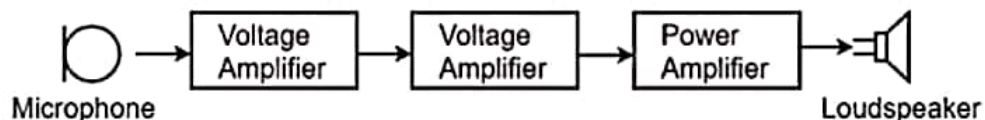


Power Amplifiers

In practice, any amplifier consists of few stages of amplification. If we consider audio amplification, it has several stages of amplification, depending upon our requirement.

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,

DC power input = AC power output + 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

$$A_v = \beta(R_c/R_{in})$$

The characteristics of a voltage amplifier are as follows –

- The base of the transistor should be thin and hence the value of β 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 thickened to handle large currents. The value of β 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	β	High (>100)	Low (5 to 20)
2	R_C	High (4-10 K Ω)	Low (5 to 20 Ω)
3	Coupling	Usually R-C coupling	Invariably transformer coupling
4	Input voltage	Low (a few mV)	High (2-4 V)
5	Collector current	Low (≈ 1 mA)	High (> 100 mA)
6	Power output	Low	High
7	Output impedance	High (≈ 12 K Ω)	Low (200 Ω)

The Power amplifiers amplify the power level of the signal. This amplification is done in the last stage in audio applications. The applications related to radio frequencies employ radio power amplifiers. But the **operating point** of a transistor plays a very important role in determining the efficiency of the amplifier. The **main classification** is done based on this mode of operation.

The classification is done based on their frequencies and also based on their mode of operation.

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**.

There forms another amplifier called Class AB amplifier, if we combine the class A and class B amplifiers so as to utilize the advantages of both. Before going into the details of these amplifiers, let us have a look at the important terms that have to be considered to determine the efficiency of an amplifier.

Terms Considering Performance

The primary objective of a power amplifier is to obtain maximum output power. In order to achieve this, the important factors to be considered are collector efficiency, power dissipation capability and distortion. Let us go through them in detail.

Collector Efficiency

This explains how well an amplifier converts DC power to AC power. When the DC supply is given by the battery but no AC signal input is given, the collector output at such a condition is observed as **collector efficiency**.

The collector efficiency is defined as

$$\eta = \text{average a.c power output} / \text{average d.c power input to transistor}$$

The main aim of a power amplifier is to obtain maximum collector efficiency. Hence the higher the value of collector efficiency, the efficient the amplifier will be.

Power Dissipation Capacity

Every transistor gets heated up during its operation. As a power transistor handles large currents, it gets more heated up. This heat increases the temperature of the transistor, which alters the operating point of the transistor. So, in order to maintain the operating point stability, the temperature of the transistor has to be kept in permissible limits. For this, the heat produced has to be dissipated. Such a capacity is called as Power dissipation capability.

Power dissipation capability can be defined as the ability of a power transistor to dissipate the heat developed in it. Metal cases called heat sinks are used in order to dissipate the heat produced in power transistors.

Distortion

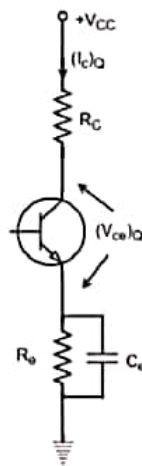
A transistor is a non-linear device. When compared with the input, there occur few variations in the output. In voltage amplifiers, this problem is not pre-dominant as small

currents are used. But in power amplifiers, as large currents are in use, the problem of distortion certainly arises.

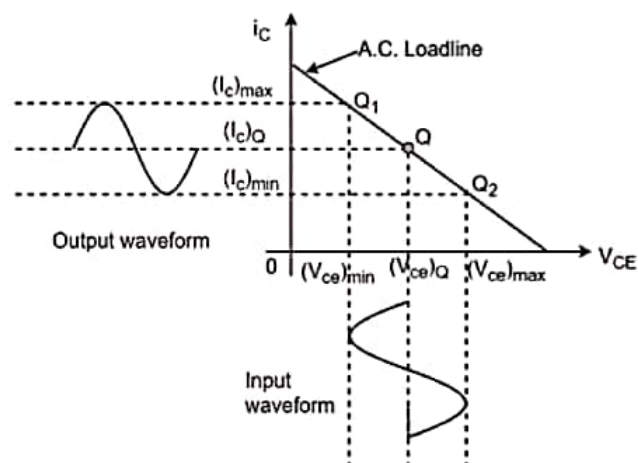
Distortion is defined as the change of output wave shape from the input wave shape of the amplifier. An amplifier that has lesser distortion, produces a better output and hence considered efficient.

We have already come across the details of transistor biasing, which is very important for the operation of a transistor as an amplifier. Hence to achieve faithful amplification, the biasing of the transistor has to be done such that the amplifier operates over the linear region.

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 Q_1 and Q_2 . 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

$$P_{tr} = P_{in} - P_{RC} = V_{cc} - (I_c)_Q R_C$$

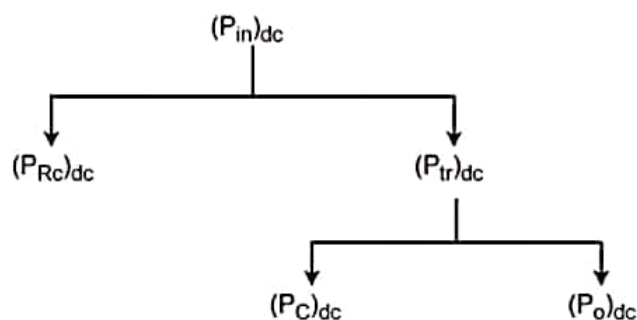
When signal is applied, the power given to transistor is used in the following two parts –

- A.C. Power developed across load resistors R_C which constitutes the a.c. power output.

$$(P_o)_{ac} = I^2 R_C = V^2 / R_C = (V_m / \sqrt{2})^2 / R_C = V_m^2 / 2R_C$$

- Where I is the R.M.S. value of a.c. output current through load, V is the R.M.S. value of a.c. voltage, and V_m is the maximum value of V .
- The D.C. power dissipated by the transistor (collector region) in the form of heat, i.e., $(P_C)_{dc}$

We have represented the whole power flow in the following diagram.



This class A power amplifier can amplify small signals with least distortion and the output will be an exact replica of the input with increased strength.

Let us now try to draw some expressions to represent efficiencies.

Overall Efficiency

The overall efficiency of the amplifier circuit is given by

$$\begin{aligned}
 (\eta)_{\text{overall}} &= \frac{\text{a. c power delivered to the load}}{\text{total power delivered by d. c supply}} \\
 &= \frac{(P_O)_{ac}}{(P_{in})_{dc}}
 \end{aligned}$$

Collector Efficiency

The collector efficiency of the transistor is defined as

$$\begin{aligned}
 (\eta)_{\text{collector}} &= \frac{\text{average a. c power output}}{\text{average d. c power input to transistor}} \\
 &= \frac{(P_O)_{ac}}{(P_{tr})_{dc}}
 \end{aligned}$$

Expression for overall efficiency

$$\begin{aligned}
 (P_O)_{ac} &= V_{rms} \times I_{rms} \\
 &= \frac{1}{\sqrt{2}} \left[\frac{(V_{ce})_{max} - (V_{ce})_{min}}{2} \right] \times \frac{1}{\sqrt{2}} \left[\frac{(I_C)_{max} - (I_C)_{min}}{2} \right] \\
 &= \frac{[(V_{ce})_{max} - (V_{ce})_{min}] \times [(I_C)_{max} - (I_C)_{min}]}{8}
 \end{aligned}$$

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

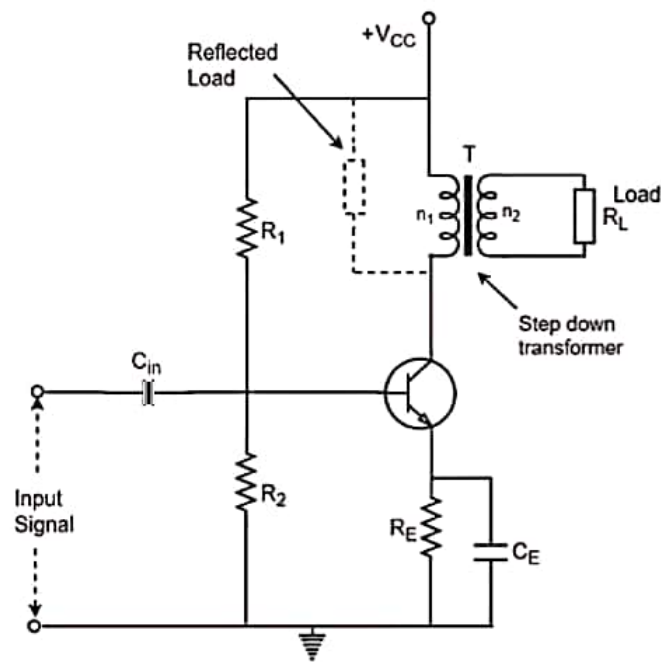
The advantages of Class A power amplifier are as follows –

- Low power output
- Low collector efficiency

The class A power amplifier as discussed in the previous chapter, is the circuit in which the output current flows for the entire cycle of the AC input supply. We also have learnt about the disadvantages it has such as low output power and efficiency. In order to

minimize those effects, the transformer coupled class A power amplifier has been introduced.

The construction of class A power amplifier can be understood with the help of below figure. This is similar to the normal amplifier circuit but connected with a transformer in the collector load.

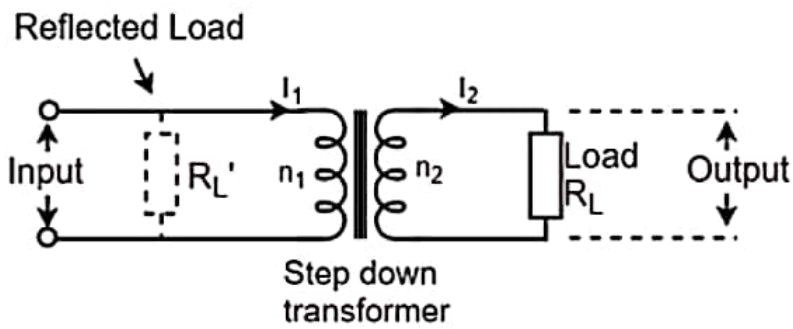


Here R_1 and R_2 provide potential divider arrangement. The resistor R_e provides stabilization, C_e is the bypass capacitor and R_e to prevent a.c. voltage. The transformer used here is a step-down transformer. The high impedance primary of the transformer is connected to the high impedance collector circuit. The low impedance secondary is connected to the load (generally loud speaker).

Transformer Action:

The transformer used in the collector circuit is for impedance matching. R_L is the load connected in the secondary of a transformer. R_L' is the reflected load in the primary of the transformer.

The number of turns in the primary are n_1 and the secondary are n_2 . Let V_1 and V_2 be the primary and secondary voltages and I_1 and I_2 be the primary and secondary currents respectively. The below figure shows the transformer clearly.



We know that

$$\frac{V_1}{V_2} = \frac{n_1}{n_2} \text{ and } \frac{I_1}{I_2} = \frac{n_1}{n_2}$$

Or

$$V_1 = \frac{n_1}{n_2} V_2 \text{ and } I_1 = \frac{n_1}{n_2} I_2$$

Hence

$$\frac{V_1}{I_1} = \left(\frac{n_1}{n_2} \right)^2 \frac{V_2}{I_2}$$

But $V_1/I_1 = R_L' =$ effective input resistance

And $V_2/I_2 = R_L =$ effective output resistance

Therefore,

$$R_L' = \left(\frac{n_1}{n_2} \right)^2 R_L = n^2 R_L$$

Where

$$n = \frac{\text{number of turns in primary}}{\text{number of turns in secondary}} = \frac{n_1}{n_2}$$

A power amplifier may be matched by taking proper turn ratio in step down transformer.

Circuit Operation

If the peak value of the collector current due to signal is equal to zero signal collector current, then the maximum a.c. power output is obtained. So, in order to achieve complete amplification, the operating point should lie at the center of the load line.

The operating point obviously varies when the signal is applied. The collector voltage varies in opposite phase to the collector current. The variation of collector voltage appears across the primary of the transformer.

Circuit Analysis

The power loss in the primary is assumed to be negligible, as its resistance is very small.

The input power under dc condition will be

$$(P_{in})_{dc} = (P_{tr})_{dc} = V_{CC} \times (I_C)Q$$

Under maximum capacity of class A amplifier, voltage swings from $(V_{ce})_{max}$ to zero and current from $(I_C)_{max}$ to zero.

Hence

$$V_{rms} = \frac{1}{\sqrt{2}} \left[\frac{(V_{ce})_{max} - (V_{ce})_{min}}{2} \right] = \frac{1}{\sqrt{2}} \left[\frac{(V_{ce})_{max}}{2} \right] = \frac{2V_{CC}}{2\sqrt{2}} \\ = \frac{V_{CC}}{\sqrt{2}}$$

$$I_{rms} = \frac{1}{\sqrt{2}} \left[\frac{(I_C)_{max} - (I_C)_{min}}{2} \right] = \frac{1}{\sqrt{2}} \left[\frac{(I_C)_{max}}{2} \right] = \frac{2(I_C)Q}{2\sqrt{2}} \\ = \frac{(I_C)Q}{\sqrt{2}}$$

Therefore,

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

Therefore,

$$\text{Collector Efficiency} = \frac{(P_O)_{ac}}{(P_{tr})_{dc}}$$

Or,

$$(\eta)_{collector} = \frac{V_{CC} \times (I_C)Q}{2 \times V_{CC} \times (I_C)Q} = \frac{1}{2} \\ \approx \frac{1}{2} \times 100 = 50\%$$

The efficiency of a class A power amplifier is nearly than 30% whereas it has got improved to 50% by using the transformer coupled class A power amplifier.

Advantages

The advantages of transformer coupled class A power amplifier are as follows.

- No loss of signal power in the base or collector resistors.
- Excellent impedance matching is achieved.
- Gain is high.
- DC isolation is provided.

Disadvantages

The disadvantages of transformer coupled class A power amplifier are as follows.

- Low frequency signals are less amplified comparatively.

- Hum noise is introduced by transformers.
- Transformers are bulky and costly.
- Poor frequency response.

Applications

The applications of transformer coupled class A power amplifier are as follows. This circuit is where impedance matching is the main criterion. These are used as driver amplifiers and sometimes as output amplifiers. 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**.