Chapter 12 # POWER AMPLIFIERS

18/11/20

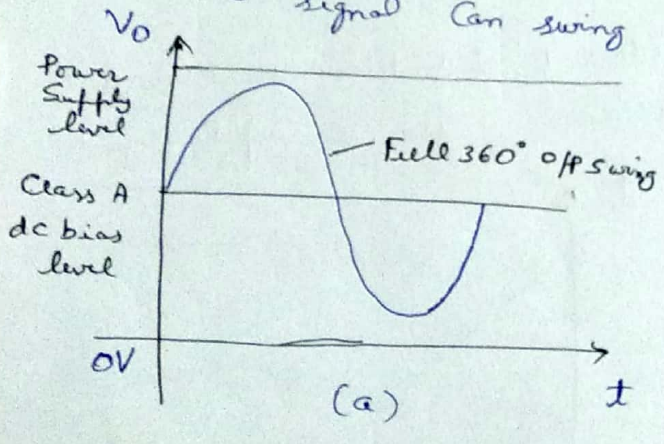
* Large-signal or power amplifiers primarily provide sufficient power to an output load to drive a speaker or other power device, typically a few watts to tens of watts.

* The main features of a large-signal amplifier are the circuit's power efficiency, the maximum amount of power that the circuit is capable of handling, and the impedance matching to the output device.

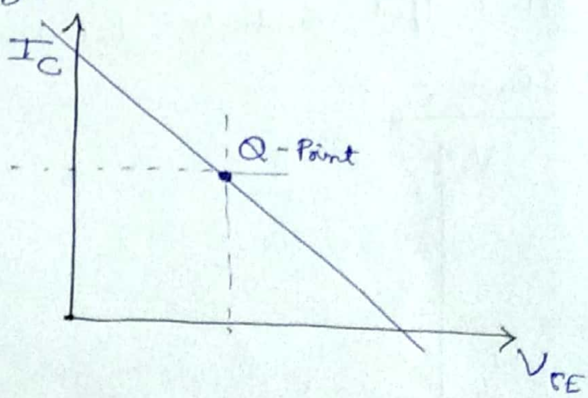
* One method used to categorize amplifiers is by class. Basically, amplifier classes represent the amount the output signal varies over one cycle of operation for a full cycle of input signal.

1) Class A amplifier:

* The output signal varies for a full 360° of the cycle. The Q point is set at the middle of the load line so that the AC signal can swing a full cycle.

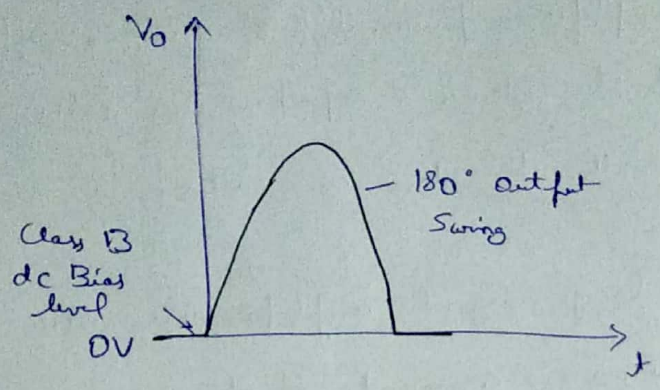


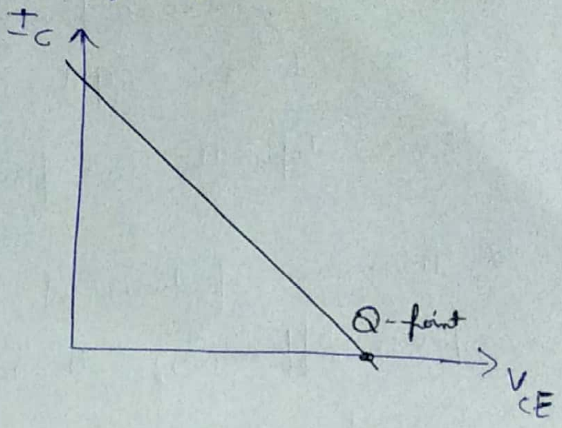
(a)




* Remember that the DC load line indicates the max. and min. limits set by the DC power supply.
* Power efficiency of class 'A' amplifier is very low (25% to 50%) and delivers small power outputs for a large drain on the DC power supply.
* Class 'A' amplifier provides better high frequency and feedback loop stability.

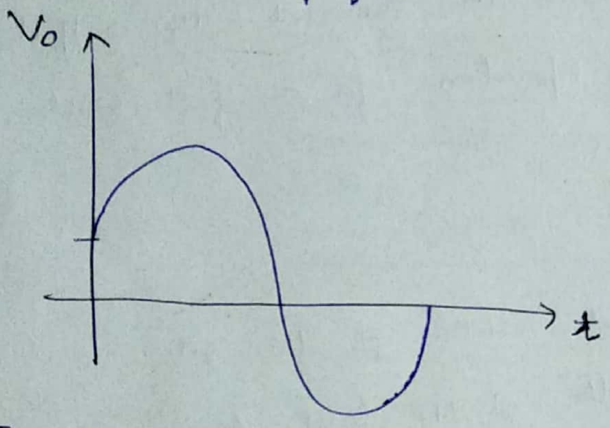
2) **Class B**: A Class B circuit provides an output signal varying over one-half the input signal cycle, or for 180° of signal.

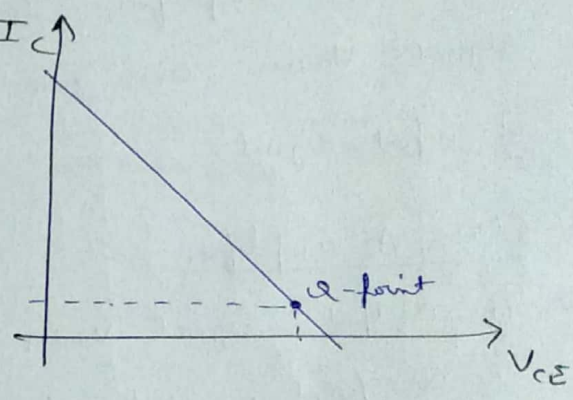



The Q-point is at 0V on the load line, so that the AC signal can only swing for one-half cycle.

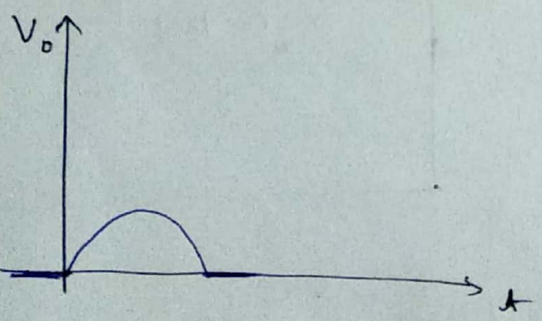
3) **Class AB**: This amplifier is a compromise between the Class 'A' & Class 'B' amplifier

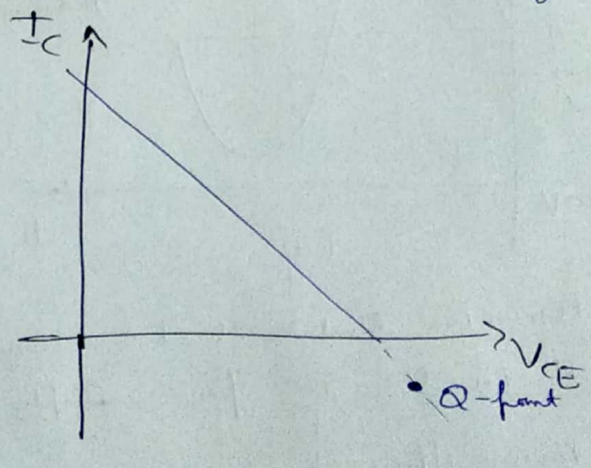



The Q-point is above that of the Class B' but below the Class A'
The output conducts between 180° and 360° of the AC input signal.

4) **Class C**:



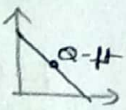
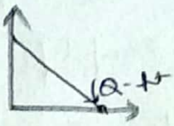
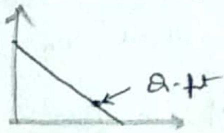
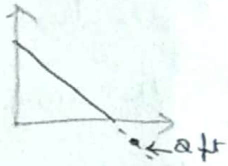

The output of the Class C conducts for less than 180° of the AC cycle.
The Q-point is below cut-off.

## Amplifier Efficiency

It represents the amount of ac power delivered from the dC source which is given by

$$\boxed{\% \eta = \frac{P_{o\,(ac)}}{P_{i\,(dc)}} \times 100\,\%}$$

## Summary

| | Parameter | Class A | Class B | Class AB | Class C |
|---|---|---|---|---|---|
| 1) | Angle of Conduction | 360° | 180° | 180° to 360° | Less than 180° |
| 2) | Efficiency | 25% to 50% | 78.5 % | 78.5 % | 95% |
| 3) | Position of Q-point (Operating point) | Exactly at the Centre of the loadline   | on X-axis   | Just above x-axis   | Below x-axis   |
| 4) | Distortion | No Distortion | More than A & AB Less than C | Less distortion than B, C but more distortion than A | Maximum Distortion |

## Applications of Power Amplifiers

1. Consumer Electronics: Audio power amplifiers are used in almost all Consumer electronic devices ranging from microwave ovens, headphone drivers, televisions, mobile phones and home theatre systems.
2. Industrial: Switching type power amplifiers are used for Controlling most of the industrial actuator systems like servos and DC motors.
3. Wireless Communication: High power amplifier are important in transmission Cellular or FM broadcasting signals to user and also used in satellite Communication equipment.

## Series - Fed Class 'A' amplifier

* This is similar to the small-signal amplifier except that it will handle higher voltages.
* The transistors used are capable of handling large power while not providing much voltage gain.

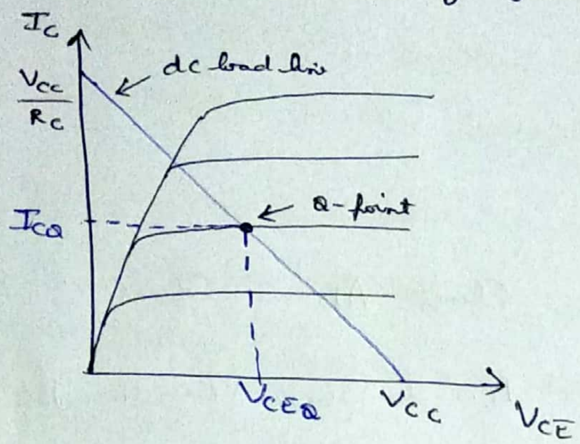



Fig: Transistor characteristic showing load line and Q-point

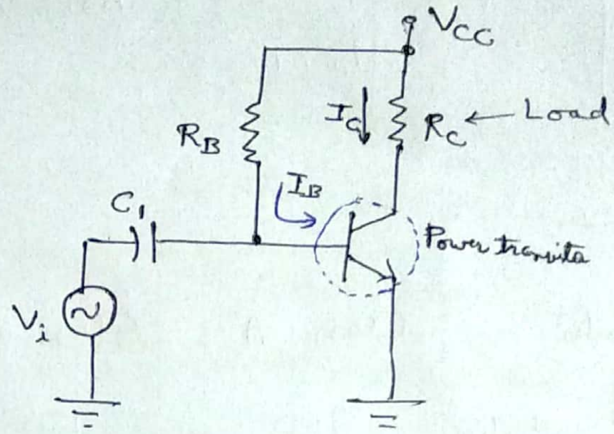



Fig: Series-fed Class A large-signal amplifier

* The above diagram shows a simple fixed bias Class A amplifier.
* The transistor used in this amplifier is capable of operating in the range of a few to tens of watts.

### DC bias operation

The dc bias set by $V_{CC}$ and $R_B$ fixes the dc base-bias current at

$$I_B = \frac{V_{CC} - 0.7V}{R_B} \quad \text{—— (1)}$$

With the collector current

$$I_C = \beta I_B \quad \text{—— (2)}$$

Then,

With the collector-emitter voltage

$$V_{CE} = V_{CC} - I_C R_C \quad \text{—— (3)}$$

* A dc load line is drawn using the value of $V_{CC}$ & $R_C$.
* The intersection of the dc bias value of $I_B$ with the dc load line then determines the operating point (Q-point) for the circuit.

## AC Operation



* When an input ac signal is applied to the amplifier, the output will vary from its dc bias operating voltage and current.
* A small input signal will cause the base current to vary above & below the dc bias point, which will then cause the collector current (output) to vary from the dc bias point set as well as the collector-emitter voltage to vary around its dc bias value.
* As the input signal is made larger, the output will vary further around the established dc bias point until either the current or voltage reaches a limiting condition.
* For the current, this limiting condition is either zero current at the low end or $V_{CC}/R_C$ at the high end of its swing.
* For the collector-emitter voltage, the limit is either 0V or $V_{CC}$.

## Power Consideration:

* The power into an amplifier is provided by the supply.
* With no input signal, the dc current drawn is the collector bias current $I_{CQ}$.
* The power then drawn from the supply is,

$$\boxed{P_i(dc) = V_{CC} I_{CQ}} \quad \text{—— (4)}$$

* Even with an ac signal applied, the average current drawn from the supply remains equal to $I_{CQ}$.

**Output Power**: Using rms values, we can write expression for output power as

$$\boxed{P_o(ac) = V_{CE(rms)} I_{C(rms)}} \quad \text{—— (5)}$$

$$P_o(ac) = I^2_{c(rms)} R_C \quad \text{—— (6)}$$

$$P_o(ac) = \frac{V^2_{c(rms)}}{R_C} \quad \text{—— (7)}$$

Efficiency: It represents the amount of ac power delivered (transferred) from the dc source.

$$\% \eta = \frac{P_o(ac)}{P_i(dc)} \times 100\% \quad \text{--- (8)}$$

Maximum Efficiency:

For the Class A series-fed amplifier, the maximum efficiency can be determined using the maximum voltage and current swings.

For the voltage swing it is

$$\text{maximum } V_{CE} \text{ (peak to peak)} = V_{CC}$$

For the current swing it is

$$\text{maximum } I_C (p\text{-}p) = \frac{V_{CC}}{R_C}$$

Using the maximum voltage swing in eq$^n$ (7) yields,

$$\text{maximum } P_o(ac) = \frac{V_{CC}(V_{CC}/R_C)}{8}$$

$$= \frac{V_{CC}^2}{8R_C}$$

* The maximum power input can be calculated using the dc bias current set to one-half the maximum value:

$$\text{maximum } P_i(dc) = V_{CC}(\text{maximum } I_C) = V_{CC} \cdot \frac{V_{CC}/R_C}{2}$$

$$= \frac{V_{CC}^2}{2R_C}$$

Using eq$^n$ (8), to calculate maximum efficiency:

$$\text{maximum } \% \eta = \frac{\text{maximum } P_o(ac)}{\text{maximum } P_i(dc)} \times 100\%$$

$$= \frac{V_{CC}^2/8R_C}{V_{CC}^2/2R_C} \times 100\% \quad \simeq 25\%$$

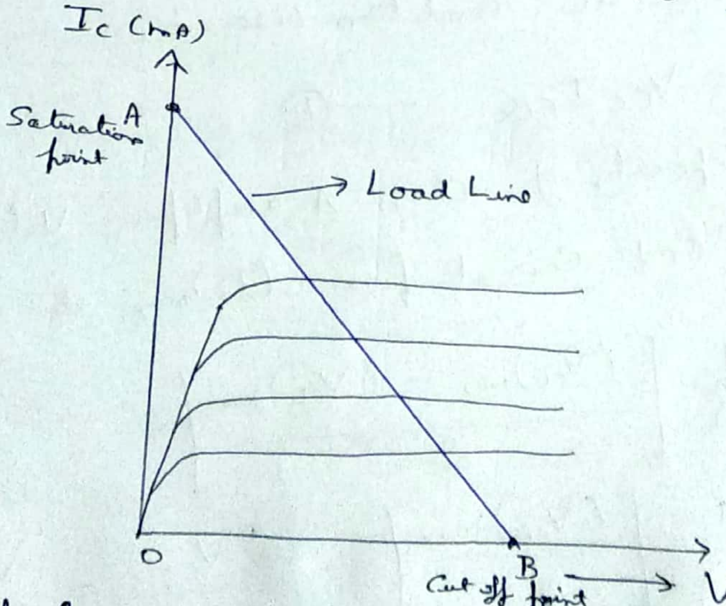
The maximum efficiency of a class A series-fed amplifier is 25%. Since this maximum efficiency will occur only for ideal conditions of both voltage swing and current swing, most series-fed circuits will provide efficiencies of much less than 25%.

## NOTE:

### Load Line:

When the value for the maximum possible current (Collector current) is considered, that point will be present on the Y-axis, which is nothing but the Saturation point. As well, when a value for the maximum possible Collector emitter voltage is considered, that point will be present on X-axis, which is the Cutoff point.

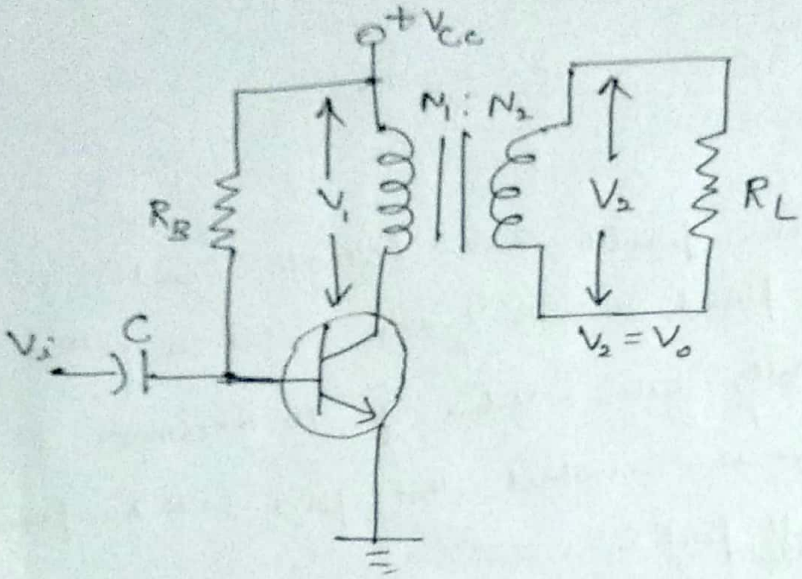
When a line is drawn joining these two points, (as shown in fig. point A & B) such a line can be called as Load line. This is called so as it symbolizes the output at the load. This line, when drawn over the output characteristic curve, makes contact at a point called as 'Operating point' or Quiescent point or simply Q-point.




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

## Transformer - Coupled Class A amplifier

* A form of Class A amplifier having maximum efficiency of 50%. uses a transformer to couple the output signal to the load as shown in Fig:




**Circuit operation:**

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

The input power under dc condition will be

$$P_i(dc) = V_{CC} I_{CQ} \quad \text{—— (1)}$$

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

Hence

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

$$= \frac{1}{\sqrt{2}}\left[\frac{(V_{CE})_{max}}{2}\right] = \frac{2V_{CC}}{2\sqrt{2}} = \frac{V_{CC}}{\sqrt{2}}$$

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

$$= \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max}}{2}\right] = \frac{2 I_{CQ}}{2\sqrt{2}} = \frac{I_{CQ}}{\sqrt{2}}$$

Therefore,

$$P_{O(ac)} = V_{CE(rms)} I_{C(rms)}$$

$$= \frac{V_{CC}}{\sqrt{2}} \times \frac{I_{CQ}}{\sqrt{2}}$$

$$P_{O(ac)} = \frac{V_{CC} I_{CQ}}{2} \quad \text{—— (2)}$$

Therefore,

$$\% \text{ Collector Efficiency} = \frac{(P_o)_{ac}}{(P_i)_{dc}} \times 100\%$$

or

$$\% (\eta)_{collector} = \frac{\frac{V_{CC} I_{CQ}}{2}}{V_{CC} I_{CQ}} \times 100\%$$

$$= \frac{1}{2} \times 100 = 50\%$$

The efficiency of Class A amplifier got improved to 50% by using the transformer Coupled Class A power amplifier.

## Maximum Theoretical Efficiency:

Class A transformer - Coupled amplifier efficiency can be expressed as

$$\% \eta = 50 \left( \frac{V_{CE\,max} - V_{CE\,min}}{V_{CE\,max} + V_{CE\,min}} \right)^2 \%$$

The larger the value of $V_{CE\,max}$ and the smaller the value of $V_{CE\,min}$, the closer the efficiency approaches the theoretical limit of 50%.

## Class B Amplifier:

* Class B amplifier is a type of power amplifier where the transistor conducts only for one-half cycle of the input signal. That means the conduction angle is 180° for a class B amplifier.
* Since the active device (transistor) is switched off for half the input cycle, the active device dissipates less power and hence the efficiency is improved.
* Theoretical maximum efficiency of class B power amplifier is 78.5%

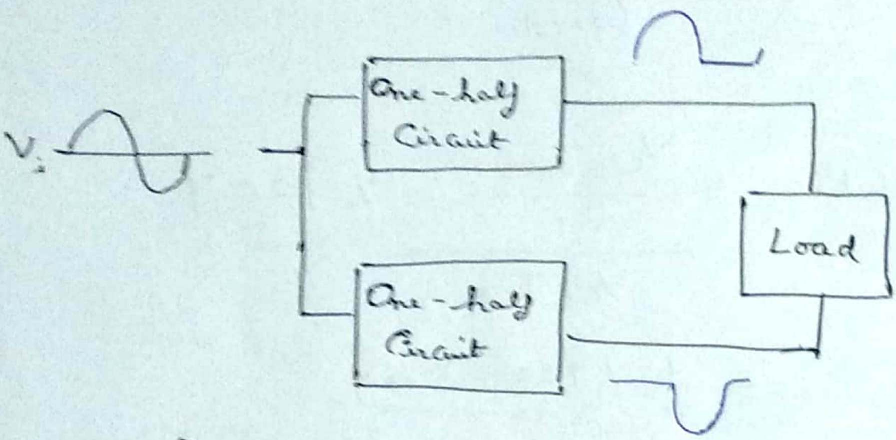
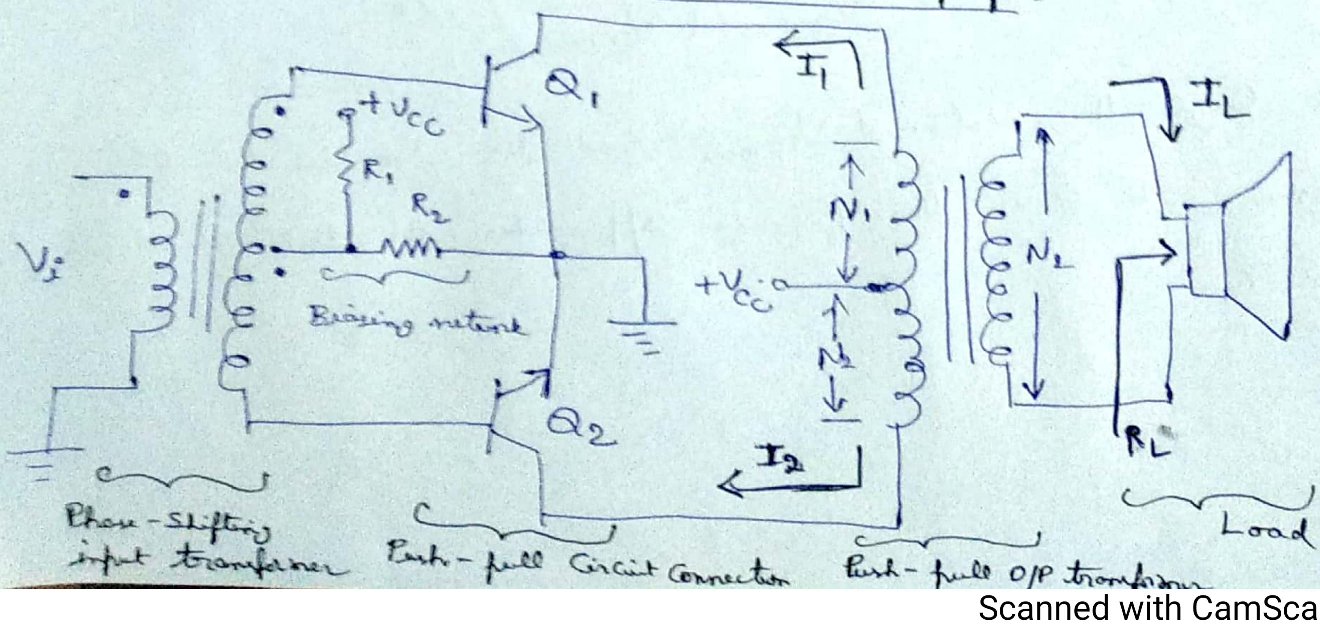



Fig: Block representation of push-pull operation.

* Figure shows a diagram for push-pull operation. An ac input signal is applied to the push-pull circuit, with each half operating on alternate half-cycles, the load then receiving a signal for the full ac cycle.

## Transformer-Coupled Push-Pull Class B Amplifier



* During the positive cycle of the AC input, transistor $Q_1$ (npn) is Conducting and $Q_2$ (pnp) is OFF.

* During the negative cycle of the AC input, transistor $Q_2$ (pnp) is Conducting and $Q_1$ (npn) is OFF.

* Each transistor produces one-half of an AC cycle. The transformer Combines the two output to form a full AC cycle.

The power supplied to the load by an amplifier is drawn from input dc given by,

$$\boxed{P_i(dc) = V_{CC} I_{dc}} \quad \text{——— (1)}$$

where $I_{dc} \rightarrow$ average or dc current drawn from the power supplies ($V_{cc} \rightarrow$ Power supply) and given by

$$I_{dc} = \frac{2}{\pi} I(p)$$

where $I(p)$ is the peak value of the output current waveform $= \frac{V_{cc}}{R_L}$

$$\boxed{P_i(dc) = V_{CC} \frac{2}{\pi} I(p)} \quad \text{——— (2)}$$

Output (AC) Power

The power delivered to the load (usually referred to as a resistance $R_L$) is given by,

$$\boxed{P_o(ac) = \frac{V_L^2(rms)}{R_L}} \quad \text{——— (3)}$$

The peak-to-peak output voltage can be measured using

$$\boxed{P_o(ac) = \frac{V_L^2(p-p)}{8R_L} = \frac{V_L^2(p)}{2R_L}} \quad \text{——— (4)}$$

Efficiency

The efficiency of Class 'B' amplifier is given by,

$$\% \eta = \frac{P_o(ac)}{P_i(dc)} \times 100\% = \frac{V_L^2(p)/2R_L}{V_{cc}\left[(2/\pi)I(p)\right]} \times 100\% = \frac{\pi}{4} \frac{V_L(p)}{V_{cc}} \times 100\%$$

## Maximum Power Consideration

For Class B operation, the maximum output power is delivered to the load when $V_L(p) = V_{CC}$.

$$\boxed{\text{maximum } P_o(ac) = \frac{V_{CC}^2}{2R_L}} \quad \text{———} \quad (5)$$

The corresponding peak ac current $I(p)$ is then

$$I(p) = \frac{V_{CC}}{R_L}$$

So that the maximum value of average current from the power supply is

$$\text{maximum } I_{dc} = \frac{2}{\pi} I(p) = \frac{2V_{CC}}{\pi R_L}$$

Using this current to calculate the maximum value of input power,

$$\boxed{\text{maximum } P_i(dc) = V_{CC}(\text{maximum } I_{dc}) = V_{CC}\left(\frac{2V_{CC}}{\pi R_L}\right) = \frac{2V_{CC}^2}{\pi R_L}} \quad \text{———} \quad (6)$$

The maximum circuit efficiency for Class B operation is then

$$\text{maximum } \%\eta = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

$$= \frac{V_{CC}^2/2R_L}{V_{CC}\left[(2/\pi)(V_{CC}/R_L)\right]} \times 100\%$$

$$\text{maximum } \%\eta = \frac{\pi}{4} \times 100\% = \underline{\underline{78.54\%}}$$

When the input signal results in less than the maximum output signal swing, the circuit efficiency is less than 78.5%.

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