF Amplifiers:** In radio-frequency (RF) applications, common emitter amplifiers are utilized to amplify signals in the RF range. These amplifiers are crucial in RF communication systems, such as those found in radio receivers and transmitters.
- **Voltage Amplifiers:** Common emitter amplifiers are often used as voltage amplifiers in electronic systems. They can amplify voltage signals while providing a relatively high input impedance and a low output impedance, making them suitable for interfacing with other circuit components.
- **Low-Frequency Signal Amplification:** Applications that involve the amplification of low-frequency signals, such as those in audio and communication systems, commonly use common emitter amplifiers. Their frequency response is well-suited for signals in the audio frequency range.
- **Amplitude Modulation (AM) Systems:** Common emitter amplifiers play a role in amplitude modulation (AM) systems, where they amplify the modulating signal before it modulates the carrier signal. This is a key component in the transmission of information in AM radio broadcasting.

- **Biomedical Instrumentation**: In biomedical instrumentation, common emitter amplifiers are employed for amplifying weak biological signals from sensors or electrodes. They can be used in applications like electrocardiography (ECG) and electromyography (EMG).
- **Signal Conditioning**: Common emitter amplifiers are used for signal conditioning in various applications. They can shape and amplify signals before they are processed by other stages in a circuit or before being fed into an analog-to-digital converter.
- **Temperature and Pressure Sensors**: Common emitter amplifiers can be utilized in sensor applications, such as amplifying signals from temperature or pressure sensors. The amplification allows for better signal detection and processing.
- **Inverting Amplifiers**: The common emitter configuration provides an inverted output signal with respect to the input. This property is useful in applications where an inverted signal is required, such as inverting amplifiers or phase shifters.
- **Laboratory Instrumentation:** Common emitter amplifiers find use in various laboratory instruments where signal amplification is necessary. They can be employed in signal generators, oscilloscopes, and other measurement devices.
- **Tone Control Circuits:** Common emitter amplifiers are integrated into tone control circuits in audio systems, allowing users to adjust bass and treble levels by manipulating the amplification of specific frequency ranges.

Advantages

- The advantages of a common emitter amplifier include the following.
- The common emitter amplifier has a low input impedance and it is an inverting amplifier
- The output impedance of this amplifier is high
- This amplifier has the highest power gain when combined with medium voltage and current gain
- The current gain of the common emitter amplifier is high

Advantages of CE

High Voltage Gain: The common emitter amplifier provides relatively high voltage gain compared to other transistor amplifier configurations. This makes it suitable for applications where signal amplification is a primary requirement.

- **Inverting Configuration:** The output of the common emitter amplifier is 180 degrees out of phase with the input signal, making it an inverting amplifier. This property is advantageous in various applications where phase inversion is needed.
- **Moderate Input and Output Impedances:** The common emitter configuration provides moderate input and output impedances. The input impedance is typically higher than that of the common base configuration, making it suitable for interfacing with various signal sources.
- **Stable DC Biasing:** The common emitter amplifier is relatively stable in terms of DC biasing. Proper biasing can be achieved to ensure the transistor operates in its active region, providing a stable operating point for the amplifier.
- **Ease of Coupling to Other Stages:** The common emitter amplifier is easily coupled to other stages in a circuit. Its moderate input and output impedances facilitate effective interfacing with both preceding and succeeding circuit elements.

6. Wide Frequency Response: The common emitter configuration can provide a relatively wide frequency response, making it suitable for amplifying signals across a broad range of frequencies. This is advantageous in applications such as audio amplification and certain RF applications.

7. Single-Stage Amplification: In many applications, a single common emitter stage may provide sufficient amplification. This can simplify the circuit design and reduce the need for additional amplifier stages.

8.Ease of Biasing for Bipolar Junction Transistor (BJT): Biasing a common emitter amplifier with a BJT is straightforward, and the biasing network can be easily designed to establish the desired operating point for the transistor.

9. Simple to Design and Implement: The common emitter amplifier is relatively simple to design and implement, especially for small-signal applications. This simplicity makes it a preferred choice in educational settings and practical electronics.

10. Suitable for Cascading: The common emitter configuration is suitable for cascading multiple amplifier stages, allowing for increased overall gain while maintaining stability. This makes it adaptable to more complex amplifier designs.

11. Low Output Impedance: The common emitter amplifier typically exhibits a lower output impedance compared to the common collector configuration. This lower output impedance enhances its ability to drive loads efficiently.

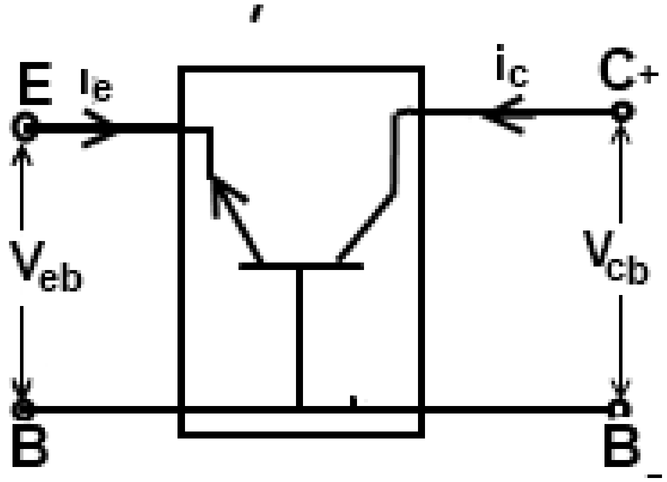
Disadvantages

- The disadvantages of a common emitter amplifier include the following.
- In the high frequencies, the common emitter amplifier does not respond
- The voltage gain of this amplifier is unstable
- The output resistance is very high in these amplifiers
- In these amplifiers, there is a high thermal instability
- High output resistance

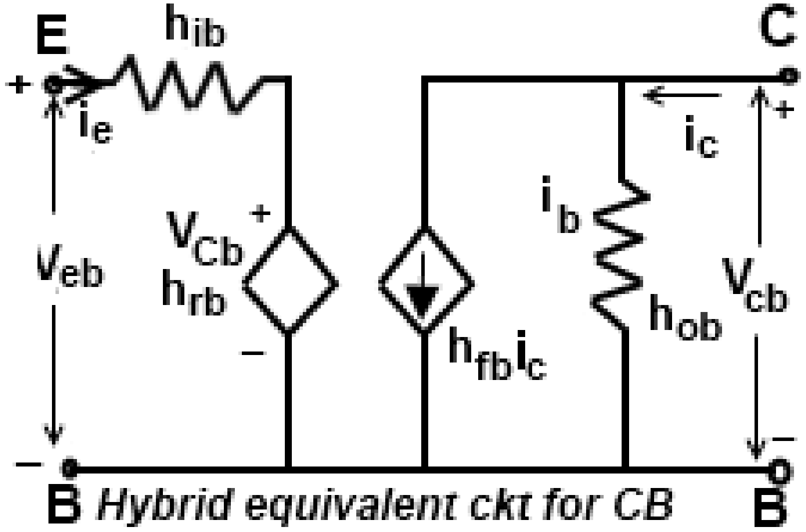
Hybrid Equivalent For CB Transistor

- The figure shows the transistor connected in common base configuration and the figure also shows the hybrid equivalent circuit of such a transistor.
- In common base transistor configuration, the input signal is applied between the base and emitter terminals of the transistor and output appears between the collector and base terminals. The input voltage (V_{be}) and the output current (i_c) are given by the following equations:

$$V_{be} = h_{ib}.i_b + h_{rb}.V_c$$
$$i_e = h_{fb}.i_b + h_{ob}.V_c$$



Common base transistor



Hybrid equivalent ckt for CB

Characteristics of Common Base Amplifier Circuit

- The following are the characteristics of the Common Base amplifier circuit.
- High voltage gain
- Low current gain
- Low power gain
- Input and output phase relation is 0o
- It has low input impedance
- It has high output impedance

Applications of CB

- The common base amplifier circuit is used, where the low input impedance is required. The following are the applications of the common base amplifier circuit.
- It is used in moving coil microphones Preamplifiers.
- It is used in UHF and VHF RF amplifiers.

Some applications of the common base amplifier:

1. **UHF and Microwave Amplifiers:** The common base amplifier is well-suited for ultra-high frequency (UHF) and microwave applications. Its relatively low input impedance and low noise figure make it advantageous in these frequency ranges.
2. **Wideband Amplifiers:** Common base amplifiers are often used in wideband amplifier designs. The configuration provides a relatively flat frequency response over a broad frequency range, making it suitable for applications requiring wide bandwidth.
3. **Low Noise Preamplifiers:** In applications where low noise is critical, such as in communication receivers or sensitive measurement equipment, the common base amplifier can be employed as a low noise preamplifier. Its inherent low input impedance helps reduce noise.
4. **Impedance Matching:** The common base configuration is often used for impedance matching between a low-impedance source and a high-impedance load. It provides a step-up voltage gain and can efficiently match the impedance between stages in a multi-stage amplifier.
5. **High-Frequency RF Front-Ends:** Common base amplifiers are employed in the front-end stages of high-frequency radio-frequency (RF) receivers. Their capability to provide a low input impedance and good isolation makes them suitable for these applications.

6. Cascode Amplifiers: The common base configuration is sometimes used in cascode amplifier configurations. Cascode amplifiers combine a common emitter and a common base transistor in a stacked arrangement to achieve enhanced performance in terms of gain and bandwidth.

7. Transimpedance Amplifiers: The common base amplifier is suitable for transimpedance amplifier designs, where the output is proportional to the input current. This configuration can be employed in photodetectors or other applications where a current-to-voltage conversion is needed.

8. Photodetector Amplifiers: In optical communication systems, common base amplifiers can be used as amplifiers for photodetectors, converting the current generated by the photodetector into a voltage signal.

9. Low-Input Impedance Buffer: Common base amplifiers can serve as low-input impedance buffers between stages in a circuit. This is particularly useful when there is a need to prevent loading effects on the preceding stage.

10. Frequency Mixers: Common base amplifiers are utilized in frequency mixer circuits, where two signals are combined to generate sum and difference frequencies. The configuration's inherent characteristics make it suitable for certain mixer applications.

11. Microwave Oscillators: The common base amplifier can be employed in the design of microwave oscillators, contributing to the generation of stable microwave signals in electronic systems.

Advantages of Common Base Amplifier

1. **High voltage gain** – Common Base Amplifier boosts the voltage significantly, allowing for stronger signals without needing much power.
2. **Wide bandwidth** – It handles a range of frequencies effectively, making it versatile for different types of signals.
3. **Stable current gain** – The amount of current that flows through remains consistent, providing reliable performance.
4. **Low input impedance** – It's easy for signals to enter due to its low resistance at the input, which is helpful for certain applications.
5. **Uniform response** – The output remains consistent across different frequencies, ensuring a predictable and even signal amplification.

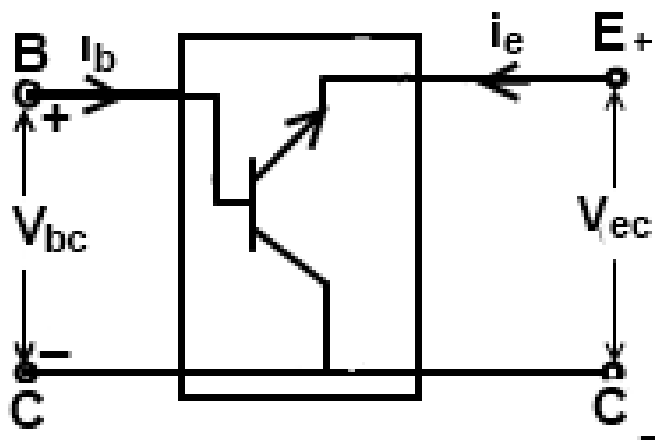
Disadvantages of Common Base Amplifier

1. **Low input impedance** – A common base amplifier makes it hard to connect sources with higher impedance because it can’t accept high resistance inputs well.
2. **High voltage requirements** – It needs more voltage to operate compared to other configurations, which can make it less efficient for certain applications.
3. **No current gain** – This type of amplifier doesn’t increase the strength of the electrical current passing through it, which isn’t ideal when current boosting is needed.
4. **Unstable temperature response** – Its performance can change with temperature variations, causing inconsistency in amplification over different environmental conditions.
5. **Limited power output** – It’s not suited for applications requiring a lot of power since it can only handle a limited amount of power output without distortion or damage.

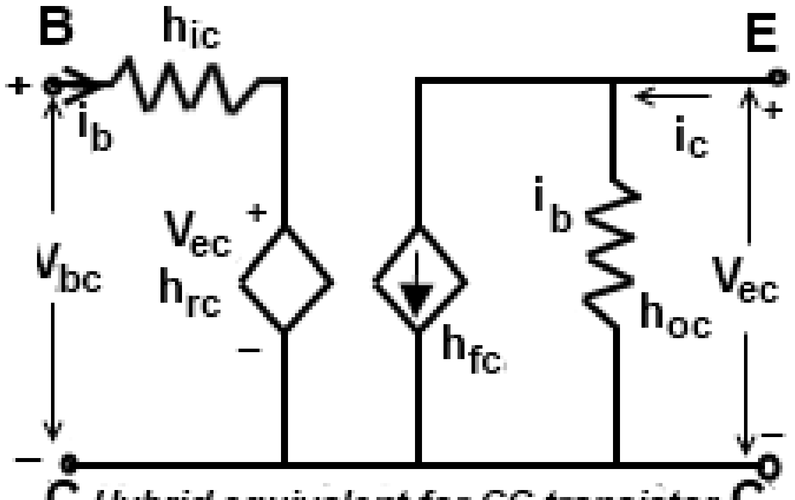
Hybrid Equivalent For CC Transistor

- The figure shows the transistor connected in common emitter configuration and the figure also shows the hybrid equivalent circuit of such a transistor.
- In common emitter transistor configuration, the input signal is applied between the base and emitter terminals of the transistor and output appears between the collector and base terminals. The input voltage (V_{bc}) and the output current (i_c) are given by the following equations:

$$V_{bc} = h_{ic}.i_b + h_{re}.V_{ec}$$
$$i_e = h_{fe}.i_b + h_{oe}.V_{ec}$$



Common Collector Transistor



Hybrid equivalent for CC transistor

- **Characteristics**
- The basic characteristics of the common collector amplifier are as follows.

1. The variation in between the applied input and the output voltage is directly related to each other. That is increase in the input voltage also makes the output voltage to increase. Practically if there simulation results are noted there will be only 0.7 volts difference between the signals generated at the output because of the input.
2. As the circuit of this configuration is designed its input is taken across base and the output is across the emitter.
3. In this type of amplifier the load resistance is able to receive the currents from both the emitter and the base terminals.
4. The resultant emitter current is the combination of the base and the collector currents. This makes the circuit to achieve the higher current gains.
5. It maintains the gain of the voltage at the level of unity.
6. The gain of power for this transistor is to be at medium.
7. There is no evident phase shift between applied input and the generated output signals.
8. The resistance at the input of this circuit is high enough.
9. The resistance value at the output for this circuit is considered to be low.

Applications

- This amplifier is used as an impedance matching circuit.
- It is used as a switching circuit.
- The high current gain combined with near-unity voltage gain makes this circuit a great voltage buffer
- It is also used for circuit isolation.

Some common applications of the common collector amplifier:

1. **Voltage Buffering:** The common collector amplifier is often used as a voltage buffer. It provides a high input impedance and a low output impedance, making it effective for isolating the preceding stage from the load, preventing signal distortion.
2. **Impedance Matching:** Common collector amplifiers are used for impedance matching between low-impedance sources and high-impedance loads. The configuration's low output impedance helps match the source impedance to the load impedance efficiently.
3. **Signal Level Shifting:** The common collector amplifier is utilized for level shifting applications. It can shift the DC level of a signal while maintaining the signal's amplitude and preserving its waveform.
4. **Unity Voltage Gain Applications:** In applications where unity voltage gain (gain ≈ 1) is acceptable, the common collector amplifier is employed. Its primary function in such cases is to provide isolation and impedance matching rather than amplification.
5. **Emitter Follower for Voltage Regulation:** The common collector configuration is commonly used as an emitter follower in voltage regulation circuits. The emitter follower can help stabilize the output voltage and provide a low-impedance source for the load.
6. **Low-Noise Amplification:** Common collector amplifiers can be used in low-noise amplification circuits. While they may not provide high voltage gain, their low noise figure makes them suitable for applications where minimizing noise is crucial.

7. Driver Stage in Power Amplifiers: In audio amplifier designs, the common collector configuration can be employed as a driver stage. It can provide a low-impedance drive to the output stage while isolating the input stage.

8. RF Amplifiers in Receivers: The common collector amplifier is used in RF amplifiers within radio-frequency (RF) receivers. Its low input impedance helps match the impedance with the antenna and provides a stable output.

9. Emitter Follower for Voltage Isolation: Common collector amplifiers are used to provide voltage isolation between stages in a circuit. The input voltage is applied to the base, and the emitter follows the input voltage, providing a low-impedance output.

10. Transistor Voltage Regulators: Common collector configurations are employed in transistor voltage regulators, where a stable and regulated output voltage is required. The emitter follower can provide a regulated output while offering low output impedance.

11. Current Buffers: The common collector amplifier can function as a current buffer. It can deliver a relatively constant output current while isolating the input from changes in load resistance.

12. Isolation Amplifiers: In applications where input and output stages need to be isolated, common collector amplifiers are used as isolation amplifiers. The low output impedance and high input impedance contribute to effective isolation.

Advantages of CC amplifier:

1. It has current gain but maintain voltage gain unchanged
2. It has the lowest output impedance compare to other type amplifier
3. It can be used for impedance matching between an amplifier stage with a high output impedance and an amplifier stage with a low input impedance.
4. When used like this it is sometimes called a buffer amp or isolation amp.
5. When placed between the the two stages it prevents the stage with the low input impedance from overloading the stage with the high output impedance.
6. The Voltage gain of a common collector amp is at best slightly less than 1

Disadvantages of CC amplifier

1. **Voltage Gain Less than Unity:**

   The common collector amplifier typically has a voltage gain less than unity (less than 1). This means that the output voltage is slightly lower than the input voltage. While this configuration provides high current gain, it sacrifices voltage gain.

2. **Limited Voltage Swing:**

   The voltage swing at the output is limited, especially when compared to other configurations like the common emitter amplifier. This limitation can impact the ability of the amplifier to handle large input signals without distortion.

3. **Low Input Impedance:**

   The input impedance of the common collector amplifier is relatively low. This characteristic makes it less suitable for applications where a high input impedance is required to avoid loading the preceding stage.

4. **Inverted Output Phase:**

   The output signal is inverted concerning the input signal. This inversion might not be desirable in certain applications where a non-inverted output is required.

5. **Higher Output Resistance:**

   The output resistance of the common collector amplifier is higher compared to the common emitter configuration. This higher output resistance can affect the matching with subsequent stages, potentially leading to signal distortion.

Disadvantages of CC amplifier

6. Lower Power Gain:

While the common collector configuration provides a high current gain, it usually has a lower power gain compared to other configurations like the common emitter amplifier. This can limit its effectiveness in certain applications.

7. Thermal Stability Challenges:

The common collector amplifier can face challenges in terms of thermal stability, especially when it comes to biasing. Changes in temperature may impact the operating point and, consequently, the performance of the amplifier.

8. Higher Noise Figure:

The common collector amplifier may have a higher noise figure compared to other configurations. This makes it less suitable for low-noise applications where minimizing signal noise is crucial.

9. Lower Voltage Headroom:

The voltage headroom, or the maximum allowable input voltage before distortion occurs, is lower in the common collector amplifier. This limitation may restrict its use in applications with high input signal levels.

10. Complex Biasing Arrangement:

Achieving proper biasing in a common collector amplifier can be more complex compared to other configurations. This complexity may add to the design challenges, especially for beginners.

Current Gain

- It is the ratio of output current (i_L) to input currents (i_1). Mathematically, the current gain,
- $A_i = i_1/i_1 = i_2/i_1$
- Putting the value of V_2 (equal to $-i_2.r_L$) in equation (2)
- $i_2 = h_f.i_1 + h_o(-i_2.r_L) = h_f.i_1 - h_o.i_2.r_L$
  $i_2 + h_o.i_2.r_L = h_f.i_1$
  $i_2(1 + h_o.r_L) = h_f.i_1$
  $i_2/i_1 = h_f/(1 + h_o.r_L)$
  $A_i = i_2/i_1 = -(h_f/(1 + h_o.r_L))$ -------------------(3)

Input Resistance

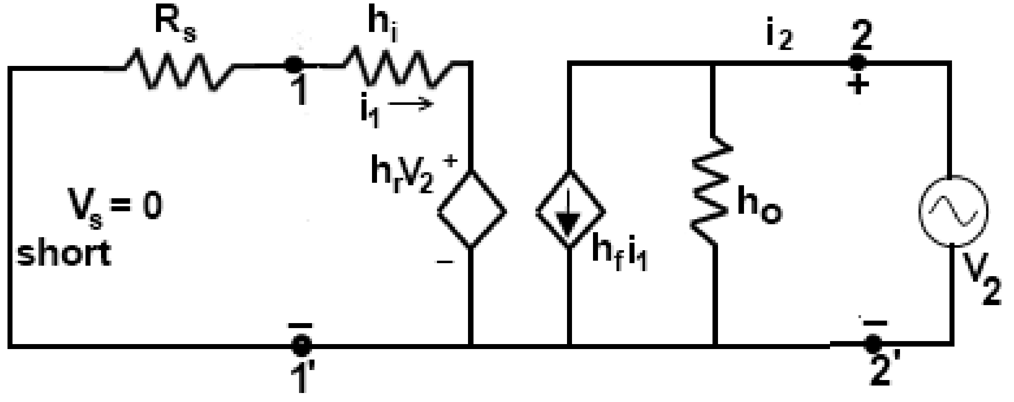
- Input resistance value is given by the ratio of input voltage (V_1) to the input current (i_1).
  Mathematically,
- $R_i = V_1/i_1$
- Again putting the value of V_2 (equal to $-i_2.r_L$) in equation (1)
- $V_1 = h_i.i_1 + h_r(-i_2.r_L)$
  $= h_i.i_1 - h_r.i_2.r_L$
- Dividing the equation (1) by i_1 on both sides,
- $V_1/i_1 = (h_i.i_1 - h_r.i_2.r_L)/i_1 = h_i - h_r(i_2/i_1)r_L$
- Replacing $v1/i_1$ with R_i and i_2/i_1 by $-A_i$ in the above equation.
- $R_i = h_i - h_r(-A_i).r_L = h_i + h_r.A_i.r_L$ --------------(4)
- Putting the value of A_i equal to $-h_f/(1 + h_o.r_L)$ from equation (3) in the above expression.
- $R_i = h_i + h_r\,(-(h_f/(1 + h_o.r_L)r_L)$
  $= h_i - (h_r.h_f/h_o + (1 / r_L))$ ------------------ (5)

Voltage Gain

- It is defined as the ratio of output voltage (V_2) to the input voltage (V_1). Mathematically, the voltage gain,
- $A_v = V_2/V_1 = -(i_2.r_L/V_1)$ (as $V_2 = -i_2.r_L$)
- Putting the value of i_2 (equal to $–A_i.i_1$) from equation (2) the above expression,
- $A_v = (A_i.i_1.r_L/V_1) = A_i.r_L(i_1/V_1)$
- Replacing i_1/V_1 by R_i in the above expression,
- $A = A_i.r_L/R_i$
- Putting the value of A_i (equal to $–h_f/(1 + h_o.r_L)$ and
- R_i (equal to $h_i – h_r/h_f(h_o + 1/r_L)$) in the above expression and re-arranging,
- $A_v = - (h_f.r_L/(h_i + (h_i.h_o – h_r.h_f)r_1))$
- If we replace ($h_i.h_o – h_r.h_f = \Delta h$) in the above expression then the voltage gain,
- $A_v = -(h_r.r_L/ (h_i + \Delta h.r_L))$

Output Resistance

- It is obtained by setting the source voltage (V_s) to zero and the load resistance (r_L) to infinity and by driving the output terminals from a source V_2 as shown in below Figure (b).
- Then output resistance is the ratio of voltage (V_2) to the current drawn from the voltage source (i_2).
- Mathematically, the output resistance,
- $R_o = V_2/i_2 = (V_2/(h_r.i_1 + h_o.V_2)$ ------------(6)
- The value of current (i_1) can be obtained by applying Kirchhoff's Law to the input side of transistor amplifier circuit.
- $R_s.i_1 + h_i.i_1 + h_r.V2 = 0$
  As $i_1 = -(h_r.V_2)/ (R_s + h_i)$
- Putting this value of i_1 in equation (6)



Hybrid equivalent circuit of a general transisotr amplifier with voltage source connected across output terminal
Figure (b)

$$R_o = \frac{V_2}{h_f\left(-\frac{h_r V_2}{R_s h_i}\right) + h_o.V_2}$$

$$= \frac{V_2}{\frac{h_f.h_i.V_2}{R_s + h_i} + h_o.V_2}$$

Rearranging the above equation

$$R_o = \frac{R_s + h_i}{(R_s + h_i)h_o - h_f.h_i}$$

$$= \frac{R_s + h_i}{R_s.h_o + \left(h_i.h_o - h_f.h_r\right)}$$

$$= \frac{R_s + h_i}{R_s.h_o + \Delta h}$$

If source resistance (R_s) is zero, then output resistance is,

$R_o = h_i/\Delta h$

Power Gain

- It is defined as the product of voltage gain (A_v) and the current gain (Δi).
- Mathematically, the power gain is,
- $\Delta p = A_v . A_i$

Current Gain

- **Hybrid Equivalent For CB Transistor**
- It is given by the relation,
- $A_i = -(h_{fb}/(1 + h_{ob}.r_L))$
- Where r_L is the A.C load resistance. Its value is equal to the parallel combination of resistance R_c and R_L. Since h_{fb} of a transistor is a positive number, therefore A_i of a common emitter amplifier is negative.

- **Hybrid Equivalent For CE Transistor**
- It is given by the relation,
- $A_i = -(h_{fe}/(1 + h_{oe}.r_L))$
- Where r_L is the A.C load resistance. Its value is equal to the parallel combination of resistance R_c and R_L. Since h_{fe} of a transistor is a positive number, therefore A_i of a common emitter amplifier is negative.

- **Hybrid Equivalent For CC Transistor**
- It is given by the relation,
- $A_i = -(h_{fc}/(1 + h_{oc}.r_L))$
- Where r_L is the A.C load resistance. Its value is equal to the parallel combination of resistance R_E and R_C. Since h_{fe} of a transistor is a positive number, therefore A_i of a common emitter amplifier is negative.

Input Resistance

- **Hybrid Equivalent For CB Transistor**
- The resistance looking into the amplifier input terminals (i.e. base of a transistor) is given by the relation,
- $R_i = h_{ib} + h_{rb}.A_i.r_L = h_{ib} – ((h_{rb}.h_{fb})/(h_{ob} + (1/r_L)))$
- The input resistance of the amplifier stage (called stage input resistance R_{is}) depends upon the biasing arrangement. For a fixed bias circuit, the stage input resistance is,
- $R_{is} = R_i$

- **Hybrid Equivalent For CE Transistor**
- The resistance looking into the amplifier input terminals (i.e. base of a transistor) is given by the relation,
- $R_i = h_{ie} + h_{re}.A_i.r_L = h_{ie} – ((h_{re}.h_{fe})/(h_{oe} + (1/r_L)))$
- The input resistance of the amplifier stage (called stage input resistance R_{is}) depends upon the biasing arrangement. For a fixed bias circuit, the stage input resistance is,
- $R_{is} = R_i//R_B$
- If the circuit has no biasing resistances, then $R_{is} = R_i$

- **Hybrid Equivalent For CC Transistor**
- The resistance looking into the amplifier input terminals (i.e. base of a transistor) is given by the relation,
- $R_i = h_{ie} + h_{re}.A_i.r_L = h_{ie} – ((h_{rc}.h_{fc})/(h_{oc} + (1/r_L)))$
- The input resistance of the amplifier stage (called stage input resistance R_{is}) depends upon the biasing arrangement. For a fixed bias circuit, the stage input resistance is,
- $R_{is} = R_s$

Voltage Gain

- **Hybrid Equivalent For CB Transistor**
- It is given by the relation,
- $A_v = A_i.r_1/R_i$
- Since the current gain (A_i) of a common base amplifier is positive, therefore the voltage gain (A_v) is also positive. It means that there is no phase difference between the input and output signals of the common base amplifier. The voltage gain, in terms of h-parameters, is given by the relation.
- $A_v = h_{fb}.r_L/(h_{ib} + \Delta h.r_L)$
- Where
- $\Delta h = h_{ib}.h_{ob} - h_{rb}.h_{fb}$

- **Hybrid Equivalent For CE Transistor**
- It is given by the relation,
- $A_v = A_i.r_1/R_i$
- Since the current gain (A_i) of a common emitter amplifier is negative, therefore the voltage gain (A_v) is also negative. It means that there is a phase difference of 180^o between the input and output. In other words, the input signal is inverted at the output of a common emitter amplifier. The voltage gain, in terms of h-parameters, is given by the relation.
- $A_v = h_{fe}.r_1/(h_{ie} + \Delta h.r_L)$
- Where
- $\Delta h = h_{ie}.h_{oe} - h_{re}.h_{fe}$

- **Hybrid Equivalent For CC Transistor**
- It is given by the relation,
- $A_v = A_i.r_1/R_i$
- Since the current gain (A_i) of a common base amplifier is positive, therefore the voltage gain (A_v) is also positive. It means that there is no phase difference between the input and output signals of the common base amplifier. The voltage gain, in terms of h-parameters, is given by the relation.
- $A_v = h_{fc}.r_L/(h_{ic} + \Delta h.r_L)$
- Where
- $\Delta h = h_{ic}.h_{oc} - h_{rc}.h_{fc}$

Output Resistance

- **Hybrid Equivalent For CB Transistor**
- The resistance looking into the amplifier output terminals is given by the relation,
- $R_o = (R_s + h_{ib})/(R_s.h_{ob} + \Delta h)$
- Where
- R_s = Resistance of the source, and
- $\Delta h = h_{ib}.h_{ob} – h_{rb}.h_{fb}$
- The output resistance of the stage,
- $R_{os} = R_o \,//\, r_L$
- **Overall Voltage Gain**
- It is given by the relation,
- $A_{vs} = (A_v.R_{is})/(R_s + R_{is})$
- **Overall Current Gain**
- It is given by relation,
- $A_{is} = A_i.R_s/(R_s + R_{is})$

- **Hybrid Equivalent For CE Transistor**
- The resistance looking into the amplifier output terminals is given by the relation,
- $R_o = (R_s + h_{ie})/(R_s.h_{oe} + \Delta h)$
- Where
- R_s = Resistance of the source, and
- $\Delta h = h_{ie}.h_{oe} – h_{re}.h_{fe}$
- The output resistance of the stage,
- $R_{oe} = R_o \,//\, r_L$
- Overall Voltage Gain
- $A_v = (A_v.R_{is})/(R_s + R_{is})$
- Overall Current Gain
- $A_{ie} = A_i.R_s/(R_s + R_{is})$

- **Hybrid Equivalent For CC Transistor**
- The resistance looking into the amplifier output terminals is given by the relation,
- $R_o = (R_s + h_{ic})/(R_s.h_{oc} + \Delta h)$
- Where
- R_s = Resistance of the source, and
- $\Delta h = h_{ic}.h_{oc} – h_{rc}.h_{fc}$
- **Overall Voltage Gain**
- It is given by the relation,
- $A_{vc} = (A_v.R_{is})/(R_s + R_{is})$
- **Overall Current Gain**
- It is given by relation,
- $A_{is} = (A_i + R_s)/(R_i + R_{is})$

Power Gain

- **Hybrid Equivalent For CB Transistor**
- **Hybrid Equivalent For CE Transistor**
- **Hybrid Equivalent For CC Transistor**

- **Example 1**
- A transistor used in a common base amplifier has the following vaules of h-parameters:
- $\mathbf{h_{ib}}$ = 28 **Ω**, $\mathbf{h_{fb}}$ = -0.98, $\mathbf{h_{rb} = 5 \times 10^{-4}}$ and $\mathbf{h_{ob}}$ = 0.34 X $\mathbf{10^{-6}}$ S
- Calculate the values of input resistance, output resistance, current gain and voltage gain, if the load resistance is 1.2 K**Ω**. Assume source resistance as zero.

Solution 1:

Given Data:

$h_{ib} = 28\ \Omega$

$h_{rb} = 5 \times 10^{-4}$

$h_{ob} = 0.34 \times 10^{-6}$ S

$r_L = 1.2\ K\Omega$

$R_s = 0$

Input resistance of the amplifier stage

We know that the input resistance,

Ri = hib + hrb.Ai.rL

$= 28 + [(5 \times 10^{-4}) \times 0.98 \times 1200]$

$= 28 + 0.5 = 28\ \Omega$ Ans

Output Resistance of Amplifier Stage

We know that:

$\Delta h = h_{ib}.h_{ob} - h_{rb}.h_{fb}$

$= [23 \times (0.34 \times 10^{-6})] - [5 \times 10^{-4}) \times (-0.98)]$

- **Output resistance**
- Ro = (Rs + hib) / (Rs.hib + Δh) = hib/Δh -------------(as Rs = 0)
- $= 28/5 \times 10^{-4} = 5.5 \times 10^{-4}\Omega = 56\ K\Omega$ Ans.
- **Current Gain of Amplifier Stage**
- We know that the current gain of amplifier stage,
- $A_i = -(h_{fb}/(1+ h_{ob}.r_L) = -(-0.98)/(1 + [(0.34 \times 10^{-6}) \times 1200] = 0.98$ ***Ans.***
- **Voltage Gain Amplifier Stage**
- We know that voltage gain of a transistor,
- $A_v = A_i.r_L/R_i = (0.98 \times 1200) / 28.6$
- = 41 Ans.

- **Example 2**
- A transistor used in a common collector amplifier has the following vaules of h-parameters:
- $\mathbf{h_{ic}}$ = 2 K**Ω**, $\mathbf{h_{fc}}$ = -.51, $\mathbf{h_{rc}}$ **= 1** and $\mathbf{h_{oc}}$ = 25 X $\mathbf{10^{-6}}$mhos
- Calculate the values of input resistance, output resistance, current gain and voltage gains of the amplifier stage.

Solution 2

Given Data:
h_{ic} = 2 KΩ = 2000 Ω
h_{fc} = -.51
h_{rc} = 1
h_{oc} = 25 X 10^{-5}mhos
r_L = R_E = 5 KΩ = 5 X 10^3 Ω
R_s = 1 KΩ = 1000 Ω
R_1= R_2 = 10 KΩ
Input resistance of the amplifier stage
We know that the input resistance,
$A_i = -(h_{fc}/(1 + h_{oc}.r_L))$
$= -51/[1 + \{(25 \times 10^{-6}) \times (5 \times 10^3)\}]$
= 45.3
and input resistance
$R_i = h_{ie} + h_{re}.A_i.r_L$
= 2000 + (1 x 45.3 x 5 x 10^3 Ω
= 228 x 10^3Ω
= 228 kΩ
As input resistace of the amplifier
$R_{is} = R_1 // (R_1 // R_2)$
= 228 // (10 // 10) = 4.9 kΩ
= 4900 Ω Ans

- **Output Resistance of Amplifier Stage**
- We know that:
- R_o = **-** $(R_s + R_{ic})/h_{fc}$
- = **-** (1000 + 2000)/-51
- = 59 **Ω**
- and output resistance of the amplifier stage
- $R_{os} = R_o // R_E$
- = 59 // (5 x 10^{-3})
- = 58.3 ***Ans***
- **Current Gain**
- We know that the current gain of amplifier stage,
- $A_{is} = -(A_i.R_s)/(R_s.R_{is})$ = (45.3 x 1000)/(1000 + 4900) = 7.7 ***Ans.***
- **Voltage Gain Amplifier Stage**
- We know that voltage gain is
- $A_v = A_i.r_L/R_i$ = (45.3 X (5 x 10^3) / 228 x 10^3= 1 Ans.
- and the voltage gain of the amplifier stage
- $A_{vs} = A_v.A_{is}/(R_s + R_{is})$ = (1 + 4900)/ (1000 + 4900) = 0.83 Ans

- **Example 3**
- The h-parameters of a transistor used in a common emitter circuit are h_{ie} = 1.0 KΩ, h_{re} = 1.0 x 10^{-4}, h_{fe} = 50 and h_{oe} = 100 μmhos. The load resistor for the transistor is 1KΩ in the collector circuit. The transistor is supplied from a signal source of resistance 1000Ω. Determine the value of input and output impedance, voltage and current gains in the amplifier stage.

Solution 3

Given Data:
h_{ie} = 1KΩ = 1000Ω
h_{re} = 1.0 x 10^{-4}
h_{oe} = 100 μmhos = 100 x 10^{-6} mhos
R_c = 1KΩ = 1000Ω
R_s = 1000Ω

Input resistance of the amplifier stage

We know that thereis no load connected at the output of the amplifier (i.e. $R_L = 0$),
therefore the value of A.C load resistance,
$r_L = Rc = 1000\Omega$
we also know that current gain of a transistor,
$A_i = -(h_{fe}/(1 + h_{oe}.r_L) = -(50 / (1 + (100 \times 10^{-6}) \times 1000)$
$= -45.5$
And the input resistance of a transistor,
$R_i = h_{ie} + h_{re}.A_i.r_L = 1000 + [(1.0 \times 10^{-4}) \times (-45.5) \times 1000]$
$= 995\ \Omega$
Input resistance of the amplifier stage is,
$R_{is} = R_i = 995\ \Omega$ ***Ans.***

- **Output Resistance of Amplifier Stage**
- We know that:
- $\Delta h = h_{ie}.h_{oe} - h_{re}.h_{fe}$
- $= [1000 \times (100 \times 10^{-5})] - (1.0 \times 10^{-4}) \times 50 = 95 \times 10^{-3} = 0.095$
- Output resistance of the transistor looking directly into collector.
- $R_e = (R_s + h_{ie})/(R_s.h_{oe} + \Delta h)$
- $= (1000 + 1000)/[1000 \times (100 \times 10^{-6})] + 0.95 = 2000/(0.1 + 0.95)$
- $= 10300\ \Omega$
- And output resistance of the amplifier stage,
- $R_{oe} = R_o // r_L = 10300 // 1000 = 910\ \Omega$ Ans.
- **Current Gain of Amplifier Stage**
- We know that the current gain of amplifier stage,
- $A_{is} = A_i.R_s/(R_s + R_{ie}) = (-45.5) \times (1000)/(1000 + 995) = -22.8$ ***Ans.***
- **Voltage Gain Amplifier Stage**
- We know that voltage gain of a transistor,
- $A_v = A_i.r_L/R_i = (-45.5) \times (1000)/995 = -45.7$
- Voltage gain of amplifier stage,
- $A_{vs} = A_v.R_{ie}/(R_s + R_{ie}) = (-45.7) \times 995/(1000 + 995) = -22.8$ ***Ans***

What is a Rectifier?

- A rectifier is an electrical component that converts alternating current (AC) to direct current (DC). A rectifier is analogous to a one-way valve that allows an electrical current to flow in only one direction. The process of converting AC current to DC current is known as rectification.

TYPES OF RECTIFIERS

The rectifiers are mainly classified into two types:

- Half wave rectifier
- Full wave rectifier

- **Half wave rectifier**

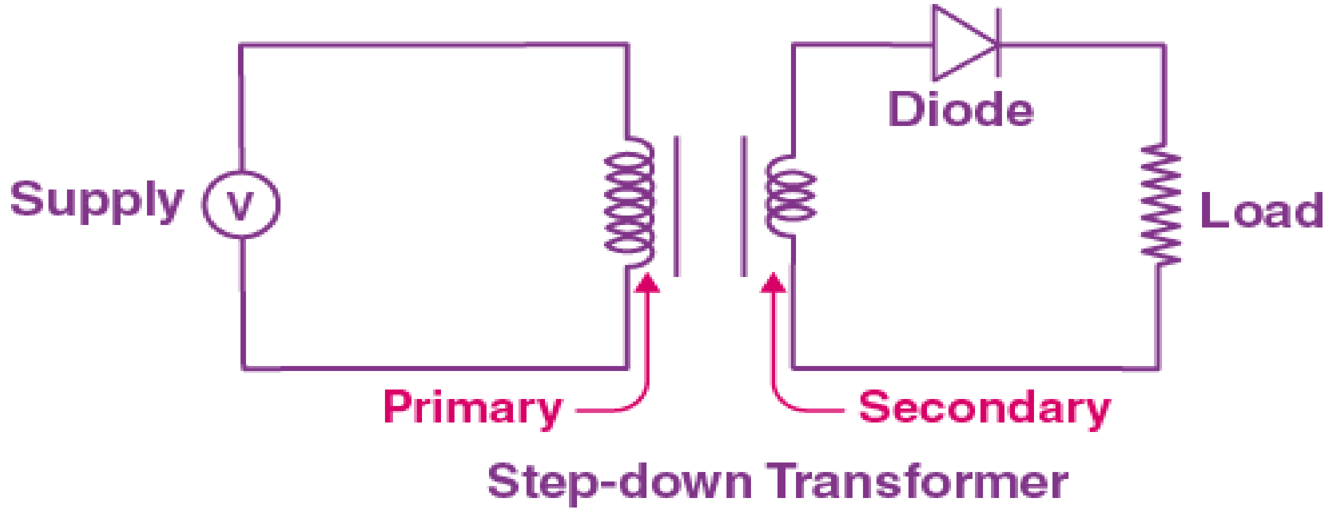
As the name suggests, the half wave rectifier is a type of rectifier which converts half of the AC input signal (positive half cycle) into pulsating DC output signal and the remaining half signal (negative half cycle) is blocked or lost. In half wave rectifier circuit, we use only a single diode.

- **Full wave rectifier**

The full wave rectifier is a type of rectifier which converts the full AC input signal (positive half cycle and negative half cycle) to pulsating DC output signal. Unlike the half wave rectifier, the input signal is not wasted in full wave rectifier. The efficiency of full wave rectifier is high as compared to the half wave rectifier.

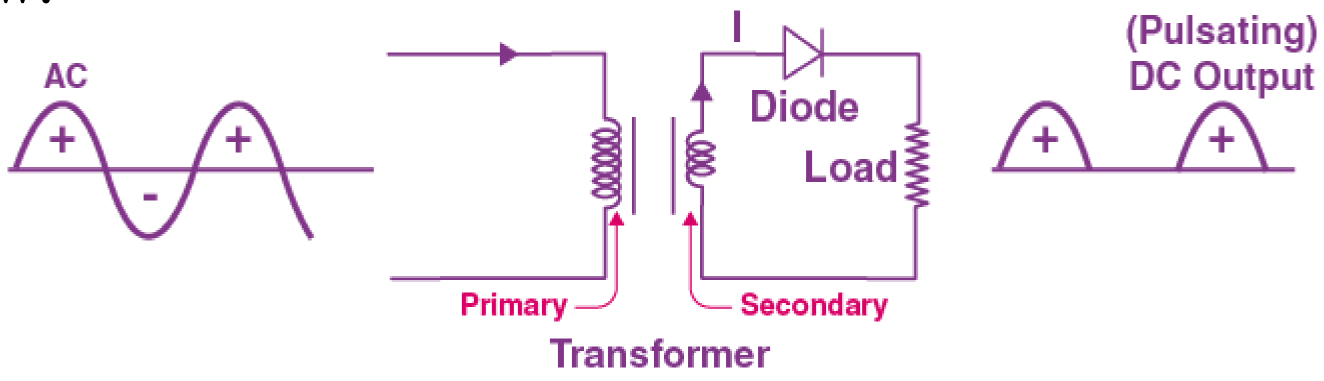
HALF-WAVE RECTIFIER

- A half-wave rectifier is the simplest form of the rectifier and requires only one diode for the construction of a halfwave rectifier circuit.
- A halfwave rectifier circuit consists of three main components as follows:
- A diode
- A transformer
- A resistive load

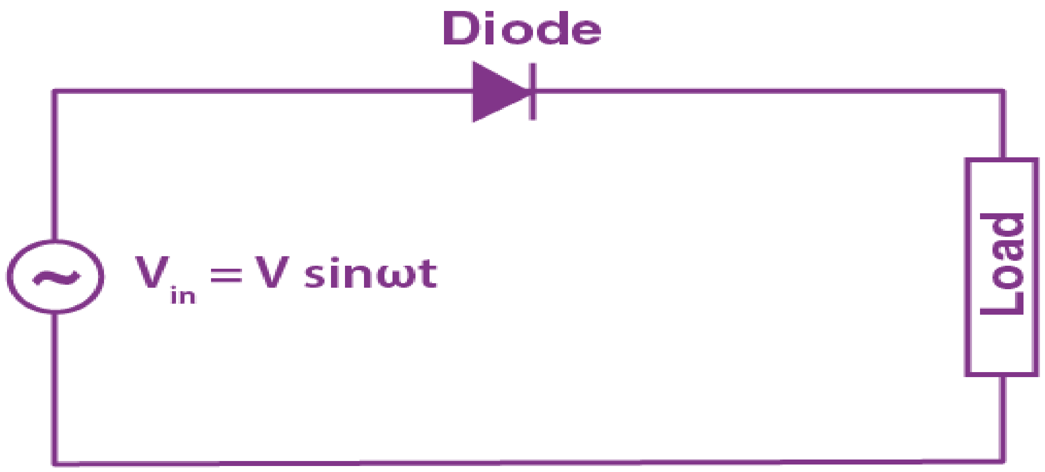


- Working of Half Wave Rectifier
- In this section, let us understand how a half-wave rectifier transforms AC into DC.
- A high AC voltage is applied to the primary side of the step-down transformer. The obtained secondary low voltage is applied to the diode.
- The diode is forward biased during the positive half cycle of the AC voltage and reverse biased during the negative half cycle.

The final output voltage waveform is as shown in the figure below:



For better understanding, let us simplify the half-wave circuit by replacing the secondary transformer coils with a voltage source as shown below:

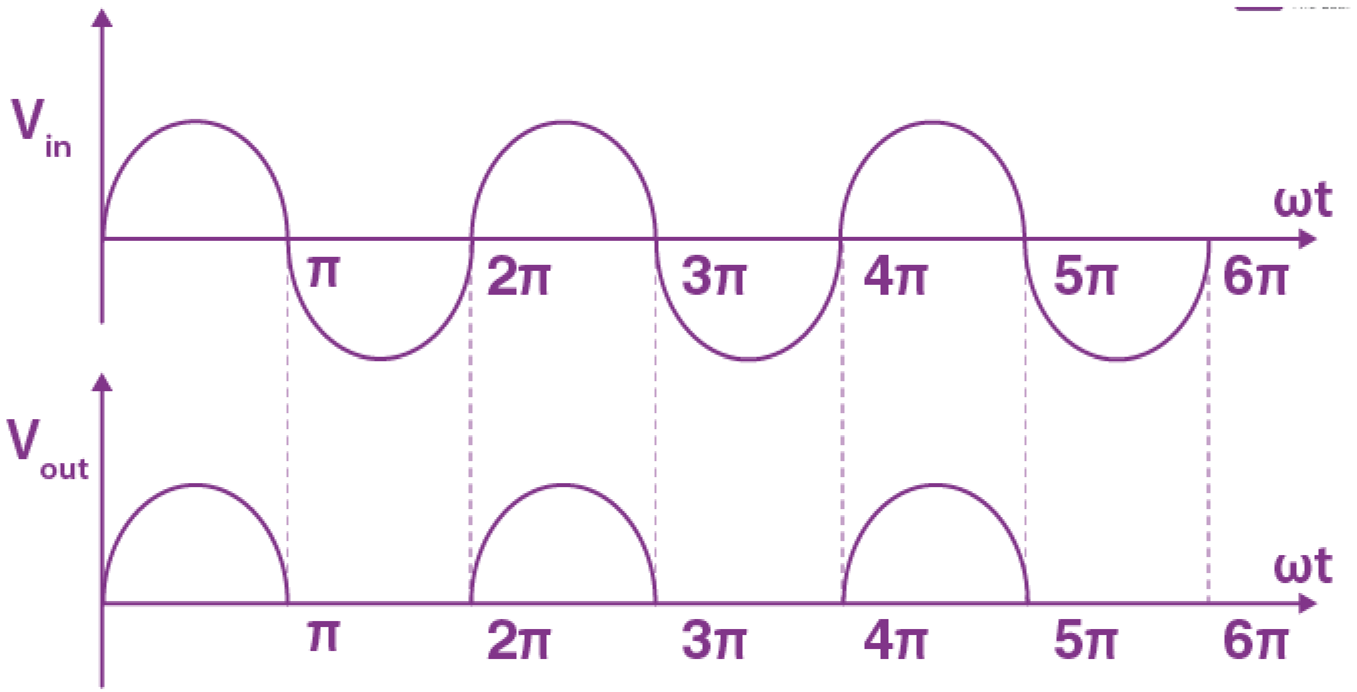


For the positive half cycle of the AC source voltage, the circuit effectively becomes as shown below in the diagram:

When a diode is reverse biased, it acts as an open switch. Since no current can flow to the load, the output voltage is equal to zero.

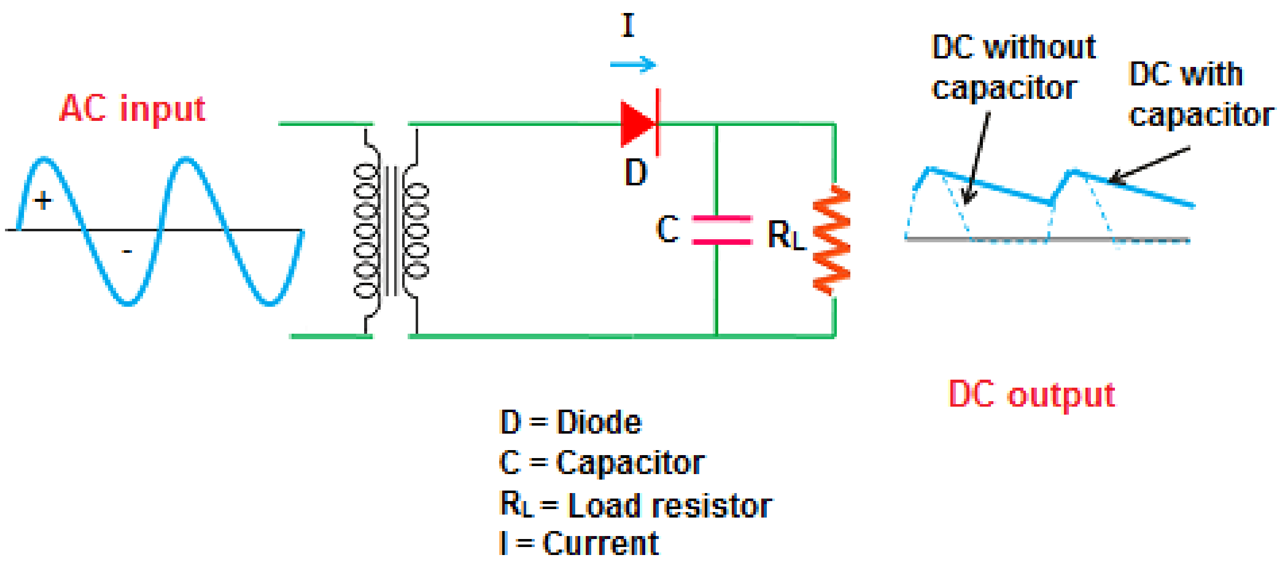
Half Wave Rectifier Waveform

- The halfwave rectifier waveform before and after rectification is shown below in the figure.



Half Wave Rectifier Capacitor Filter

- The output waveform of a halfwave rectifier is a pulsating DC waveform. Filters in halfwave rectifiers are used to transform the pulsating waveform into constant DC waveforms. A capacitor or an inductor can be used as a filter.
- The circuit diagram below shows how a capacitive filter is used with halfwave rectifier to smoothen out a pulsating DC waveform into a constant DC waveform. In the below circuit diagram, the capacitor C is connected in shunt with load resistor (R_L).



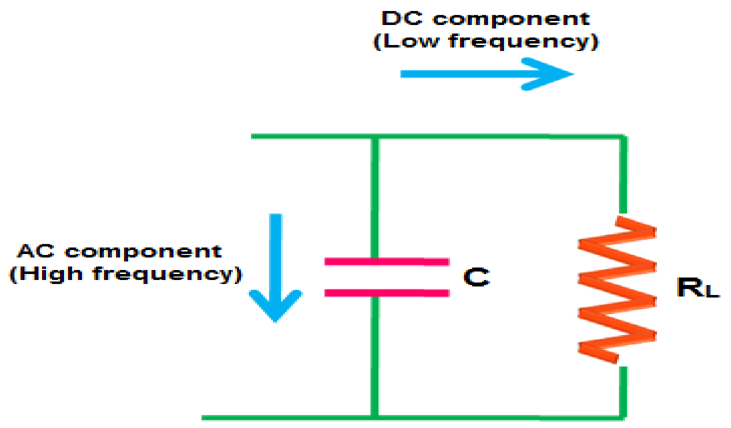
Half wave rectifier with capacitor filter

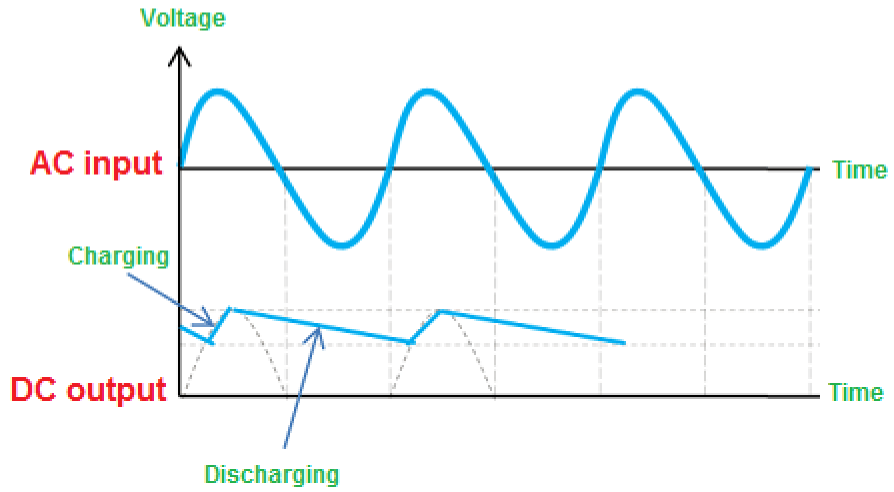
NOTE: The filter is made up of a combination of components such as capacitors, resistors, and inductors. The capacitor allows the ac component and blocks the dc component. The inductor allows the dc component and blocks the ac component.

When AC voltage is applied, during the positive half cycle, the diode D is forward biased and allows electric current through it.
As we already know that, the capacitor provides high resistive path to dc components (low-frequency signal) and low resistive path to ac components (high-frequency signal).

Electric current always prefers to flow through a low resistance path. So when the electric current reaches the filter, the dc components experience a high resistance from the capacitor and ac components experience a low resistance from the capacitor.

The dc components does not like to flow through the capacitor (high resistance path). So they find an alternative path (low resistance path) and flows to the load resistor (RL) through that path.





Half wave rectifier with filter o/p waveforms

On the other hand, the ac components experience a low resistance from the capacitor. So the ac components easily passes through the capacitor. Only a small part of the ac components passes through the load resistor (R_L) producing a small ripple voltage at the output.
The passage of ac components through the capacitor is nothing but charging of the capacitor. During the conduction period, the capacitor charges to the maximum value of the supply voltage. When the voltage between the plates of the capacitor is equal to the supply voltage, the capacitor is said to be fully charged.

Half Wave Rectifier Formula

Ripple Factor of Half Wave Rectifier

- Ripple factor determines how well a halfwave rectifier can convert AC voltage to DC voltage.
- Ripple factor can be quantified using the following formula:

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

The ripple factor of a halfwave rectifier is 1.21.

Efficiency of Halfwave rectifier

The efficiency of a halfwave rectifier is the ratio of output DC power to the input AC power.

The efficiency formula for halfwave rectifier is given as follows;

$$\eta = \frac{P_{DC}}{P_{AC}}$$

RMS value of Half Wave Rectifier

The RMS value of the load current for a half-wave rectifier is given by the formula:

$$I_{rms} = \frac{I_m}{2}$$

Form factor of a Halfwave Rectifier

The form factor is the ratio between RMS value and average value and is given by the formula:

$$\text{Form Factor} = \frac{\text{RMS value}}{\text{Average Value}}$$

Applications of Half Wave Rectifier

- They are used for signal demodulation purpose
- They are used for rectification applications
- They are used for signal peak applications

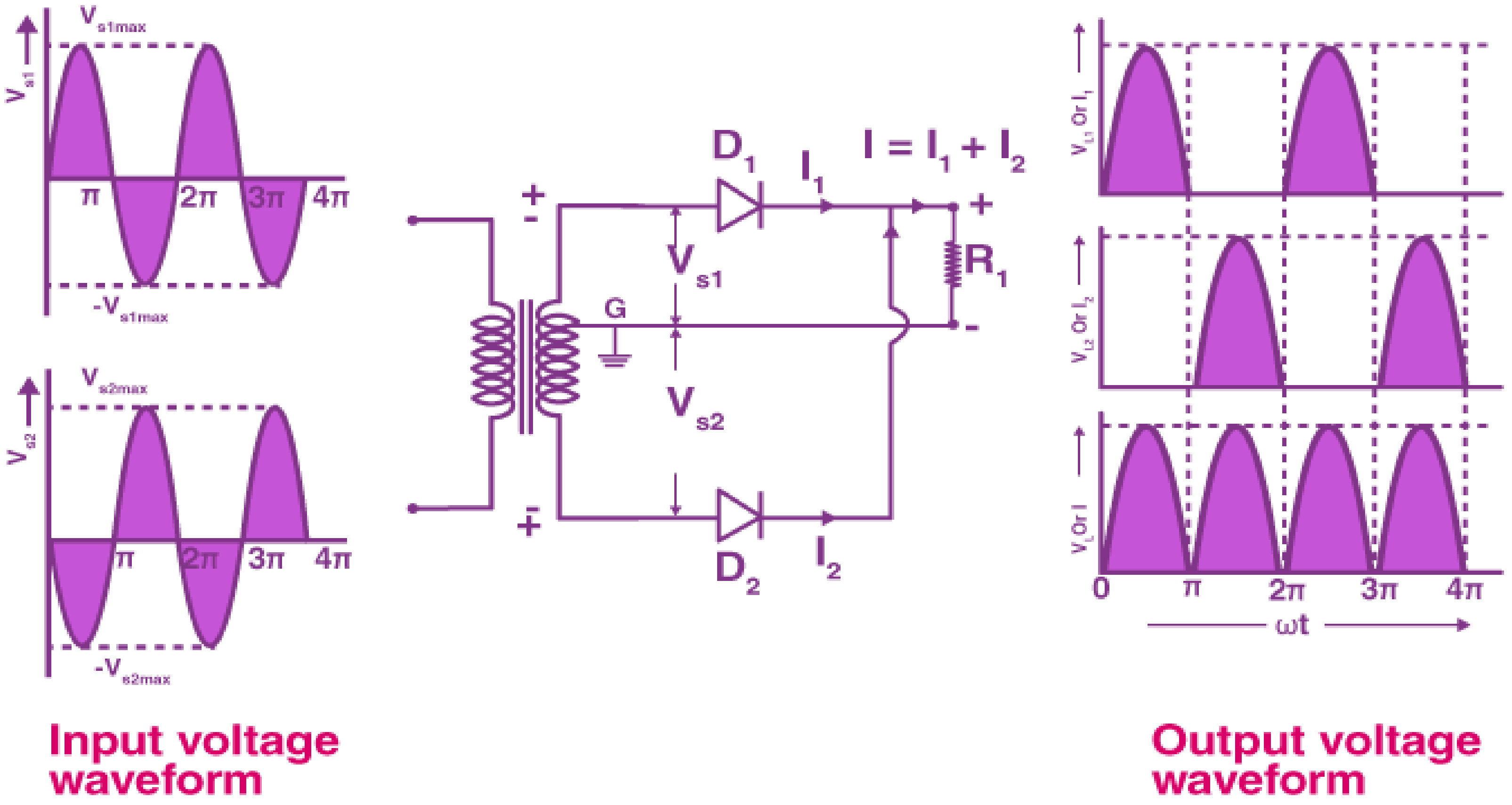
Disadvantages of Half Wave Rectifier

- Power loss
- Low output voltage
- The output contains a lot of ripples

Full Wave Rectifiers

- A full wave rectifier is defined as a rectifier that converts the complete cycle of alternating current into pulsating DC. Unlike halfwave rectifiers that utilize only the halfwave of the input AC cycle, full wave rectifiers utilize the full cycle. The lower efficiency of the half wave rectifier can be overcome by the full wave rectifier.
- The circuit of the full wave rectifier can be constructed in two ways. The first method uses a centre tapped transformer and two diodes. This arrangement is known as a centre tapped full wave rectifier. The second method uses a standard transformer with four diodes arranged as a bridge. This is known as a bridge rectifier.

CENTRE TAPPED FULL WAVE RECTIFIER



The circuit of the full wave rectifier consists of a step-down transformer and two diodes that are connected and centre tapped. The output voltage is obtained across the connected load resistor.

Working of Full Wave Rectifier

- The input AC supplied to the full wave rectifier is very high. The step-down transformer in the rectifier circuit converts the high voltage AC into low voltage AC. The anode of the centre tapped diodes is connected to the transformer's secondary winding and connected to the load resistor. During the positive half cycle of the alternating current, the top half of the secondary winding becomes positive while the second half of the secondary winding becomes negative.
- During the positive half cycle, diode D_1 is forward biased as it is connected to the top of the secondary winding while diode D_2 is reverse biased as it is connected to the bottom of the secondary winding. Due to this, diode D_1 will conduct acting as a short circuit and D_2 will not conduct acting as an open circuit
- During the negative half cycle, the diode D_1 is reverse biased and the diode D_2 is forward biased because the top half of the secondary circuit becomes negative and the bottom half of the circuit becomes positive. Thus in a full wave rectifiers, DC voltage is obtained for both positive and negative half cycle.

Full Wave Rectifier Formula

Peak Inverse Voltage

Peak inverse voltage is the maximum voltage a diode can withstand in the reverse-biased direction before breakdown. The peak inverse voltage of the full-wave rectifier is double that of a half-wave rectifier. The PIV across D_1 and D_2 is $2V_{max}$.

- **DC Output Voltage**
- The following formula gives the average value of the DC output voltage:

$$V_{dc} = I_{av}R_L = \frac{2}{\pi} I_{max}R_L$$

- **RMS Value of Curre...**
- The RMS value of the current can be calculated using the following formula:

$$I_{rms} = \frac{I_{max}}{\sqrt{2}}$$

- **Form Factor:** Form Factor of an ac waveform is the ratio of the RMS value to the average value. For a full wave rectifier is calculated using the formula:

$$K_f = \frac{RMS\ value\ of\ current}{Average\ value\ of\ current} = \frac{I_{rms}}{I_{dc}} = \frac{I_{max}/\sqrt{2}}{2I_{max}/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

- **Peak Factor: t**he peak factor is the peak amplitude of the waveform divided by the RMS value of the waveform.
- The following formula gives the peak factor of the full wave rectifier:

$$K_p = \frac{Peak\ value\ of\ current}{RMS\ value\ of\ current} = \frac{I_{max}}{I_{max}/\sqrt{2}} = \sqrt{2}$$

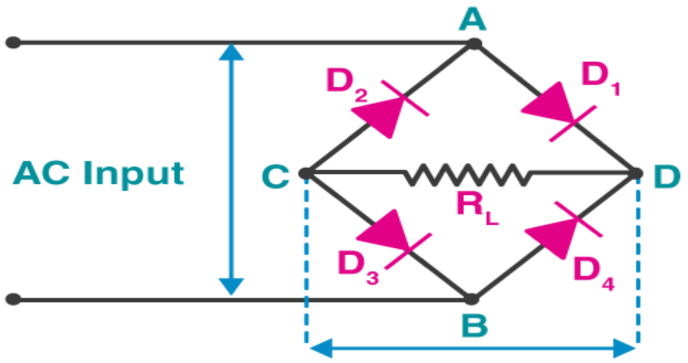
- **Rectification Efficiency**
- The rectification efficiency of the full-wave rectifier can be obtained using the following formula:
- The efficiency of the full wave rectifiers is 81.2%.

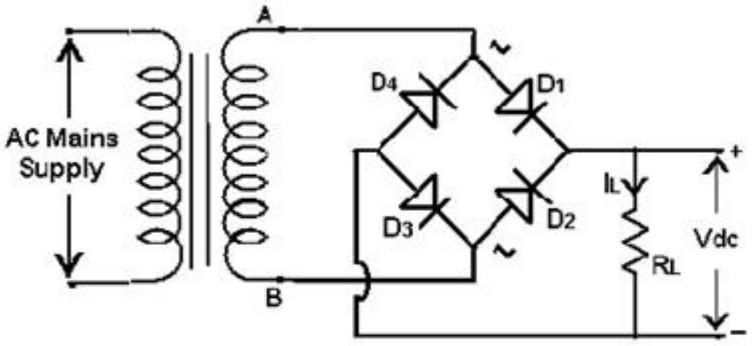
$$\eta = \frac{DC\ Output\ Power}{AC\ Output\ Power}$$

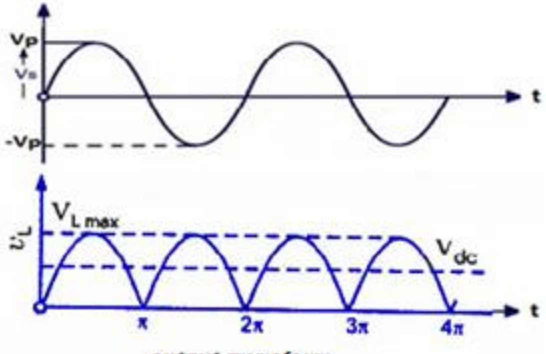
- **Advantages of Full Wave Rectifier**
- The rectification efficiency of full wave rectifiers is double that of half wave rectifiers. The efficiency of half wave rectifiers is 40.6% while the rectification efficiency of full wave rectifiers is 81.2%.
- The ripple factor in full wave rectifiers is low hence a simple filter is required. The value of ripple factor in full wave rectifier is 0.482 while in half wave rectifier it is about 1.21.
- The output voltage and the output power obtained in full wave rectifiers are higher than that obtained using half wave rectifiers.
- The only disadvantage of the full wave rectifier is that they need more circuit elements than the half wave rectifier which makes, making it costlier.

Bridge Rectifier

A bridge rectifier circuit can be built with four diodes which are used to change both input AC half-cycle to DC output. So, in this kind of rectifier, the four diodes are mainly connected in an exact form. In the positive half cycle of the bridge rectifier, the two diodes like D_1 & D_2 will become forward bias whereas diodes D_3 & D_4 will become reverse bias. From a closed loop, the diodes D_1 & D_2 will provide a +Ve output voltage across the R_L (load resistor).

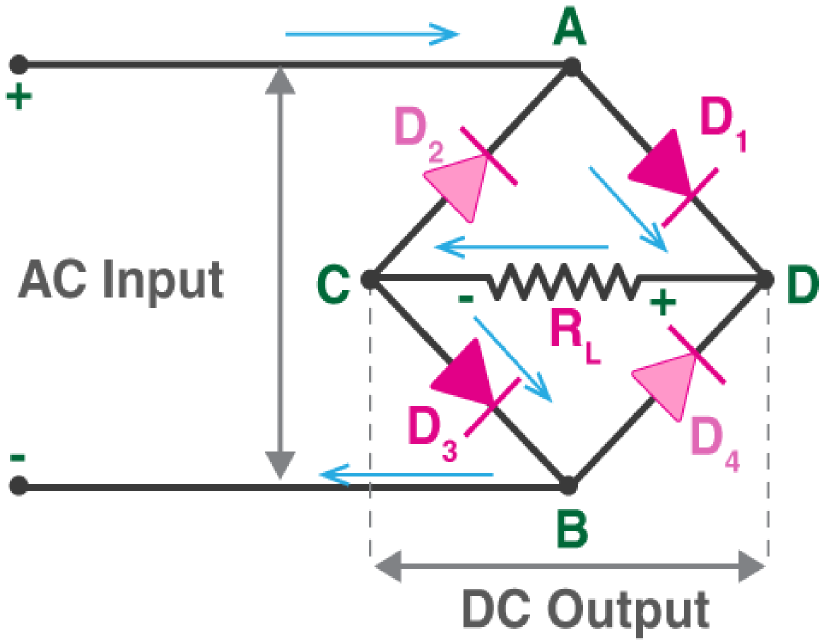




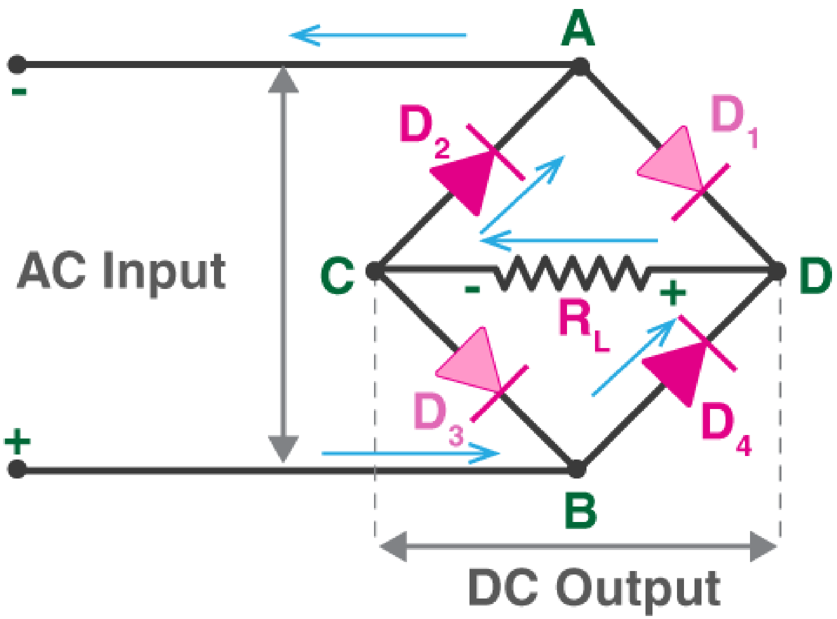


- **Working**

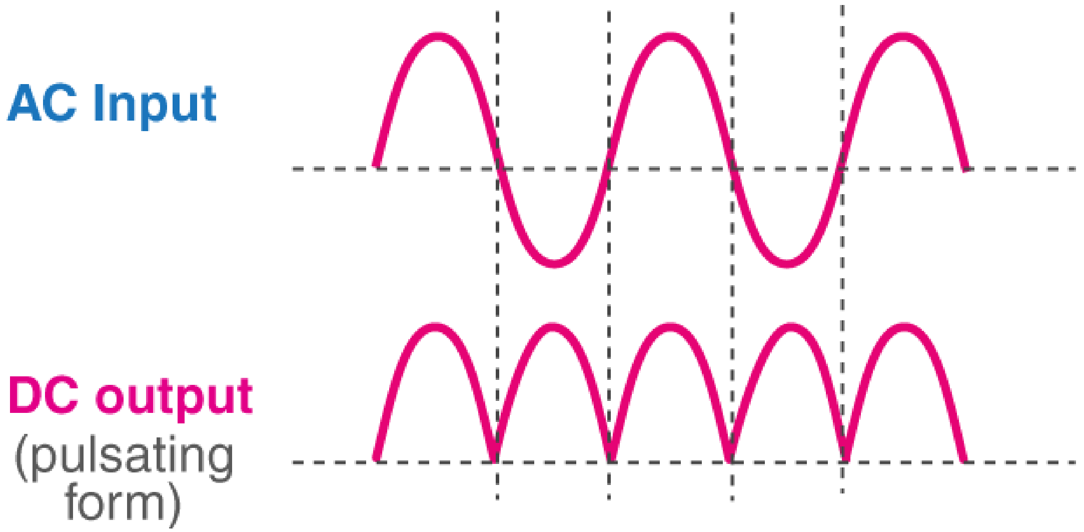
When an AC signal is applied across the bridge rectifier, terminal A becomes positive during the positive half cycle while terminal B becomes negative. This results in diodes D_1 and D_3 becoming forward biased while D_2 and D_4 becoming reverse biased. The current flow during the positive half-cycle is shown in the figure below:



During the negative half-cycle, terminal B becomes positive while terminal A becomes negative. This causes diodes D_2 and D_4 to become forward biased and diode D_1 and D_3 to be reverse biased.
The current flow during the negative half cycle is shown in the figure below:



- From the figures given above, we notice that the current flow across load resistor R_L is the same during the positive and negative half-cycles. The output DC signal polarity may be either completely positive or negative. In our case, it is completely positive. If the diodes' direction is reversed, we get a complete negative DC voltage.
- Thus, a bridge rectifier allows electric current during both positive and negative half cycles of the input AC signal.
- The output waveforms of the bridge rectifier are shown in the below figure.



Characteristics of Bridge Rectifier

- **Ripple Factor**

The smoothness of the output DC signal is measured by a factor known as the ripple factor. The output DC signal with fewer ripples is considered a smooth DC signal while the output with high ripples is considered a high pulsating DC signal.

- Mathematically, the ripple factor is defined as the ratio of ripple voltage to pure DC voltage.
- The ripple factor for a bridge rectifier is given by

$$\gamma = \sqrt{\left(\frac{V_{rms}{}^2}{V_{DC}}\right) - 1}$$

- For bridge rectifiers, the ripple factor is 0.48.
- **Peak Inverse Voltage**

The maximum voltage that a diode can withstand in the reverse bias condition is known as a peak inverse voltage. During the positive half cycle, the diodes D_1 and D_3 are in the conducting state while D_2 and D_4 are in the non-conducting state. Similarly, during the negative half cycle, diodes D_2 and D_4 are in the conducting state, and diodes D_1 and D_3 are in the non-conducting state.

- **Efficiency**
- The rectifier efficiency determines how efficiently the rectifier converts Alternating Current (AC) into Direct Current (DC). Rectifier efficiency is defined as the ratio of the DC output power to the AC input power. The maximum efficiency of a bridge rectifier is 81.2%.

$$\eta = \frac{DC\ Output\ Power}{AC\ Output\ Power}$$

- **Advantages**
- The efficiency of the bridge rectifier is higher than the efficiency of a half-wave rectifier. However, the rectifier efficiency of the bridge rectifier and the centre-tapped full-wave rectifier is the same.
- The DC output signal of the bridge rectifier is smoother than the output DC signal of a half-wave rectifier.
- In a half-wave rectifier, only half of the input AC signal is used, and the other half is blocked. Half of the input signal is wasted in a half-wave rectifier. However, in a bridge rectifier, the electric current is allowed during both positive and negative half cycles of the input AC signal. Hence, the output DC signal is almost equal to the input AC signal.
- **Disadvantages**
- The circuit of a bridge rectifier is complex when compared to a half-wave rectifier and centre-tapped full-wave rectifier. Bridge rectifiers use 4 diodes while half-wave rectifiers and centre-tapped full wave rectifiers use only two diodes.
- When more diodes are used more power loss occurs. In a centre-tapped full-wave rectifier, only one diode conducts during each half cycle. But in a bridge rectifier, two diodes connected in series conduct during each half cycle. Hence, the voltage drop is higher in a bridge rectifier.

Applications and Uses of Rectifiers

- The primary application of the rectifier is to derive DC power from AC power. Rectifiers are used inside the power supplies of almost all electronic equipment. In power supplies, the rectifier is normally placed in series following the transformer, a smoothing filter, and possibly a voltage regulator. Below, we have discussed a few rectifier applications:
- **A rectifier is used for powering appliances**
- As we know, all electrical appliances use a DC power supply to function. Using a rectifier in the power supply helps in converting AC to DC power supply. Bridge rectifiers are widely used for large appliances, which can convert high AC voltage to low DC voltage.
- **These are used with transformers**
- Using a half-wave rectifier can help us achieve the desired dc voltage by using step-down or step-up transformers. Full-wave rectifiers are even used for powering up the motor and led, which works on DC voltage.
- **Uses of rectifier while soldering**
- A half-wave rectifier is used in soldering iron types of circuits and is also used in mosquito repellent to drive the lead for the fumes. In electric welding, bridge rectifier circuits are used to supply steady and polarized DC voltage.

- **It is also used in AM radio**
- A half-wave rectifier is used in AM radio as a detector because the output consists of an audio signal. Due to the less intensity of the current, it is of very little use to the more complex rectifier.
- **Uses of Rectifier in circuits**
- A half-wave rectifier is used in firing circuits and pulse generating circuits.
- **It is used for modulation**
- A half-wave rectifier is used to demodulate the amplitude of a modulated signal. In a radio signal, a full-wave bridge rectifier is used to detect the amplitude of a modulating signal.
- **It is used in the voltage multiplier**
- For the purpose of the voltage multiplier, a half-wave rectifier is used.

Other Applications

- The rectifier diodes have many applications. Here are a few of the typical applications of diodes include:
- Rectifying a voltage, such as turning the AC into DC voltages
- Isolating signals from a supply
- Voltage Reference
- Controlling the size of a signal
- Mixing signals
- Detection signals
- Lighting systems

Questions and Answers

- **What is a halfwave rectifier?**

The rectifier circuit that converts alternating current into the direct current is known as a halfwave rectifier circuit. The half-wave rectifier passes only one half of the input sine wave and rejects the other half.

- **Where is a halfwave rectifier used?**

A half-wave rectifier is used in firing circuits and pulse generating circuits. Halfwave rectifiers are used along with step up and step down transformers to achieve the desired voltage.

- **How does a half-wave rectifier work?**

Half wave rectifier circuit uses a PN junction to convert the supplied AC into DC. In a half-wave rectifier circuit, the load resistance is connected in series with the PN junction diode.

- **Is the half-wave rectifier better or the full-wave rectifier?**

Full-wave rectifiers are more efficient than half-wave rectifiers. A full-wave rectifier passes twice as many waves as a half-wave rectifier. Hence, more of the input is transferred to the load.

- **What is the use of a filter in a half-wave rectifier?**

The filter in a half-wave rectifier is used to smoothen the pulsating fluctuating DC component.

- **What is a full wave rectifier?**

Full wave rectifiers convert both polarities of the input AC waveform to pulsating DC.

- **Why do we use a capacitor in full wave rectifier circuit?**

A capacitor is used in the circuit to reduce the ripple factor.

- **What is a centre tapped full wave rectifier?**

A centre tapped full wave rectifier is a type of rectifier that uses a centre tapped transformer and two diodes to convert the complete AC signal into DC signal.

- **Where is a full wave rectifier used?**

A full wave rectifier is used in signal modulation and in electric welding.

- **What are the disadvantages of full wave rectifiers?**

The full wave rectifiers are not suitable to use when a small voltage is required to be rectified. This is because, in a full wave circuit, two diodes are connected in series and offer double voltage drop due to internal resistances.

- **Define bridge rectifiers.**
- The bridge rectifier is a type of full-wave rectifier that uses four or more diodes in a bridge circuit configuration to convert alternating (AC) current to a direct (DC) current.
- **What is a rectifier?**
- A rectifier is an electronic device that converts an alternating current into a direct current by using one or more P-N junction diodes.
- **State true or false: The bridge rectifier allows electric current flow during both negative and positive half cycles of the input AC signal.**
- TRUE.
- **What is the maximum efficiency of a bridge rectifier?**
- The maximum efficiency of a bridge rectifier is 81.2%.

SOLVED PROBLEMS

ON TRANSISTOR

EXAMPLE 1

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

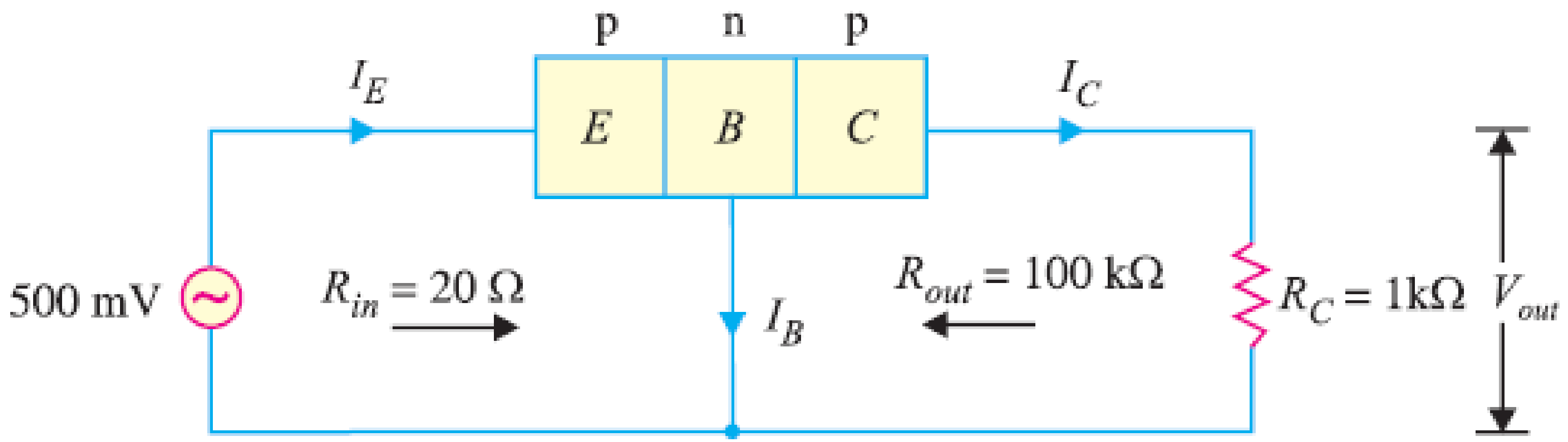


Fig. 1

Solution 1

- Fig.1 shows the conditions of the problem. Here the output resistance is very high as compared to input resistance, since the input junction (base to emitter) of the transistor is forward biased while the output junction (base to collector) is reverse biased.

Input current, $I_E = \frac{\text{Signal}}{R_{in}} = \frac{500\text{ mV}}{20\ \Omega} = 25\text{ mA}$. Since α_{ac} is nearly 1, output current, $I_C = I_E = 25\text{ mA}$.

$$\text{Output voltage, } V_{out} = I_C R_C = 25\text{ mA} \times 1\text{ k}\Omega = 25\text{ V}$$

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

Example 2

- **In a common base connection, I_E = 1mA, I_C = 0.95mA. Calculate the value of I_B .**

- Solution

Using the relation,

$$
\begin{aligned}
I_E &= I_B + I_C \\
1 &= I_B + 0.95 \\
I_B &= 1 - 0.95 = \mathbf{0.05\ mA}
\end{aligned}
$$

Example 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

$$\text{Here,}\quad \alpha = 0.9, \quad I_E = 1\text{ mA}$$

$$\text{Now} \qquad \alpha = \frac{I_C}{I_E}$$

$$\text{or} \qquad I_C = \alpha I_E = 0.9 \times 1 = 0.9\text{ mA}$$

$$\text{Also} \qquad I_E = I_B + I_C$$

$$\therefore \qquad \text{Base current, } I_B = I_E - I_C = 1 - 0.9 = \mathbf{0.1\ mA}$$

Example 4

- **In a common base connection, I_C = 0.95 mA and I_B = 0.05 mA. Find the value of α.**

- **Solution**

$$\text{We know } I_E = I_B + I_C = 0.05 + 0.95 = 1\ \text{mA}$$

$$\therefore \quad \text{Current amplification factor, } \alpha = \frac{I_C}{I_E} = \frac{0.95}{1} = \mathbf{0.95}$$

Example 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 α = 0.92.**
- **Solution**

$$\text{Here, } I_E = 1 \text{ mA}, \alpha = 0.92, \quad I_{CBO} = 50 \text{ µA}$$

$$\therefore \quad \text{Total collector current, } I_C = \alpha I_E + I_{CBO} = 0.92 \times 1 + 50 \times 10^{-3}$$

$$= 0.92 + 0.05 = \mathbf{0.97 \text{ mA}}$$

Example 6

- **In a common base connection, α = 0.95. The voltage drop across 2 kΩ resistance which is connected in the collector is 2V. Find the base current.**

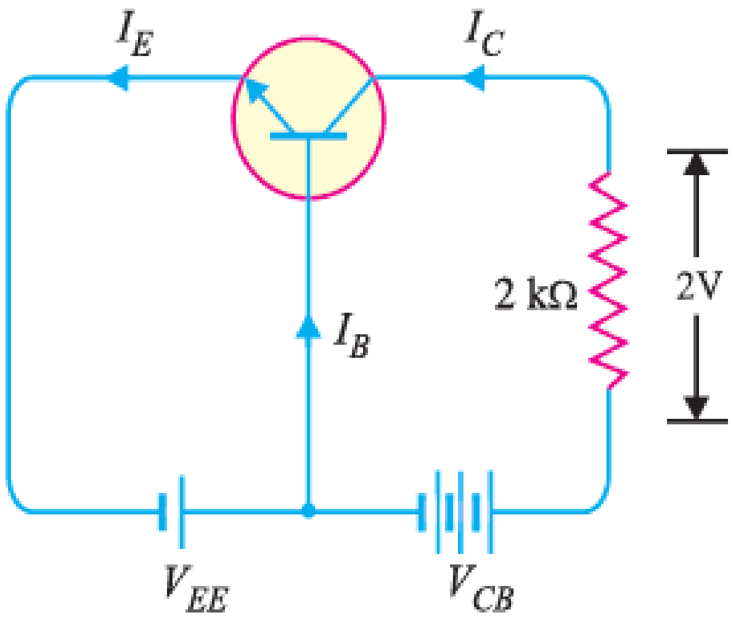


Fig. 2

Solution 6

- Fig. 2 shows the required common base connection.
- The voltage drop across RC (= 2 kΩ) is 2V.

$$\therefore \quad I_C = 2\text{ V}/2\text{ k}\Omega = 1\text{ mA}$$

Now $\quad \alpha = I_C/I_E$

$$\therefore \quad I_E = \frac{I_C}{\alpha} = \frac{1}{0.95} = 1.05\text{ mA}$$

Using the relation, $I_E = I_B + I_C$

$$\therefore \quad I_B = I_E - I_C = 1.05 - 1$$

$$= \mathbf{0.05\text{ mA}}$$

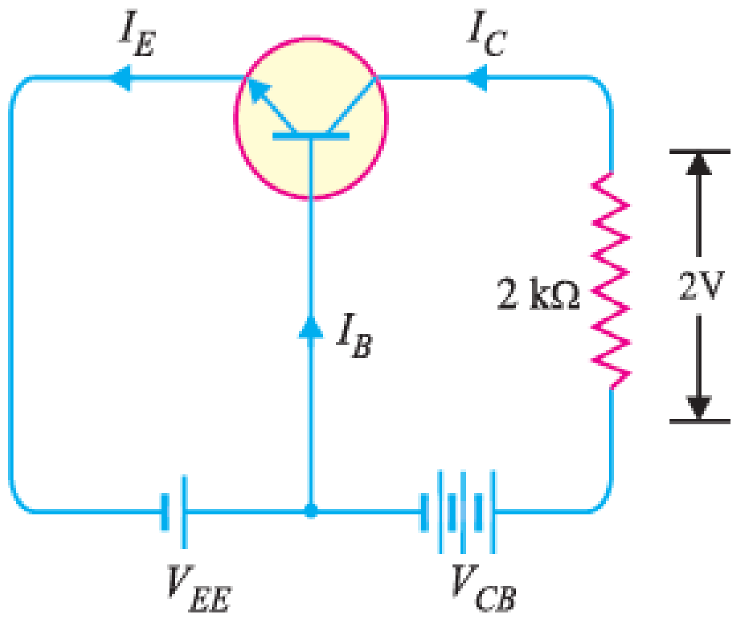


Fig. 2

Example 7

- **For the common base circuit shown in Fig. 3, determine I_C and V_{CB}. Assume the transistor to be of silicon.**

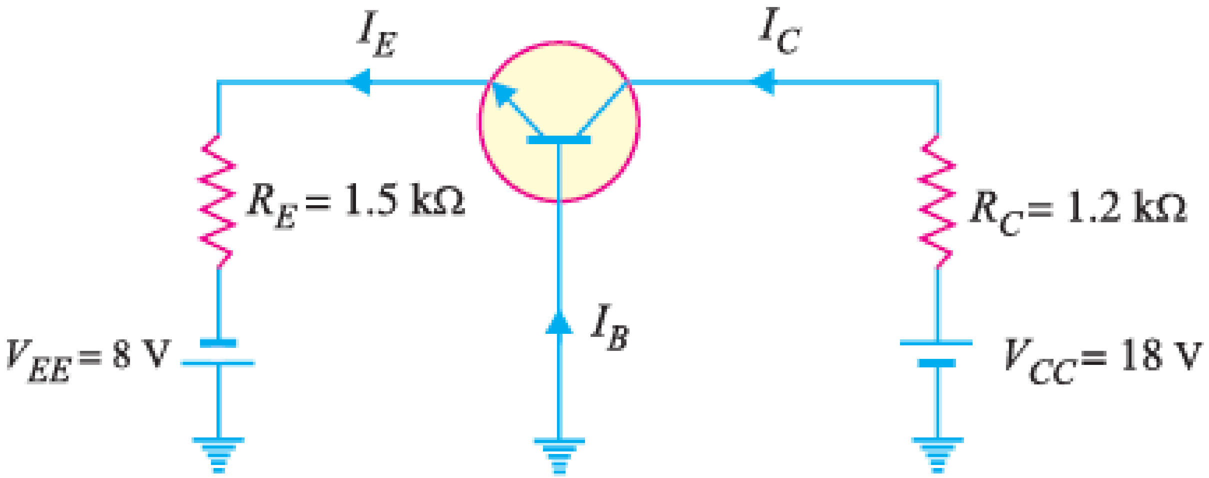


Fig. 3

Solution 7

Since the transistor is of silicon, VBE = 0.7V.

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

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

$$\text{or} \qquad I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

$$= \frac{8V - 0.7V}{1.5\ \text{k}\Omega} = 4.87\ \text{mA}$$

$$\therefore \qquad I_C \simeq I_E = 4.87\ \text{mA}$$

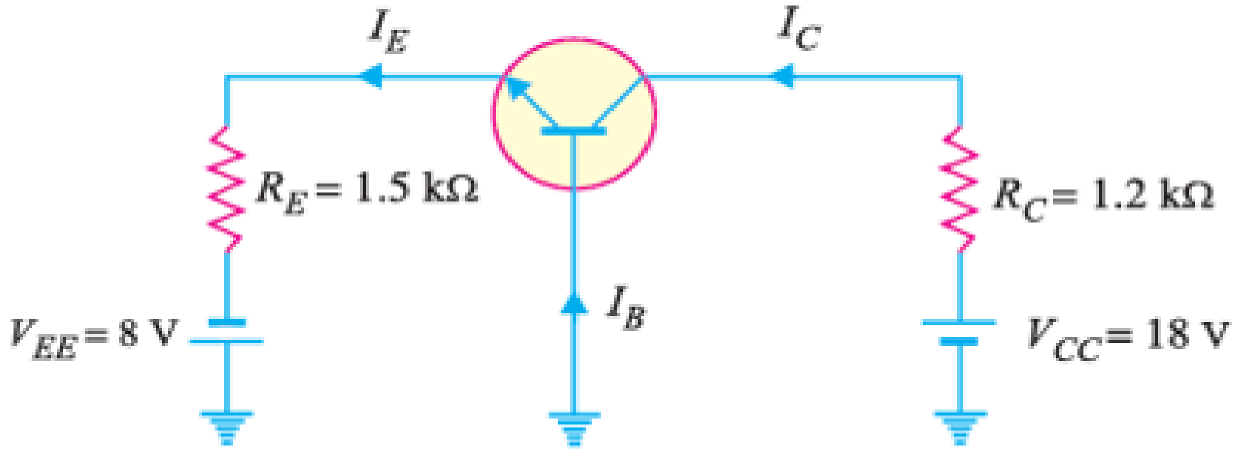


Fig. 3

Applying Kirchhoff's voltage law to the collector-side loop, we have,

$$V_{CC} = I_C R_C + V_{CB}$$

$$\therefore \qquad V_{CB} = V_{CC} - I_C R_C$$

$$= 18\ \text{V} - 4.87\ \text{mA} \times 1.2\ \text{k}\Omega = 12.16\ \text{V}$$

Example 8

Find the value of β if (i) α = 0.9 (ii) α = 0.98 (iii) α = 0.99.

(i) $\alpha = 0.9$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = 9$$

(ii) $\alpha = 0.98$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = 49$$

(iii) $\alpha = 0.99$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = 99$$

Example 9

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

Solution:

$$\text{Here } \beta = 50, \quad I_B = 20\mu A = 0.02 \text{ mA}$$

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

$$I_C = \beta I_B = 50 \times 0.02 = 1 \text{ mA}$$

$$\text{Using the relation, } I_E = I_B + I_C = 0.02 + 1 = 1.02 \text{ mA}$$

Example 10

- **Find the α rating of the transistor shown in Fig. 4. Hence determine the value of I_C using both α and β rating of the transistor.**

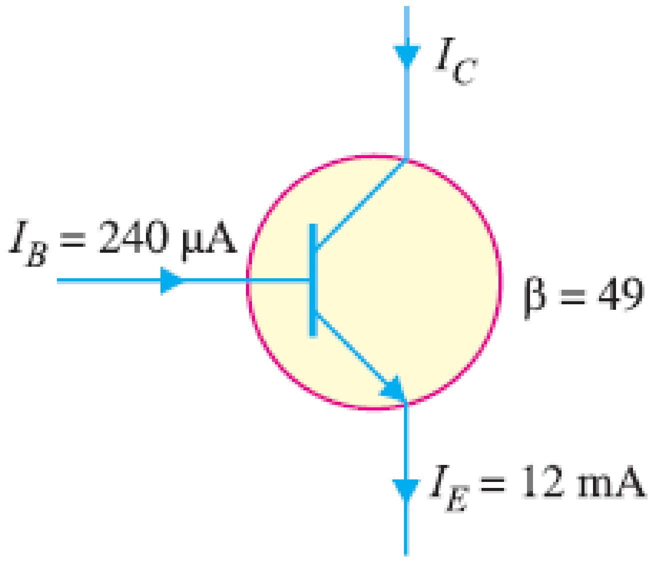


Fig. 4

Solution 10

$$\alpha = \frac{\beta}{1+\beta} = \frac{49}{1+49} = \mathbf{0.98}$$

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

$$I_C = \alpha I_E = 0.98\ (12\ \text{mA}) = \mathbf{11.76\ mA}$$

Also $$I_C = \beta I_B = 49\ (240\ \mu\text{A}) = \mathbf{11.76\ mA}$$

Example 11

For a transistor, β = 45 and voltage drop across 1kΩ which is connected in the collector circuit is 1 volt. Find the base current for common emitter connection.

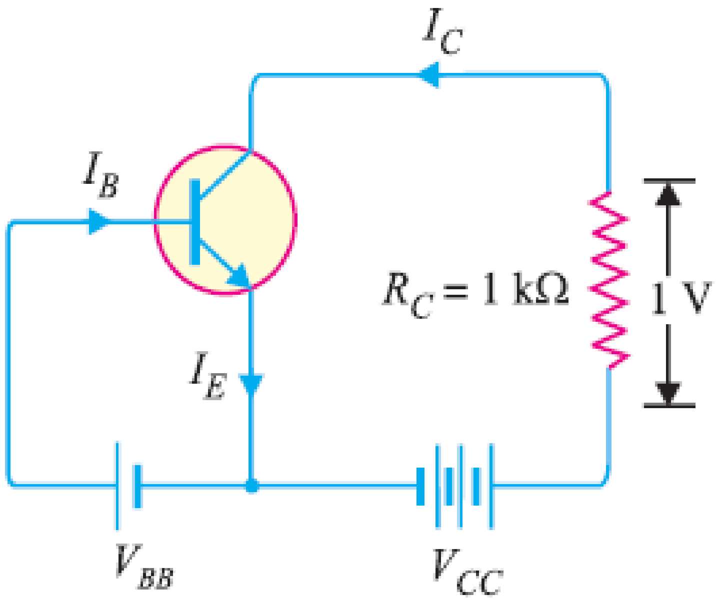


Fig. 5

Solution 11

- Fig. 5 shows the required common emitter connection. The voltage drop across RC (= 1 kΩ) is 1 volt.

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

$$\text{Now} \qquad \beta = \frac{I_C}{I_B}$$

$$\therefore \qquad I_B = \frac{I_C}{\beta} = \frac{1}{45} = \mathbf{0.022\text{ mA}}$$

Example 12

A transistor is connected in common emitter (CE) configuration in which collector supply is 8 V and the voltage drop across resistance R_C connected in the collector circuit is 0.5 V. The value of R_C = 800 Ω. If α = 0.96, determine : (i) collector-emitter voltage (ii) base current.

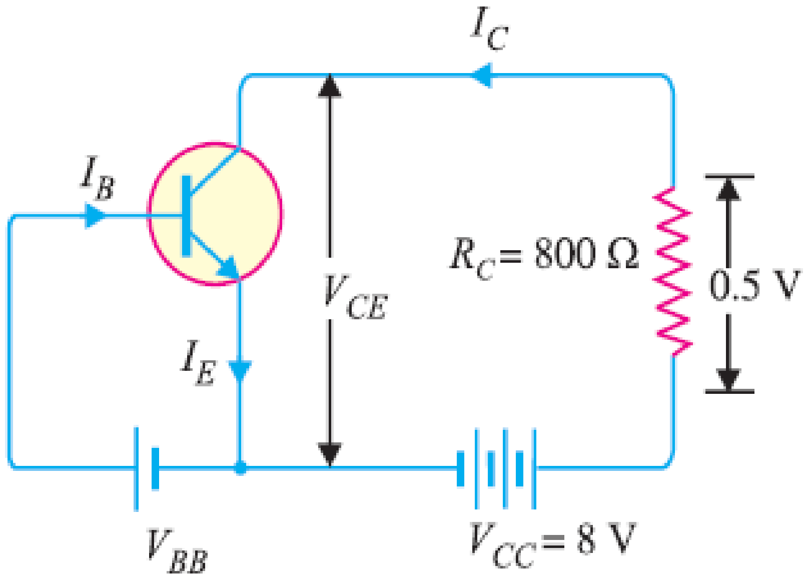


Fig.6

Solution 12

Fig. 6 shows the required common emitter connection with various values.

Collector-emitter voltage, **(i)**

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

(ii)

The voltage drop across R_C (= 800 Ω) is 0.5 V.

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

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

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

Example 13

An n-p-n transistor at room temperature has its emitter disconnected. A voltage of 5 V is applied between collector and base. With collector positive, a current of 0.2 μA flows. When the base is disconnected and the same voltage is applied between collector and emitter, the current is found to be 20 μA. Find α, I_E and I_B when collector current is 1 mA.

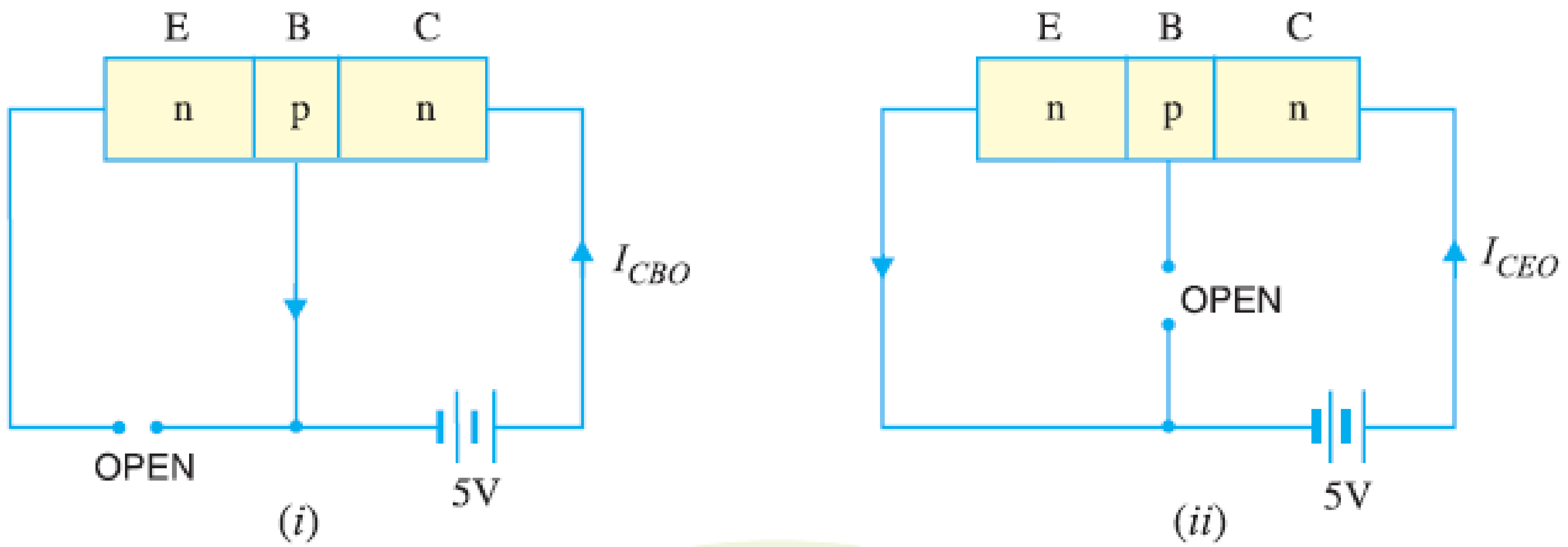


Fig. 7

Solution 13

When the emitter circuit is open as shown in Fig.7 (i) , the collector-base junction is reverse biased. A small leakage current ICBO flows due to minority carriers.

$$\therefore \quad I_{CBO} = 0.2\ \mu A \quad \text{...given}$$

When base is open [See Fig. 8.23 (*ii*)], a small leakage current I_{CEO} flows due to minority carriers.

$$\therefore \quad I_{CEO} = 20\ \mu A \quad \text{... given}$$

We know $$I_{CEO} = \frac{I_{CBO}}{1-\alpha}$$

or $$20 = \frac{0.2}{1-\alpha}$$

$$\therefore \quad \alpha = \mathbf{0.99}$$

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

Here $$I_C = 1\text{mA} = 1000\ \mu A\ ;\ \alpha = 0.99\ ;\ I_{CBO} = 0.2\ \mu A$$

$$\therefore \quad 1000 = 0.99 \times I_E + 0.2$$

or $$I_E = \frac{1000 - 0.2}{0.99} = \mathbf{1010\ \mu A}$$

and $$I_B = I_E - I_C = 1010 - 1000 = \mathbf{10\ \mu A}$$

Example 14

- **The collector leakage current in a transistor is 300 μA in CE arrangement. If now the transistor is connected in CB arrangement, what will be the leakage current? Given that β = 120.**

Solution 14

$$I_{CEO} = 300\ \mu A$$

$$\beta = 120 \quad ; \quad \alpha = \frac{\beta}{\beta+1} = \frac{120}{120+1} = 0.992$$

$$I_{CEO} = \frac{I_{CBO}}{1-\alpha}$$

$$I_{CBO} = (1-\alpha)\, I_{CEO} = (1-0.992) \times 300 = \mathbf{2.4\ \mu A}$$

Note that leakage current in *CE* arrangement (*i.e.* I_{CEO}) is much more than in *CB* arrangement (*i.e.* I_{CBO}).

Example 15

- **Determine V_{CB} in the transistor circuit shown in Fig. 10 (i). The transistor is of silicon and has β = 150.**

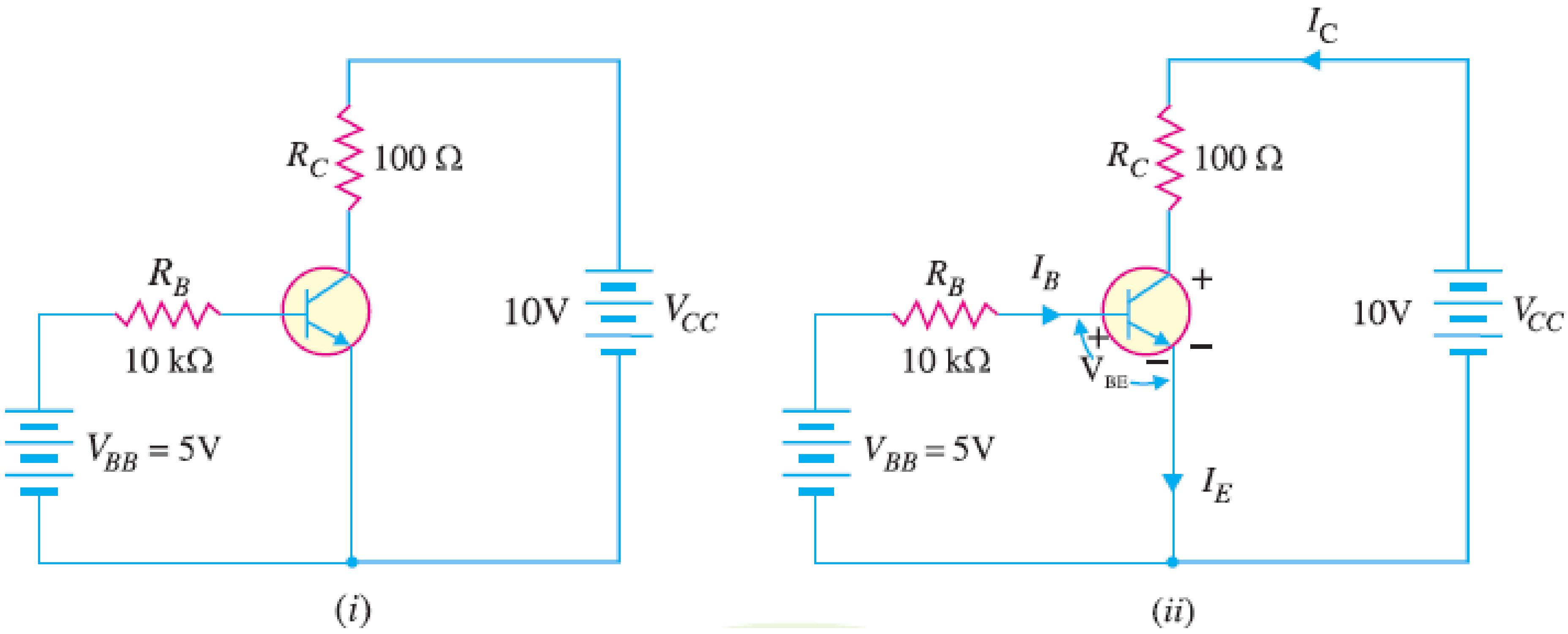


Fig.10

Solution 15

Fig. 10 (i) shows the transistor circuit while Fig. 10 (ii) shows the various currents and voltages along with polarities.

Applying Kirchhoff's voltage law to base-emitter loop, we have,

$$V_{BB} - I_B R_B - V_{BE} = 0$$

or $$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{V} - 0.7\text{V}}{10\ k\Omega} = 430\ \mu\text{A}$$

∴ $$I_C = \beta I_B = (150)(430\ \mu\text{A}) = 64.5\text{ mA}$$

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

$$= 10\text{V} - (64.5\text{ mA})\,(100\Omega) = 10\text{V} - 6.45\text{V} = 3.55\text{V}$$

We know that : $$V_{CE} = V_{CB} + V_{BE}$$

∴ $$V_{CB} = V_{CE} - V_{BE} = 3.55 - 0.7 = 2.85\text{V}$$

Example 16

For the circuit shown in Fig. 12 , draw the d.c. load line.

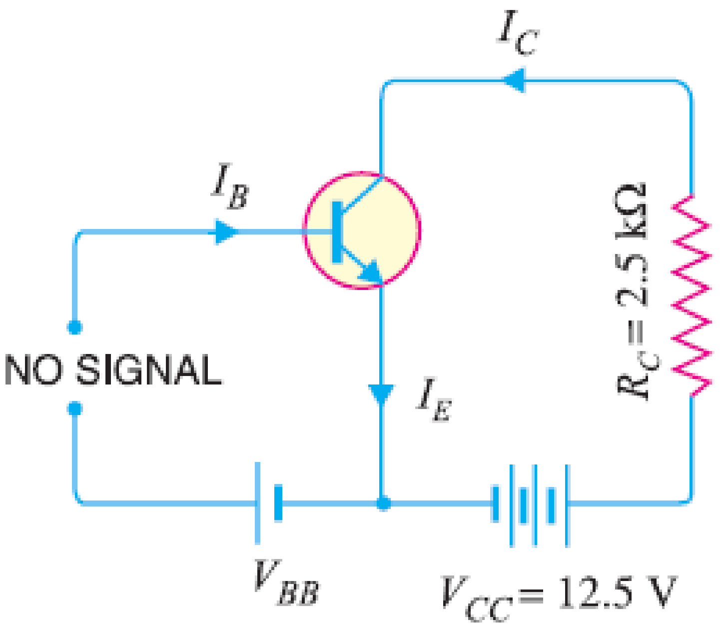


Fig.12

Solution 16

The collector-emitter voltage V_{CE} is given by;

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

When $I_C = 0$, then,

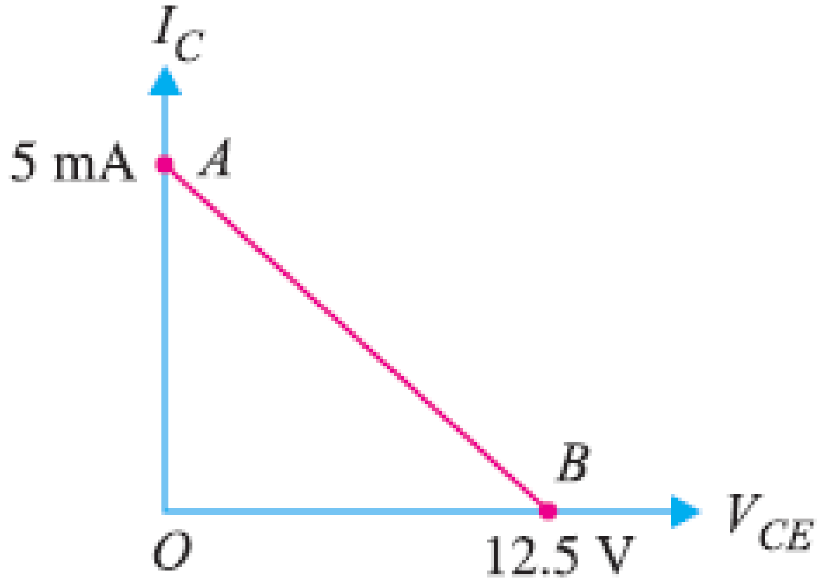
$$V_{CE} = V_{CC} = 12.5 \text{ V}$$

This locates the point B of the load line on the collector-emitter voltage axis.

When $V_{CE} = 0$, then,

$$I_C = V_{CC}/R_C = 12.5 \text{ V}/2.5 \text{ k}\Omega = 5 \text{ mA}$$

This locates the point A of the load line on the collector current axis. By joining these two points, we get the d.c. load line AB as shown in Figure.



Example 17

- **In the circuit diagram shown in Fig. 14, if V_{CC} = 12V and R_C = 6 kΩ, draw the d.c. load line. What will be the Q point if zero signal base current is 20μA and β = 50 ?**

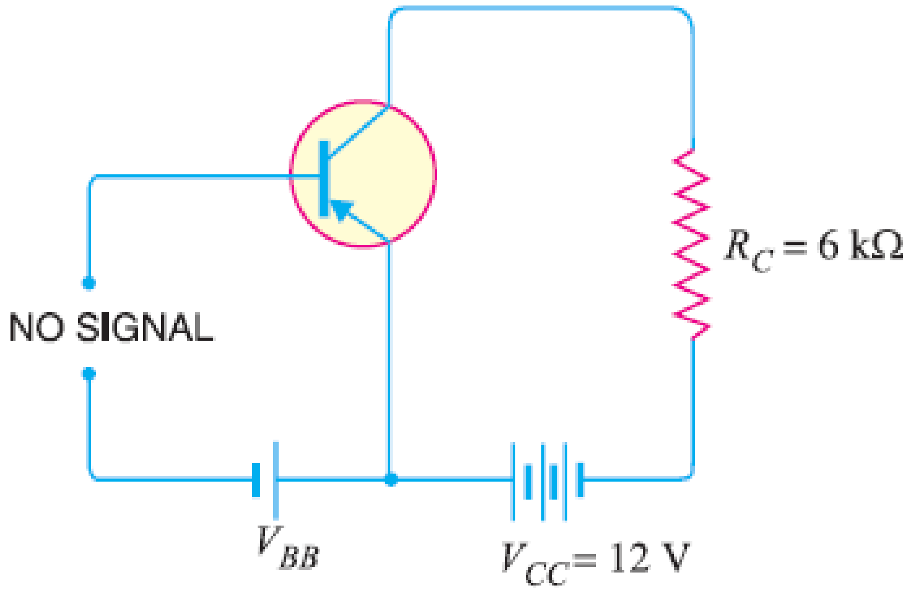


Fig.14

Solution 17

The collector-emitter voltage V_{CE} is given by :

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

When $I_C = 0$, $V_{CE} = V_{CC} = 12$ V. This locates the point B of the load line.
When $V_{CE} = 0$, $I_C = V_{CC} / R_C = 12\text{ V}/6\text{ k}\Omega = 2\text{ mA}$.
This locates the point A of the load line. By joining these two points, load line AB is constructed as shown in 15.

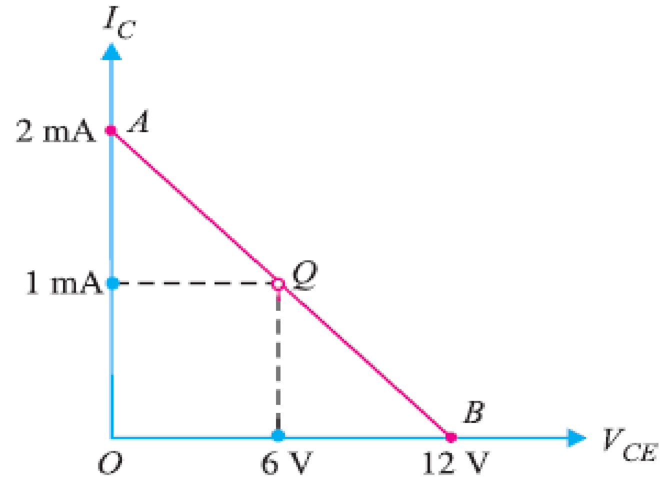


Fig. 15

Zero signal base current, $I_B = 20\ \mu A = 0.02$ mA

Current amplification factor, $\beta = 50$

$\therefore$ Zero signal collector current, $I_C = \beta I_B = 50 \times 0.02 = 1$ mA

Zero signal collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C = 12 - 1\text{ mA} \times 6\text{ k}\Omega = 6\text{ V}$$

$\therefore$ Operating point is **6 V, 1 mA.**

Fig. 15 shows the Q point. Its co-ordinates are $I_C = 1$ mA and $V_{CE} = 6$ V.

Example 18

In a transistor circuit, collector load is 4 kΩ whereas quiescent current (zero signal collector current) is 1 mA. (i) What is the operating point if V_{CC} = 10 V ? (ii) What will be the operating point if R_C = 5 kΩ ?

- **Solution :**

$$V_{CC} = 10\text{ V}, I_C = 1\text{ mA}$$

(i) When collector load RC = 4 k Ω , then,

$$V_{CE} = V_{CC} - I_C R_C = 10 - 1\text{ mA} \times 4\text{ k}\Omega = 10 - 4 = 6\ V$$

∴ Operating point is 6 V, 1 mA.

(ii) When collector load RC = 5 k Ω , then,

$$V_{CE} = V_{CC} - I_C R_C = 10 - 1\text{ mA} \times 5\text{ k}\Omega = 10 - 5 = 5\ V$$

∴ Operating point is 5 V, 1 mA.

Example 19

- **Determine the Q point of the transistor circuit shown in Fig. 16. Also draw the d.c. load line. Given β = 200 and V_{BE} = 0.7V.**

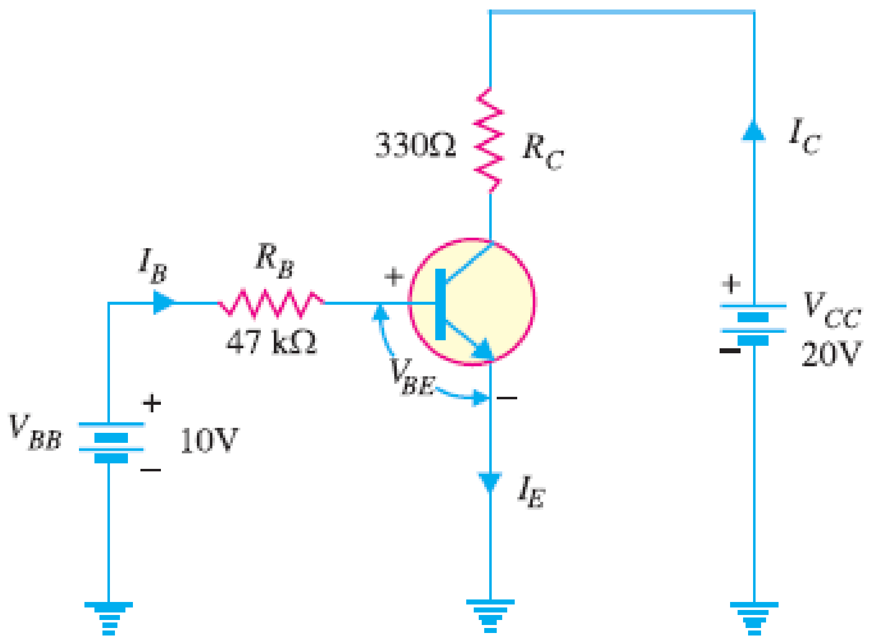


Fig. 16

Solution 19

The presence of resistor R_B in the base circuit should not disturb you because we can apply Kirchhoff's voltage law to find the value of I_B and hence I_C (= βI_B). Referring to Fig. 16 and applying Kirchhoff's voltage law to base-emitter loop, we have,

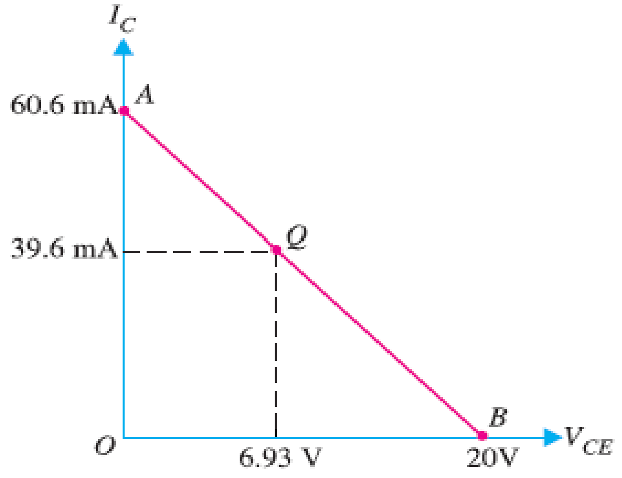
$$V_{BB} - I_B R_B - V_{BE} = 0$$

$$\therefore \quad I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{10V - 0.7V}{47\,k\Omega} = 198\ \mu A$$

Now $\quad I_C = \beta I_B = (200)(198\ \mu A) = 39.6\ mA$

Also $\quad V_{CE} = V_{CC} - I_C R_C = 20V - (39.6mA)(330\ \Omega) = 20V - 13.07V = 6.93V$

Therefore, the Q-point is I_C = **39.6 mA** and V_{CE} = **6.93V.**



D.C. load line:

In order to draw the d.c. load line, we need two end points.

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

When $I_C = 0$, $V_{CE} = V_{CC}$ = 20V. This locates the point B of the load line on the collector-emitter voltage axis as shown in Fig. 17. When $V_{CE} = 0$, $I_C = V_{CC} / R_C$ = 20V/330Ω = 60.6 mA. This locates the point A of the load line on the collector current axis. By joining these two points, d.c. load line AB is constructed as shown in Fig. 17.

Example 20

Determine the Q point of the transistor circuit shown in Fig. 18. Also draw the d.c. load line. Given $\beta = 100$ and $V_{BE} = 0.7V$.

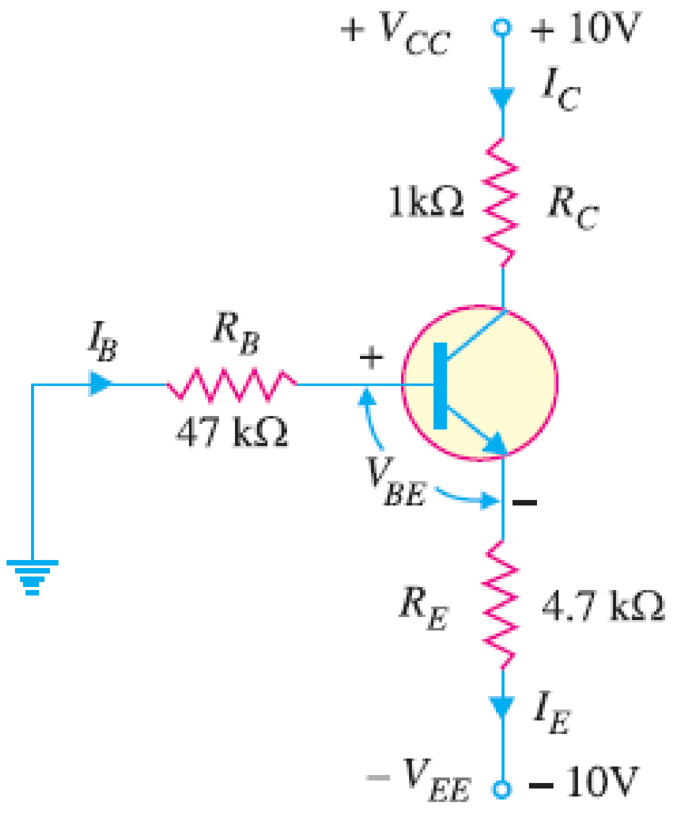


Fig.18

Solution 20

The transistor circuit shown in Fig. 18 may look complex but we can easily apply Kirchhoff's voltage law to find the various voltages and currents in the circuit.

Applying Kirchhoff's voltage law to the base-emitter loop, we have,

$$-I_B R_B - V_{BE} - I_E R_E + V_{EE} = 0 \quad \text{or} \quad V_{EE} = I_B R_B + I_E R_E + V_{BE}$$

Now $I_C = \beta I_B$ and $I_C \simeq I_E$. $\therefore$ $I_B = I_E/\beta$. Putting $I_B = I_E/\beta$ in the above equation, we have,

$$V_{EE} = \left(\frac{I_E}{\beta}\right) R_B + I_E R_E + V_{BE}$$

or $$I_E\left(\frac{R_B}{\beta} + R_E\right) = V_{EE} - V_{BE} \quad \text{or} \quad I_E = \frac{V_{EE} - V_{BE}}{R_E + R_B/\beta}$$

Since $I_C \simeq I_E$, $$I_C = \frac{V_{EE} - V_{BE}}{R_E + R_B/\beta} = \frac{10\text{V} - 0.7\text{V}}{4.7\text{ k}\Omega + 47\text{ k}\Omega/100} = \frac{9.3\text{ V}}{5.17\text{ k}\Omega} = 1.8\text{ mA}$$

Applying Kirchhoff's voltage law to the collector side, we have,

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

or $$V_{CE} = V_{CC} + V_{EE} - I_C(R_C + R_E) \qquad (\because\ I_E \simeq I_C)$$

$$= 10\text{V} + 10\text{V} - 1.8\text{ mA}\,(1\text{ k}\Omega + 4.7\text{ k}\Omega) = 9.74\text{V}$$

Therefore, the operating point of the circuit is I_C = **1.8 mA** and V_{CE} = **9.74V.**

DC load line

The d.c. load line can be constructed as under :

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

When $I_C = 0$; $V_{CE} = V_{CC} + V_{EE} = 10V + 10V = 20V$. This locates the first point B ($OB = 20V$) of the load line on the collector-emitter voltage axis. When $V_{CE} = 0$,

$$I_C = \frac{V_{CC} + V_{EE}}{R_C + R_E} = \frac{10V + 10V}{1\,k\Omega + 4.7\,k\Omega} = \frac{20V}{5.7\,k\Omega} = 3.51 \text{ mA}$$

This locates the second point A (OA = 3.51 mA) of the load line on the collector current axis. By joining points A and B, d.c. load line AB is constructed as shown in Fig. 19.

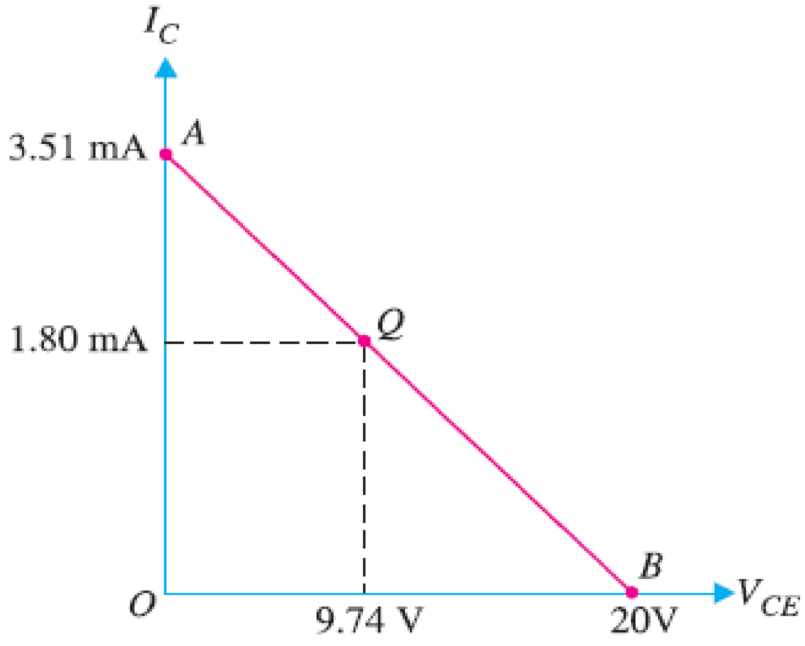


Fig 19