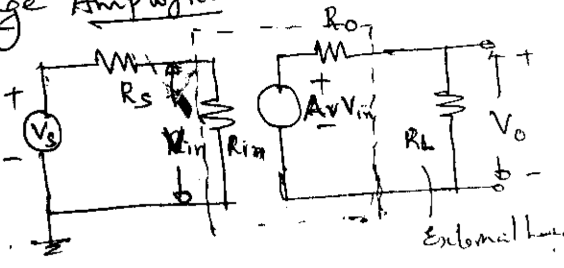
Feedback Amplifiers

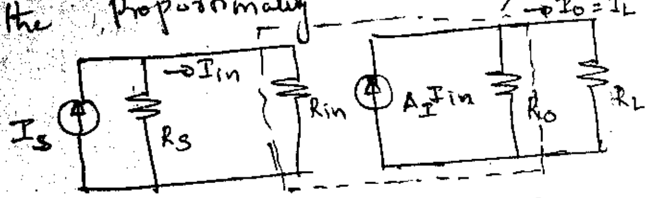
Classification of Amplifiers: The amplifiers can be classified as follows: Voltage, Current & transconductance and transresistance amplifiers.

Voltage Amplifier



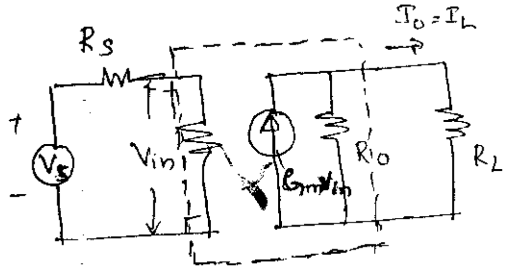
The thevenin equ ckt of a two port network which represents an amplifier is shown in the fig. If $R_{in} >> R_s$, then $V_{in} \approx V_s$. If the external resistor R_L is large compared with the o/p Resistance R_o of the amplifier, then $V_o \approx A_V V_{in} \approx A_V V_s$. The o/p voltage is proportional to i/p voltage and proportionality constant is independent of source and load Resistance. This type of ckts is called Voltage amplifier. The ideal voltage amplifiers must have infinite i/p impedance and zero o/p impedance. The voltage gain $A_V = \frac{V_o}{V_{in}}$ with $R_L = \infty$ and hence represents the open ckt voltage amplification or gain.

Current Amplifier: An ideal current amplifier is defined as an amplifier which provides an o/p current proportional to the signal current, and the proportionality constant is independent of R_s and R_L. An ideal current amplifier must have zero i/p impedance ($R_{in} = 0$) and infinite o/p impedance ($R_o = \infty$). In practice the amplifier will have low i/p impedance and high o/p impedance (i.e. $R_{in} << R_s$ & $R_o >> R_L$).



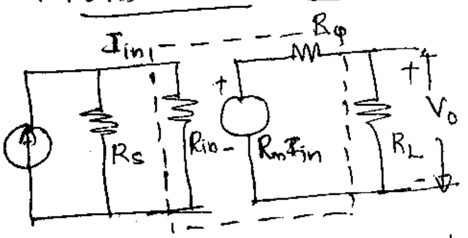
The fig shows the Norton's equt of the current amplifier ckt. The $A_I = I_L / I_{in}$ with $R_L = 0$, representing the short circuit current amplification or gain. If $R_{in} << R_s$, $I_{in} \approx I_s$ and if $R_o >> R_L$, $I_L \approx A_I I_{in} \approx A_I I_s$. Hence o/p current is proportional to signal current.

Transconductance Amplifier: In an ideal transconductance amplifier the o/p current is proportional to the signal voltage, independent of the magnitudes of R_s and R_L. The amplifier must have infinite input Resistance R_{in} and infinite o/p resistance R_o. A practical Transconductance amplifier has large input resistance ($R_{in} >> R_s$), i.e. amplifier is driven by a low resistance source, it presents high o/p Resistance ($R_o >> R_L$) and hence drives a low-resistance load. The equt ckt of transconductance amplifier is shown below



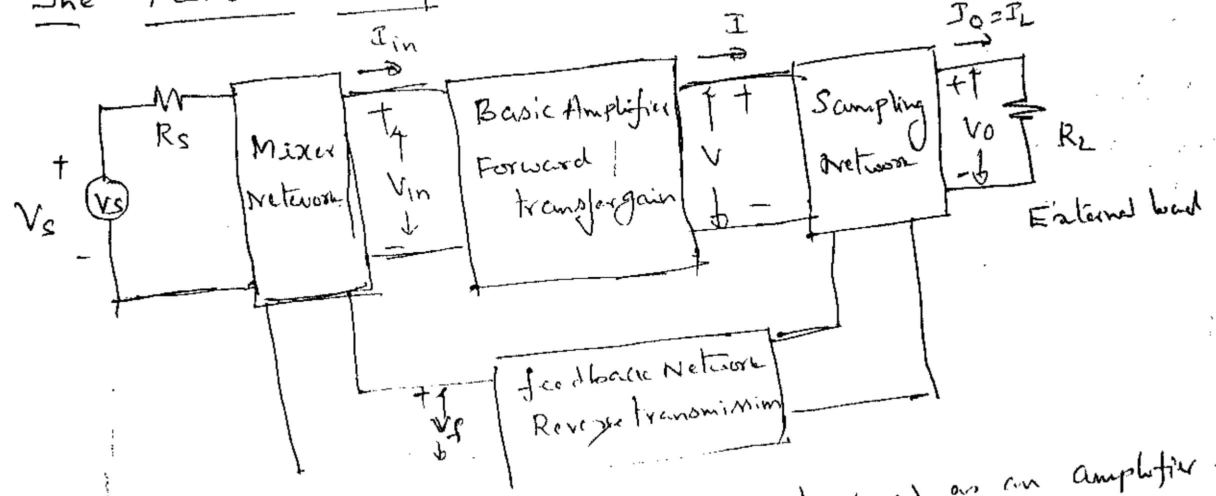
$R_{in} >> R_s$
$R_o >> R_L$

Transresistance Amplifier : The equt Ckt of an amplifier which ideally supplies an output Voltage V_o in proportion to the Signal Current I_s independently of R_s and R_L. For a Practical transresistance amplifier we must have $R_{in} << R_s$ and $R_o << R_L$



Hence the I/p and o/p Resb are low relative to Source and load resistances. Since $R_s >> R_{in}$ $I_{in} \approx I_s$ and if $R_o << R_L$, then $V_o \approx R_m I_{in}$. We note that $R_m = \frac{V_o}{I_{in}}$ with $R_L = \infty$

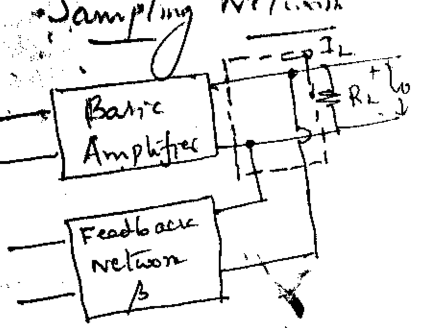
The Feedback Concept



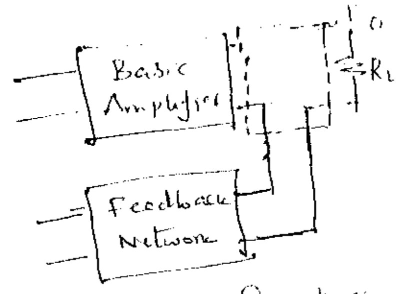
Any one of the above four amplifiers can be used as an amplifier. In they amplifier we may sample either current or voltage by means of a suitable sampling network and this signal is applied to the I/p through a feedback two port network as shown in the fig. At the I/p the feedback signal is combined with the external (source) signal through a mixer network and is fed into the amplifier proper.

Feedback network : It is usually passive two port network which may contain resistors, capacitors and inductors. Very oftenly it is made up of only resistive configuration.

Sampling Network



Voltage Sampling

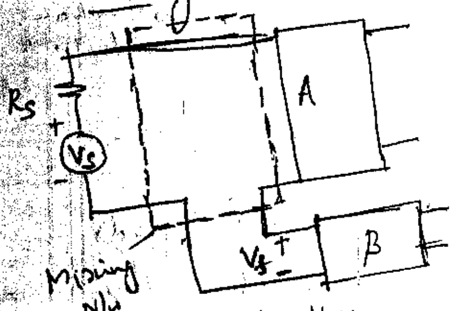


Current Sampling

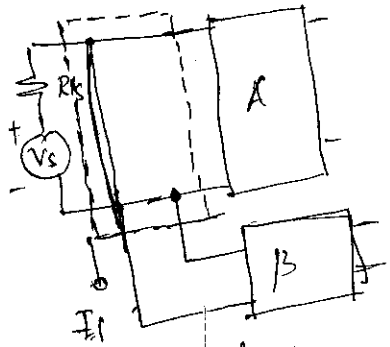
In the first block diagram, the output voltage is sampled by connecting the feedback network in shunt across the output. In this ckt it is desirable that the I/p impedance of the feedback network be much greater than R_L so that feedback N/w will not to load the output of the amplifier. Another feedback connection which samples the output current is shown in Current Sampling ckt, where the feedback N/w is connected in series with the output. In this ckt the I/p impedance of the feedback N/w should be much smaller than R_L inorder not to reduce the current gain.

The fig shows simple block diagram approach of series & shunt feedback ckts. Feedback may be classified as either positive or negative. In the former case any increase in o/p signal results in a feedback into the I/p in such a way as to increase further the magnitude of the o/p signal. When the feedback results in decrease in the magnitude of the output signal, the amplifier is said to have negative feedback.

Mixing Network

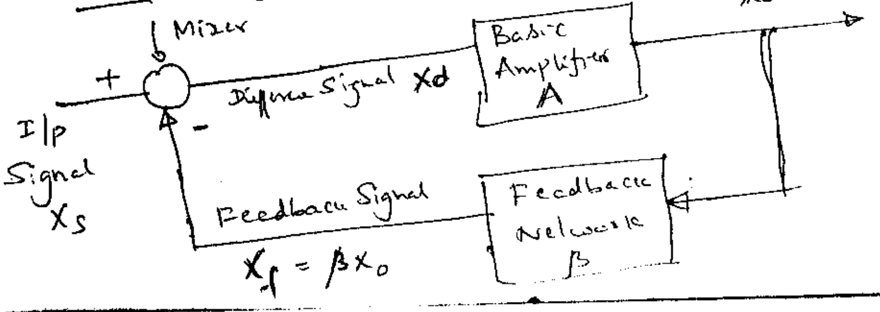


Series Feedback



Shunt feedback

Shematic block Diagram Ideal single loop feedback amplifier



The transfer gain with a Feedback

Considering β, as a feedback factor

the feedback signal $X_f = \beta X_o$.

where X_o is o/p of an amplifier (either voltage or current).

If I/p to an amplifier is X_d and o/p is proportional to the I/p by an proportionality constant A (which independent of source & load impedance)

then $X_o = A X_d$

Therefore $X_o = A(X_s - X_f) = A(X_s - \beta X_o)$

$$X_o(1+A\beta) = A X_s$$

$$A_f = \text{gain with feedback} = \frac{X_o}{X_s} = \frac{A}{1+A\beta}$$

In case of negative feedback $|A_f| < |A|$. In case of positive feedback $|A_f| > |A|$. Since in negative feedback gain reduces by the factor $(1+A\beta)$ which is greater than one. This factor $(1+A\beta)$ is also called as De sensitivity factor

∴ Gain Reduces with negative feedback i.e. $A_f = \frac{A}{1+A\beta}$ Gain without feedback; Gain with feedback; feedback factor.

General Characteristics of negative Feedback amplifiers

Increases the Stability i.e. Stability of Gain

The transfer gain of the amplifier is not constant as it depends on the factors such as operating point, temperature etc. This lack of stability in an amplifier can be reduced by using negative feedback.

Proof $\quad A_f = \frac{A}{1+A\beta}$

Differentiating both sides w.r.to A we get

$$\frac{dA_f}{dA} = \frac{(1+A\beta)(1) - A(\beta)}{(1+A\beta)^2} = \frac{1}{(1+A\beta)^2}$$

$$dA_f = \frac{dA}{(1+A\beta)^2}$$

Dividing both sides by A_f we get

$$\frac{dA_f}{A_f} = \frac{dA}{(1+A\beta)^2} \cdot \frac{1}{A_f} = \frac{dA}{(1+A\beta)^2} \cdot \frac{(1+A\beta)}{A}$$

$$\frac{dA_f}{A_f} = \frac{dA}{A}\left(\frac{1}{1+A\beta}\right) = \frac{dA/A}{(1+A\beta)}$$

$\frac{dA_f}{A_f}$ = Change in amplification w.r.t original amplification with feedback

$\frac{dA}{A}$ = Change in amplification w.r.to original amplification without feedback.

The above expression shows that the the change in gain with feedback is less than Change in gain without feedback by a factor $(1+A\beta)$

<u>Increase Bandwidth</u>

We know that $A_f = \frac{A}{1+A\beta}$

Using this equation we can write

$$(A_f)_{mid} = \frac{A_{mid}}{1+A_{mid}\beta}$$

$$(A_f)_{Low} = \frac{A_{Low}}{1+A_{Low}\beta}$$

$$(A_f)_{high} = \frac{A_{high}}{1+A_{high}\beta}$$

<u>Effect of Negative feedback on lower cutoff frequency</u>

We know that

$$(A_f)_{low} = \frac{A_{low}}{1+A_{low}\beta}$$

where $A_{low} = \frac{A_{mid}}{1 - j\frac{f_L}{f}}$

6.

$$(A_f)_{low} = \frac{A_{mid} / \left(1 - j\frac{f_L}{f}\right)}{1 + \dfrac{A_{mid}}{\left(1 - j\frac{f_L}{f}\right)}\beta}$$

$$(A_f)_{low} = \frac{A_{mid}}{1 - j\frac{f_L}{f} + A_{mid}\beta} = \frac{A_{mid} / (1 + A_{mid}\beta)}{1 - j\left(\dfrac{\frac{f_L}{1+A_{mid}\beta}}{f}\right)}$$

$$\frac{(A_f)_{low}}{A_{f\,mid}} = \frac{1}{1 - j\left(\frac{f_{Lf}}{f}\right)}$$

where $f_{Lf} = \dfrac{f_L}{1 + A_{mid}\beta}$

Lower cutoff frequency with feedback reduces compared to without feedback.

<u>Upper cutoff frequency</u>

$$(A_f)_{high} = \frac{A_{high}}{1 + A_{high}\beta}$$

$$= \frac{A_{mid} / \left(1 + j\frac{f}{f_H}\right)}{1 + \dfrac{A_{mid}}{\left(1 + j f/f_H\right)}\beta}$$

$$= \frac{A_{mid}}{1 + j f/f_H + A_{mid}\beta} = \frac{A_{mid} / (1 + A_{mid}\beta)}{1 + j\left(\frac{f}{f_H(1 + A_{mid}\beta)}\right)}$$

$$(A_f)_{high} = \frac{(A_f)_{mid}}{1 + j\left(\frac{f}{f_{Hf}}\right)}$$

$f_{Hf} = f_H(1 + A_{mid}\beta)$

Here upper cutoff frequency increases by a factor $(1+A_{mid}\beta)$ with feedback.

Therefore Bandwidth = upper cutoff freq − Lower cutoff freq.

$$(BW)_f = f_{Hf} - f_{Lf} = (1+A_{mid}\beta)f_H - \frac{f_L}{(1+A_{mid}\beta)}$$

Therefore $(f_{Hf} - f_{Lf}) > (f_H - f_L)$

i.e. Bandwidth increases with feedback.

Frequency Distortion

$$A_f = \frac{A}{1+A\beta} \approx \frac{A}{A\beta} = \frac{1}{\beta}$$

In the above expression, if the feedback network does not contain reactive elements, the overall gain becomes independent of frequency. Thus a substantial reduction in frequency and phase distortion is obtained.

Nonlinear distortion: If large signal is applied to an amplifier, then amplifier will operate in nonlinear region along with linear region of operation. As a result of this, the output signal gets distorted. This can be reduced by using negative feedback. To illustrate this, let us assume that a sinusoidal signal is applied as input and there is only second harmonic generated within the active device. Let second harmonic be B_2 in the absence of feedback and B_{2f} in the presence of negative feedback. Now we will find relationship between B_2 and B_{2f}. Once the feedback is applied, the output contains two terms (1) B_2 generated within the active device and (2) $-A\beta B_{2f}$, representing the effect of feedback. Hence we may write

$$B_{2f} = B_2 - A\beta B_{2f}$$

$$\therefore B_{2f}(1+A\beta) = B_2$$

$$B_{2f} = \frac{B_2}{1+A\beta} = \frac{B_2}{D}$$ where D = Desensitivity factor.

Reduction in Noise: It is seen that the nonlinear distortion introduced in an amplifier gets divided by the factor D if the negative feedback is used. By similar reasoning the noise introduced in an amplifier also gets divided by the factor D on using negative feedback. By keeping D large noise can be reduced to larger extent.

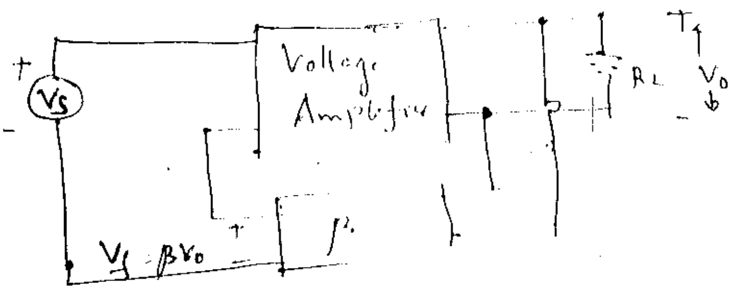
Modification of I/p and o/p Resistance: The I/p & o/p resistance of the feedback amplifier get modified depending on the topology of the feedback amplifier.

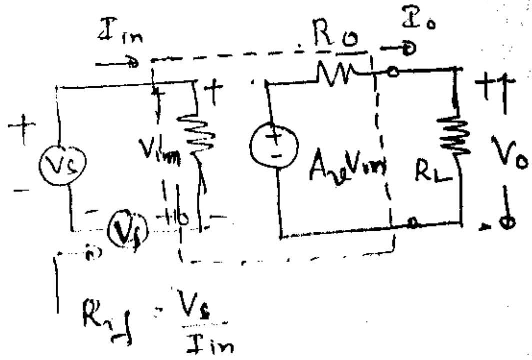
We may now summarise the merits of negative feedback.

(i) Stability of transfer gain
(ii) Reduction in frequency & phase distortion
(iii) Reduction in nonlinear distortion
(iv) Reduction in noise
(v) modification of I/p & o/p impedance
(vi) Increase Bandwidth

Input and output Resistances

Voltage Series feedback





Equt Ckt of the block Diagram

Here A_v is open Ckt Voltage gain ($R_L = \infty$) with $R_s \neq 0$ is. Instead of A_{vs} we will write this as A_v.

$$(R_{in})_f = R_{if} = \frac{V_s}{I_{in}}$$

Applying KVL to the I/p side we get

$$V_s - I_{in} R_{in} - V_f = 0$$

$V_s = I_{in}R_{in} + V_f$

$V_s = I_{in}R_{in} + \beta V_o$

$V_o = \frac{A_v V_{in} R_L}{R_L + R_o} = A_V V_{in}$

where A_V is the gain without feedback taking R_L into account

i.e. $A_V = \frac{A_v R_L}{R_L + R_o}$

$V_s = I_{in}R_{in} + \beta A_V V_{in}$

where $V_{in} = I_{in}R_{in}$

$V_s = I_{in}R_{in} + \beta A_V I_{in} R_{in}$

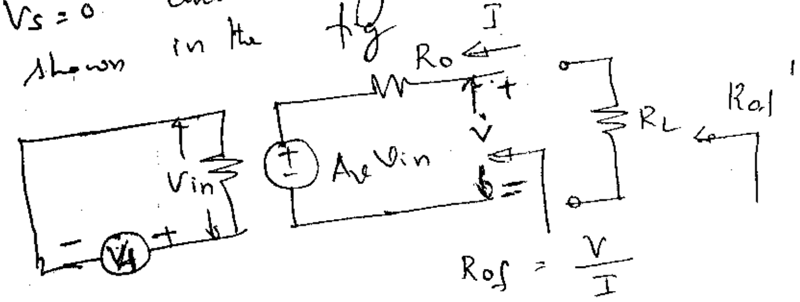
$V_s = I_{in}R_{in}(1 + A_V\beta)$

$\therefore \frac{V_s}{R_{in}} = \boxed{(R_{in})_f = R_{in}(1 + A_V\beta)}$

The input impedance increases with feedback

Output Impedance or o/p Resistance

The o/p resistance can be calculated by shorting I/p source i.e. $V_s = 0$ and looking into the output terminals with R_L disconnected as shown in the fig



$R_{of} = \frac{V}{I}$

Applying KVL for o/p loop

$A_v V_{in} + I R_o - V = 0$

$I = \frac{V - A_v V_{in}}{R_o}$

$V_{in} = -V_f = -\beta V$ because $V_s = 0$ $(V_o = V)$

$\therefore I = \frac{V + A_v \beta V}{R_o} = \frac{V(1 + A_v\beta)}{R_o}$

$R_{of} = \frac{V}{I} = \frac{R_o}{1 + \beta A_v}$

$R_{of}' = R_{of} \parallel R_L$

(10)

$$R_{of}' = R_{of} \parallel R_L = \frac{R_{of} R_L}{R_{of} + R_L}$$

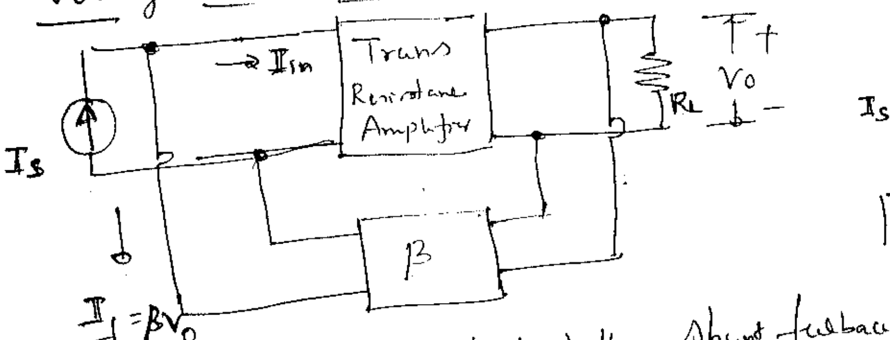
$$R_{of}' = \frac{\frac{R_o}{1+A_v\beta} \, R_L}{\frac{R_o}{1+A_v\beta} + R_L} = \frac{R_o R_L}{R_o + R_L(1+A_v\beta)}$$

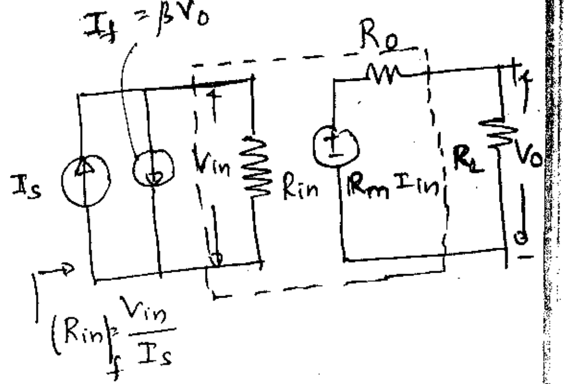
$$R_{of}' = \frac{(R_o R_L)/(R_o + R_L)}{1 + A_v\left(\frac{R_L}{R_o+R_L}\right)\beta}$$

$$\boxed{R_{of}' = \frac{R_o'}{1 + A_V\beta}}$$ where $R_o' = R_o \parallel R_L$

where A_v is gain taking both R_s and R_L into account.

Voltage Shunt feedback





Transresistance Amplifier with Voltage shunt feedback

The block diagram can be represented by an equi Ckt as shown in the fig.

Applying KCL at i/p node we get

$$I_s = I_{in} + I_f$$

$$= I_{in} + \beta V_o$$

The o/p voltage $V_o = \frac{R_m I_{in} R_L}{R_o + R_L} = R_M I_{in}$

where $R_M = \frac{R_m R_L}{R_o + R_L}$

where R_m represents the open Ckt transresistance without feedback and R_M represents the transresistance without feedback taking R_L into account

Therefore $I_s = I_{in} + \beta R_m I_{in}$

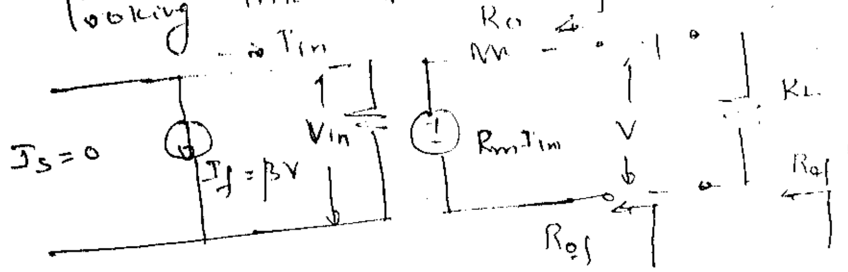
$$I_s = I_{in}(1+\beta R_m)$$

$$R_{if} = \frac{V_{in}}{I_s} = \frac{V_{in}}{I_{in}(1+\beta R_m)} = \frac{V_{in}/I_{in}}{(1+\beta R_m)} = \frac{R_{in}}{1+\beta R_m}$$

∴ Input Resistance reduces with feedback.

Output Resistance

The o/p resistance is measured by shorting the input source $V_s = 0$ and looking into o/p terminals with R_L disconnected.



Applying KVL to the output loop

$$R_m I_{in} + I R_o - V = 0$$

$$I = \frac{V - R_m I_{in}}{R_o}$$

from the I/p side

$$I_{in} = -I_f = -\beta V$$

$$\therefore I = \frac{V + R_m \beta V}{R_o} = \frac{V(1+R_m\beta)}{R_o}$$

$$\therefore \boxed{\frac{V}{I} = \frac{R_o}{1+R_m\beta} = R_{of}}$$

Taking R_L into Consideration

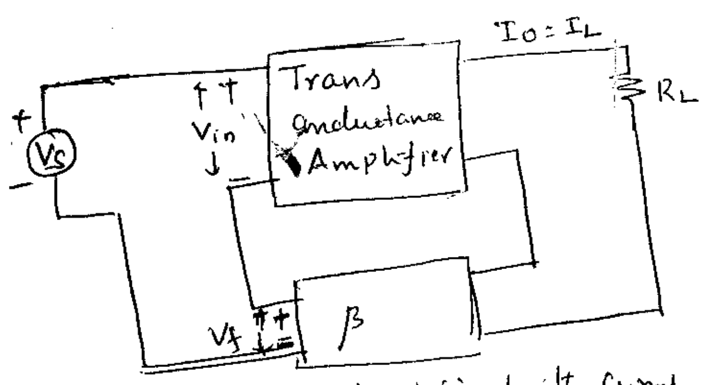
$$R_{of}' = R_{of} \parallel R_L = \frac{R_{of} R_L}{R_{of} + R_L}$$

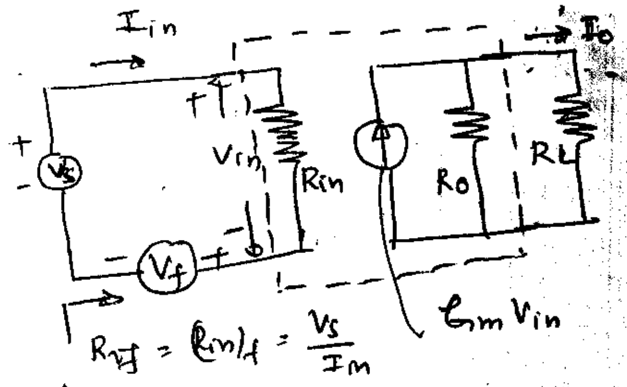
$$R_{of}' = \frac{\left(R_o/(1+R_m\beta)\right)(R_L)}{\left(\frac{R_o}{(1+R_m\beta)} + R_L\right)} = \frac{R_o R_L}{R_o + R_L(1+R_m\beta)}$$

$$R_{of}' = \frac{(R_o R_L)/(R_o + R_L)}{1 + \frac{R_m R_L}{R_o + R_L}\beta} = \frac{R_o'}{1+R_m\beta}$$

where $R_o' = R_o \parallel R_L$

current Series feedback





Transconductance Amplifier with current series feedback

Applying KVL for I/p side

$$V_S - I_{in}R_{in} - V_f = 0$$

$$V_S = I_{in}R_{in} + V_f$$

$$V_s = I_{in}R_{in} + \beta I_o$$

$$I_o = \frac{G_m V_{in} R_o}{R_o + R_L} = G_M V_{in}$$

$$\text{where } G_M = \frac{G_m R_o}{R_o + R_L}$$

G_m represents transconductance without feedback and for open ckt condition, where G_M represents transconductance without feedback taking R_L into account.

$$V_s = I_{in}R_{in} + \beta G_M V_{in}$$

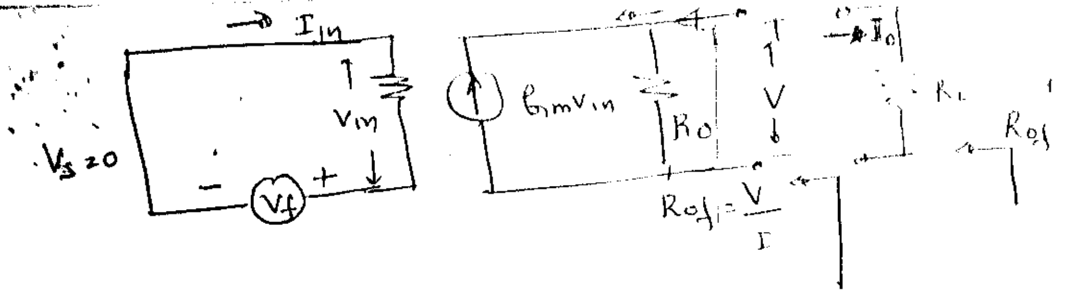
$$V_s = I_{in}R_{in} + \beta G_M I_{in}R_{in}$$

$$V_s = I_{in}R_{in}(1 + \beta G_M)$$

$$\boxed{\frac{V_S}{I_{in}} = R_{if} = (R_{in})_f = R_{in}(1+\beta G_M)}$$

To find o/p impedance

To find o/p impedance $V_s = 0$ and R_L should be disconnected ~~and~~



$$I = \frac{V}{R_o} - G_m V_{in}$$

where $V_{in} = -V_f = -\beta I_o = +\beta I$

$$I = \frac{V}{R_o} - G_m \beta I$$

$$I(1 + G_m\beta) = \frac{V}{R_o}$$

$$R_o(1 + G_m\beta) = \frac{V}{I} = R_{of}$$

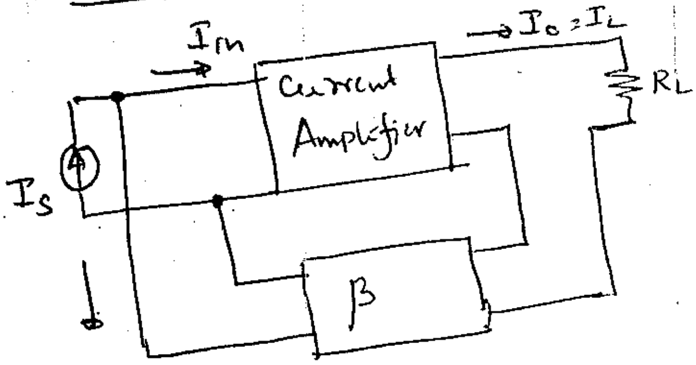
$$R_{of}' = R_{of} \parallel R_L$$

$$R_{of}' = \left[R_o(1 + G_m\beta)\right] \parallel R_L$$

$$R_{of}' = \frac{R_o R_L (1 + G_m\beta)}{R_o(1 + G_m\beta) + R_L} = \frac{\left(\frac{R_o R_L}{R_o + R_L}\right)(1 + G_m\beta)}{1 + \frac{R_o G_m \beta}{R_o + R_L}}$$

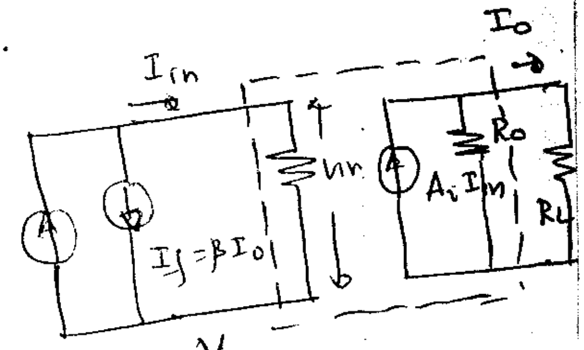
$$R_{of}' = \frac{R_o'(1 + G_m\beta)}{1 + \beta G_M}$$ Because $G_M = \frac{G_m R_o}{R_o + R_L}$

Current Shunt feedback



$I_f = \beta I_o$

Current Amplifier with Current Shunt feedback



$$(R_{in})_f = \frac{V_{in}}{I_s}$$

Applying KCL to the I/p node we get

$$I_s = I_{in} + I_f$$

$$I_s = I_{in} + \beta I_o$$

The o/p Voltage $V_o = \left(\frac{A_i I_{in} R_o}{R_o + R_L}\right) R_L$

and $I_o = \frac{A_i I_{in} R_o}{R_o + R_L} = A_I I_{in}$

where $A_I = \frac{A_i R_o}{R_o + R_L}$ taking R_L into Consideration.

$$I_s = I_{in} + \beta A_I I_{in}$$

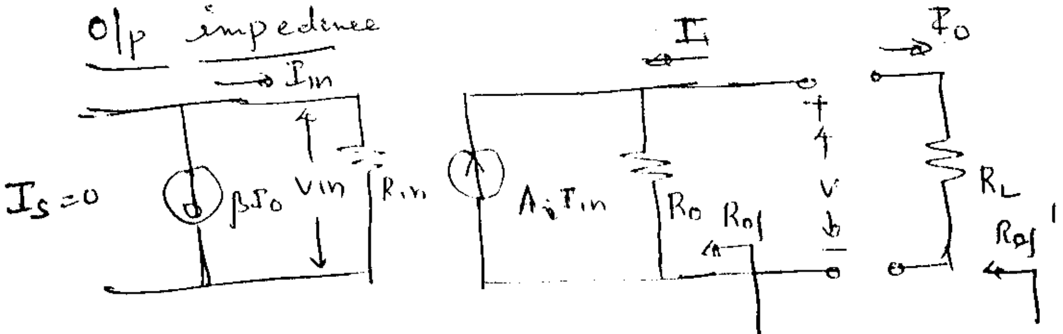
$$I_s = I_{in}(1 + A_I \beta)$$

$$I_{in} = \frac{V_{in}}{R_{in}}$$

$$\therefore \quad I_s = \frac{V_{in}}{R_{in}}(1 + A_I \beta)$$

$$\boxed{\frac{V_{in}}{I_s} = (R_{in})_f = \frac{R_{in}}{1 + A_I \beta}}$$

O/p impedance



Applying KCL to o/p Side

$$I = \frac{V}{R_o} - A_i I_{in}$$

$$I_{in} = -I_f = -\beta I_o$$

where $I_o = -I$

Therefore $I_{in} = \beta I$

Therefore $\frac{V}{R_o} - A_i \beta I$

$$\therefore I + A_i \beta I = \frac{V}{R_o}$$

$$I(1 + A_i\beta) = \frac{V}{R_o}$$

Therefore $\boxed{\frac{V}{I} = R_o(1+\beta A_i) = R_{of}}$

$$R_{of}' = R_{of} \parallel R_L$$

$$\frac{R_o(1+\beta A_i) R_L}{R_L + R_o(1+\beta A_i)}$$

$$= \frac{\frac{R_o R_L}{R_o + R_L}(1+\beta A_i)}{1 + \frac{\beta R_o A_i}{R_o + R_L}}$$

$$R_{of}' = \frac{R_o'(1+\beta A_i)}{1+\beta A_I}$$ where $R_o' = R_o \parallel R_L$

$$A_I = \frac{A_i R_o}{R_o + R_L}$$

Method of Analysis of Feedback Amplifier

The entire feedback amplifier may be separated into two blocks, the basic amplifier A and the feedback network β. Then with the knowledge of A & β, we may calculate the characteristics of the feedback amplifier

The Procedure that is applied to obtain the basic amplifier configuration without feedback, but taking the loading of β network into consideration

(A) To find the I/p Ckt

(i) For Voltage Sampling Set $V_o = 0$ by short ckt the o/p

(ii) For Current Sampling Set $I_o = 0$ by o/p loop is open circuited

(B) To find the o/p ckt

(i) For Series Comparism Set $I_{in} = 0$ by open the I/p loop

(ii) For Shunt Comparism Set $V_{in} = 0$ by Short the I/p node

Complete Analysis: The complete analysis of a feedback amplifier may be done by carrying out the following steps.

(I) Identify the topology

(a) To find whether the feedback signal is applied in series or in shunt with external excitation.

(b) find whether the sampled signal is voltage or current

(II) Basic amplifier ckt is drawn without feedback but taking into the effect of loading because of feedback network

(III) If the feedback signal is a voltage the Thevenin source is used, if feedback signal is current the Norton source is used.

(IV) Each active device is replaced by its eqvt ckt.

(V) β is calculated

(VI) Calculate Gain A

(VII) Then finally calculate A, β, D, R_{if}, R_{of} & R_{of}'

Analysis of Feedback Amplifier (Table)

Topology characteristic	Voltage Series	Current Series	Current Shunt	Voltage Shunt
Feedback Signal	Voltage	Voltage	Current	Current
Sampled Signal	Voltage	Current	Current	Voltage
To find I/p loop, set	$V_o = 0$	$I_o = 0$	$I_o = 0$	$V_o = 0$
To find O/p loop set	$I_{in} = 0$	$I_{in} = 0$	$V_{in} = 0$	$V_{in} = 0$
Signal Source form (I/p Side)	Thevenin	Thevenin	Norton	Norton
β (feedback factor)	V_f / V_o	V_f / I_o	I_f / I_o	I_f / V_o
Transfer Gain	$A_V = \frac{V_o}{V_{in}}$	$G_M = \frac{I_o}{V_{in}}$	$A_I = \frac{I_o}{I_{in}}$	$R_M = \frac{V_o}{I_{in}}$
$D = 1+\beta A$	$1+\beta A_V$	$1+\beta G_M$	$1+\beta A_I$	$1+\beta R_M$
A_f	A_V / D	G_M / D	A_I / D	R_M / D
R_{if}	$R_i D$	$R_i D$	R_o / D	R_i / D
R_{of}	$R_o / (1+\beta A_V)$	$R_o (1+\beta G_M)$	$R_o (1+\beta A_I)$	$\frac{R_o}{1+\beta R_M}$
R_{of}'	R_o' – $((R_o')/(D))$	$[R_o'(1+\beta G_m)] / D$	$\frac{R_o'(1+\beta A_i)}{}$	$\frac{R_o'}{}$

POWER AMPLIFIERS (Large Signal Amplifiers)

Power amplifiers are large signal amplifiers, which raise the power level of the signals. In power amplifiers, the output voltage and current swings are so large that the amplifying device cannot be replaced by its linear model. In such case a graphical analysis is used.

Difference between Voltage and Power amplifiers

Voltage Amplifiers A voltage amplifier is designed to achieve maximum voltage amplification. The voltage gain is given by $A_v = \frac{\beta R_c}{R_{in}}$. Inorder to achieve high voltage amplification, the following features are incorporated. Such as

(i) The transistors with high β (>100) is used & the transistors have thin base.

(ii) The I/p Resistance R_{in} should be low in comparison to collector Resistance R_c

(iii) To achieve high gain R_c should be high

(iv) Usually RC coupling is used.

(v) I/p voltage is low and o/p power is low.

(vi) It has only magnitude and phase distortion.

Power Amplifiers : The power amplifiers are designed to obtain maximum o/p power. In order to achieve high power amplification, the following features are incorporated in such amplifiers.

(i) The transistors with comparatively smaller value of β is used because it uses power transistors. In power transistor base width is higher to handle large currents, therefore I_B is higher & β will be less.

(ii) Collector Resistance is made low

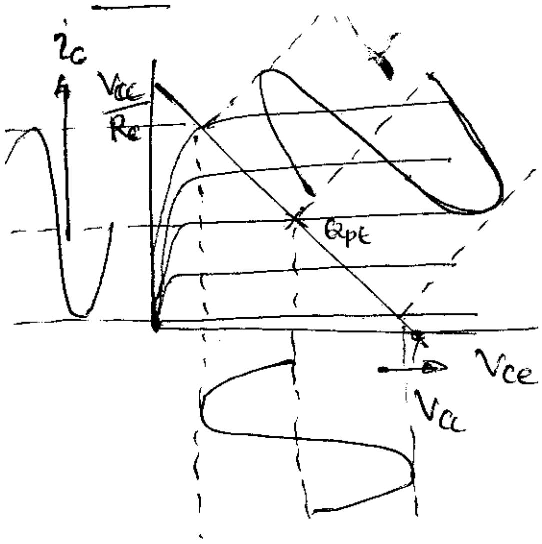
(iii) Transformer coupled is normally used

(iv) Collector current is high.

(v) I/p voltage is high & o/p power is high

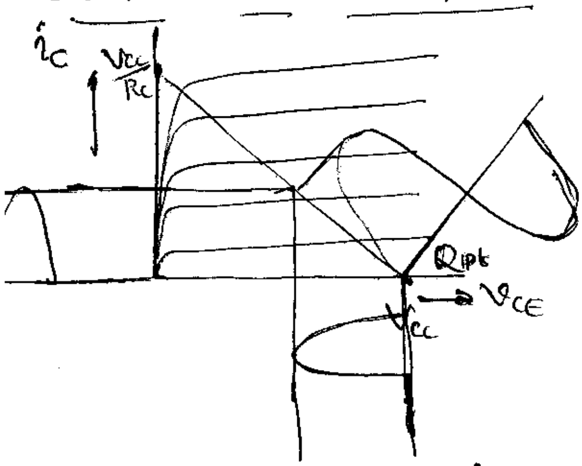
Classification of power Amplifiers : The operating point is fixed by selecting the proper dc biasing. The operating point is selected on the dc loadline which plotted on the o/p characteristics of the transistor. The position of the Qpt decides the class of operation of the power amplifier. It can be classified as Class A, Class B, Class AB & Class C.

Class A Power Amplifier : Operating point (Qpt) is selected on the middle of the load line. Therefore transistor conducts for entire I/p cycle.



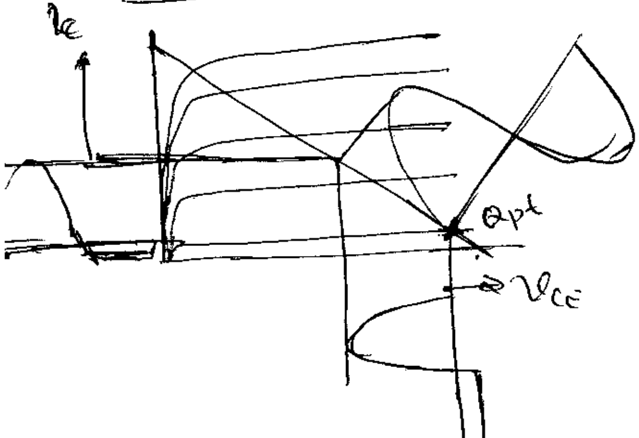
- The transistor conducts for entire 360°
- The %η is 25% with R_c and 50% with Transformer in the collector instead of R_c
- It needs only one transistor to get o/p

Class B Power Amplifier



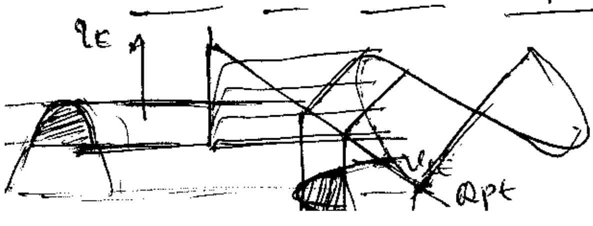
- Operating point is selected exactly at cutoff or on x axis. Therefore transistor conducts only 180°
- The %η is of max of 78.5%.
- It needs two transistors to get o/p
- There is a distortion at o/p (called Crossover distortion)

Class AB Power Amplifier



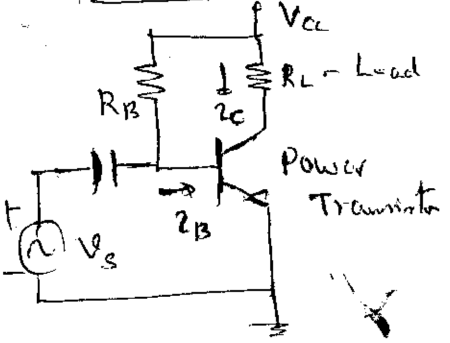
- Operating point is selected slightly above cutoff
- Conduction angle is slightly greater than 180°
- The 50% < %η < 78.5%.
- It needs two transistors to get o/p
- Crossover distortion is eliminated

Class C Power Amplifier

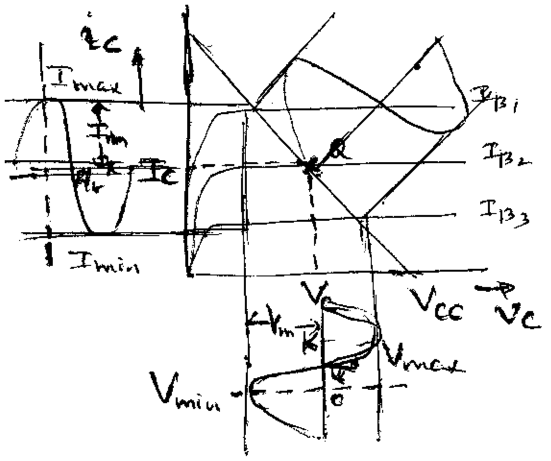


- The operating point is fixed beyond cutoff
- Conduction angle is less than 180°
- The %η > 78.5%.
- It needs one transistor and he cut in the collector to get o/p.

Class A Power Amplifier : The ckt showing simple transistor amplifier that supplies power to a pure resistance load R_L. i_C represents the total instantaneous collector current, i_c designates the instantaneous variation from the quiescent value I_C of the collector current. Similarly i_B, i_b, I_B represents corresponding base currents. The total instantaneous collector-to-emitter voltage is given by v_C and the instantaneous variation from the quiescent value V_C is represented by v_c



Let us assume that static o/p characteristics are equidistant for equal increments of input base current i_b. Then input signal i_b is sinusoidal, then o/p current and voltage are also sinusoidal. Under these condition nonlinear distortion is negligible.



The output power may be found graphically as follows $P = V_c I_c = I_c^2 R_L$

The V_c and I_c are the rms values of o/p voltage & o/p current can be determined graphically in terms of the maximum and minimum voltage and current swings.

$$I_c = \frac{I_m}{\sqrt{2}} = \frac{I_{max} - I_{min}}{2\sqrt{2}}$$

$$V_c = \frac{V_m}{\sqrt{2}} = \frac{V_{max} - V_{min}}{2\sqrt{2}}$$

The total power $P_{out} = \frac{V_m I_m}{2} = \frac{I_m^2 R_L}{2} = \frac{V_m^2}{2R_L}$

which may be also written as $P = \frac{(V_{max}-V_{min})(I_{max}-I_{min})}{8}$

$$\% \eta = \frac{P_{out}}{P_{in}} = \frac{P_{ac}}{P_{dc}} = \frac{(V_{max}-V_{min})(I_{max}-I_{min})}{8\, I_{dc} V_{cc}} \times 100$$

% max η when $V_{min} = 0$, $I_{min} = 0$

$V_{max} = V_{CE}$ $V_{min} = 0$ $I_{max} = 2I_C$

$$\max \% \eta = \frac{V_{CC}\, 2 I_C}{8 (V_{CC})(I_C)} \times 100 = 25\%$$

<u>Second - Harmonic Distortion</u>. We know that the transistor used ideally not operate in perfectly as a linear device. This is true from dynamic transfer characteristic is not a straight line. This nonlinearity arises because the static o/p characteristics are not equidistant straight lines for constant increments of input excitation. If the dynamic curve is nonlinear over the operating range, the waveform of the output voltage differs from that of the I/p signal. Distortion of this type is called nonlinear or amplitude distortion. To investigate this distortion we assume that the dynamic curve with respect to Q_{pt} can be represented by a parabola rather than a straight line. Therefore the incremental collector current i_c and incremental base current i_b is related by the expression

$$i_c = G_1 i_b + G_2 i_b^2 + \cdots$$

where G is constant

If I/p $i_b = I_m \cos \omega t$

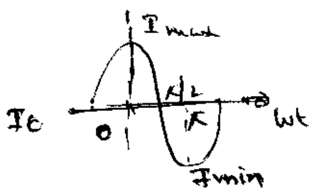
Then $i_c = G_1 I_m \cos \omega t + G_2 I_m^2 \cos^2 \omega t$

Since $\cos^2 \omega t = \frac{1}{2} + \frac{1}{2} \cos 2\omega t$

Then the expression for the total instantaneous current i_c reduces to the form

$$i_c = I_c + i_c = I_c + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + \cdots$$

where the B's are constants which may be evaluated in terms of G's. The term B_0 is the dc term added after applying I/p. The term $\cos 2\omega t$ represents second harmonic and $\cos 3\omega t$ etc represents higher harmonic terms. The total dc component of the ckt is $I_c + B_0$. Parabolic nonlinear distortion introduces into the o/p a component whose frequency is twice that of the sinusoidal input excitation. Also, since a sinusoidal I/p signal changes the average value of the o/p current, rectification takes place.



When $\omega t = 0$ $\quad i_c = I_{max}$

$\omega t = \pi/2$ $\quad i_c = I_c$

$\omega t = \pi$ $\quad i_c = I_{min}$.

Substituting this values in the above expression

$$I_{max} = I_C + B_0 + B_1 + B_2$$
$$I_C = I_C + B_0 - B_2$$
$$I_{min} = I_C + B_0 - B_1 + B_2$$

from the second expression $B_0 = B_2$

from the first & third expression

$$B_1 = \frac{I_{max} - I_{min}}{2}$$

Substituting this value of B_1 in first expression it yields

$$B_2 = B_0 = \frac{I_{max} + I_{min} - 2I_C}{4}$$

The second harmonic distortion $D_2 = \left|\frac{B_2}{B_1}\right|$

<u>Higher-order Harmonic distortion</u>: In earlier case we assume Parabolic dynamic characteristics considering the o/p swing is small. Since in power amplifier o/p swing is very large, then it is necessary to express the dynamic transfer characteristic by a power series of the form

$$i_c = G_1 i_b + G_2 i_b^2 + G_3 i_b^3 + G_4 i_b^4 + \cdots$$

Replacing $i_b = I_m \cos\omega t$, then by proper trigonometric transformation we can write

$$i_c = I_C + B_0 + B_1 \cos\omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \cdots$$

It clearly says that the o/p waveform process even symmetry

i.e. $i(\omega t) = i(-\omega t)$.

<u>Power output</u>. If the distortion is not negligible, the power delivered at the fundamental frequency is

$$P_1 = \frac{B_1^2 R_L}{2}$$

However the total o/p power is

$$P = (B_1^2 + B_2^2 + B_3^2 + B_4^2 + \cdots)\frac{R_L}{2}$$
$$= \frac{B_1^2 R_L}{2}\left[1 + \left(\frac{B_2}{B_1}\right)^2 + \left(\frac{B_3}{B_2}\right)^2 + \left(\frac{B_4}{B_2}\right)^2 + \cdots\right]$$

or $P = P_1 [1 + D^2]$

where the total distortion or distortion factor is defined as

$$D = \sqrt{D_2^2 + D_3^2 + D_4^2 + D_5^2 + \cdots}$$

The Transformer Coupled Audio Power Amplifier (84)

If the load resistance is connected directly in the o/p ckt of the power stage, then the Q pt current passes through the load resistance, this current represents a considerable wastage of power because it doesnot contribute to ac component of power. Furthermore it is not advisable to pass dc through the load resistance, because load Resist may be speaker also.. For these reasons usually an arrangement with output transformer is employed.

Impedence matching: To transfer a significant amount of power to a load such as loudspeaker with voice coil impedence of 5Ω to 15Ω, it is necessary to use an o/p matching transformer. This is required because the internal resistance of the device is more when compared to load Resist, therefore most of the power is lost in the active device.

The impedence matching property says

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

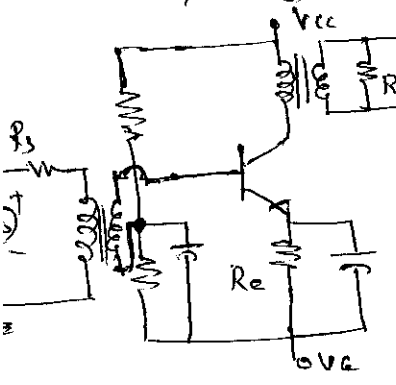
where $V_1 (V_2)$ are Primary (Secondary) voltages
$I_1 (I_2)$ are Primary (Secondary) current
$N_1 (N_2)$ are number of Primary (secondary) turns.

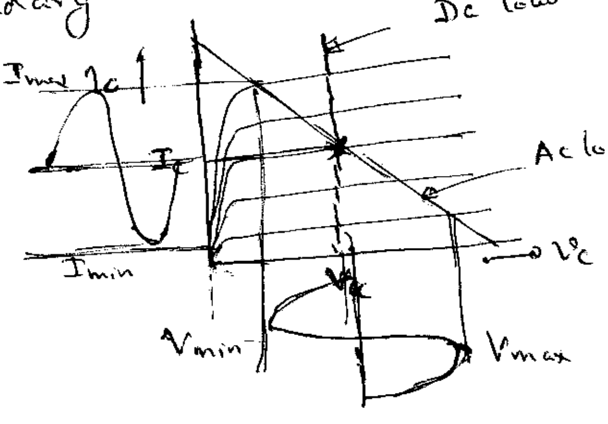
If $N_2 < N_1$ then the transformer reduces the voltage in proportion to turns ratio $n = N_2/N_1$ and steps up the current in the same ratio because o/p power = I/p power.

$$\therefore \frac{V_1}{I_1} = \frac{1}{n^2}\frac{V_2}{I_2}$$

where the $\frac{V_1}{I_1} = R_L'$ is reflected load rest in the Primary because of secondary load Rest R_L

$R_e \approx 0$ (very small)
$R_p \approx 0$ (Primary Rest of Transformer)





We will now examine various components of power. Suppose that the stage is supplying power to a pure resistive load. The average power i/p from the dc supply is $V_{cc} I_c$. The power absorbed by the o/p ckt is $I_c^2 R_1 + I_c V_c$, where I_c, V_c are the rms o/p current and voltage, respectively and where R_1 is the static load resistance. If P_D is the average power dissipated by the active device, then

$$V_{cc} I_c = I_c^2 R_1 + I_c V_c + P_D$$

Since $V_{cc} = V_c + I_c R_1$

P_D may be written as $P_D = V_c I_c - V_c I_c$

If load is not pure resistive then $V_c I_c$ is replaced by $V_c I_c \cos\theta$

where $\cos\theta$ is the power factor of the load.

This clearly says that if signal is not applied then the transistor is capable of withstanding entire power $V_c I_c$.

Conversion Efficiency: A measure of the ability of an active device to convert the dc power into the ac (signal) power delivered to the load is called the conversion efficiency or theoretical efficiency. The figure of merit, designated η, is also called the collector-ckt efficiency for a transistor amplifier

$$\eta \triangleq \frac{\text{Signal Power delivered to load}}{\text{dc Power supplied to o/p ckt}} \times 100$$

$$\text{In general} = \frac{\frac{1}{2} B_1^2 R_L}{V_{cc}(I_c + B_0)} \times 100$$

If distortion is negligiable then $\eta = \dfrac{\frac{1}{2} V_m I_m}{V_{cc} I_c} \times 100$

$$V_m = \frac{V_{max} - V_{min}}{2}$$

$$I_m = \frac{I_{max} - I_{min}}{2}$$

$$\therefore \quad \% \eta = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 V_{cc} I_c} \times 100$$

Max $\% \eta$ $\quad V_{max} = 2V_{cc} \quad V_{min} = 0 \quad I_{max} = 2I_c$

$I_{min} = 0$

$$\% \eta = \frac{2V_{cc} \; 2I_c}{8(V_{cc} I_c)} \times 100 = 50\%$$

we know that generalized formula for

$$\% \eta = \left(\frac{V_{max} - V_{min}}{V_{max} + V_{min}}\right) 50 \qquad \because V_{cc} = \frac{V_{max} + V_{min}}{2}$$

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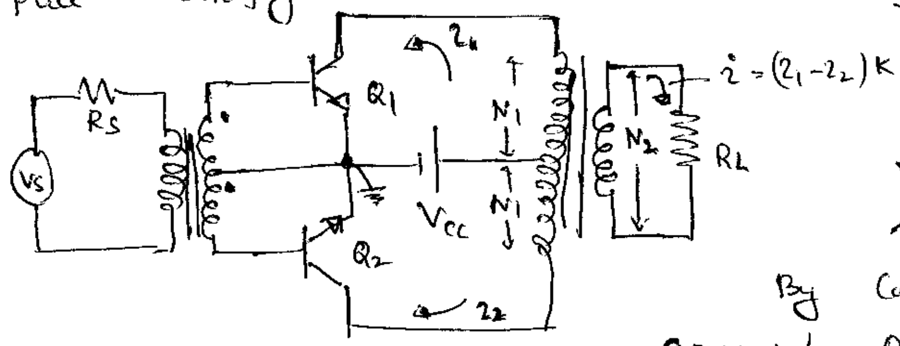
If $V_{min} << V_{max}$, then $\% \eta$ approches to 50%.

<u>Push - Pull Amplifier</u> : The distortion introduced by the nonlinearity of the dynamic transfer characteristic may be eliminated by using Push Pull configuration.



The Push pull amplifier uses center tap transformer, if this makes Q_1 base +ve, then it makes Q_2 base -ve by the same amount.

By considering $i_{b1} = I_m \cos\omega t$ applied to Q_1, then

$$i_1 = I_c + B_0 + B_1 \cos\omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \cdots$$

Corresponding to Q_2 $\quad i_{b2} = -i_{b1} = I_m \cos(\omega t + \pi)$

$$i_2(\omega t) = i_1(\omega t + \pi)$$

$$\therefore \quad i_2 = I_c + B_0 + B_1 \cos(\omega t + \pi) + B_2 \cos 2(\omega t + \pi) + \cdots$$

$$i_2 = I_c + B_0 - B_1 \cos\omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t + \cdots$$

$\therefore$ o/p current $i = K(i_1 - i_2) = 2K(B_1 \cos\omega t + B_3 \cos 3\omega t + \cdots)$

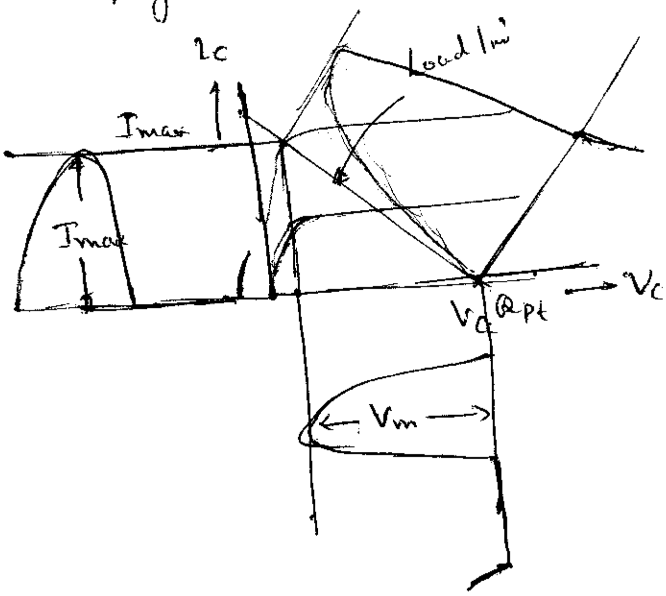
In this expression we can see that all even harmonics are eliminated. This will be applicable only if two transistors are identical. Since o/p current does not contain even harmonic terms, we can say that the pushpull system possess both "half wave" or "mirror" symmetry in addition to the zero axis symmetry.

<u>Advantages</u> (i) Because it avoids even harmonics in the o/p, the o/p power per active device is more for a given amount of distortion.

(ii) Since current flows in the transformer is equal & opposite, there is no problem of dc saturation in the transformer.

(iii) The ripple in the power supply will affect the load because its error is canceled because current flows in the opp direction in the transformer.

<u>Class B Amplifier</u>. The ckt in class B push pull amplifier is the same as in class A except that the device is biased at cutoff. Class B is preferred over because of higher efficiency, greater o/p power and negligible power loss when there is no signal. The disadvantage is harmonic distortion is higher, therefore self bias cannot be used and the supply must have good regulation.



The waveform shows only for one transistor Q_1 and the o/p for other transistor Q_2 is of same type with 180° phase shift. The load current is because of two transistors is a perfect sinusoidal if transistors are ideal.

$$\therefore \quad P_{out} = \frac{I_m}{\sqrt{2}}\frac{V_m}{\sqrt{2}} = \frac{I_m V_m}{2}$$

(considering the both the transistor & o/p is sine wave $\therefore I_{rms} = \frac{I_m}{\sqrt{2}}$)

$$P_{out} = \frac{I_m}{2}(V_{max} - V_{min}) = \frac{I_m}{2}(V_{cc} - V_{min})$$

Since the transistor conducts only after applying I/p signal, the initial current is zero, then once the transistor conducts the $I_{dc} = \frac{I_m}{\pi}$ for one transistor. But the total dc current drawn because of two transistor is given by

$$P_{dc} = P_{in} = \frac{2 I_m}{\pi} V_{cc}$$

$\therefore$ Collector ckt efficiency $\eta = \frac{P}{P_i} \times 100 = \frac{\pi V_m}{4 V_{cc}} \times 100$

$$\% \eta = \frac{\pi}{4}\left(1 - \frac{V_{min}}{V_{cc}}\right)100$$

$\therefore$ Max efficiency will be when $V_{min} = 0$ i.e. 78.5% is for Class B when compared to 50% for Class A.

The collector dissipation P_c (in both transistors) is the difference between the power I/p to the collector ckt and the power delivered to the load.

$$P_c = P_{in} - P_{out} = \frac{2 I_m V_{cc}}{\pi} - \frac{I_m V_m}{2} = \frac{2}{\pi}\frac{V_{cc} V_m}{R_L'} - \frac{V_m^2}{2R_L'}$$

$$\left(\because I_m = \frac{V_m}{R_L'}\right)$$

This above equation shows that collector power dissipation is zero at no signal ($V_m = 0$), rises as V_m increases, & passes through a max at $V_m = \frac{2V_{cc}}{\pi}$

$$\because \quad \frac{dP_c}{dV_m} = \frac{2}{\pi}\frac{V_{cc}}{R_L'} - \frac{2V_m}{2R_L'} = 0$$

$$\frac{V_m}{R_L'} = \frac{2V_{cc}}{\pi R_L'} \qquad \therefore V_m = \frac{2V_{cc}}{\pi}$$

$\therefore$ Peak power dissipation is

$$P_c = (P_c)_{max} = \frac{2}{\pi}\left(\frac{V_{cc}}{R_L'}\right)\left(\frac{2V_{cc}}{\pi}\right) - \left(\frac{2V_{cc}}{\pi}\right)^2\left(\frac{1}{2R_L'}\right) = \frac{2V_{cc}^2}{\pi^2 R_L'}$$

$$(P_{out})_{max} = \frac{I_m}{2}(V_m - V_{min}) \qquad \text{when } V_m = V_{cc} \quad I_m = \frac{V_m}{R_L'} = \frac{V_{cc}}{R_L'}$$
$$V_{min} = 0$$

$$(P_{out})_{max} = \frac{V_{cc}^2}{2R_L'}$$

$$\boxed{\therefore \quad (P_c)_{max} = \frac{4}{\pi^2}(P_{out})_{max}}$$

The two transistor dissipates 40% of its output power is of its total o/p power. If the each transistor dissipates 20% of its total o/p power is low and the each transistor dissipates max power of 2w.

If power dissipation is max, the % η reduces to 50%.

$$\%\eta = \frac{P_{out}}{P_{in}} = \frac{\frac{I_m}{2}(V_{max} - V_{min})}{2\frac{I_m V_{cc}}{\pi}} \times 100 = \frac{V_m}{4(V_{cc}/\pi)} \times 100$$

$$\%\eta = \frac{2V_{cc}/\pi}{4(V_{cc}/\pi)} \times 100 = 50\% \qquad \left[\text{when } (P_c)_{max} \quad V_m = \frac{2V_{cc}}{\pi}\right]$$

Difference between Class A & Class B Power Amplifier

1. The max conversion η is 78.5% in Class B system compared with 50% in Class A operation.
2. There is no collector current in Class B system if there is no excitation, whereas there is a drain from the power supply in Class A system even at zero signal.
3. We also note that in Class B amplifier the dissipation at the collectors is zero in the quiescent state and increases with the excitation, whereas the heating of the collectors in Class A system is a maximum at zero I/p & decreases

as the signal increases.

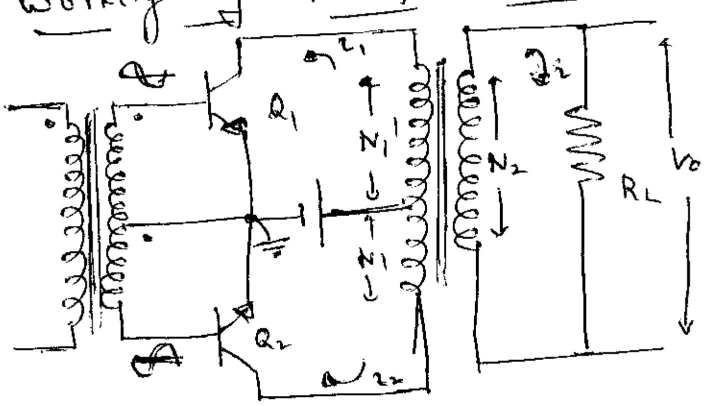
(4) Since the direct current increases with the signal in a Class B amplifier, the power supply must have good regulation.

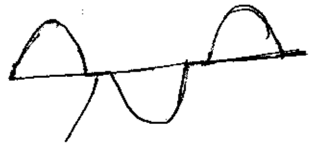
(5) The Power dissipation across each transistor in Class A system is higher when compared to Class B System.

Distortion in Class B Power Amplifier: The principal contribution to distortion is the third harmonic (because all even harmonics are cancelled out because of Push pull operation), given by $D_3 = |B_3| / |B_1|$. Therefore $P = (1 + D^2) \frac{B_1^2 R_L'}{2} = (1 + D_3^2) \frac{B_1^2 R_L'}{2}$

where $R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L$.

Working of Pushpull amplifier

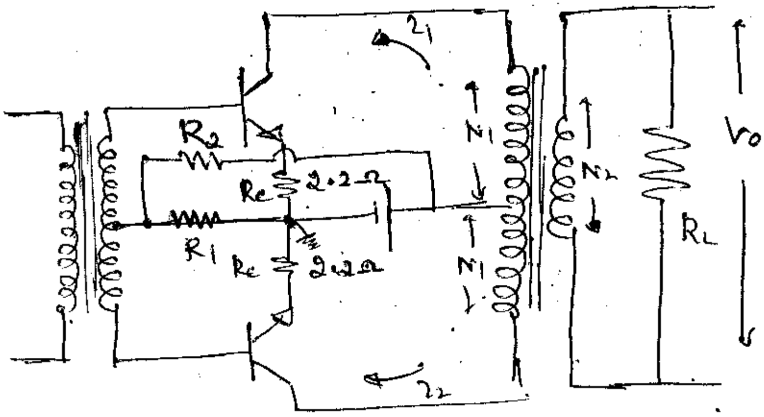




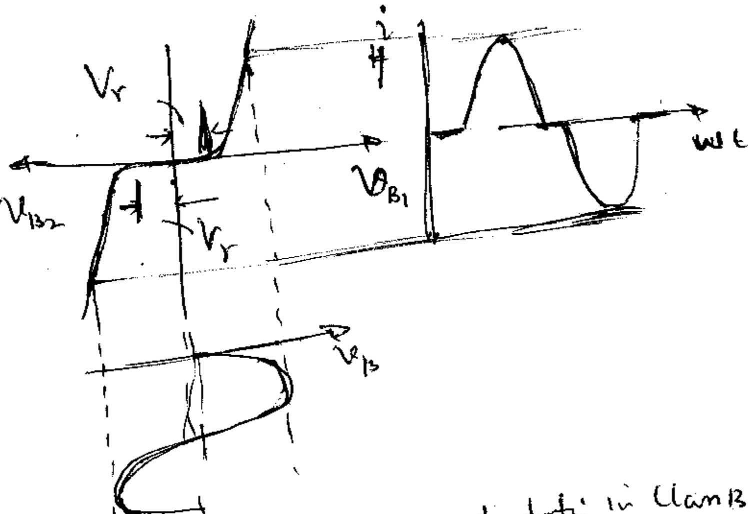
Crossover distortion

In the above Ckt we have seen that in the positive cycle transistor Q_1 conducts, but it conducts only after the I/p voltage exceeds the cutin voltage of BE junction diode. Till that o/p = 0. Similarly when the I/p is of -ve cycle Q_2 conducts. therefore the base of transistor Q_2 will be +ve & the transistor Q_2 will be pushed into conduction and transistor Q_1 is pulled out of conduction hence the name Push-Pull operation. But Q_2 conducts only if I/p becomes more negative compared to -0.6v because, the transistor Q_2 base exceeds 0.6v till transistor Q_2 conducts o/p is zero. Therefore the o/p voltage zero when I/p is crossing over from 0.6v to -0.6v. This type of distortion in the o/p is called Crossover distortion. ~~the~~ o/p is obtained because current flowing at $(i_1 - i_2)$. Here the problem of dc saturation the o/p is of the transformer is eliminated because the current will flow in opposite direction in the primary winding. The even harmonics are eliminated therefore distortion is less. The ripple in the power supply is eliminated. The power dissipation across each transistor is 20% of the max o/p power. The %η is of 78.5%. (90) the power dissipation is max. The %η reduces to 50%.

Class AB operation



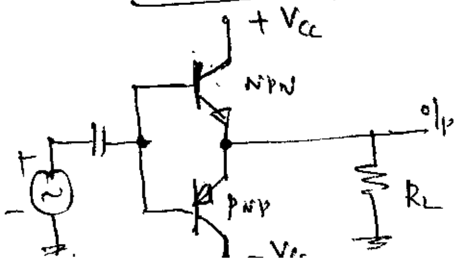
: In addition to the distortion introduced by not using matched transistors and due to nonlinearity in the o/p char, there is one more distortion, caused by nonlinearity of the I/p characteristic. In earlier we have seen that there will not be any appreciable current for es until emitter junction is forward biased. Under these condition, the sinusoidal base excitation will not result in sinusoidal o/p current.



Crossover distortion in Class B

We have seen that o/p is zero when I/p is crossing over from 0.6v to −0.6v because here both transistors are reverse biased. To avoid this crossover distortion transistors must operate in Class AB mode (Class A push pull), where a small standby current flows at zero excitation. The voltage drop across R_1 in the ckt the voltage is adjusted for cut in voltage V_r. Compared to Class B with the crossover distortion is avoided in Class AB loss in efficiency & standby power. The resistors Re provide stability for the ckt.

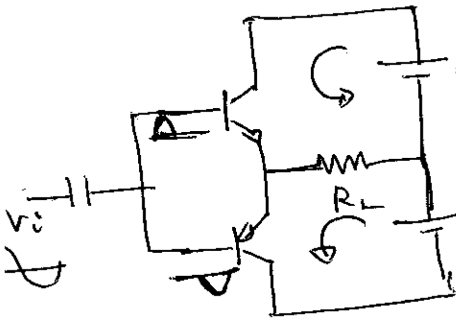
Complementary Symmetry (one n-p-n & one p-n-p type) Power Amplifier



The ckt eliminates both I/p & o/p transformer. It uses npn & pnp transistors so it is called as complementary symmetry. It will be difficult to get identical transistors. Here even harmonics will not be cancelled out. Very often it uses negative feedback. It also leads to crossover distortion of

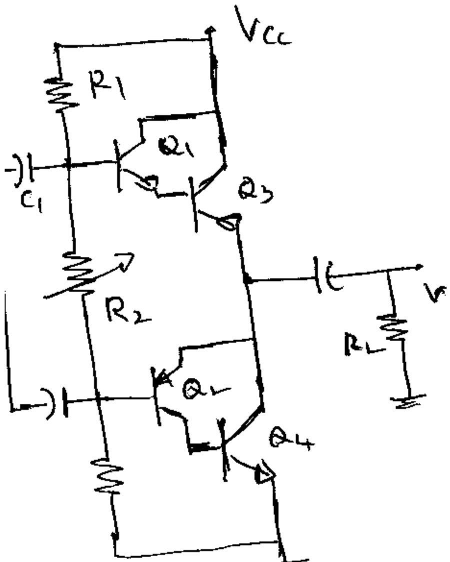
Complementary - Symmetry Circuit.

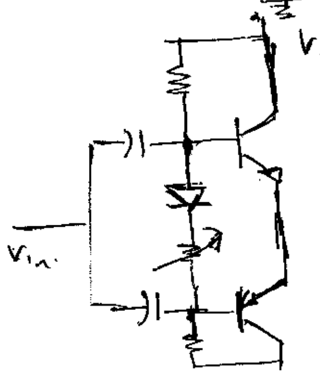
Using Complementary - transistors (npn & pnp) it is possible to obtain a full cycle o/p across a load using half - cycle of operation from each transistor whereas a single I/p signal is applied to the base of both transistors, the transistors being of opposite type, will conduct on opposite half cycle of the I/p. For positive half cycle npn transistor will conduct and it will result in the o/p across the load & for negative half cycle pnp transistor will conduct and results in the o/p across the load.



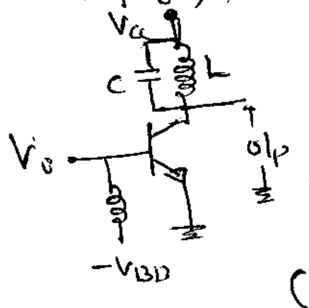
During a complete cycle of the I/p, a complete cycle of o/p signal is developed across the load. One disadvantage of the circuit is the need of two separate voltage supplies. Another, less obvious disadvantage is crossover distortion. It refers to the fact that during the signal crossover from positive to negative (or vice versa) there is some nonlinearity in the o/p signal. During crossing over of the I/p, both the transistors will not conduct, because of this o/p voltage is zero. Biasing the transistors in class AB improves the operation by biasing both transistors to be on for more than half cycles.

Quasi - Complementary Push-Pull Amplifier. In practical power amplifier ckt, it is preferable to use npn transistors for both high current - o/p devices. Since the push-pull operation requires complementary devices, a pnp high power transistor must be used. A practical means of obtaining complementary operation while using the same matched npn transistors for the o/p provided by a quasi - complementary ckt. The push pull operation is achieved by using complementary transistors before the matched npn o/p transistors. where Q_1 & Q_3 form a Darlington pair and Q_2 & Q_4 form a feedback pair. Both provides a low impedance drive to the load. The resistor R_2 can be adjusted to minimize the crossover distortion by adjusting the dc bias condition. The I/p signal is applied to the push pull stage results in a full cycle o/p to the load. It is commonly used power amplifier.



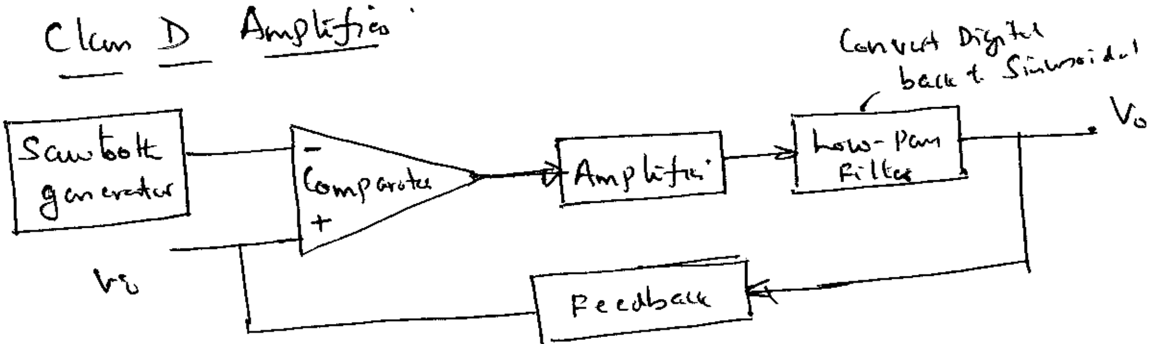


Class C and Class D Amplifiers: Class D amplifier is popular because of their very high efficiency. Class C amplifier, although not used as audio amplifier, but it is used in tuned circuits as in communication.



Class C Amplifier: Here the transistor is biased to operate for less than 180° of the I/p signal cycle. The tuned ckt in o/p, however will provide a full cycle of the o/p signal for the fundamental resonance frequency of the tuned ckt (L & C ckt) of the o/p. This type of operation is therefore limited to use at one fixed frequency, as occurs in communication circuit.

Class D Amplifier:



Block Diagram of Class D Amplifier

A class D amplifier is designed to operate with digital or pulse type signals. An efficiency of over 90% is achieved using this type of circuit, making it quite desirable in power amplifiers. It is necessary, however, to convert any I/p signal into pulse-type waveform before using it to drive a large power load & to convert the signal back into a sinusoidal type signal to recover the original signal. The Fig shows how a sinusoidal signal may be converted into pulse type signal using some form of sawtooth or chopping waveform to be applied with the I/p into a comparator type opAmp ckt so that a representative pulse type signal is produced. Although the D is used to describe the next type of bias operation after class C, the D could also be considered to stand for "Digital" since that is the nature of the signals provided to the class D amplifier.

The above block diagram needed to amplify the class D signal & then convert back into the sinusoidal-type signal using a low pass filter. Since the amplifier's transistor devices used to provide the o/p are basically either off or on, they provide current only when they turned on, with little power loss due to their low "on" voltage. Since most of the power applied to the amplifier is transferred to the load, the efficiency of the ckt is typically very high. Power MOSFET devices have been quite popular as the driver devices for the class D amplifier.