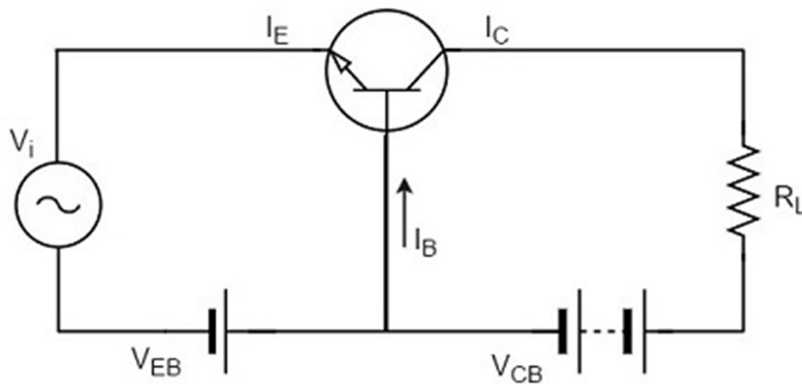


## UNIT II

### Transistor as an Amplifier

A transistor acts as an amplifier by raising the strength of a weak signal. The DC bias voltage applied to the emitter base junction, makes it remain in forward biased condition. This forward bias is maintained regardless of the polarity of the signal. The below figure shows how a transistor looks like when connected as an amplifier.



The low resistance in input circuit, lets any small change in input signal to result in an appreciable change in the output. The emitter current caused by the input signal contributes the collector current, which when flows through the load resistor  $R_L$ , results in a large voltage drop across it. Thus a small input voltage results in a large output voltage, which shows that the transistor works as an amplifier.

### Example

Let there be a change of 0.1v in the input voltage being applied, which further produces a change of 1mA in the emitter current. This emitter current will obviously produce a change in collector current, which would also be 1mA.

A load resistance of 5k $\Omega$  placed in the collector would produce a voltage of

$$5 \text{ k}\Omega \times 1 \text{ mA} = 5\text{V}$$

Hence it is observed that a change of 0.1v in the input gives a change of 5v in the output, which means the voltage level of the signal is amplified.

### Performance of Amplifier

As the common emitter mode of connection is mostly adopted, let us first understand a few important terms with reference to this mode of connection.

#### Input Resistance

As the input circuit is forward biased, the input resistance will be low. The input resistance is the opposition offered by the base-emitter junction to the signal flow.

By definition, it is the ratio of small change in base-emitter voltage ( $\Delta V_{BE}$ ) to the resulting change in base current ( $\Delta I_B$ ) at constant collector-emitter voltage.

$$\text{Output resistance} = R_o = \frac{\Delta V_{CE}}{\Delta I_C}$$

Where  $R_o$  = Output resistance,  $V_{CE}$  = Collector-emitter voltage, and  $I_C$  = Collector-emitter voltage.

### Effective Collector Load

The load is connected at the collector of a transistor and for a single-stage amplifier, the output voltage is taken from the collector of the transistor and for a multi-stage amplifier, the same is collected from a cascaded stages of transistor circuit.

By definition, it is the total load as seen by the a.c. collector current. In case of single stage amplifiers, the effective collector load is a parallel combination of  $R_C$  and  $R_o$ .

$$\begin{aligned} \text{Effective Collector Load, } R_{AC} &= R_C // R_o \\ &= \frac{R_C \times R_o}{R_C + R_o} = R_{AC} \end{aligned}$$

Hence for a single stage amplifier, effective load is equal to collector load  $R_C$ .

In a multi-stage amplifier (i.e. having more than one amplification stage), the input resistance  $R_i$  of the next stage also comes into picture.

Effective collector load becomes parallel combination of  $R_C$ ,  $R_o$  and  $R_i$  i.e.,

$$\begin{aligned} \text{Effective Collector Load, } R_{AC} &= R_C // R_o // R_i \\ R_C // R_i &= \frac{R_C R_i}{R_C + R_i} \end{aligned}$$

As input resistance  $R_i$  is quite small, therefore effective load is reduced.

### Current Gain

The gain in terms of current when the changes in input and output currents are observed, is called as **Current gain**. By definition, it is the ratio of change in collector current ( $\Delta I_C$ ) to the change in base current ( $\Delta I_B$ ).

$$\text{Current gain, } \beta = \frac{\Delta I_C}{\Delta I_B}$$

The value of  $\beta$  ranges from 20 to 500. The current gain indicates that input current becomes  $\beta$  times in the collector current.

### Voltage Gain

The gain in terms of voltage when the changes in input and output currents are observed, is called as **Voltage gain**. By definition, it is the ratio of change in output voltage ( $\Delta V_{CE}$ ) to the change in input voltage ( $\Delta V_{BE}$ ).

$$\begin{aligned}\text{Voltage gain, } A_V &= \frac{\Delta V_{CE}}{\Delta V_{BE}} \\ &= \frac{\text{Change in output current} \times \text{effective load}}{\text{Change in input current} \times \text{input resistance}} \\ &= \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i} = \frac{\Delta I_C}{\Delta I_B} \times \frac{R_{AC}}{R_i} = \beta \times \frac{R_{AC}}{R_i}\end{aligned}$$

For a single stage,  $R_{AC} = R_C$ .

However, for Multistage,

$$R_{AC} = \frac{R_C \times R_i}{R_C + R_i}$$

### Power Gain

The gain in terms of power when the changes in input and output currents are observed, is called as **Power gain**.

By definition, it is the ratio of output signal power to the input signal power.

$$\begin{aligned}\text{Power gain, } A_P &= \frac{(\Delta I_C)^2 \times R_{AC}}{(\Delta I_B)^2 \times R_i} \\ &= \left( \frac{\Delta I_C}{\Delta I_B} \right) \times \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i} \\ &= \text{Current gain} \times \text{Voltage gain}\end{aligned}$$

### Multi-stage Amplifier:

In practical applications, the output of a single state amplifier is usually insufficient, though it is a voltage or power amplifier. Hence they are replaced by **Multi-stage transistor amplifiers**.

In Multi-stage amplifiers, the output of first stage is coupled to the input of next stage using a coupling device. These coupling devices can usually be a capacitor or a transformer. This process of joining two amplifier stages using a coupling device can be called as **Cascading**.

The following figure shows a two-stage amplifier connected in cascade.



The overall gain is the product of voltage gain of individual stages.

$$A_V = A_{V1} \times A_{V2} = \frac{V_2}{V_1} \times \frac{V_0}{V_2} = \frac{V_0}{V_1}$$

Where  $A_V$  = Overall gain,  $A_{V1}$  = Voltage gain of 1<sup>st</sup> stage, and  $A_{V2}$  = Voltage gain of 2<sup>nd</sup> stage.

If there are **n** number of stages, the product of voltage gains of those **n** stages will be the overall gain of that multistage amplifier circuit.

### Purpose of coupling device

The basic purposes of a coupling device are

- To transfer the AC from the output of one stage to the input of next stage.
- To block the DC to pass from the output of one stage to the input of next stage, which means to isolate the DC conditions.

### Types of Coupling

Joining one amplifier stage with the other in cascade, using coupling devices form a **Multi-stage amplifier circuit**. There are **four** basic methods of coupling, using these coupling devices such as resistors, capacitors, transformers etc. Let us have an idea about them.

#### Resistance-Capacitance Coupling

This is the mostly used method of coupling, formed using simple **resistor-capacitor** combination. The capacitor which allows AC and blocks DC is the main coupling element used here.

The coupling capacitor passes the AC from the output of one stage to the input of its next stage. While blocking the DC components from DC bias voltages to effect the next stage. Let us get into the details of this method of coupling in the coming chapters.

#### Impedance Coupling

The coupling network that uses **inductance** and **capacitance** as coupling elements can be called as Impedance coupling network.

In this impedance coupling method, the impedance of coupling coil depends on its inductance and signal frequency which is  $j\omega L$ . This method is not so popular and is seldom employed.

#### Transformer Coupling

The coupling method that uses a **transformer as the coupling** device can be called as Transformer coupling. There is no capacitor used in this method of coupling because the transformer itself conveys the AC component directly to the base of second stage.

The secondary winding of the transformer provides a base return path and hence there is no need of base resistance. This coupling is popular for its efficiency and its impedance matching and hence it is mostly used.

#### Direct Coupling

If the previous amplifier stage is connected to the next amplifier stage directly, it is called as **direct coupling**. The individual amplifier stage bias conditions are so designed that the stages can be directly connected without DC isolation.

The direct coupling method is mostly used when the load is connected in series, with the output terminal of the active circuit element. For example, head-phones, loud speakers etc.

### **Role of Capacitors in Amplifiers**

Other than the coupling purpose, there are other purposes for which few capacitors are especially employed in amplifiers. To understand this, let us know about the role of capacitors in Amplifiers.

#### **The Input Capacitor $C_{in}$**

The input capacitor  $C_{in}$  present at the initial stage of the amplifier, couples AC signal to the base of the transistor. This capacitor  $C_{in}$  if not present, the signal source will be in parallel to resistor  $R_2$  and the bias voltage of the transistor base will be changed.

Hence  $C_{in}$  allows, the AC signal from source to flow into input circuit, without affecting the bias conditions.

#### **The Emitter By-pass Capacitor $C_e$**

The emitter by-pass capacitor  $C_e$  is connected in parallel to the emitter resistor. It offers a low reactance path to the amplified AC signal.

In the absence of this capacitor, the voltage developed across  $R_E$  will feedback to the input side thereby reducing the output voltage. Thus in the presence of  $C_e$  the amplified AC will pass through this.

#### **Coupling Capacitor $C_C$**

The capacitor  $C_C$  is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the operating point from shifting. This is also called as **blocking capacitor** because it does not allow the DC voltage to pass through it.

In the absence of this capacitor,  $R_C$  will come in parallel with the resistance  $R_1$  of the biasing network of the next stage and thereby changing the biasing conditions of the next stage.

### **Amplifier Consideration**

For an amplifier circuit, the overall gain of the amplifier is an important consideration. To achieve maximum voltage gain, let us find the most suitable transistor configuration for cascading.

#### **CC Amplifier**

- Its voltage gain is less than unity.
- It is not suitable for intermediate stages.

#### **CB Amplifier**

- Its voltage gain is less than unity.
- Hence not suitable for cascading.

## CE Amplifier

- Its voltage gain is greater than unity.
- Voltage gain is further increased by cascading.

The characteristics of CE amplifier are such that, this configuration is very suitable for cascading in amplifier circuits. Hence most of the amplifier circuits use CE configuration.

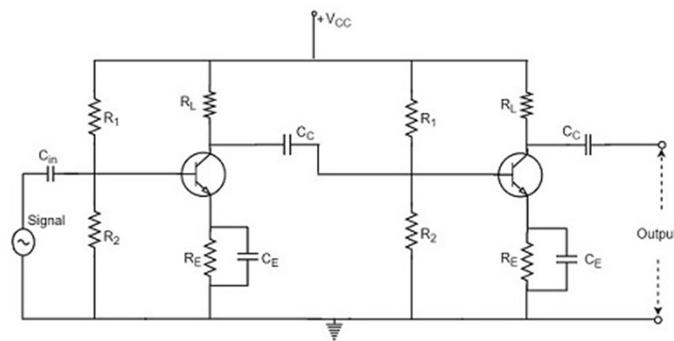
## RC Coupling Amplifier

The resistance-capacitance coupling is, in short termed as RC coupling. This is the mostly used coupling technique in amplifiers.

### Construction of a Two-stage RC Coupled Amplifier

The constructional details of a two-stage RC coupled transistor amplifier circuit are as follows. The two stage amplifier circuit has two transistors, connected in CE configuration and a common power supply  $V_{CC}$  is used. The potential divider network  $R_1$  and  $R_2$  and the resistor  $R_E$  form the biasing and stabilization network. The emitter by-pass capacitor  $C_E$  offers a low reactance path to the signal.

The resistor  $R_L$  is used as a load impedance. The input capacitor  $C_{in}$  present at the initial stage of the amplifier couples AC signal to the base of the transistor. The capacitor  $C_C$  is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the shift of operating point. The figure below shows the circuit diagram of RC coupled amplifier.



### Operation of RC Coupled Amplifier

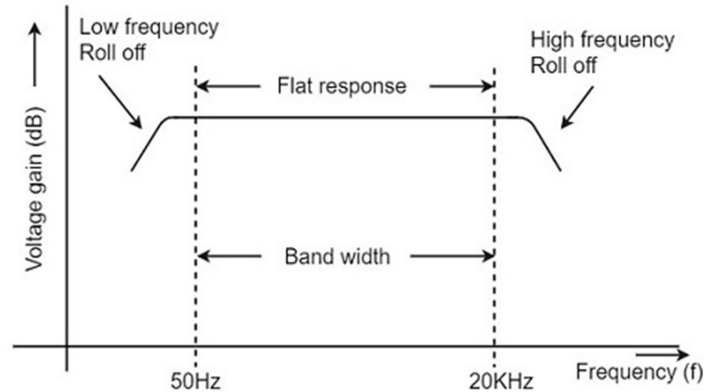
When an AC input signal is applied to the base of first transistor, it gets amplified and appears at the collector load  $R_L$  which is then passed through the coupling capacitor  $C_C$  to the next stage. This becomes the input of the next stage, whose amplified output again appears across its collector load. Thus the signal is amplified in stage by stage action.

The important point that has to be noted here is that the total gain is less than the product of the gains of individual stages. This is because when a second stage is made to follow the first stage, the **effective load resistance** of the first stage is reduced due to the shunting effect of the input resistance of the second stage. Hence, in a multistage amplifier, only the gain of the last stage remains unchanged.

As we consider a two stage amplifier here, the output phase is same as input. Because the phase reversal is done two times by the two stage CE configured amplifier circuit.

### Frequency Response of RC Coupled Amplifier

Frequency response curve is a graph that indicates the relationship between voltage gain and function of frequency. The frequency response of a RC coupled amplifier is as shown in the following graph.



From the above graph, it is understood that the frequency rolls off or decreases for the frequencies below 50Hz and for the frequencies above 20 KHz. whereas the voltage gain for the range of frequencies between 50Hz and 20 KHz is constant.

We know that,

$$X_C = \frac{1}{2\pi f_c}$$

It means that the capacitive reactance is inversely proportional to the frequency.

#### At Low frequencies (i.e. below 50 Hz)

The capacitive reactance is inversely proportional to the frequency. At low frequencies, the reactance is quite high. The reactance of input capacitor  $C_{in}$  and the coupling capacitor  $C_C$  are so high that only small part of the input signal is allowed. The reactance of the emitter by pass capacitor  $C_E$  is also very high during low frequencies. Hence it cannot shunt the emitter resistance effectively. With all these factors, the voltage gain rolls off at low frequencies.

#### At High frequencies (i.e. above 20 KHz)

Again considering the same point, we know that the capacitive reactance is low at high frequencies. So, a capacitor behaves as a short circuit, at high frequencies. As a result of this, the loading effect of the next stage increases, which reduces the voltage gain. Along with this, as the capacitance of emitter diode decreases, it increases the base current of the transistor due to which the current gain ( $\beta$ ) reduces. Hence the voltage gain rolls off at high frequencies.

#### At Mid-frequencies (i.e. 50 Hz to 20 KHz)

The voltage gain of the capacitors is maintained constant in this range of frequencies, as shown in figure. If the frequency increases, the reactance of the capacitor  $C_C$  decreases which tends to increase the gain. But this lower capacitance reactive increases the loading effect of the next stage by which there is a reduction in gain.

Due to these two factors, the gain is maintained constant.

### **Advantages of RC Coupled Amplifier**

The following are the advantages of RC coupled amplifier.

- The frequency response of RC amplifier provides constant gain over a wide frequency range, hence most suitable for audio applications.
- The circuit is simple and has lower cost because it employs resistors and capacitors which are cheap.
- It becomes more compact with the upgrading technology.

### **Disadvantages of RC Coupled Amplifier**

The following are the disadvantages of RC coupled amplifier.

- The voltage and power gain are low because of the effective load resistance.
- They become noisy with age.
- Due to poor impedance matching, power transfer will be low.

### **Applications of RC Coupled Amplifier**

The following are the applications of RC coupled amplifier.

- They have excellent audio fidelity over a wide range of frequency.
- Widely used as Voltage amplifiers
- Due to poor impedance matching, RC coupling is rarely used in the final stages.

### **Transformer Coupled Amplifier:**

We have observed that the main drawback of RC coupled amplifier is that the effective load resistance gets reduced. This is because, the input impedance of an amplifier is low, while its output impedance is high.

When they are coupled to make a multistage amplifier, the high output impedance of one stage comes in parallel with the low input impedance of next stage. Hence, effective load resistance is decreased. This problem can be overcome by a **transformer coupled amplifier**.

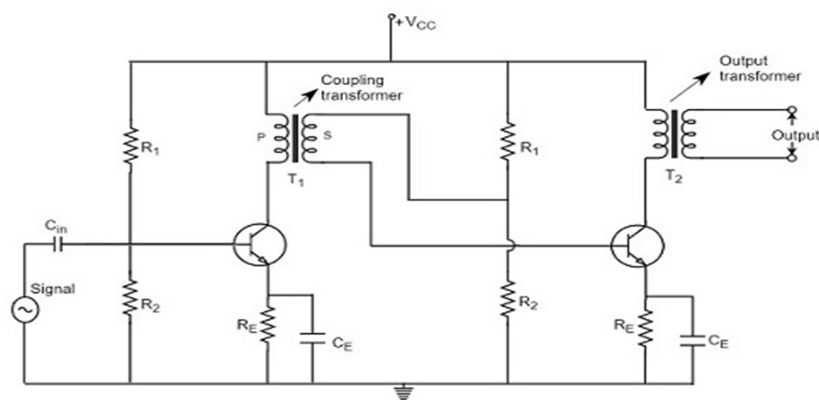
In a transformer-coupled amplifier, the stages of amplifier are coupled using a transformer. Let us go into the constructional and operational details of a transformer coupled amplifier.

### **Construction of Transformer Coupled Amplifier**

The amplifier circuit in which, the previous stage is connected to the next stage using a coupling transformer, is called as Transformer coupled amplifier.

The coupling transformer  $T_1$  is used to feed the output of 1<sup>st</sup> stage to the input of 2<sup>nd</sup> stage. The collector load is replaced by the primary winding of the transformer. The secondary winding is connected between the potential divider and the base of 2<sup>nd</sup> stage, which provides the input to the 2<sup>nd</sup> stage. Instead of coupling capacitor like in RC coupled amplifier, a transformer is used for coupling any two stages, in the transformer coupled amplifier circuit.

The figure below shows the circuit diagram of transformer coupled amplifier.



The potential divider network  $R_1$  and  $R_2$  and the resistor  $R_e$  together form the biasing and stabilization network. The emitter by-pass capacitor  $C_e$  offers a low reactance path to the signal. The resistor  $R_L$  is used as a load impedance. The input capacitor  $C_{in}$  present at the initial stage of the amplifier couples AC signal to the base of the transistor. The capacitor  $C_C$  is the coupling capacitor that connects two stages and prevents DC interference between the stages and controls the shift of operating point.

### Operation of Transformer Coupled Amplifier

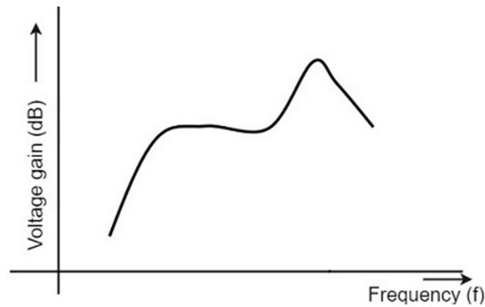
When an AC signal is applied to the input of the base of the first transistor then it gets amplified by the transistor and appears at the collector to which the primary of the transformer is connected.

The transformer which is used as a coupling device in this circuit has the property of impedance changing, which means the low resistance of a stage (or load) can be reflected as a high load resistance to the previous stage. Hence the voltage at the primary is transferred according to the turns ratio of the secondary winding of the transformer.

This transformer coupling provides good impedance matching between the stages of amplifier. The transformer coupled amplifier is generally used for power amplification.

### Frequency Response of Transformer Coupled Amplifier

The figure below shows the frequency response of a transformer coupled amplifier. The gain of the amplifier is constant only for a small range of frequencies. The output voltage is equal to the collector current multiplied by the reactance of primary.



At low frequencies, the reactance of primary begins to fall, resulting in decreased gain. At high frequencies, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence gain.

So, the amplification of audio signals will not be proportionate and some distortion will also get introduced, which is called as **Frequency distortion**.

### Advantages of Transformer Coupled Amplifier

The following are the advantages of a transformer coupled amplifier –

- An excellent impedance matching is provided.
- Gain achieved is higher.
- There will be no power loss in collector and base resistors.
- Efficient in operation.

### Disadvantages of Transformer Coupled Amplifier

The following are the disadvantages of a transformer coupled amplifier –

- Though the gain is high, it varies considerably with frequency. Hence a poor frequency response.
- Frequency distortion is higher.
- Transformers tend to produce hum noise.
- Transformers are bulky and costly.

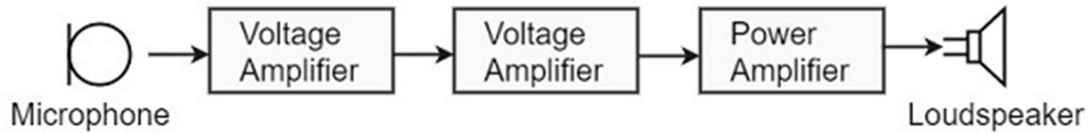
### Applications

The following are the applications of a transformer coupled amplifier –

- Mostly used for impedance matching purposes.
- Used for Power amplification.
- Used in applications where maximum power transfer is needed.

### Power Amplifier

After the audio signal is converted into electrical signal, it has several voltage amplifications done, after which the power amplification of the amplified signal is done just before the loud speaker stage. This is clearly shown in the below figure.



While the voltage amplifier raises the voltage level of the signal, the power amplifier raises the power level of the signal. Besides raising the power level, it can also be said that a power amplifier is a device which converts DC power to AC power and whose action is controlled by the input signal.

The DC power is distributed according to the relation,

$$\text{DC power input} = \text{AC power output} + \text{losses}$$

### Power Transistor

For such Power amplification, a normal transistor would not do. A transistor that is manufactured to suit the purpose of power amplification is called as a **Power transistor**.

A Power transistor differs from the other transistors, in the following factors.

- It is larger in size, in order to handle large powers.
- The collector region of the transistor is made large and a heat sink is placed at the collector-base junction in order to minimize heat generated.
- The emitter and base regions of a power transistor are heavily doped.
- Due to the low input resistance, it requires low input power.

Hence there is a lot of difference in voltage amplification and power amplification. So, let us now try to get into the details to understand the differences between a voltage amplifier and a power amplifier.

### Difference between Voltage and Power Amplifiers

Let us try to differentiate between voltage and power amplifier.

#### Voltage Amplifier

The function of a voltage amplifier is to raise the voltage level of the signal. A voltage amplifier is designed to achieve maximum voltage amplification.

The voltage gain of an amplifier is given by

$$A_v = \beta \left( \frac{R_c}{R_{in}} \right)$$

The characteristics of a voltage amplifier are as follows –

- The base of the transistor should be thin and hence the value of  $\beta$  should be greater than 100.
- The resistance of the input resistor  $R_{in}$  should be low when compared to collector load  $R_C$ .
- The collector load  $R_C$  should be relatively high. To permit high collector load, the voltage amplifiers are always operated at low collector current.

- The voltage amplifiers are used for small signal voltages.

### Power Amplifier

The function of a power amplifier is to raise the power level of input signal. It is required to deliver a large amount of power and has to handle large current.

The characteristics of a power amplifier are as follows –

- The base of transistor is made thicken to handle large currents. The value of  $\beta$  being ( $\beta > 100$ ) high.
- The size of the transistor is made larger, in order to dissipate more heat, which is produced during transistor operation.
- Transformer coupling is used for impedance matching.
- Collector resistance is made low.

The comparison between voltage and power amplifiers is given below in a tabular form.

| S.No | Particular        | Voltage Amplifier                | Power Amplifier                 |
|------|-------------------|----------------------------------|---------------------------------|
| 1    | $\beta$           | High ( $>100$ )                  | Low (5 to 20)                   |
| 2    | $R_C$             | High (4-10 K $\Omega$ )          | Low (5 to 20 $\Omega$ )         |
| 3    | Coupling          | Usually R-C coupling             | Invariably transformer coupling |
| 4    | Input voltage     | Low (a few m V)                  | High (2-4 V)                    |
| 5    | Collector current | Low ( $\approx 1$ mA)            | High ( $> 100$ mA)              |
| 6    | Power output      | Low                              | High                            |
| 7    | Output impedance  | High ( $\approx 12$ K $\Omega$ ) | Low (200 $\Omega$ )             |

### Classification of Power Amplifier:

#### Classification Based on Frequencies

Power amplifiers are divided into two categories, based on the frequencies they handle. They are as follows.

- **Audio Power Amplifiers** – The audio power amplifiers raise the power level of signals that have audio frequency range (20 Hz to 20 KHz). They are also known as **Small signal power amplifiers**.
- **Radio Power Amplifiers** – Radio Power Amplifiers or tuned power amplifiers raise the power level of signals that have radio frequency range (3 KHz to 300 GHz). They are also known as **large signal power amplifiers**.

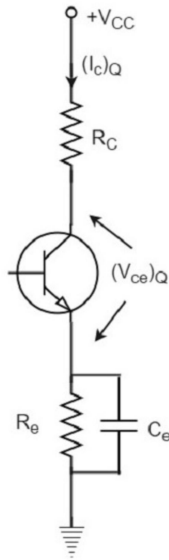
#### Classification Based on Mode of Operation

On the basis of the mode of operation, i.e., the portion of the input cycle during which collector current flows, the power amplifiers may be classified as follows.

- **Class A Power amplifier** – When the collector current flows at all times during the full cycle of signal, the power amplifier is known as **class A power amplifier**.
- **Class B Power amplifier** – When the collector current flows only during the positive half cycle of the input signal, the power amplifier is known as **class B power amplifier**.
- **Class C Power amplifier** – When the collector current flows for less than half cycle of the input signal, the power amplifier is known as **class C power amplifier**.

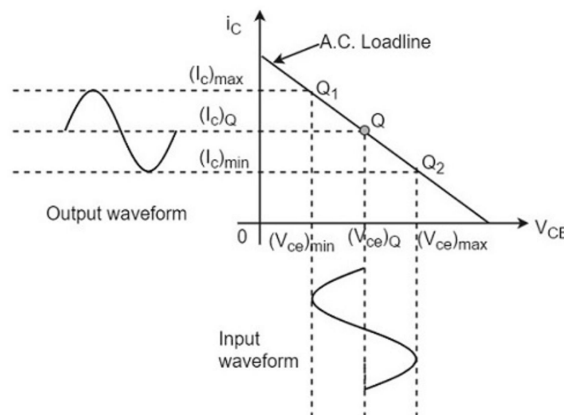
### Class A Power Amplifiers

A Class A power amplifier is one in which the output current flows for the entire cycle of the AC input supply. Hence the complete signal present at the input is amplified at the output. The following figure shows the circuit diagram for Class A Power amplifier.



From the above figure, it can be observed that the transformer is present at the collector as a load. The use of transformer permits the impedance matching, resulting in the transference of maximum power to the load e.g. loud speaker.

The operating point of this amplifier is present in the linear region. It is so selected that the current flows for the entire ac input cycle. The below figure explains the selection of operating point.



The output characteristics with operating point Q is shown in the figure above. Here  $(I_C)_Q$  and  $(V_{CE})_Q$  represent no signal collector current and voltage between collector and emitter respectively. When signal is applied, the Q-point shifts to Q1 and Q2. The output current increases to  $(I_C)_{max}$  and decreases to  $(I_C)_{min}$ . Similarly, the collector-emitter voltage increases to  $(V_{CE})_{max}$  and decreases to  $(V_{CE})_{min}$ .

D.C. Power drawn from collector battery  $V_{CC}$  is given by

$$P_{in} = \text{voltage} \times \text{current} = V_{CC}(I_C)_Q$$

This power is used in the following two parts –

- Power dissipated in the collector load as heat is given by

$$P_{RC} = (\text{current})^2 \times \text{resistance} = (I_C)_Q^2 R_C$$

- Power given to transistor is given by

$$P_{tr} = P_{in} - P_{RC} = V_{CC} - (I_C)_Q^2 R_C$$

### Overall Efficiency

The overall efficiency of the amplifier circuit is given by

$$\begin{aligned} (\eta)_{overall} &= \frac{\text{a. c power delivered to the load}}{\text{total power delivered by d. c supply}} \\ &= \frac{(P_O)_{ac}}{(P_{in})_{dc}} \\ (P_O)_{ac} &= V_{rms} \times I_{rms} \\ &= \frac{1}{\sqrt{2}} \left[ \frac{(V_{CE})_{max} - (V_{CE})_{min}}{2} \right] \times \frac{1}{\sqrt{2}} \left[ \frac{(I_C)_{max} - (I_C)_{min}}{2} \right] \\ &= \frac{[(V_{CE})_{max} - (V_{CE})_{min}] \times [(I_C)_{max} - (I_C)_{min}]}{8} \end{aligned}$$

Therefore

$$(\eta)_{overall} = \frac{[(V_{CE})_{max} - (V_{CE})_{min}] \times [(I_C)_{max} - (I_C)_{min}]}{8 \times V_{CC}(I_C)_Q}$$

### Advantages of Class A Amplifiers

The advantages of Class A power amplifier are as follows –

- The current flows for complete input cycle
- It can amplify small signals
- The output is same as input
- No distortion is present

### Disadvantages of Class A Amplifiers

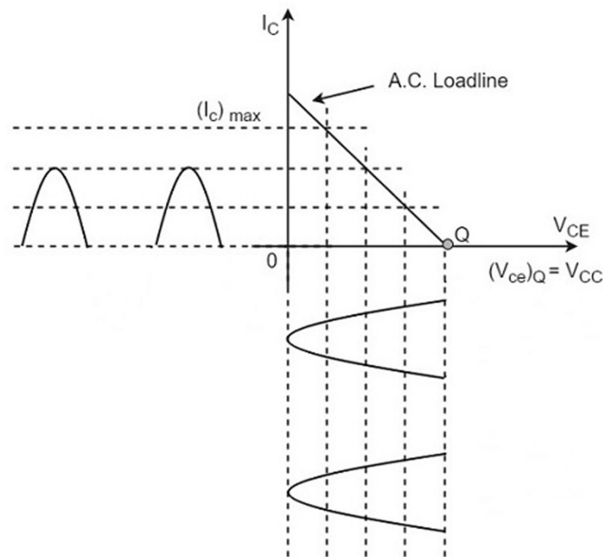
The advantages of Class A power amplifier are as follows –

- Low power output
- Low collector efficiency

### Class B Operation

The biasing of the transistor in class B operation is in such a way that at zero signal condition, there will be no collector current. The **operating point** is selected to be at collector cut off voltage. So, when the signal is applied, **only the positive half cycle** is amplified at the output.

The figure below shows the input and output waveforms during class B operation.



When the signal is applied, the circuit is forward biased for the positive half cycle of the input and hence the collector current flows. But during the negative half cycle of the input, the circuit is reverse biased and the collector current will be absent. Hence **only the positive half cycle** is amplified at the output.

As the negative half cycle is completely absent, the signal distortion will be high. Also, when the applied signal increases, the power dissipation will be more. But when compared to class A power amplifier, the output efficiency is increased.

Well, in order to minimize the disadvantages and achieve low distortion, high efficiency and high output power, the push-pull configuration is used in this class B amplifier.

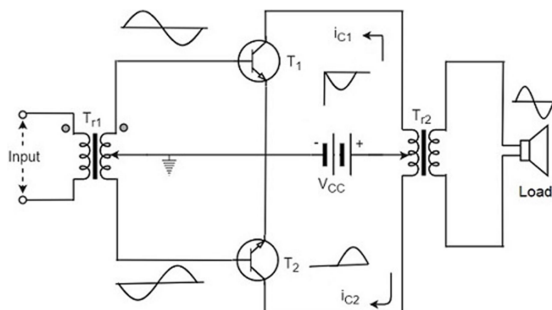
### Class B Push-Pull Amplifier

Though the efficiency of class B power amplifier is higher than class A, as only one half cycle of the input is used, the distortion is high. Also, the input power is not completely utilized. In order to compensate these problems, the push-pull configuration is introduced in class B amplifier.

## Construction

The circuit of a push-pull class B power amplifier consists of two identical transistors  $T_1$  and  $T_2$  whose bases are connected to the secondary of the center-tapped input transformer  $T_{r1}$ . The emitters are shorted and the collectors are given the  $V_{CC}$  supply through the primary of the output transformer  $T_{r2}$ .

The circuit arrangement of class B push-pull amplifier, is same as that of class A push-pull amplifier except that the transistors are biased at cut off, instead of using the biasing resistors. The figure below gives the detailing of the construction of a push-pull class B power amplifier.

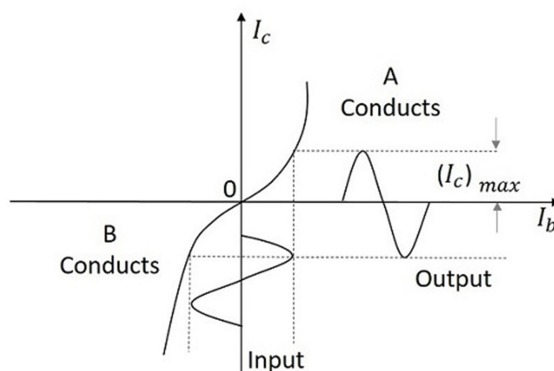


The circuit operation of class B push pull amplifier is detailed below.

## Operation

The circuit of class B push-pull amplifier shown in the above figure clears that both the transformers are center-tapped. When no signal is applied at the input, the transistors  $T_1$  and  $T_2$  are in cut off condition and hence no collector currents flow. As no current is drawn from  $V_{CC}$ , no power is wasted.

When input signal is given, it is applied to the input transformer  $T_{r1}$  which splits the signal into two signals that are 180° out of phase with each other. These two signals are given to the two identical transistors  $T_1$  and  $T_2$ . For the positive half cycle, the base of the transistor  $T_1$  becomes positive and collector current flows. At the same time, the transistor  $T_2$  has negative half cycle, which throws the transistor  $T_2$  into cutoff condition and hence no collector current flows. The waveform is produced as shown in the following figure.



For the next half cycle, the transistor  $T_1$  gets into cut off condition and the transistor  $T_2$  gets into conduction, to contribute the output. Hence for both the cycles, each transistor conducts alternately.

The output transformer  $T_{r3}$  serves to join the two currents producing an almost undistorted output waveform.

### Power Efficiency of Class B Push-Pull Amplifier

The current in each transistor is the average value of half sine loop.

For half sine loop,  $I_{dc}$  is given by

$$I_{dc} = \frac{(I_C)_{max}}{\pi}$$

Therefore,

$$(P_{in})_{dc} = 2 \times \left[ \frac{(I_C)_{max}}{\pi} \times V_{CC} \right]$$

Here factor 2 is introduced as there are two transistors in push-pull amplifier.

$$\text{R.M.S. value of collector current} = (I_C)_{max} / \sqrt{2}$$

$$\text{R.M.S. value of output voltage} = V_{CC} / \sqrt{2}$$

Under ideal conditions of maximum power

Therefore,

$$(P_O)_{ac} = \frac{(I_C)_{max}}{\sqrt{2}} \times \frac{V_{CC}}{\sqrt{2}} = \frac{(I_C)_{max} \times V_{CC}}{2}$$

Now overall maximum efficiency

$$\begin{aligned} \eta_{overall} &= \frac{(P_O)_{ac}}{(P_{in})_{dc}} \\ &= \frac{(I_C)_{max} \times V_{CC}}{2} \times \frac{\pi}{2(I_C)_{max} \times V_{CC}} \\ &= \frac{\pi}{4} = 0.785 = 78.5\% \end{aligned}$$

The collector efficiency would be the same.

Hence the class B push-pull amplifier improves the efficiency than the class A push-pull amplifier.

### Advantages

The advantages of Complementary symmetry push pull class B amplifier are as follows.

- As there is no need of center tapped transformers, the weight and cost are reduced.
- Equal and opposite input signal voltages are not required.

## Disadvantages

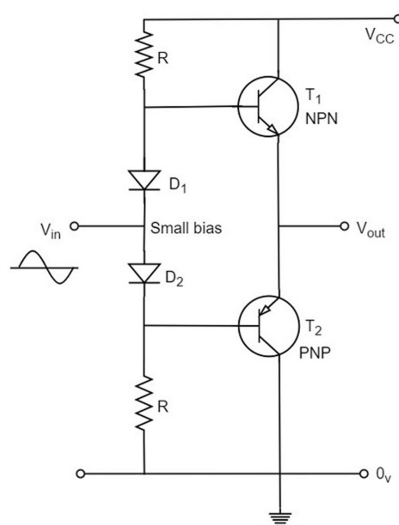
The disadvantages of Complementary symmetry push pull class B amplifier are as follows.

- It is difficult to get a pair of transistors (NPN and PNP) that have similar characteristics.
- We require both positive and negative supply voltages.

## Class AB Power Amplifier

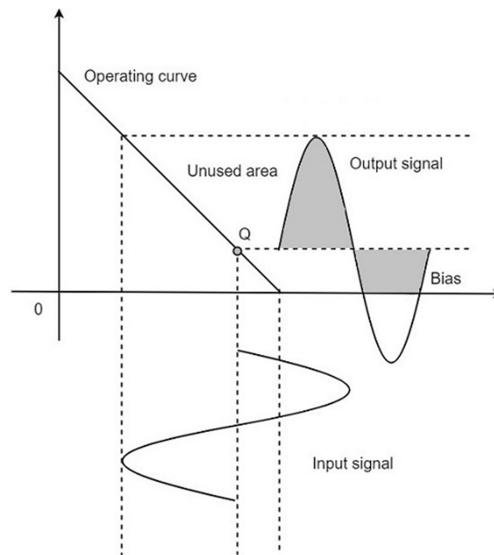
As the name implies, class AB is a combination of class A and class B type of amplifiers. As class A has the problem of low efficiency and class B has distortion problem, this class AB is emerged to eliminate these two problems, by utilizing the advantages of both the classes.

The cross over distortion is the problem that occurs when both the transistors are OFF at the same instant, during the transition period. In order to eliminate this, the condition has to be chosen for more than one half cycle. Hence, the other transistor gets into conduction, before the operating transistor switches to cut off state. This is achieved only by using class AB configuration, as shown in the following circuit diagram.



Therefore, in class AB amplifier design, each of the push-pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

The conduction angle of class AB amplifier is somewhere between  $180^\circ$  to  $360^\circ$  depending upon the operating point selected. This is understood with the help of below figure.



The small bias voltage given using diodes  $D_1$  and  $D_2$ , as shown in the above figure, helps the operating point to be above the cutoff point. Hence the output waveform of class AB results as seen in the above figure. The crossover distortion created by class B is overcome by this class AB, as well the inefficiencies of class A and B don't affect the circuit.

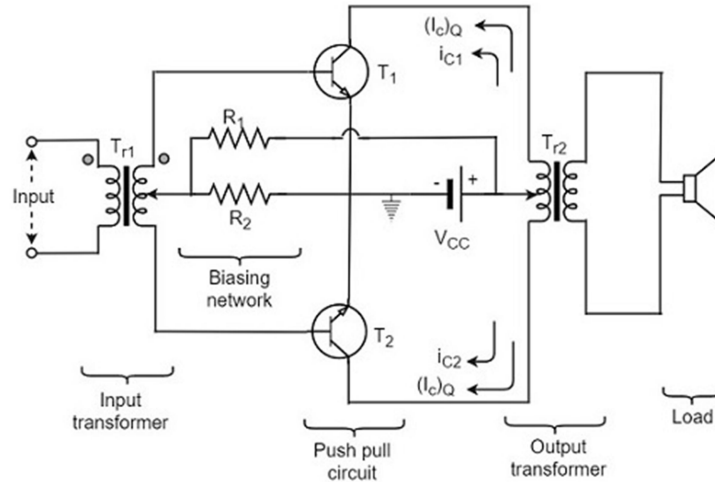
So, the class AB is a good compromise between class A and class B in terms of efficiency and linearity having the efficiency reaching about 50% to 60%. The class A, B and AB amplifiers are called as **linear amplifiers** because the output signal amplitude and phase are linearly related to the input signal amplitude and phase.

### **PUSH-PULL Power Amplifier:**

In this circuit, we use two complementary transistors in the output stage with one transistor being an NPN or N-channel type while the other transistor is a PNP or P-channel (the complement) type connected in order to operate them like **PUSH a transistor to ON** and **PULL another transistor to OFF** at the same time. This push-pull configuration can be made in class A, class B, class C or class AB amplifiers.

### **Construction of Push-Pull Class A Power Amplifier**

The construction of the class A power amplifier circuit in push-pull configuration is shown as in the figure below. This arrangement mainly reduces the harmonic distortion introduced by the non-linearity of the transfer characteristics of a single transistor amplifier.



In Push-pull arrangement, the two identical transistors  $T_1$  and  $T_2$  have their emitter terminals shorted. The input signal is applied to the transistors through the transformer  $T_{r1}$  which provides opposite polarity signals to both the transistor bases. The collectors of both the transistors are connected to the primary of output transformer  $T_{r2}$ . Both the transformers are center tapped. The  $V_{CC}$  supply is provided to the collectors of both the transistors through the primary of the output transformer.

The resistors  $R_1$  and  $R_2$  provide the biasing arrangement. The load is generally a loudspeaker which is connected across the secondary of the output transformer. The turns ratio of the output transformer is chosen in such a way that the load is well matched with the output impedance of the transistor. So maximum power is delivered to the load by the amplifier.

### Circuit Operation

The output is collected from the output transformer  $T_{r2}$ . The primary of this transformer  $T_{r2}$  has practically no dc component through it. The transistors  $T_1$  and  $T_2$  have their collectors connected to the primary of transformer  $T_{r2}$  so that their currents are equal in magnitude and flow in opposite directions through the primary of transformer  $T_{r2}$ .

When the a.c. input signal is applied, the base of transistor  $T_1$  is more positive while the base of transistor  $T_2$  is less positive. Hence the collector current  $i_{c1}$  of transistor  $T_1$  increases while the collector current  $i_{c2}$  of transistor  $T_2$  decreases. These currents flow in opposite directions in two halves of the primary of output transformer. Moreover, the flux produced by these currents will also be in opposite directions.

Hence, the voltage across the load will be induced voltage whose magnitude will be proportional to the difference of collector currents i.e.

$$(i_{c1} - i_{c2})$$

Similarly, for the negative input signal, the collector current  $i_{c2}$  will be more than  $i_{c1}$ . In this case, the voltage developed across the load will again be due to the difference

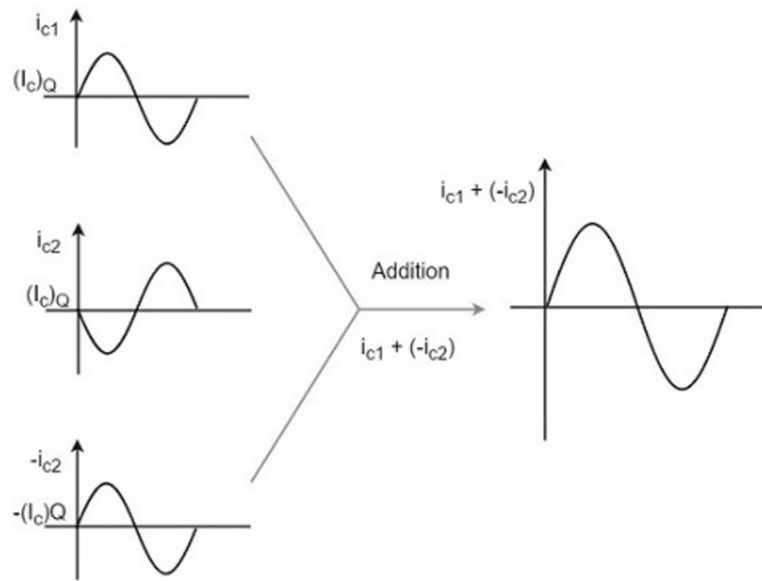
$$(i_{c1} - i_{c2})$$

$$\text{As } i_{c2} > i_{c1}$$

The polarity of voltage induced across load will be reversed.

$$i_{c1} - i_{c2} = i_{c1} + (-i_{c2})$$

To have a better understanding, let us consider the below figure.



The overall operation results in an a.c. voltage induced in the secondary of output transformer and hence a.c. power is delivered to that load.

It is understood that, during any given half cycle of input signal, one transistor is being driven (or pushed) deep into conduction while the other being non-conducting (pulled out). Hence the name **Push-pull amplifier**. The harmonic distortion in Push-pull amplifier is minimized such that all the even harmonics are eliminated.

### Advantages

The advantages of class A Push-pull amplifier are as follows

- High a.c. output is obtained.
- The output is free from even harmonics.
- The effect of ripple voltages are balanced out. These are present in the power supply due to inadequate filtering.

### Disadvantages

The disadvantages of class A Push-pull amplifier are as follows

- The transistors are to be identical, to produce equal amplification.
- Center-tapping is required for the transformers.
- The transformers are bulky and costly.