UNIT IV

LARGE SIGNAL AMPLIFIERS or POWER AMPLIFIER

Classification of amplifiers (Class A, B, AB, C&D), Efficiency of class A, RC coupled and transformer coupled power amplifiers. Class B complementary-symmetry, push-pull power amplifiers. Calculation of power output, efficiency and power dissipation. Crossover distortion and methods of eliminating it. Heat flow calculations using analogous circuit. Calculation of actual power handling capacity of transistors with and without heat sink. Heat sink design.

Objectives

- **Induction of Power Amplifier**
- **Power and Efficiency**
- **Amplifier Classification**
- **Basic Class A Amplifier**
- **Transformer Coupled Class A Amplifier**

Introduction

- Power amplifiers are used to deliver a relatively **high amount of power**, usually **to** a **low resistance load**.
- Typical load values range from 300W (for transmission antennas) to 8W (for audio speaker).
- Although these load values do not cover every possibility, they do illustrate the fact that power amplifiers **usually drive low-resistance loads**.
- Typical output power rating of a power amplifier will be **1W or higher**.
- **Ideal** power amplifier will deliver **100%** of the power it draws from the supply to load. In **practice**, this can never occur.
- The reason for this is the fact that the components in the amplifier will all **dissipate** some of the power that is being drawn form the supply.

Amplifier Power Dissipation

The **total** amount of power being dissipated by the amplifier, ***Ptot ,*** is

$$P_{tot} = P_1 + P_2 + P_C + P_T + P_E$$

The difference between this total value and the total power being drawn from the supply is the power that actually goes to the **load – i.e. output power**.

Amplifier Efficiency *h*

- A **figure of merit** for the power amplifier is its efficiency, *h* .
- **Efficiency（*h*）** of an amplifier is defined as the ratio of ac output power (power delivered to load) to dc input power .
- By formula :

$$\eta = \frac{ac \quad output \quad power}{dc \quad input \quad power} \times 100\% = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

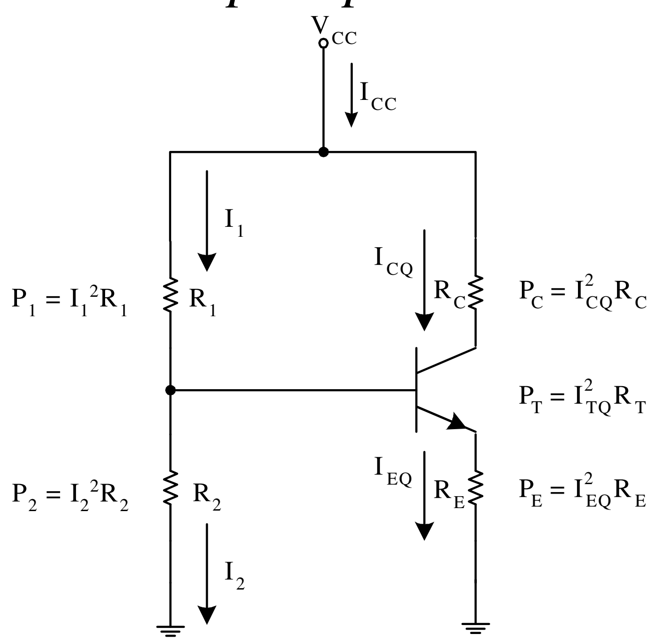


Fig. 4.1

- As we will see, certain amplifier configurations have much higher efficiency ratings than others.
- This is primary consideration when deciding which type of power amplifier to use for a specific application.

Amplifier Classifications

- Power amplifiers are classified according to the percent of time that collector current is **nonzero**.
- The amount the **output** signal varies over **one cycle** of operation for a **full cycle** of **input** signal.

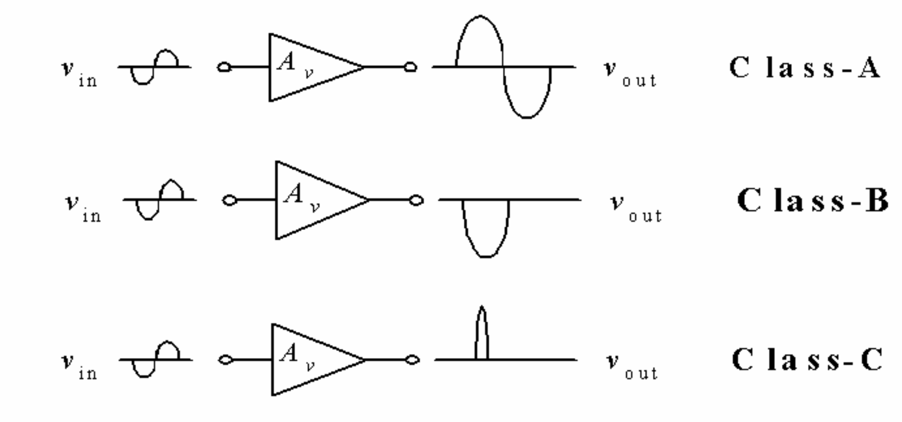


Fig. 4.2

Efficiency Ratings

The **maximum theoretical efficiency** ratings of class-A, B, and C amplifiers are

Amplifier	Maximum Theoretical Efficiency, **ηmax**
Class A	25%
Class B	78.5%
Class C	99%

4.1. Class A Amplifier

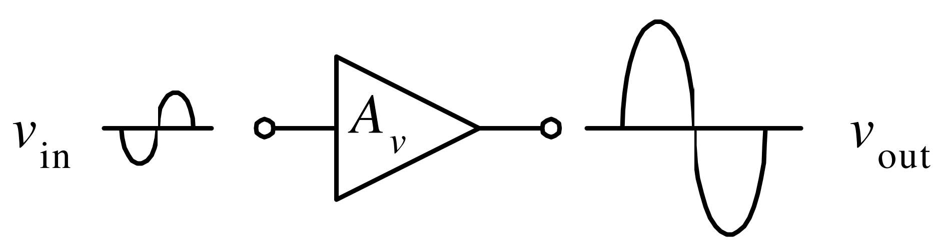


Fig 4.3

- Voutput waveform $\rightarrow$ **same shape** $\rightarrow$ vinput waveform **+ π phase shift.**

- The collector current is **nonzero** 100% of the time.
  $\rightarrow$ **inefficient**, since even with zero input signal, ICQ is nonzero
  (i.e. transistor dissipates power in the rest, or quiescent, condition)

4.1.1 Basic Operation

Common-emitter (voltage-divider) configuration (RC-coupled amplifier) This is the simplest type of Class A power amplifier circuit. It uses a single-ended transistor for its output stage with the resistive load connected directly to the Collector terminal. When the transistor switches "ON" it sinks the output current through the Collector resulting in an inevitable voltage drop across the Emitter resistance thereby limiting the negative output capability. The efficiency of this type of circuit is very low (possibly 20%) and delivers small power outputs for a large drain on the DC power supply. A Class A amplifier stage passes the same load current even when no input signal is applied so large heat sinks are needed for the output transistors.

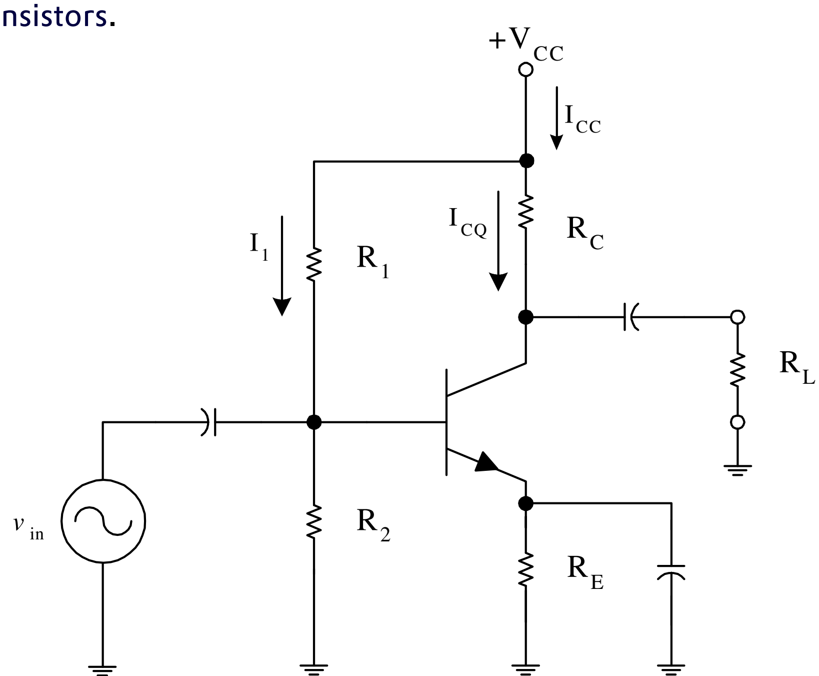


Fig 4.4

4.1.2 Typical Characteristic Curves for Class-A Operation

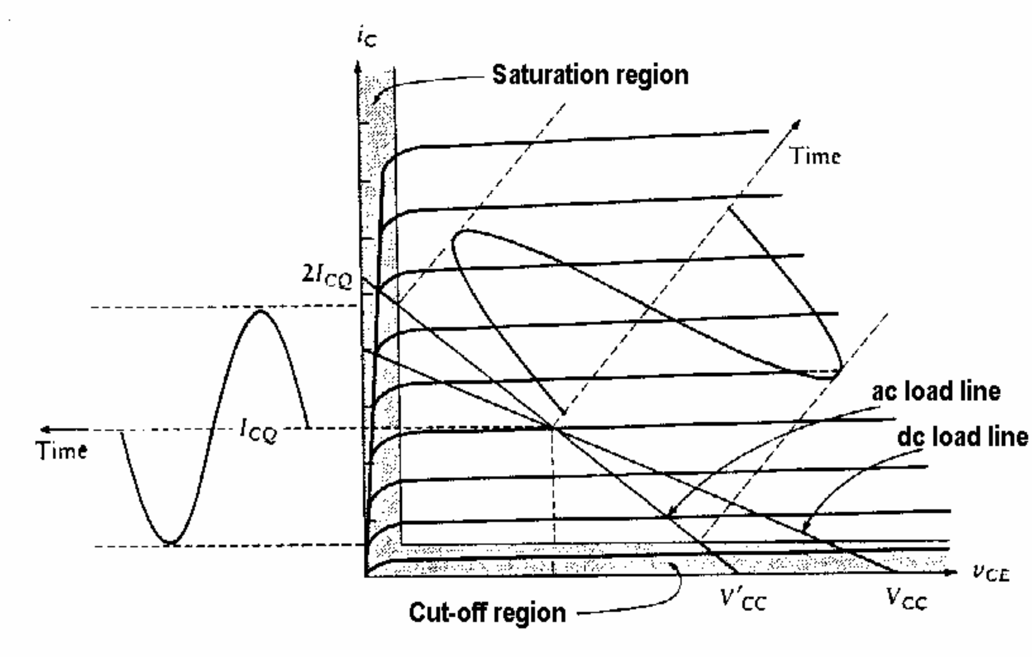


Fig 4.5

- Previous figure shows an example of a sinusoidal input and the resulting collector current at the output.
- The current, ICQ, is usually set to be in the **center** of the ac load line.

4.1.3DC Input Power

The total dc power, Pi *(dc),* that an amplifier draws from the power supply :

$$P_i(dc) = V_{CC} I_{CC}$$

$$I_{CC} = I_{CQ} + I_1$$

$$I_{CC} \approx I_{CQ} \qquad (I_{CQ} >> I_1)$$

$$P_i(dc) = V_{CC} I_{CQ} \tag{4.1}$$

Note that this equation is valid for most amplifier power analyses.

We can rewrite for the above equation for the **<u>ideal</u>** amplifier as

$$P_i(dc) = 2V_{CEQ}I_{CQ} \tag{4.2}$$

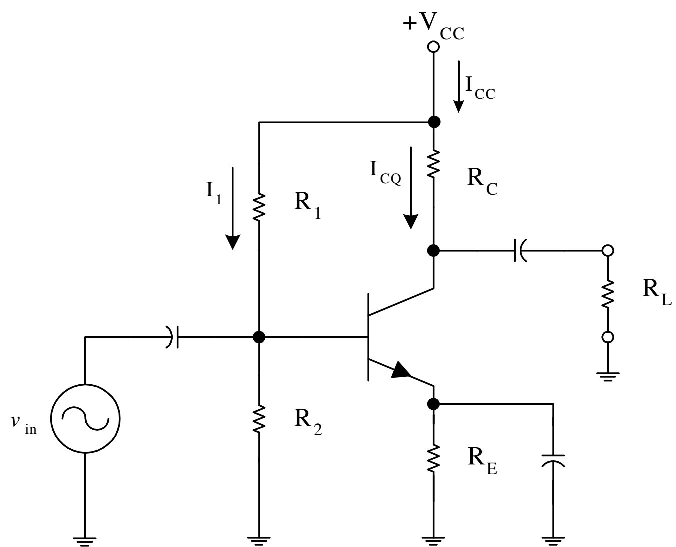


Fig 4.6

4.1.4 AC Output Power

AC output (or load) power, *Po(ac)*

$$P_o(ac) = i_{c(rms)}v_{o(rms)} = \frac{v_{o(rms)}^2}{R_L} \tag{4.3}$$

Above equations can be used to calculate the **maximum** possible value of ac load power.

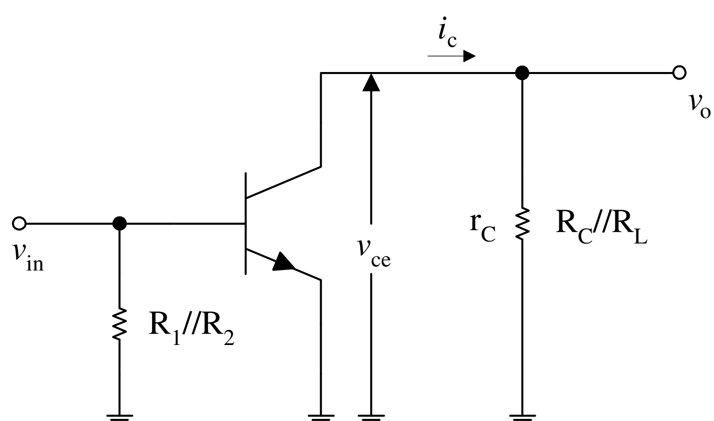


Fig 4.7

4.1.5 Disadvantage of using class-A amplifiers is the fact that their efficiency ratings are so low, $\eta max \approx$ **25%** . **Why??** A majority of the power that is drawn from the supply by a class-A amplifier is used up by the amplifier itself.

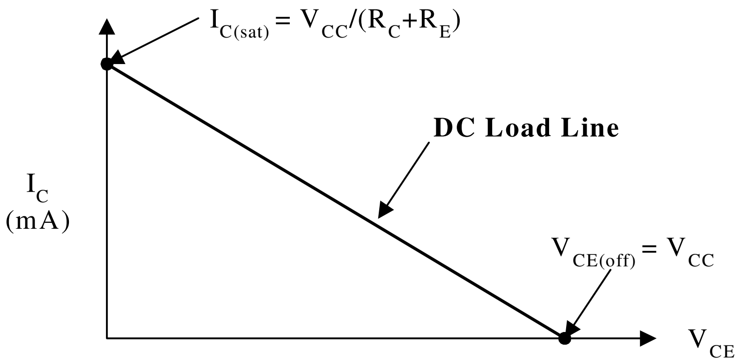
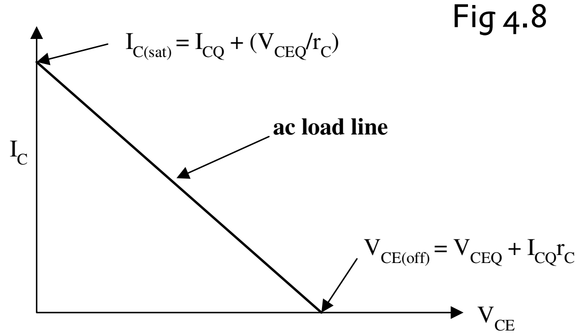


Fig 4.8



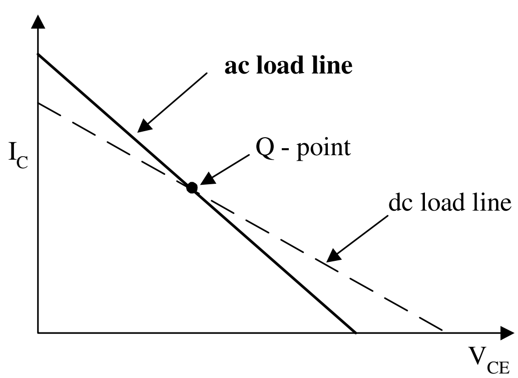


Fig 4.9

$$P_o(ac) = \left(\frac{V_{CEQ}}{\sqrt{2}}\right)\left(\frac{I_{CQ}}{\sqrt{2}}\right) = \frac{1}{2}V_{CEQ}I_{CQ} = \frac{V_{PP}^2}{8R_L} \qquad (4.4)$$

$$\eta = \frac{P_{o(ac)}}{P_{i(dc)}} \times 100\% = \frac{\frac{1}{2}V_{CEQ}I_{CQ}}{2V_{CEQ}I_{CQ}} \times 100\% = 25\%$$

P1.Calculate the input power [*Pi(dc)*], output power [*Po(ac)*], and efficiency [***h***] of the amplifier circuit for an input voltage that results in a base current of 10mA peak.

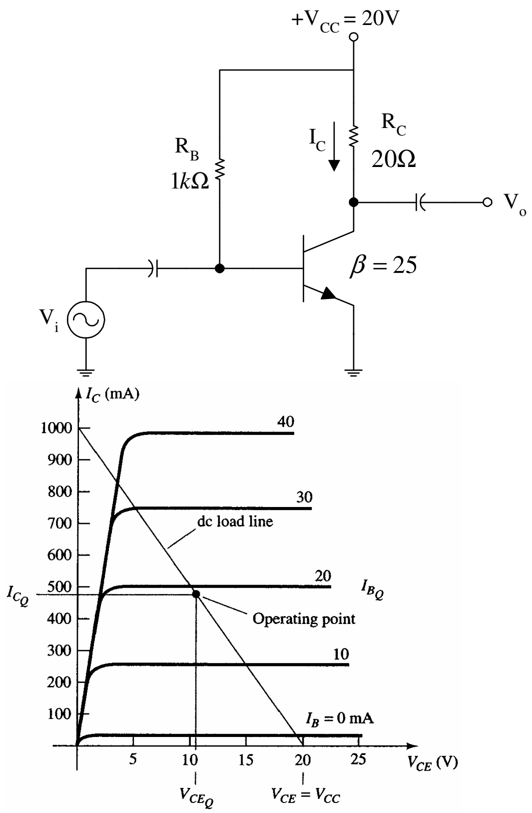


Fig 4.11

$$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{20V - 0.7V}{1k\Omega} = 19.3mA$$

$$I_{CQ} = \beta I_B = 25(19.3mA) = 482.5mA \cong 0.48A$$

$$V_{CEQ} = V_{CC} - I_C R_C = 20V - (0.48A)(20\Omega) = 10.4V$$

$$I_{c(sat)} = \frac{V_{CC}}{R_C} = \frac{20V}{20\Omega} = 1000mA = 1A$$

$$V_{CE(cutoff)} = V_{CC} = 20V$$

$$I_{C(peak)} = \beta I_{b(peak)} = 25(10mA\ \ peak) = 250mA\ \ peak$$

$$P_{o(ac)} = \frac{I^2_{C(peak)}}{2} R_C = \frac{\left(250\times 10^{-3}A\right)^2}{2}(20\Omega) = 0.625W$$

$$P_{i(dc)} = V_{CC} I_{CQ} = (20V)(0.48A) = 9.6W$$

$$\eta = \frac{P_{o(ac)}}{P} \times 100\% = 6.5\%$$

4.2 **Transformer-Coupled Class-A Amplifier**

A transformer-coupled class-A amplifier uses a transformer to couple the output signal from the amplifier to the load.

The relationship between the primary and secondary values of voltage, current and impedance are summarized as:

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$\left(\frac{N_1}{N_2}\right)^2 = \frac{Z_1}{Z_2} = \frac{Z_1}{R_L} \tag{4.5}$$

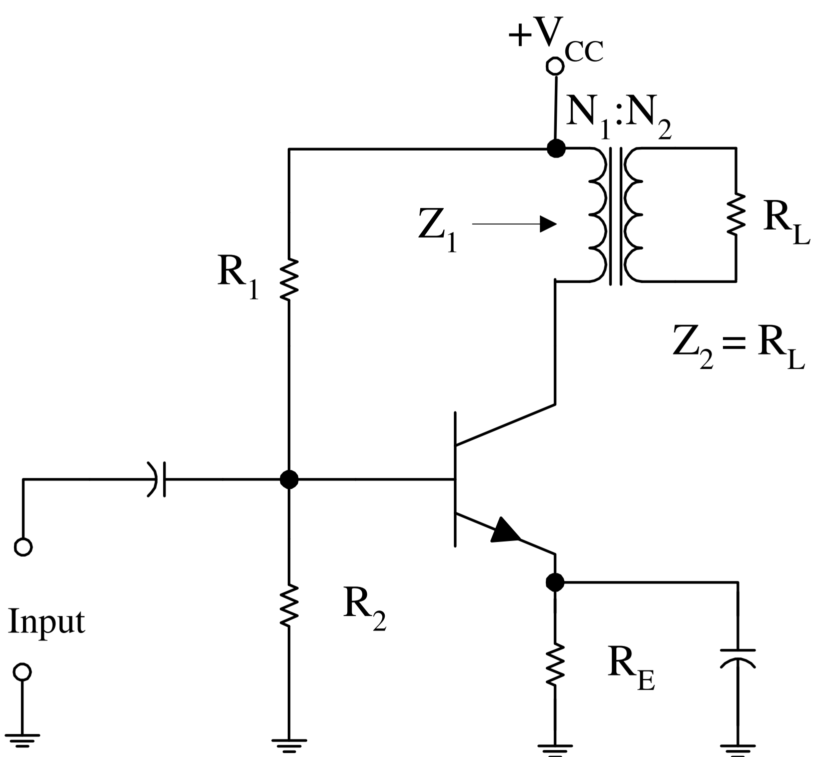


Fig. 4.12

N_1, N_2 = the number of turns in the primary and secondary

V_1, V_2 = the primary and secondary voltages

I_1, I_2 = the primary and secondary currents

Z_1, Z_2 = the primary and seconadary impedance ($Z_2 = R_L$)

4.2.1 Counter emf

- An important characteristic of the transformer is the ability to produce a counter emf, or kick emf. When an inductor experiences a rapid change in supply voltage, it will produce a voltage with a polarity that is opposite to the original voltage polarity. The counter emf is caused by the electromagnetic field that surrounds the inductor

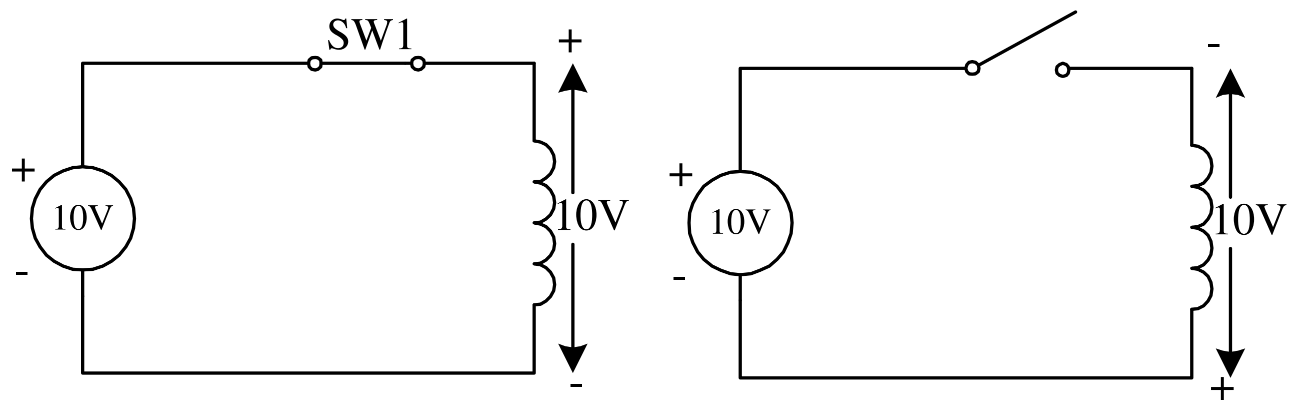


Fig. 4.13

- This counter emf will be present only for an instant.
- As the field collapses into the inductor the voltage decreases in value until it eventually reaches 0V.

As the Collector current, Ic is reduced to below the quiescent Q-point set up by the Base bias voltage, due to variations in the Base current, the magnetic flux in the transformer core collapses causing an induced emf in the transformer primary windings. This causes an instantaneous Collector voltage to rise to a value of twice the supply voltage 2Vcc giving a maximum Collector current of twice Ic when the Collector voltage is at its minimum. Then the efficiency of this type of Class A amplifier configuration can be calculated as follows.

The r.m.s. Collector voltage is given as:

$$V_{CE} = \frac{V_{C(max)} - V_{C(min)}}{2\sqrt{2}} = \frac{2V_{CC} - 0}{2\sqrt{2}} \qquad (4.5)$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_{C(max)} - I_{C(min)}}{2\sqrt{2}} = \frac{2I_C - 0}{2\sqrt{2}} \quad (4.6)$$

The r.m.s. Power delivered to the load (Pac) is therefore given as:

$$P_{ac} = V_{CE} \times I_{CE} = \frac{2V_{CC}}{2\sqrt{2}} \times \frac{2I_C}{2\sqrt{2}} = \frac{2V_{CC}\,2I_C}{8} \quad (4.7)$$

The average power drawn from the supply (Pdc) is given by:

$$P_{dc} = V_{CC} \times I_C \quad (4.8)$$

and therefore the efficiency of a Transformer-coupled Class A amplifier is given as

$$\eta_{(max)} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{CC}\,2I_C}{8V_{CC}I_C} \times 100\% \quad (4.9)$$

This improves the efficiency of the amplifier by matching the impedance of the load with that of the amplifier using the turns ratio of the transformer and efficiencies reaching 40% are possible with most commercially available Class-A type power amplifiers of this type of configuration, but the use of inductive components is best avoided. Also one big disadvantage of this type of circuit is the additional cost and size of the audio transformer required.

It is possible to obtain greater power output and efficiency than that of a **Class A amplifier** by using two transistors in the output stage in a "push-pull" configuration. This type of configuration is called a **Class B Amplifier**

There are several reasons for the difference between the practical and theoretical efficiency ratings for the amplifier:

- The derivation of the η = 50% value assumes that VCEQ = VCC . In practice, VCEQ will always be some value that is less the VCC .
- The transformer is subject to various power losses. Among these losses are couple loss and hysteresis loss. These transformer power losses are not considered in the derivation of the η = 50% value

- One of the **primary advantages** of using the transformer-coupled class-A amplifier is the **increased efficiency** over the RC-coupled class-A circuit.

- **Another advantage** is the fact that the transformer-coupled amplifier is **easily converted into** a type of amplifier that is used extensively in communications :- the **tuned amplifier**.
- A tuned amplifier is a circuit that is designed to have a specific value of power gain over a **specific range of frequency**.

4.3 Class B Amplifiers

To improve the full power efficiency of the previous Class A type amplifier it is possible to design the amplifier circuit with two transistors in its output stage producing a "**push-pull**" type amplifier configuration. Push-pull operation uses two "complementary" transistors, one an NPN-type and the other a PNP-type with both power transistors receiving the same input signal together that is equal in magnitude, but in opposite phase to each other. This results in one transistor only amplifying one half or 180° of the input waveform while the other transistor amplifies the other half or remaining 180° of the waveform with the resulting "two-halves" being put back together at the output terminal. This pushing and pulling of the alternating half cycles by the transistors gives this type of circuit its name but they are more commonly known as **Class B Amplifiers** as shown below.

4.3.1 Class B Push-pull Transformer Amplifier Circuit

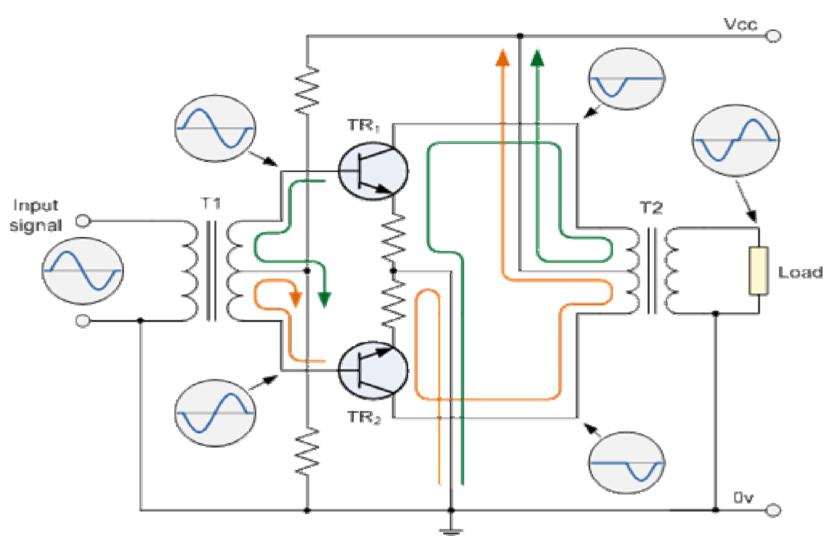


Fig. 4.14

The circuit above shows a standard push-pull amplifier circuit that uses a balanced centre-tapped input transformer, which splits the incoming waveform signal into two equal cycles that are 180° out of phase with each other and another centre-tapped transformer on the output to recombined the signals and provide the increased power to the load. The transistors used for this type of transformer push-pull amplifier circuit are both NPN transistors with their emitter terminals connected together. Here, the load current is shared between the two power transistor devices as it decreases in one device and increases in the other throughout the signal cycle reducing the output voltage and current to zero. The result is that both halves of the output waveform now swings from zero to twice the quiescent current thereby reducing dissipation. This has the effect of almost doubling the efficiency of the amplifier to around 70%.

Assuming that no input signal is present, then each transistor carries the normal quiescent collector current, the value of which is determined by the base bias which is at the cut-off point. If the transformer is accurately centre tapped, then the two collector currents will flow in opposite directions (ideal condition) and there will be no magnetization of the transformer core, thus minimizing the possibility of distortion. When a signal is present across the secondary of the driver transformer T1, the transistor base inputs are in "anti-phase" to each other as shown, thus if TR1 base goes positive driving the transistor into heavy conduction, its collector current will increase but at the same time the base current of TR2 will go negative further into cut-off and the collector current of this transistor decreases by an equal amount and vice versa. Hence negative halves are amplified by one transistor and positive halves by the other transistor giving this push-pull effect. Unlike the DC condition, these AC currents are **ADDITIVE** resulting in the two output half-cycles being combined to reform the sine-wave in the output transformers primary winding which then appears across the load. **Class B Amplifier** operation has zero DC bias as the transistors are biased at the cut-off, so each transistor only conducts when the input signal is greater than the base-emitter voltage. Therefore, at zero input there is zero output. This then means that the actual Q-point of a Class B amplifier is on the Vce part of the load line as shown below

4.3.2 Class B Output Characteristics Curves

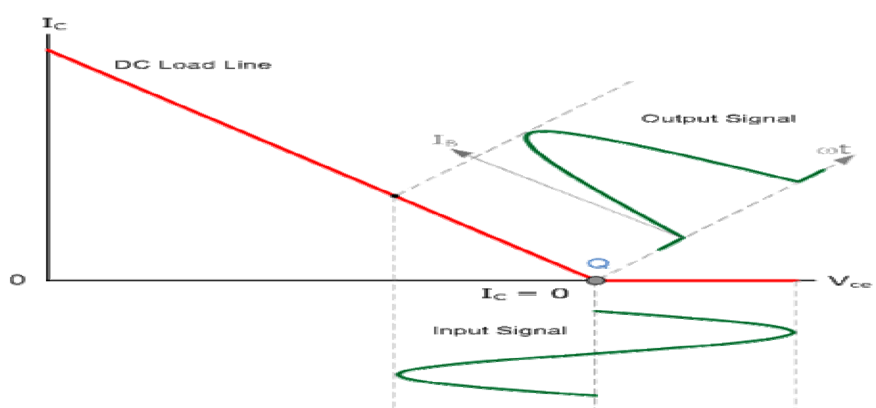


Fig. 4.15

Class B Amplifiers have the advantage over their Class A amplifier cousins in that no current flows through the transistors when they are in their quiescent state (ie, with no input signal), therefore no power is dissipated in the output transistors or transformer when there is no signal present unlike Class A amplifier stages that require significant base bias thereby dissipating lots of heat - even with no input signal. So the overall conversion efficiency (η) of the amplifier is greater than that of the equivalent Class A with efficiencies reaching as high as 75% possible resulting in nearly all modern types of push-pull amplifiers operated in this Class B mode

4.3.3 Transformerless Class B Push-Pull Amplifier

One of the main disadvantages of the Class B amplifier circuit above is that it uses balanced centre-tapped transformers in its design, making it expensive to construct. However, there is another type of Class B push-pull amplifier called a **Complementary-Symmetry Class B Amplifier** that does not use transformers in its design therefore, it is transformerless using instead complementary pairs of transistors. As transformers are not needed this makes the amplifier circuit much smaller for the same amount of output, also there are no stray magnetic effects or transformer distortion to effect the quality of the output signal. An example of a "transformerless" circuit is given below.

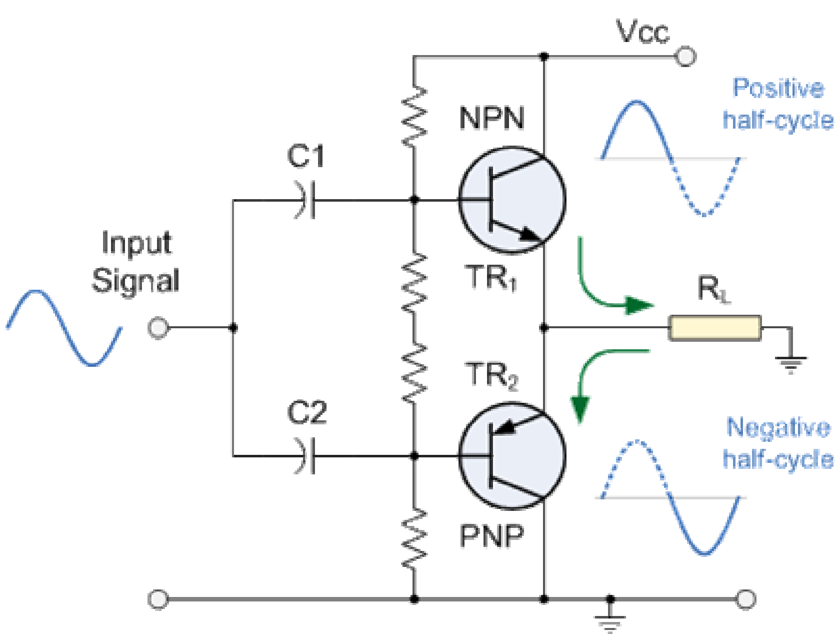


Fig. 4.16

While Class B amplifiers have a much high gain than the Class A types, one of the main disadvantages of class B type push-pull amplifiers is that they suffer from an effect known commonly as **Crossover Distortion**. This occurs during the transition when the transistors are switching over from one to the other as each transistor does not stop or start conducting exactly at the zero crossover point even if they are specially matched pairs. This is because the output transistors require a base-emitter voltage greater than 0.7v for the bipolar transistor to start conducting which results in both transistors being "OFF" at the same time. One way to eliminate this crossover distortion effect would be to bias both the transistors at a point slightly above their cut-off point. This then would give us what is commonly called an **Class AB Amplifier** circuit.

4.3.4 Transformer less Class AB Push-Pull Amplifier

We know that we need the base-emitter voltage to be greater than 0.7v for a silicon bipolar transistor to start conducting, so if we were to replace the two voltage divider biasing resistors connected to the base terminals of the transistors with two silicon **Diodes**, the biasing voltage applied to the transistors would now be equal to the forward voltage drop of the diode. These two diodes are generally called **Biasing Diodes** or **Compensating Diodes** and are chosen to match the characteristics of the matching transistors. The circuit below shows diode biasing

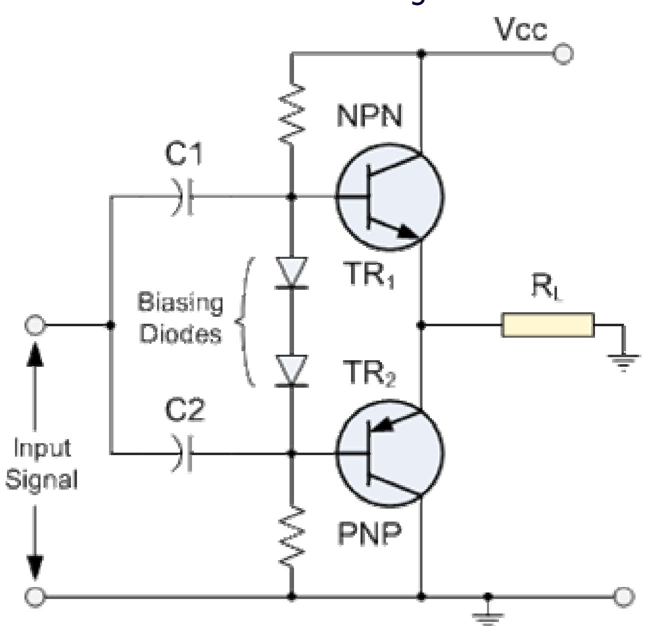


Fig 4.17

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4.4 Crossover Distortion

We have seen that one of the main disadvantages of a **Class A Amplifier** is its low full power efficiency rating. But we also know that we can improve the amplifier and almost double its efficiency simply by changing the output stage of the amplifier to a Class B push-pull type configuration. However, this is great from an efficiency point of view, but most modern Class B amplifiers are transformerless or complementary types with two transistors in their output stage. This results in one main fundamental problem with push-pull amplifiers in that the two transistors do not combine together fully at the output both halves of the waveform due to their unique zero cut-off biasing arrangement. As this problem occurs when the signal changes or "crosses-over" from one transistor to the other at the zero voltage point it produces an amount of "distortion" to the output wave shape. This results in a condition that is commonly called **Crossover Distortion**.

Crossover Distortion produces a zero voltage "flat spot" or "deadband" on the output wave shape as it crosses over from one half of the waveform to the other. The reason for this is that the transition period when the transistors are switching over from one to the other, does not stop or start exactly at the zero crossover point thus causing a small delay between the first transistor turning "OFF" and the second transistor turning "ON". This delay results in both transistors being switched "OFF" at the same instant in time producing an output wave shape as shown below.

Crossover Distortion Waveform

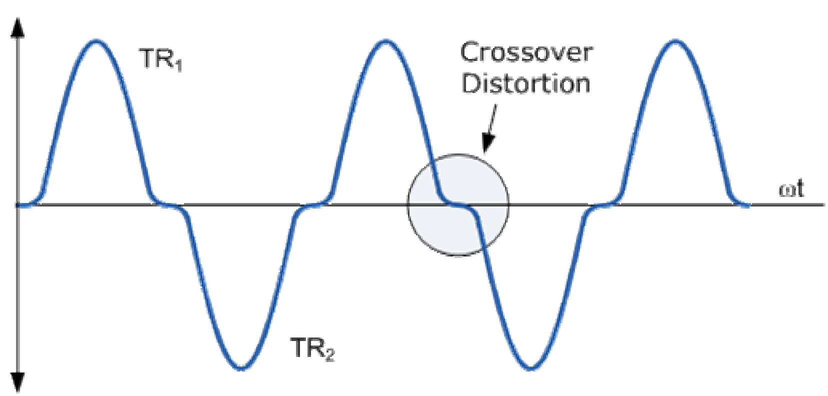


Fig.4.18

In order that there should be no distortion of the output waveform we must assume that each transistor starts conducting when its base to emitter voltage rises just above zero, but we know that this is not true because for silicon bipolar transistors the base voltage must reach at least 0.7v before the transistor starts to conduct thereby producing this flat spot. This crossover distortion effect also reduces the overall peak to peak value of the output waveform causing the maximum power output to be reduced .

4.4.1 Non-Linear Transfer Characteristics

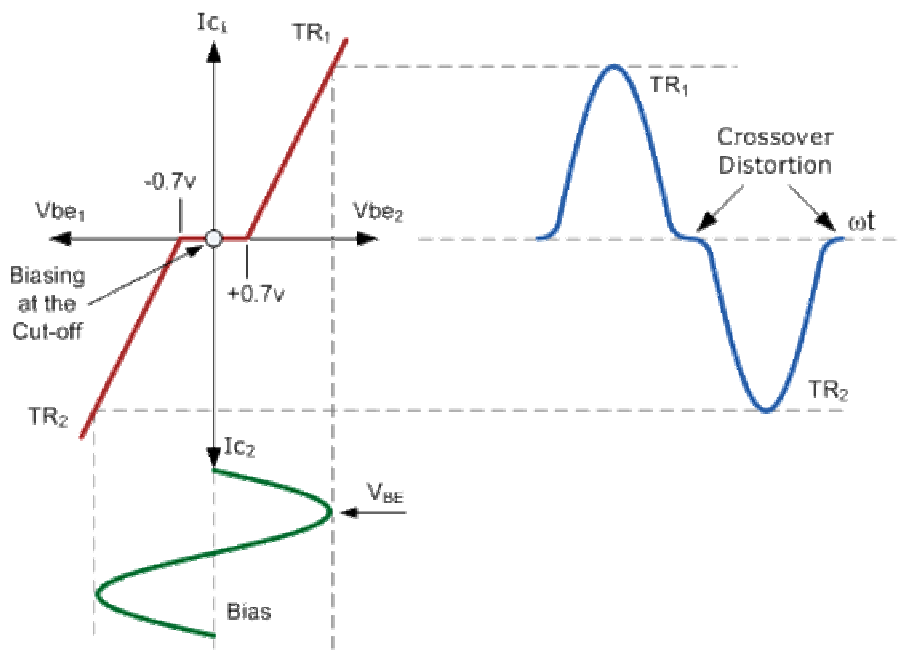


Fig 4.19

This effect is less pronounced for large input signals as the input voltage is usually quite large but for smaller input signals it can be more severe causing audio distortion to the amplifier.

4.4.2 Pre-biasing the Output

The problem of **Crossover Distortion** can be reduced considerably by applying a slight forward base bias voltage (same idea as seen in the **Transistor** tutorial) to the bases of the two transistors via the centre-tap of the input transformer, thus the transistors are no longer biased at the zero cut-off point but instead are "Pre-biased" at a level determined by this new biasing voltage shown in fig 4.20

This type of resistor pre-biasing causes one transistor to turn "ON" exactly at the same time as the other transistor turns "OFF" as both transistors are now biased slightly above their original cut-off point. However, to achieve this the bias voltage must be at least twice that of the normal base to emitter voltage to turn

"ON" the transistors. This pre-biasing can also be implemented in transformerless amplifiers that use complementary transistors by simply replacing the two potential divider resistors with **Biasing Diodes** as shown in fig 4.21.

Push-pull Amplifier with Pre-biasing

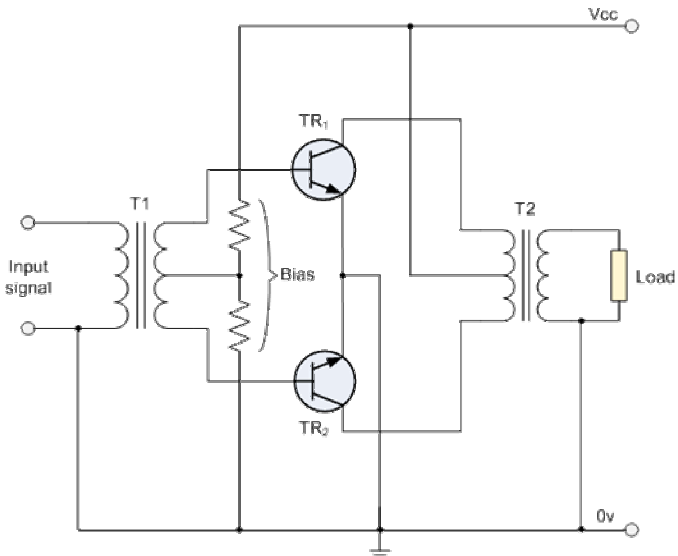


Fig 4.20

Pre-biasing with Diodes

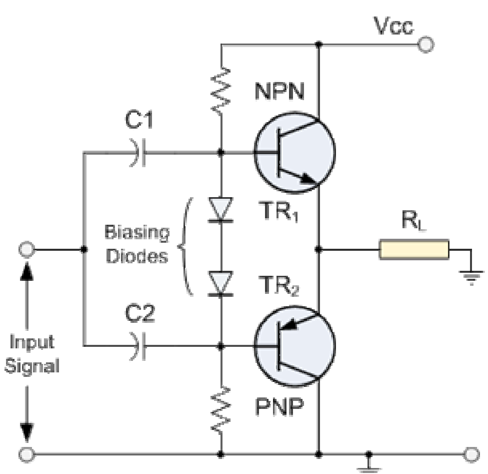


Fig . 4.21

This pre-biasing voltage either for a transformer or transformerless amplifier circuit, has the effect of moving the amplifiers Q-point past the original cut-off point thus allowing each transistor to operate within its active region for slightly more than half or 180° of each half cycle. In other words 180° + Bias. This then produces an amplifier circuit commonly called a **Class AB Amplifier** and its biasing arrangement is given below.

4.5 Class AB Amplifier

The **Class AB Amplifier** circuit is a compromise between the Class A and the Class B configurations. This very small diode biasing voltage causes both transistors to slightly conduct even when no input signal is present. An input signal waveform will cause the transistors to operate as normal in their active region thereby eliminating any crossover distortion. A small collector current will flow when there is no input signal but it is much less than that for the Class A amplifier configuration. This means then that the transistor will be "ON" for more than half a cycle of the waveform but much less than a full cycle. The amount of diode biasing voltage present at the base terminal of the transistor can also be increased in multiples by adding additional diodes in series

4.5.1 Class AB Output Characteristics

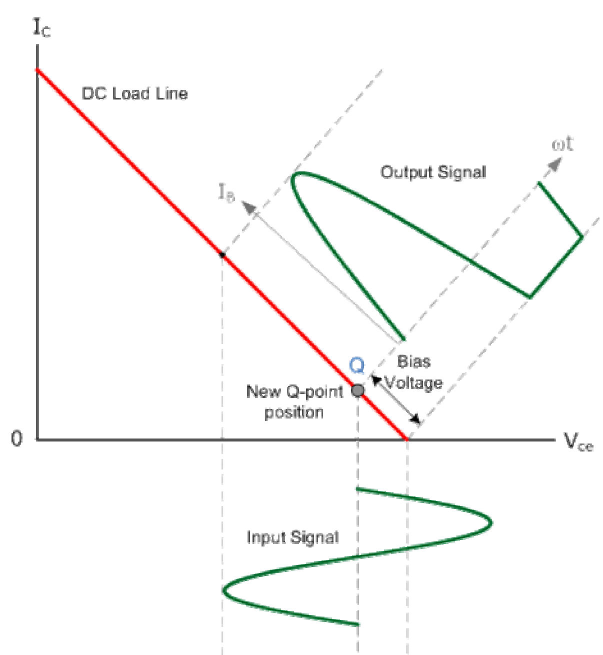


Fig 4.22

4.6 Analysis Of Class-B Push-Pull Amplifier

Consider an input signal (base current of the form $i_{b1} = I_{bm} Cos\omega t$ applied to Q_1.

The output current of this transistor is given as,

$$i_1 = I_C + B_0 + B_1 Cos\omega t + B_2 Cos2\omega t + B_3 Cos3\omega t + - - - \quad \text{---------} (1)$$

The corresponding input signal to Q_2 is

$$i_{b2} = -i_{b1} = I_{bm} Cos(\omega t + \pi)$$

The output current of this transistor is obtained by replacing ωt by $(\omega t + \pi)$ in expression for i_1. i.e.

$$i_2(\omega t) = i_1(\omega t + \pi) \quad \text{-----------------} (2)$$

$$i_2 = \quad I_C + B_0 - B_1 Cos\omega t + B_2 Cos2\omega t - B_3 Cos3\omega t + - - - - - - \text{--} (3)$$

As illustrated in the above fig, the current i_1 & i_2 are in opposite directions through the output transformer windings. The total output current is the proportional to the difference between the collector currents in the two transistors. i.e.

$$i = k(i_1 - i_2) = 2k(B_1 Cos\omega t + B_3 Cos3\omega t + - - - - - - - -) \quad \text{--------} (4)$$

4.6.1 Power Consideration

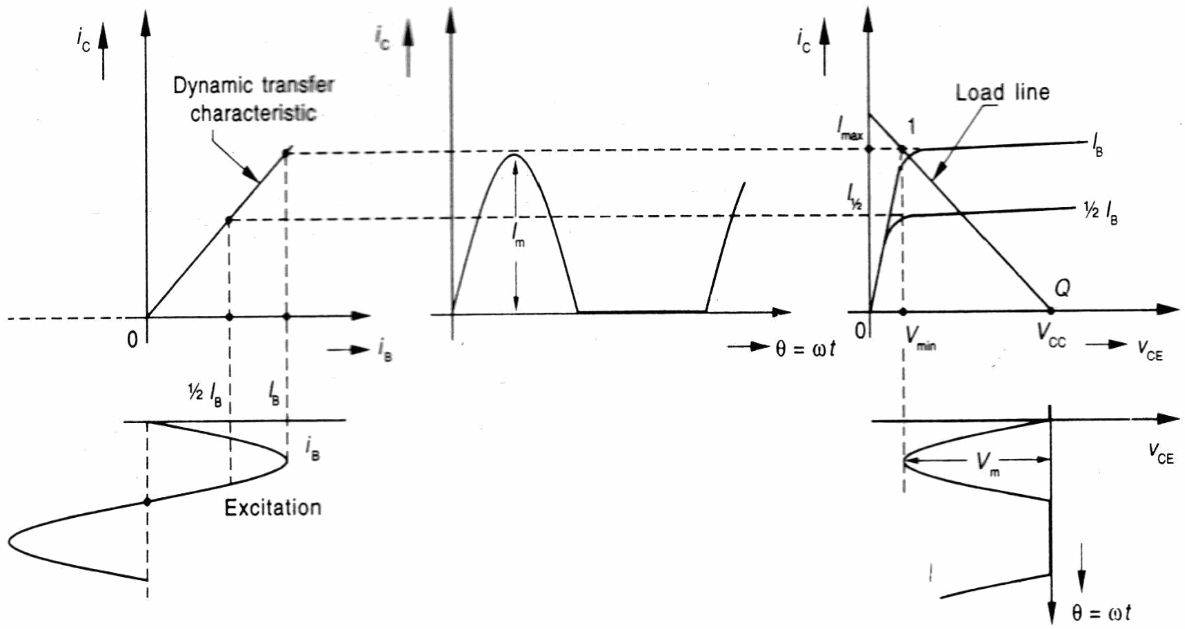


Fig. 2 Graphical construction for determining the output waveforms of a single class-B transistor stage

$$P = \frac{I_m I_m}{2} = \frac{I_m (V_{CC} - V_{min})}{2} \quad \text{-------------------------} \quad (1)$$

$$P_i = 2\frac{I_m V_{CC}}{\pi} \quad \text{----------------------} \quad (2)$$

$$\eta = \frac{P_0}{P_i} X100 = \frac{\pi}{4}\frac{V_m}{V_{CC}} = \frac{\pi}{4}\left(1 - \frac{V_{min}}{V_{CC}}\right) X100\%$$

Since $V_{min} \angle\angle V_{CC}$

$$\eta = \frac{\pi}{4} X100\% = 78.5\% \quad \text{--------------------} \quad (3)$$

4.6.2 Power Dissipation

$$P_C = P_{dc} - P_{ac} = P_i - P_0 \quad \text{---------------------------(4)}$$

$$= \frac{2}{\pi} V_{CC} I_m - \frac{V_m I_m}{2}$$

$$= \frac{2}{\pi} V_{CC} \frac{V_m}{R'_L} - \frac{V_m^{\ 2}}{2R_L'} \quad \text{--------------------------- (5)}$$

4.6.3 Maximum Power Dissipation

$$\frac{dP_C}{dV_m} = \frac{2}{\pi} \frac{V_{CC}}{R_L'} - \frac{2V_m}{2R_L'} = 0$$

$$\frac{V_m}{R_L'} = \frac{2}{\pi} \frac{V_{CC}}{R_L'}$$

$$\therefore V_m = \frac{2}{\pi} V_{CC} \quad \text{--------------------------------- (6)}$$

Substituting the value of V_m in eq.(5), we get

$$P_{C,\max} = \frac{2}{\pi}\frac{V_{CC}}{R_L'}\left(\frac{2}{\pi}V_{CC}\right) - \left(\frac{2}{\pi}V_{CC}\right)^2 X \frac{1}{2R_L'}$$

$$= \frac{4V_{CC}^2}{\pi^2 R_L'} - \frac{2}{\pi^2}\frac{V_{CC}^2}{R_L'} = \frac{2}{\pi^2}\frac{V_{CC}^2}{R_L'} \quad \text{------------ (7)}$$

Output power, $P_0 = \dfrac{V_m^2}{2R_L'}$

When $V_m = V_{CC}$

$$P_{0,\max} = \frac{V_{CC}^2}{2R_L'} \quad \text{-- (8)}$$

Equation (7) can be written as

$$P_{C,\max} = \frac{4}{\pi^2}\left(\frac{V_{CC}^2}{2R_L'}\right) = \frac{4}{\pi^2}P_{0,\max}$$

$$P_{C,\max} = \frac{4}{\pi^2}P_{0,\max} = 0.4P_{0,\max} \quad \text{--------------------- (9)}$$

$$\therefore P_{C,\max} \text{ per transistor} = \frac{4}{\pi^2}\frac{P_{0,\max}}{2} = 0.2P_{0,\max} \quad \text{-----(10)}$$

4.6.4 Harmonic Distortion in Push-Pull Circuits

The output of a push-pull system always possesses mirror symmetry, so that $I_C = 0, I_{max} = -I_{min}$ & $I_{\frac{1}{2}} = -I_{-\frac{1}{2}}$

We know that $B_0 = \frac{1}{6}\left[I_{max} + 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} + I_{min}\right] - I_C$

$$B_1 = \frac{1}{3}\left[I_{max} + I_{\frac{1}{2}} - I_{-\frac{1}{2}} - I_{min}\right]$$

$$B_2 = \frac{1}{4}\left[I_{max} - 2I_C + I_{min}\right]$$

$$B_3 = \frac{1}{6}\left[I_{max} - 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} - I_{min}\right]$$

$$B_4 = \frac{1}{12}\left[I_{max} - 4I_{\frac{1}{2}} + 6I_C - 4I_{-\frac{1}{2}} + I_{min}\right]$$

When $I_C = 0, I_{max} = -I_{min}$ & $I_{\frac{1}{2}} = -I_{-\frac{1}{2}}$, the above equations reduce to

$$B_0 = B_2 = B_4 = 0 \quad \text{----------------------(11)}$$

$$B_1 = \frac{2}{3}\left(I_{max} + I_{\frac{1}{2}}\right) \quad \text{------------------------(12)}$$

$$B_3 = \frac{1}{3}\left(I_{max} - 2I_{\frac{1}{2}}\right) \quad \text{-----------------------(13)}$$

$$D_3 = \frac{|B_3|}{|B_1|} \times 100\% \quad \text{-----------------------(14)}$$

The output power taking distortion into account is given by

$$P_0 = (1 + D_3)^2 \frac{B_1{}^2 R_L{}'}{2} \quad \text{-------------------(15)}$$

4.6.5 Advantages of Pushpull Configuration

- Even harmonics are eliminated & the overall distortion is reduced.
- Because of reduced distortion, net output power improves
- Output power per BJT is more compared to conventional circuits
- As the DC currents get cancelled, transformer core saturation problem is reduced

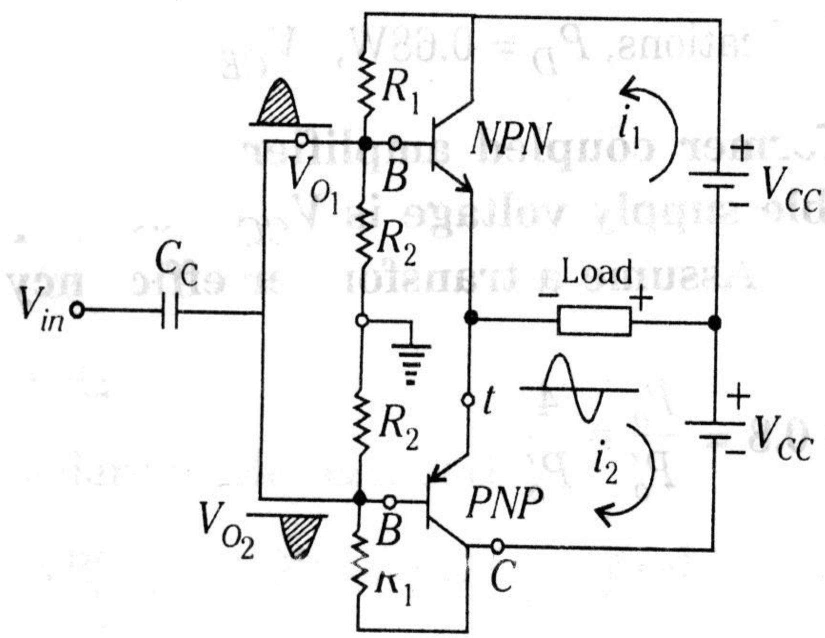
4.6.6 Drawbacks Of Pushpull Configuration

- Use of transformers makes the circuit bulky.
- Require two identical transistors if not performance deteriorates.
- Design of centre tap transformer is a difficult process

4.6.7 Special Circuits

- Can eliminate the limitations of Push-Pull configuration
- Transformers are not required on the output side
- Need one PNP & NPN Transistors

4.6.7.1 Complementary Symmetry Class B Amplifier



P2: A class A power amplifier with a direct coupled load has a collector efficiency of 30% and delivers a power input of 10W.Find (a) the dc power input (b) the power dissipation 'of full output and (C) the desirable power dissipation rating of the BJT.

SOLN: Given $P_{ac} = 10W, \eta = 30\% = 0.30$

(a) $$\eta = \frac{P_{ac}}{P_{dc}}$$

$$\therefore P_{dc} = \frac{P_{ac}}{\eta} = \frac{10}{0.3} = 33.33W$$

(b) Dissipation at full output, $P_C = 33.33 - 5 = 28.33W$

(c) Dissipation at no output, $P_C' = P_{dc} = 33.33W$

$\therefore$ BJT rating = 33.33W

P4. Design a class B push pull circuit to deliver 200mW to a 4Ω load. Output transformer efficiency is 70%., V_{CE}=25V, average rating of the transistor to be used is 165Mw at $25^0 C$.Determine V_{CC} , collector to collector resistance R_{CC},

SOLN: Given P_{ac}=20mW, R_L=4 Ω, $\eta = 0.7$, $V_{CE(max)}$ =25V, P_{trans}=165mW, at 25^0C, R_E=10Ω.

Assume that the given power delivered to the load is maximum.

$P_{ac} = \frac{P_{ac\,max}}{\eta} = \frac{200}{0.7} = 285.714mW$ on primary of transformer.

Maximum voltage rating per transistor is $2V_{CC}$.

Let $V_{CC}=12V$

$$P_{acprimary} = \frac{1}{2}\frac{V_{CC}^{2}}{R'_{L}}$$

$$R'_{L} = \frac{1}{2}\frac{V_{CC}^{2}}{P_{acprimary}} X \frac{(12)^{2}}{285.714 X 10^{-3}} = 252\Omega$$

$$\text{But}\quad R'_{L} = \frac{R_{L}}{n^{2}} = \left(\frac{N_{1}}{N_{2}}\right)^{2} R_{L}$$

P5 .Calculate the peak power dissipated in each transistor of a class B push-pull amplifier if VCC = 15V and RL'=5Ω.

In push-pull amplifier, there are two transistors. Each transistor conducts only one half cycle.

$$P_{dc} = V_{CC} I_{CQ} = V_{CC} \cdot \frac{I_{C}}{\pi} = \frac{V_{CC}}{\pi} \cdot \frac{V_{CC}}{R_{L}'}$$

$$= \frac{V_{CC}^{2}}{\pi R_{L}'}$$

Total power dissipated, $P_d = 2 \times \frac{V_{CC}^{2}}{\pi R_{L}'} = 2 \times \frac{(15)^{2}}{\pi \times 5} = 9.12W$

Peak power dissipation /device $= \frac{9.12}{2} = 4.56W$

P6. Determine the maximum power values for a class B amplifier using a supply of 30V and driving a load of 16Ω.Also calculate the conversion efficiency

Given, $V_{CC} = 30V$, $R_L = 16\Omega$

Output peak value $V_P = V_{CC}$

$$V_{0RMS} = \frac{V_P}{\sqrt{2}} = \frac{V_{CC}}{\sqrt{2}}$$

$$\text{Max Power } P_0 = \frac{V_{0RMS}}{R_L} = \frac{V_{CC}^2}{2R_L} = \frac{(30)^2}{2\times 16} = 28.125W$$

Maximum input DC power $P_{dc} = V_{CC} I_{CQ}$

$$V_{CC}\left(\frac{2I_C}{\pi}\right) = V_{CC}\cdot\frac{2V_{CC}}{\pi R_L} = \frac{2V_{CC}^2}{\pi R_L}$$

$$= \frac{2\times(30)^2}{\pi\times 16} = 35.81W$$

Conversion efficiency, $\eta = \frac{P_{0ac}}{P_{idc}}\times 100 = \frac{28.125}{35.81}\times 100 = 78.54\%$

Summary

- Large Signal Amplifiers are also known as **Power Amplifiers**.
- Power Amplifiers can be sub-divided into different Classes, for example **Class A Amplifiers**, where the output device conducts for all of the input cycle, **Class B Amplifiers,** where the output device conducts for only 50% of the input cycle and **Class AB Amplifiers**, where the output device conducts for more than 50% but less than 100% of the input cycle.
- An ideal Power Amplifier would deliver 100% of the available DC power to the load.
- Class A amplifiers are the most common form of power amplifier but only have an efficiency rating of less than 40%.
- Class B amplifiers are more efficient than Class A amplifiers at around 70% but produce high amounts of distortion.
- Class B amplifiers consume very little power when there is no input signal present.
- By using the "Push-pull" output stage configuration, distortion can be greatly reduced.
- However, simple push-pull Class B Power amplifiers can produce high levels of **Crossover Distortion** due to their cut-off point biasing.
- Pre-biasing resistors or diodes will help eliminate this crossover distortion.
- Class B Power Amplifiers can be made using Transformers or Complementary Transistors in its output stage.

    - Then to summarise, **Crossover Distortion** occurs in Class B amplifiers because the amplifier is biased at its cut-off point. This then results in BOTH transistors being switched "OFF" at the same instant in time. By applying a small base bias voltage either by using a resistive potential divider circuit or diode biasing this crossover distortion can be greatly reduced or even eliminated completely. The application of a biasing voltage produces another type or class of amplifier circuit commonly called a **Class AB Amplifier**. Then the difference between a pure Class B amplifier and an improved Class AB amplifier is in the biasing level applied to the output transistors. Therefore, we can say the a Class AB amplifier is a Class B amplifier with Bias and we can summarise as:

- Class A Amplifiers have no Crossover Distortion as they are biased in the centre of the load line.
-
- Class B Amplifiers have large amounts of Crossover Distortion due to biasing at the cut-off point.
-
- Class AB Amplifiers may have some Crossover Distortion if the biasing level is too low.