UNIT 5 LARGE SIGNAL AMPLIFIERS

Class A power amplifier with resistive and transformer coupled load - calculation of efficiency - Class B - Push pull - complementary symmetry - efficiency calculation - Class C Power Amplifier - Class AB operation and Class D type of operation - distortion in power amplifiers - Thermal stability of power amplifier

LARGE SIGNAL AMPLIFIERS

Large signal amplifiers also known as power amplifiers are capable of providing large amount of power to the load**.** They are used as last stage in electronic systems. A power amplifier takes the d.c. power supply connected to the output circuit and converts it into a.c. signal power. Output power is controlled by input signal.

Important Features of Power Amplifiers:

- Some of the features of power amplifiers are
- Impedance matching with the load is necessary for delivering max power to the load.
- Power transistors are needed. (To withstand large voltages and currents)
- Power amplifiers are bulk.
- Due to the non–linear characteristics of transistors, Harmonic Distortions are available at the output.

Performance parameters:

The performance of power amplifiers are determined by the following points.

1. **Circuit efficiency:** Also known as conversion efficiency or overall efficiency.

$$\eta = \frac{\text{Max a.c. o/p power}}{\text{d.c. i/p power}}$$

   Its value may be anywhere from 25% to 90%

2. **Distortion:** The difference between the output & input of an amplifier is known as distortion. Even though the output is enlarged and faithful reproduction of input but in actual practice there may be differences in the waveforms or frequencies.

   (1) Harmonic or amplitude distortion – Due to nonlinearity in transistor.

(2) Crossover distortion – occurs when transistors not operating in correct phase with each other.

3. **Power Dissipation capacity:** It's defined as the ability to dissipate the heat by the power transistor. Also known as power rating. During amplification process large current passes through power transistor hence Heat generated.By connecting a metal sheet (Heat sink) power dissipation capability can be increased.

Classification of power amplifiers:

Based on Transistor biasing and amplitude of input signal

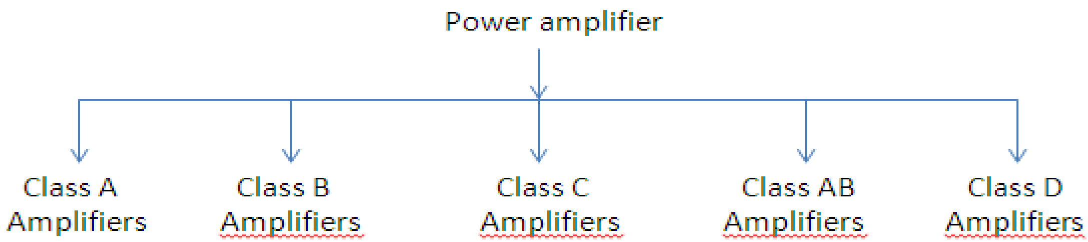


Fig (1) classification of power amplifiers

CLASS A POWER AMPLIFIER:

A power amplifier is called Class A amplifier if the transistor used in the circuit conducts for fullcycle of the input signal.

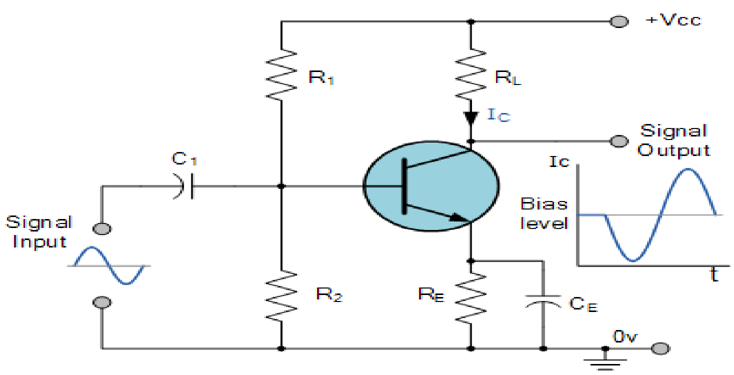


Fig (2) Class A Power amplifier

The operating point(Q) is selected approximately at the (Biased) centre, so that the output current faithfully follows the input signal. The transistor remains in the **active region** for the full input signal. Transistor is not operated in **Cut off** or **Saturation region**. Transistor conducts for full 360°as shown in Fig (3).Thus the collector current also flows for full 360˙ Or full cycle. The base current changes sinusoidally, above and below to the quiescent base current. The collector output current also changes sinusoidally above and below the quiescent current value. They are in phase with each other. Due to this **Ic** change, **Vce** will also change sinusoidally as shown in Fig (3) but out of phase 180. Input is amplified faithfully without any distortions.Since transistor is operatedin active region continuously the collector current and voltage are high.This high collector output produces large power which is dissipated as heat.Hence the efficiency of Class A power amplifier is Low.

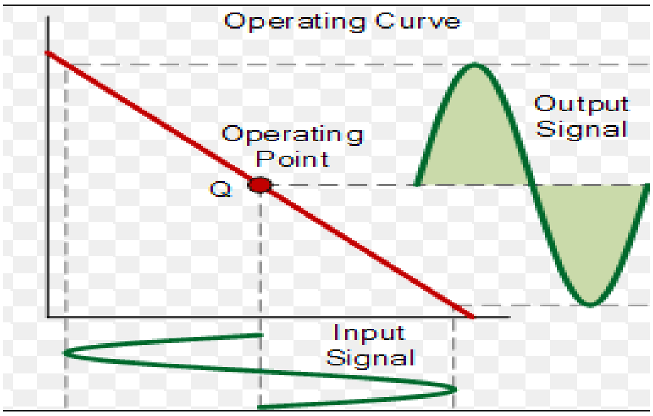


Fig (3): Load line analysis

Advantages: (1) simple construction

(2) Distortion less output voltage

Disadvantage: (1) very low efficiency (25%)

(2) Large power dissipation in the transistors.

(3) Output Impedance is very large.

Expressions: $I_{BQ} = (V_{CC} - 0.7)/R_B$

$I_{CQ} = \beta I_{BQ}$

$V_{EQ} = V_{CC} - I_{CQ} R_L$

Q point at (V_{CEQ}, I_{CQ})

$P_{dc} = V_{CC} I_{CQ}$

$P_{ac} = ((V_{max} - V_{min})(I_{max} - I_{min}))/8$

Efficiency $\%\eta = (P_{ac} / P_{dc}) * 100$

Power dissipation $P_d = P_{dc} - P_{ac}$

TRANSFORMER COUPLED CLASS A POWER AMPLIFIER:

Instead of connecting the load directly, the output is connected to the load through a transformer as shown in Fig (4). This set up is used for Impedance matching. This circuit can be useful for low impedance loads like Loudspeakers. By adjusting the turn's ratio (N1\N2) the output impedance is matched with the load impedance.

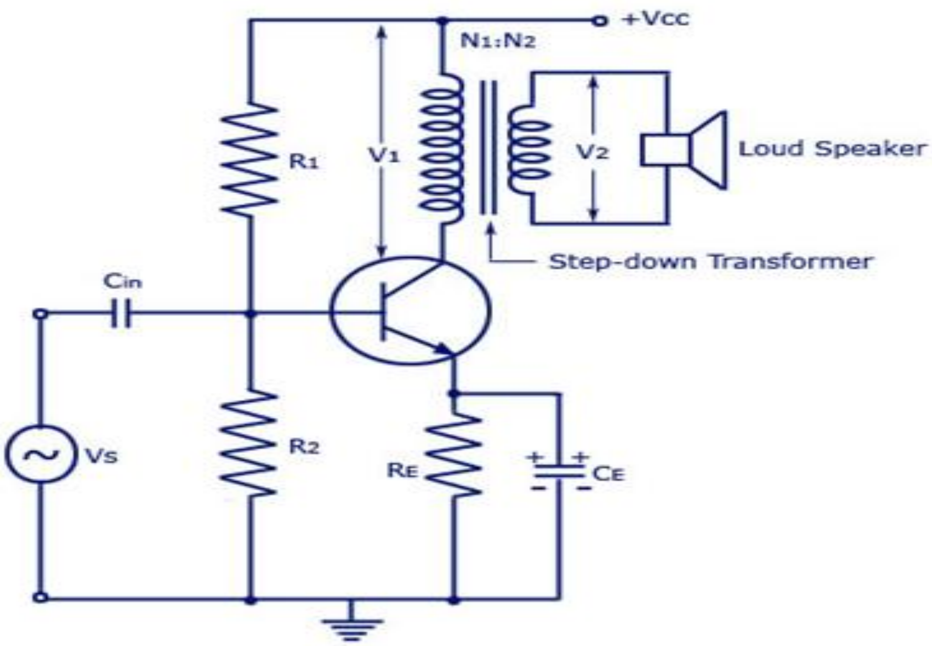


Fig (4): Transformer coupled power amplifier

This type is also known as Single ended Class A amplifier. The primary has negligible d .c. resistance hence no loss of d.c. power.This gives the necessary d.c. isolation to load.

Advantages:

- Max power transfer is done.
- Dc biasing current is doesn't flow through the load so power is saved.
- High efficiency when compared with direct coupled class A amplifier.

Disadvantage:

- Circuit design is complicated.
- Circuit is bulky and expensive.
- Due to saturation of transformer core ,secondary induced voltage is zero And primary current becomes very large.

Expressions: $R_L' = [N_1/N_2]^2 R_L$

Q point (V_{CC}, I_{CQ}), $I_{CQ} = \beta I_{BQ}$

$P_{dc} = V_{CC} I_{CQ}$

$P_{ac} = ((V_{max} - V_{min})(I_{max} - I_{min}))/8$

Efficiency $\%\eta = (P_{ac}/P_{dc}) * 100$.

$\%\eta$ max = 50%

Power dissipation $P_d = P_{dc} = V_{CC} I_{CQ}$

Impedance matching is possible

Slope of dc load line ideally ∞

Class B Power Amplifier:

The output power is obtained for one half cycle of input only. Refer Figure (4). The collector current flows for 180 degrees only. For this the Q point is adjusted so that it is in cut off region (refer figure 5& 6).

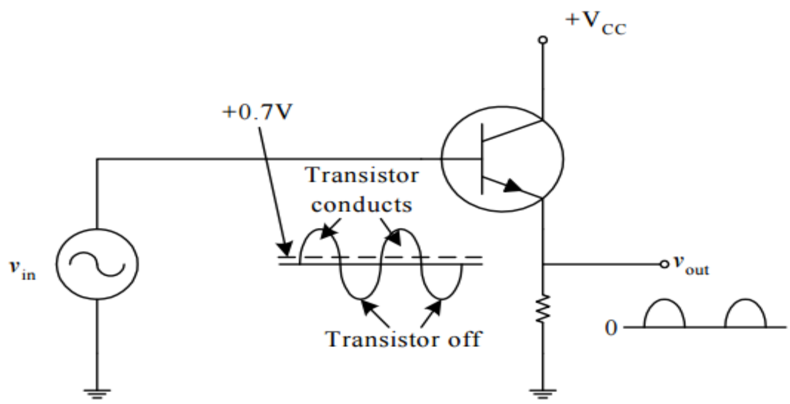


Fig (5) : Class B amplifier.

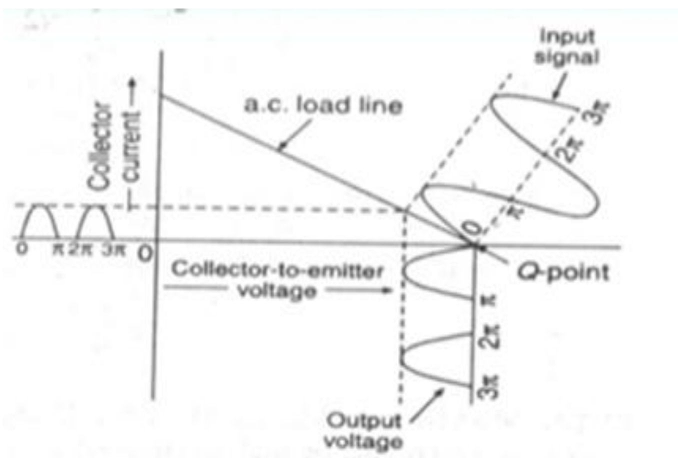


Fig (6) : Class B Operation

The transistor conducts one half cycle only for the positive half cycle of the input and in Negative cycle of input the transistor goes into Off state. Thus collector current flows only for one half cycle. Since the transistor conducts for one half cycle of the input the power dissipation of these class B amplifiers are very less. Hence efficiency gets increased.

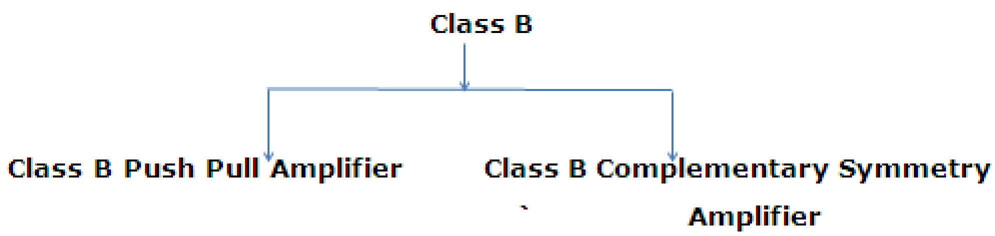
Advantages:

- Impedance with load is possible.
- Second harmonic get automatically cancelled.
- Zero power dissipation.
- High efficiency compared with class A amplifiers.

Disadvantage:

Crossover distortion is present in the output waveform. Since, the transistor is biased at cut off region the waveform is distorted near zero crossings.

Efficiency is not so high.



Push Pull Amplifier - If both the transistors are of same type (NPN or PNP) **Complementary Symmetry**- If one of the transistors is NPN & the other one PNP or vice versa.

<u>CLASS B PUSH PULL POWER AMPLIFIER:</u>

In class B amplifier output collector current flows only for half cycle for full cycle of the input hence distortion. To get out for full input signal we use Push Pull circuit. Two transformers are used in Push pull amplifiers.one at the input and the other at the load side. Both are centre tapped transformers. As shown in Fig 7 it also contains two transistors Q1 & Q2 both NPN type. Since centre tapped is used Q1 & Q2 are 180 degrees out of phase.(the voltages are equal but with opposite polarity). For positive half cycle Q1(Active region) gives output (shown in fig(7 & 8)) and Q2 is OFF(cut off region). In negative cycle Q2 is ON & Q1 is OFF. Thus at the output we get a full cycle for a full input signal.

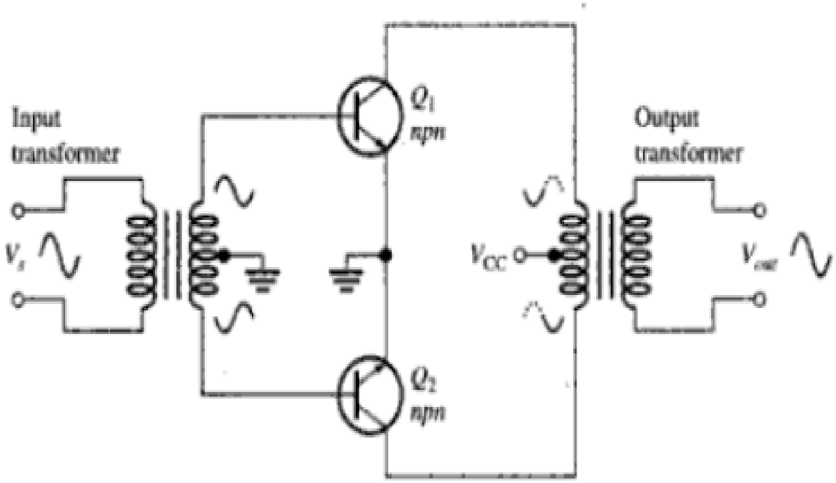


Fig (7) : Class B Push Pull Circuit

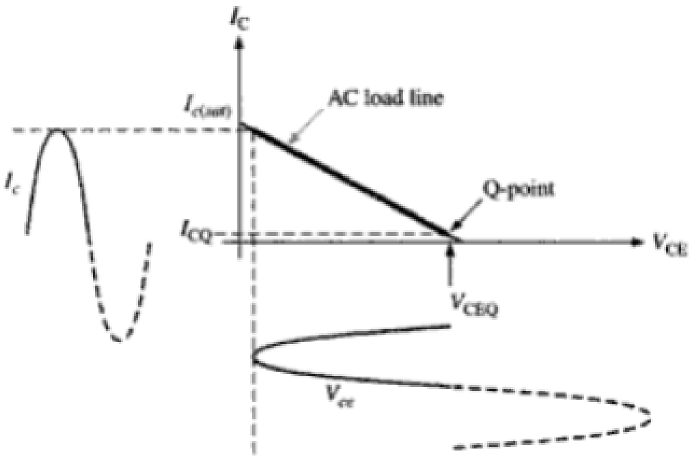


Fig (8) : Class B Push Pull Circuit operation for half cycle

Expressions

Q point at (V_{CC} ,0)

$R_L' = [N_1/N_2]^2 R_L$

$P_{dc} = (2V_{CC} I_m)/\pi$

$P_{ac} = (V_m I_m)/2$

$\%\eta = \pi/4 \, (V_m/V_{CC}) * 100$

$\%\eta$ max = 78.5%

$P_d = P_{dc} - P_{ac}$

$P_{d\,(max)} = 2\, V^2_{cc}/\pi^2 R_L'$

Advantages:

- Efficiency is much higher than class A Amplifier
- Even harmonics get cancelled so harmonic distortion is less.
- Ripples in supply voltage are eliminated

Disadvantage:

- Two centre tapped transformers are necessary
- Hence circuit is bulky and costs more.
- Frequency response is poor.

<u>CLASS B COMPLEMENTARY SYMMETRY AMPLIFIER:</u>

The circuit diagram for complementary symmetry type is shown in Figure(8)**.** This circuit uses two transistors of different type. One is NPN and another PNP. It is a transformer less circuit. For better impedance matching the tow transistors Q1 & Q2 are connected as emitter follower configuration. Positive half cycle Q1 is in Active region so ON & Q2 in cut off So OFF. In negative half cycle Q2 is ON & Q1 is OFF. Thus for a complete input cycle output is developed as shown in figure 8.The difference between complementary symmetry and push pull models is in complementary model there is no output transformer.

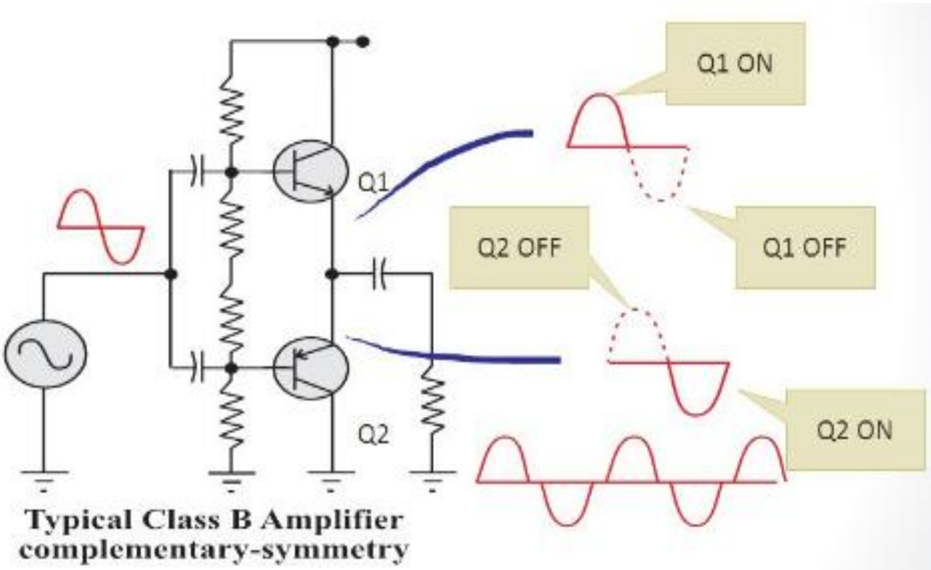


Fig (8): Class B Complementary symmetry Circuit operation

Analysis:

Note: All results for push pull amplifiers are applicable for complementary symmetry model. Only change is replace R_L' with real load R_L value. (Since, no output transformer is used).

Advantages:

- As transformer less circuit the weight and cost is less
- Due to common collector (emitter follower) impedance matching is possible.
- Frequency response is good.
- Value of efficiency is higher than push pull amplifier.

Disadvantage:

- Circuit needs two separate voltage supplies.
- Output is distorted due to crossover Distortion.
- It is necessary that both transistors Q1 & Q2 have matched characteristics.

Comparison of Push Pull & Complementary Symmetry circuits:

S No	Parameter	Push Pull	Complementary symmetry
1	Type of Transistor	Both should be of NPN or PNP type	One is PNP and other NPN
2	Use of transformers	Used at both i/p & o/p side	Not needed
3	Impedance matching	Possible due to use of two transformers	Possible due to operation of transistors in CC configuration
4	Transistor Configuration	Both transistors Operates in CE mode	Both transistors Operates in CC mode
5	Conduction Angle	180º	180º
6	Power dissipation when no input is present	Zero	Zero
7	Efficiency	Low	Higher than Push Pull type.

CLASS C AMPLIFIERS:

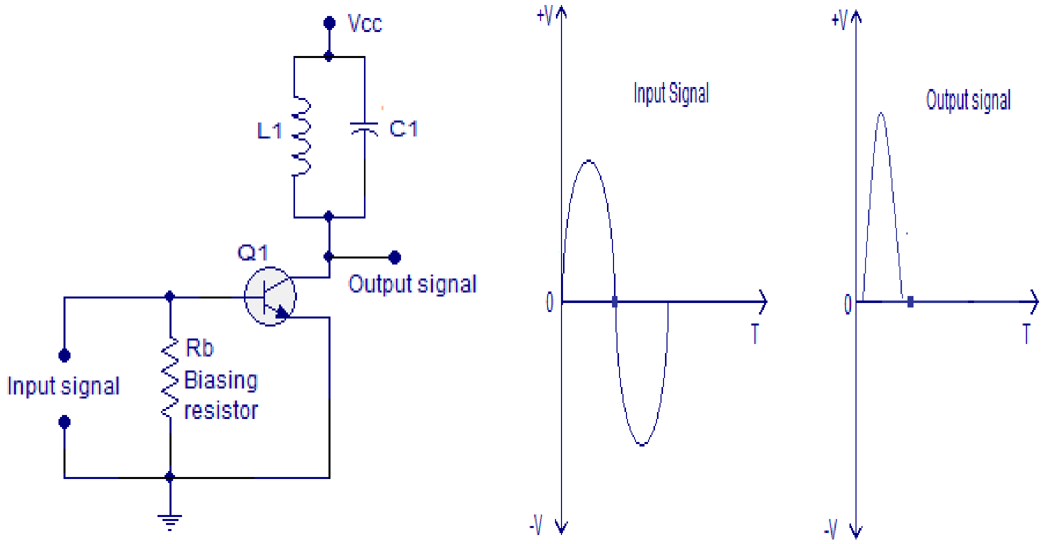


Fig (9) Class Circuit & operations

In class C the transistor conducts for less than one half cycle period of the input i.e around 80º to 120º angle. This reduced conduction angle increases the efficiency (Theoretically around 90 %). But this kind of operation causes large distortions. Hence, it is not used in Audio applications. Tuned circuit is used as load as shown in Figure(9).

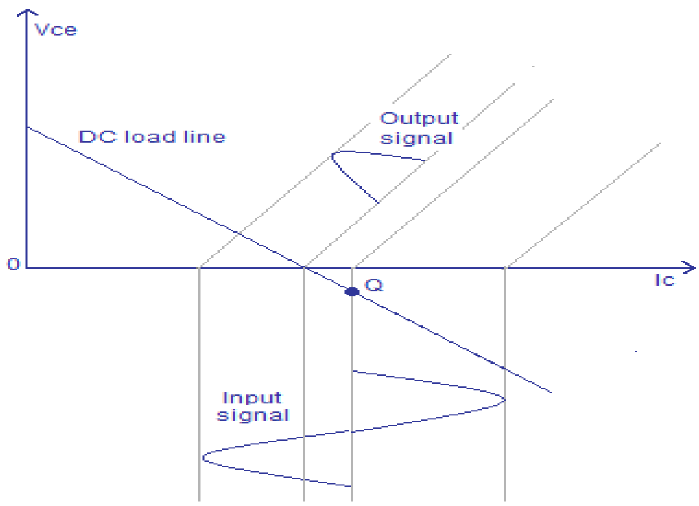


Fig (10): Class Circuit & operations

When the input signal is applied the tuned circuit starts resonating at the frequency of the input signal. Transistor produces a series of current pulses based on the input. By selecting Proper L1, C1 resonance can be achieved. This resonance frequency is extracted by the tuned load at the output. Harmonics can be eliminated by adding filters to the circuit shown in figure (9). The biasing resistance pulls the q point below Cut off region. Hence the transistor conducts only after the input amplitude is greater than the base emitter voltage. (Refer figure 9 & 10)

Advantages:

- Less Physical size.
- Used in RF applications.
- High Efficiency (higher than 95%)
- Low power loss in power transistors

Disadvantage:

- Creates lot of RF Interference.
- Selection of ideal Inductors is problem.
- Not suitable in Audio applications.

Applications: Tuned amplifiers**,** RF amplifiers, oscillators, Booster amplifiers, and High Frequency repeaters.

CLASS D AMPLIFIERS:

Class D type is designed to work with pulse or digital input signals. The Input V_{in} is compared with saw tooth wave (known as chopping wave) and accordingly a pulse waveform is generated (refer figure 11) which is fed to the amplifier.

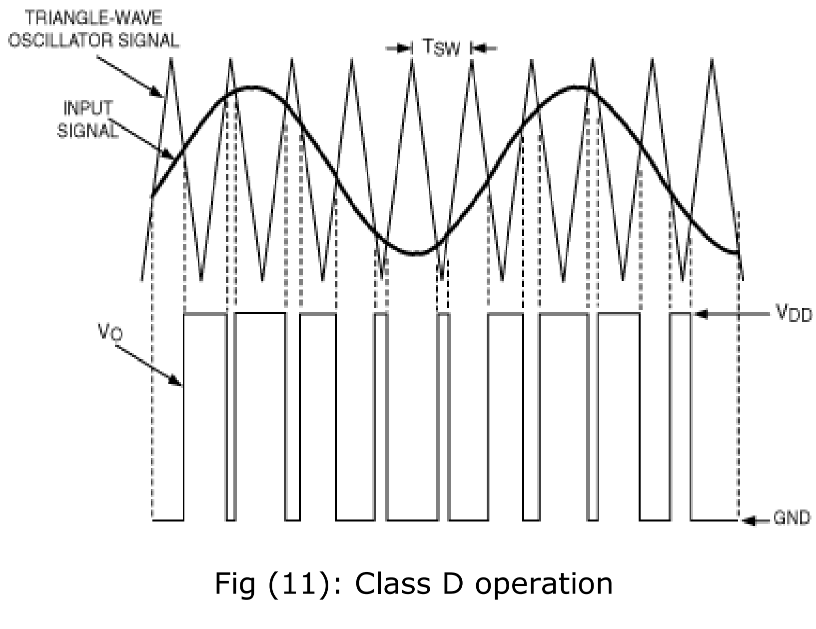


Fig (11): Class D operation

The circuit diagram of class D amplifier is shown in Figure 12.Input is applied to the non-inverting terminal of the comparator and the saw tooth wave is applied to the inverting terminal. Based on this the comparator produces an output pulse width modulated waveform and this PWM wave is amplified by the amplifier as shown in figure 11. Transistor in the amplifier circuit just acts as a switch and hence the power loss is very less. Low pass filter converts the pulse wave back into sinusoidal signal.At the output thus we have sinusoidal signal.

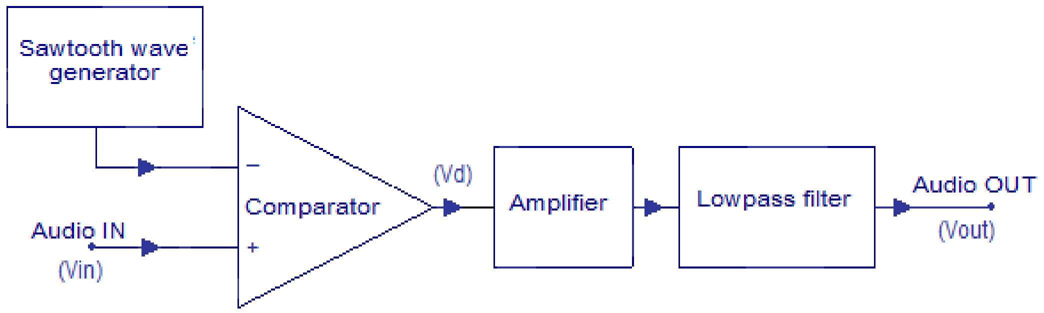


Fig (12): Class D circuit diagram

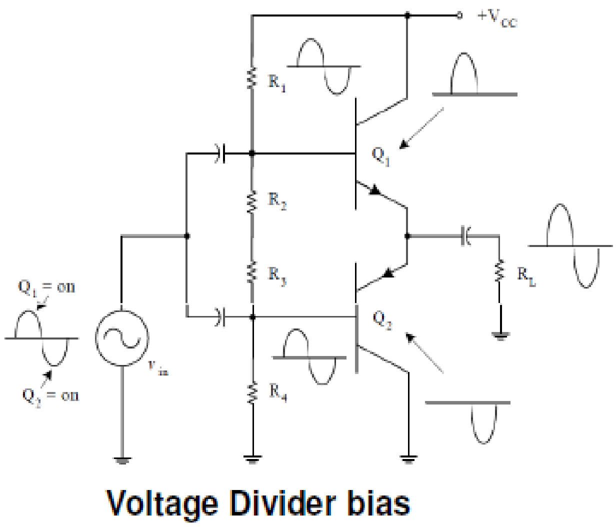
Efficiency: Transistor operates in saturation region when turned on .So V_{ce} is small. This is the reason for class D amplifiers have very high efficiency (Around 90%).

Advantages:

- High efficiency
- Possible to amplify the digital signals and analog signals as well.

CLASS AB AMPLIFIERS:

To eliminate cross over distortion in Class B Push Pull Amplifiers the Biasing of transistors can be done. This arrangement moves the transistor Q point slightly above the cut off region. Usually voltage divider bias is used as shown in Figure13 (a).Due to temperature changes V_{BE} also changes, hence no stable biasing. To avoid this we go for diode biasing as shown in figure 13.b.if D1, D2 matches with the transistor characteristics then we get a stable biasing. The d.c. voltage at the diode is connected to the transistors. (d.c. biasing).This value is equal to cut in voltage, hence conducts for full half cycle of the input. All analysis for class B holds good for class AB power amplifier.



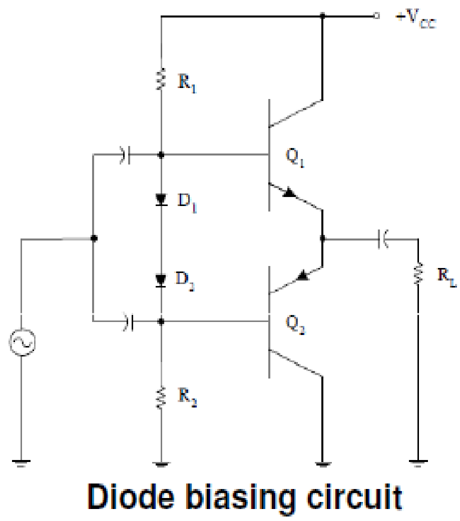


Fig (13 a): Class AB circuit diagram with Fig (13 b): Class AB circuit diagram with Voltage divider biasdiagram with Diode biasing

Distortions in amplifiers:

If the output of an amplifier is not a complete sine wave, then it is distortion. It can be analysed by using Fourier analysis.in this method any distorted periodic waveform can be broken down into different frequencycomponents. These components are harmonics of the fundamentalfrequency.Harmonics are integer multiples of a fundamental frequency (F). For example, 1st harmonic is 1 x F kHz.

<u>TYPES OF DISTORTION</u>

Amplitude or Non Linear distortion:

Due to the non-linearity of transistor (nonlinear dynamic characteristics of transistor) the output is different from the input. This kind of distortion is known as amplitude distortion or harmonic or non-linear distortion.

Harmonic distortion %D = (A_n/A_1)*100

Frequency Distortion:

When different frequency components of the input signal are amplified differently frequency amplification takes place.This is mainly due to the internal capacitance effect of the transistors.

Delay or Phase shift distortion:

If the phase shift introduced by amplifier is not proportional to the frequency then phase distortion takes place.

Note: For more information please refer the class notes.

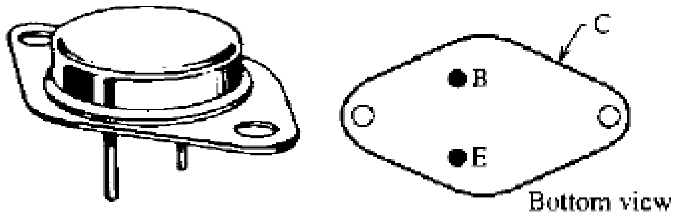
THERMAL STABILITY:

Average power of a transistor depends on the collector base junction. It is around 150 to 200º. If the temperature exceeds this limit then transistor get physically damaged.Performance of transistor depends on the ability of transistor to dissipate the heat generated in base collector junction. This can be achieved by

- ✓ Operating the transistor in safe region (proper biasing).
- ✓ By effectively removing the heat to the surrounding air quickly.

To remove the heat we use **Heat sinks**. The concept of **Heat Sink** is to keep the junction of the power device (transistor) to below a maximum operating temperature.

Heat sinks: All power devices come in complete package where there is a metal contact which connects the external heat sink to the metal surface of the device. (Usually to the collector terminal)



Fig(14) :Heat Sink(a) Top view (b) Bottom view

In figure 14(b) B – Base , E – Emitter & C – Collector terminal. From the above figure 14(b) we can notice that the Collector is connected to the metal top (chasis or heat sink) which has more area than Base & Emitter. So the heat generated at the output junction(collector junction) is dissipated fast. If more number of devices are connected to the same sink the INSULATORS are needed to shield individually. Usually Nylon material is used to ensure.

Note: For Problems and more details on quantitative analysis refer class notes.

Reference Books:

1. Donald. L, Schilling and C.Belove, "Electronic Circuits - Discrete and Integrated", 3rd Edition, McGraw Hill, 1989.
2. David A. Bell, "Electronic Devices and Circuits", PHI, 1998.
3. Gupta. J.B, "Electronic Devices and Circuits", Katson Publishers, 2009.

2 Marks Questions

1. What is Class AB operation?
2. Define the conversion efficiency of a power amplifier. What is its value for a class C power amplifier?
3. What is cross over distortion? How it can be eliminated?
4. Define thermal resistance.
5. What is meant harmonic distortion?
6. What is the drawback of class B amplifier
7. What is the difference between Class B and Class AB amplifier
8. State the types of distortions in amplifier.
9. What is the advantage of using transformer for a class A amplifier?
10. What is the difference between a voltage amplifier and a power amplifier?
11. State important features of power amplifiers.

12 Marks Questions

1. For the transformer coupled class A power amplifier circuit derive the expression for its efficiency.
2. Prove that the maximum efficiency of class A transformer coupled amplifier is 50% and that of class B type is 78.5%.
3. Draw the circuit of push pull class B amplifier coupled using transformers and explain the operation. Prove that all the even harmonics get eliminated. What is the assumption made for this?
4. Write notes on distortions in amplifiers and give the solutions to avoid the same.
5. Explain the operation of class D amplifier with suitable diagram.
6. Explain the operation of class C amplifier with neat circuit arrangement.