Chapter 5. MULTISTAGE AMPLIFIERS

A REVISIT TO AMPLIFIER BASICS:

There are many situations wherein the signal picked up from a source (say a transducers) is too feeble to be of any use and has to be magnified before it can have the capability to drive a system (say another transducer). For example, the electrical signal produced by a microphone has to be magnified before it can effectively drive a loudspeaker. This function of magnifying the amplitude of a given signal, without altering its other properties is known as amplification. In any signal transmission system, amplification will have to be done at suitable locations along the transmission link to boost up the signal level.

In order to realize the function of amplification, the transformer may appear to be a potential device. However, in a transformer, though there is magnification of input voltage or current, the power required for the load has to be drawn from the source driving the input of the transformer. The output power is always less than the input power due to the losses in the core and windings. The situation in amplification is that the input source is not capable of supplying appreciable power. Hence the functional block meant for amplification should not draw any power from the input source but should deliver finite out power to the load.

Thus the functional block required should have input power

$$P_i = V_i\, I_i = 0$$

And give the output

$$P_0 = V_0\, I_0 = \text{finite}$$

Such a functional block is called an ideal amplifier, which is shown in Fig.1 below.

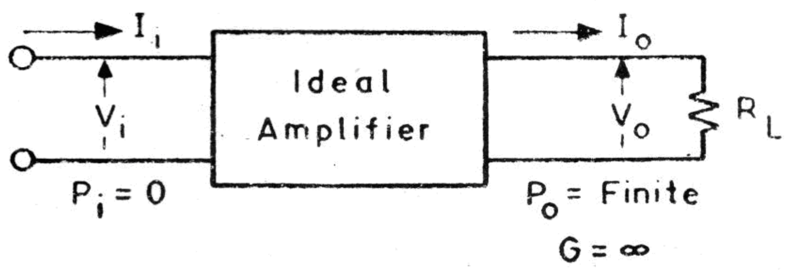


Fig. 1 Ideal amplifier

Power gain is $G = P_0/P_i$

The power gain of an ideal amplifier being infinite may sound like witchcraft in that something can be produced from nothing. The real fact is that the ideal amplifier requires dc input power. It converts dc power to ac power without any demand on the signal source to supply the power for the load.

CLASSIFICATION OF AMPLIFIERS:

Amplifiers are classified in many ways based on different criteria as given below.

I In terms of frequency range:

1. DC amplifiers. (0 Hz to 20 Hz)
2. Audio amplifiers (20 Hz to 20 KHz)
3. Radio frequency amplifiers (Few KHz to hundreds of KHz)
4. Microwave amplifiers (In the range of GHz)
5. Video amplifiers (Hundreds of GHz)

II In terms of signal strength:

1. Small signal amplifiers.
2. Large signal amplifiers.

III. In terms of coupling:

1. Direct coupling.
2. Resistance – capacitance (RC) coupling.
3. Transformer coupling.

IV. In terms of parameter:

1. Voltage amplifiers.
2. Current amplifiers.
3. Power amplifiers.

V. In terms of biasing condition:

1. Class A amplifier
2. Class B amplifier
3. Class AB amplifier
4. Class C amplifier.

VI. In terms of tuning:

1. Single tuned amplifier
2. Double tuned amplifier
3. Stagger tuned amplifier.

DECIBEL NOTATION:

The power gain of an amplifier is expressed as the ratio of the output power to the input power. When we have more than one stage of amplification i.e. when the output of one stage becomes the input to the next stage, the overall gain has to be obtained by multiplying the gains of the individual stages. When large numbers are involved, this calculation becomes cumbersome. Also, when we have passive coupling networks between amplifier stages, there will be attenuation of the signal that is gain less than unity. To find the overall gain of a typical multistage amplifier such as the one given below

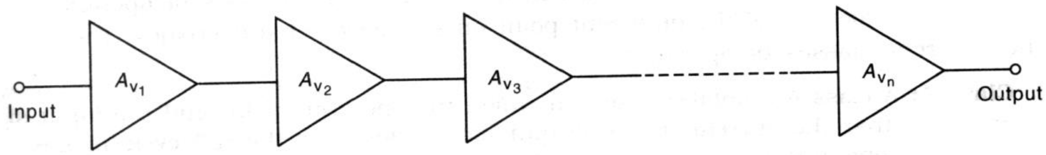


Fig. Cascaded amplifiers

We have to multiply the various gains and attenuations. Moreover, when we wish to plot the gain of an amplifier versus frequency, using large numbers for plotting is not convenient. Hence it has been the practice to use a new unit called the decibel (usually abbreviated as dB) for measuring the power gain of a four terminal network. The power gain in decibels is given by

$$G = 10 \log_{10} P_0 / P_i \ \text{dB}$$

This new notation is also significant in the field of acoustics as the response of the human ear to sound intensity is found to be following this logarithmic pattern. The overall gain in decibel notation can be obtained for the amplifier gain of the figure1 by simply adding the decibel gains of the individual networks. If any network attenuates the signal, the gain will be less than the unity and the decibel gain will be negative. Thus the overall gain for the amplifier chain shown above is given by

Overall gain = 10 – 6 + 30 – 10 + 20 = 44 dB

The absolute power level of the output of an amplifier is sometimes specified in dBm, i.e. decibels with reference to a standard power power level, which is usually, 1 Mw dissipated in a 600 Ω load. Therefore, if an amplifier has 100 Mw, its power level in dBm is equal to 10 log 100/1 = 20 dBm

MULTISTAGE AMPLIFIERS:

In real time applications, a single amplifier can't provide enough output. Hence, two or more amplifier stages are cascaded (connected one after another) to provide greater output Such an arrangement is known as multistage amplifier Though the basic purpose of this arrangement is increase the overall gain, many new problems as a consequence of this, are to be taken care. For e.g. problems such as the interaction between stages due to impedance mismatch, cumulative hum & noise etc.

MULTISTAGE VOLTAGE GAIN:

The overall voltage gain A of cascaded amplifiers as shown below, is the product of the individual gains. (Refer to FIG.2) above.

$A_T = A_{v1} \times Av_2 \times Av_3$ ------------------Av_n

Where 'n' is the number of stages.

P1: An amplifier has an input power of 5μW. The power gain of the amplifier is 40 dB.

Find the out power of the amplifier.

SOLN: Power gain in Db = $10\log_{10} P_0 / P_i = 40$.

Hence $P_0 / P_i = \text{antilog}_{10} 4 = 10^4$

Output power $P_0 = P_i \times 10^4 = 5 \times 10^4$ μW.

P2: An amplifier has at its input a signal power of 100 μW and a noise power of 1μW. The amplifier has a power gain of 20 dB. The noise contribution by the amplifier is 100μW. Find (i) the input S/N ratio (ii) out S/N ratio (iii) noise power factor and (iv) noise figure of the amplifier.

SOLN: Input S/N = 100/1 = 100

Power gain = 20 dB = ratio of 100

Hence output signal power = $100 \times 100\ \mu W$

Output noise power = input noise power × power gain + noise of amplifier

$= 1 \times 100 + 100 = 200\mu W$

S/N at output = 10000 / 200 = 50

Noise factor, $F = (S/N)_i / (S/N)_0 = 100 / 50 = 2$

Noise figure = 10 log F = 3 dB

DISTORTION IN AMPLIFIERS:

In any amplifier, ideally the output should be a faithful reproduction of the input. This is called fidelity. Of course there could be changes in the amplitude levels. However in practice this never happens. The output waveform tends to be different from the input. This is called as the distortion. The distortion may arise either from the inherent non – linearity in the transistor characteristics or from the influence of the associated circuit.

The distortions are classified as:

1. Non – linear or amplitude distortion
2. Frequency distortion
3. Phase distortion
4. Inter modulation distortion

NON – LINEAR DISTORTION:

This is produced when the operation is over the non-linear part of the transfer characteristics of the transistor. (A plot between output v/s input is called as the transfer characteristics). Since the amplifier amplifies different parts of the input differently. For example, there can be compression of the positive half cycle and expansion of the negative half cycle. Sometimes, the waveform can become clipped also. (Flattening at the tips). Such a deviation from linear amplification produces frequencies in the output, which are not originally present in the output. Harmonics (multiples) of the input signal frequency are present in the output. The percentage harmonic distortion for the n^{th}

Harmonic is given by

$$D_n = \frac{A_n \text{(amplitude of the n the harmonic)}}{A_1 \text{(amplitude of the fundamental)}} \times 100\%$$

And the total harmonic distortion by

$$D_T = \sqrt{D_2{}^2 + D_3{}^2 + ------- D_n{}^2}$$

Where $D_{2,} D_3$ ---- are harmonic components.

A distortion factor meter measures the total distortion. The spectrum or wave analyzer can be used to measure the amplitude of each harmonic.

FREQUENCY DISTORTION:

A practical signal is usually complex (containing many frequencies). Frequency distortion occurs when the different frequency components in the input signal are amplified differently. This is due to the various frequency dependent reactances (capacitive & inductive) present in the circuit or the active devices (BJT or FET).

PHASE DISTRIBUTION:

This occurs due to different frequency components of the input signal suffering different phase shifts. The phase shifts are also due to reactive effects and the active devices. This causes problems in TV picture reception. To avoid this amplifier phase shift should be proportional to the frequency.

INTERMODULATION DISTORTION:

The harmonics introduced in the amplifier can combine with each other or with the original frequencies to produce new frequencies to produce new frequencies that are not harmonics of the fundamental. This is called inter modulation distortion. This distortion results in unpleasant hearing.

FREQUENCY RESPONSE OF AN AMPLIFIER:

Frequency response of an amplifier is a plot between gain & frequency. If the gain is constant (same) for all frequencies of the input signal, then this plot would be a flat line. But this never happens in practice.

As explained earlier, there are different reactive effects present in the amplifier circuit and the active devices used. Infact there are external capacitors used for blocking, capacitors etc. Also, in tuned amplifiers, resonant LC circuits are connected in the collector circuits of the amplifier to get narrow band amplification around the resonant frequencies.

Fig below shows a frequency response of a typical amplifier.

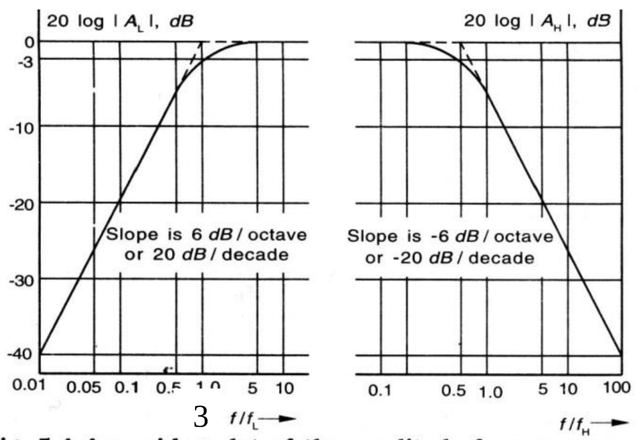


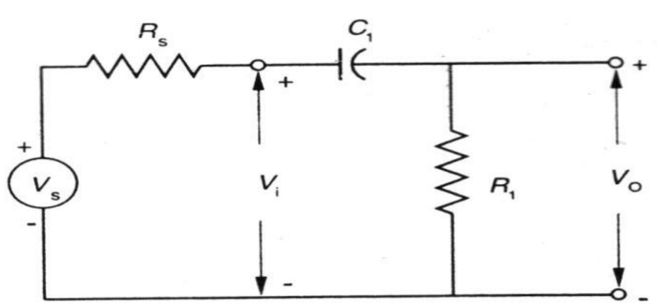
Fig. 5.4 A semi-log plot of the amplitude frequency-response (Bode) characteristic of an *RC* coupled amplifier

Where A_{mid} = mid band voltage gain (in dB)

f_L = Lower cut – off frequency. (in Hz)

f_H = Upper cut - off frequency (in Hz)

Usually the frequency response of an amplifier is divided into three regions. (i) The mid band region or flat region, over which the gain is constant (ii) The lower frequency region. Here the amplifier behaves like a high pass filter, which is shown below.



(a) High-pass circuit

FIG .4

At high frequencies, the reactance of C_1 will be small & hence it acts as a short without any attenuation (reduction in signal voltage) (iii) In the high frequency region above mid band, the circuit often behaves like the low pass filter as shown below.

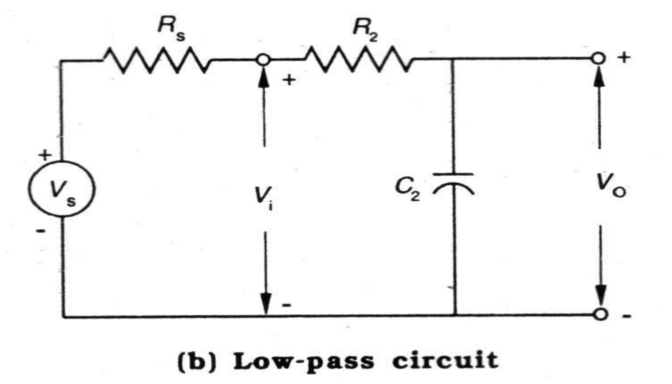


FIG.5

As the frequency is increased, the reactance of C_2 decreases. Hence more voltage is dropped across Rs and less is available at the output. Thus the voltage gain of the amplifier decreases at high frequencies.

LOW FREQUENCY RESPONSE:

In the frequency below the mid band, the High pass filter as shown above can approximate the amplifier. Using Laplace variable's' , the expression for output voltage can be written as:

$$V_0(s) = \frac{V_i(s)R_1}{R_1 + \frac{1}{sC_1}} = V_i(s)\frac{s}{s + \frac{1}{R_1C_1}} \quad \text{-----------} \quad \text{-(1)}$$

For real frequencies ($s = j\omega = 2\pi f$) , equation (1) becomes

$A_{VL}(jf) = 1 / (1 - jf_L / f)$ --(2)

Where $f_L = 1 / (2\pi R_1 C_1)$ --(3)

The magnitude of the voltage gain is given by

$$|A_{VL}(jf)| = \frac{1}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}} \quad \text{--- (4)}$$

The phase lead of the gain is given by

$\theta_L = \tan^{-1}(f_L/f)$ ---(5)

At f = f_L, $A_{VL} = \frac{1}{\sqrt{2}} = 0.707$

This is equal to 3 dB in log scale. For higher frequencies f >> f_L, A_L tends to unity. Hence, the magnitude of A_{VL} falls of to 70.7 % of the mid band value at f = $f_{L,}$ Such a frequency is called the lower cut-off or lower 3 dB frequency.

From equation (3) we see that f_L is that frequency for which the resistance R1

Equals the capacitive reactance,

$$X_C = \frac{1}{2\pi f_L C_1}$$

HIGH FREQUENCY RESPONSE:

In the high frequency region, above the mid band , the amplifier stage can be approximated by the low pass circuit shown above.(fig 2 b). In terms complex variables, ‘s’ , the output voltage is given by

$$V_0(s) = \frac{\frac{1}{sC_2}}{R_2 + \frac{1}{sC_2}} V_i(s) = \frac{1}{1+sR_2C_2} V_i(s) \text{-------------------- (6)}$$

In terms of frequency (i.e s = jω = 2πf) equation (2) becomes

$$\left|A_H(jf)\right| = \left|\frac{V_0(s)}{V_i(s)}\right|_{S=j2\pi f} = \frac{1}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}} \text{ -------------------- (7)}$$

Where $f_H = \frac{1}{2\pi R_2 C_2}$

The phase of the gain is given by

θ_H = - arc tan (f / f_H) ------------------------------------(9)

At $f = f_H$, $A_H = (1/\sqrt{2})\, A_V = 0.707A_V$, then f_H is called the upper cut off or upper 3 dB frequency. It also represents the frequency at which the resistance R_2 = Capacitive reactance of $C_2 = 1/ 2\pi f_H C_2$.

Thus, we find that at frequencies f_L & f_H , the voltage gain falls to $1/\sqrt{2}$ of the mid band voltage gain. Hence the power gain falls to half the value obtained at the mid band. Therefore these frequencies are also called as half power frequencies or –3dB

Frequency since log (1/2) = -3dB.

FREQUENCY RESPONSE PLOTS:

The gain & phase plots versus frequency can be approximately sketched by using straight-line segments called asymptotes. Such plots are called Bode plots. Being in log scale, these plots are very convenient for evaluation of cascaded amplifiers.

BANDWIDTH:

The range of frequencies from f_L to f_H is called the bandwidth of the amplifier. The product of mid band gain and the 3dB Bandwidth of an amplifier is called the Gain-bandwidth product. It is figure of merit or performance measure for the amplifier.

RC COUPLED AMPLIFIER:

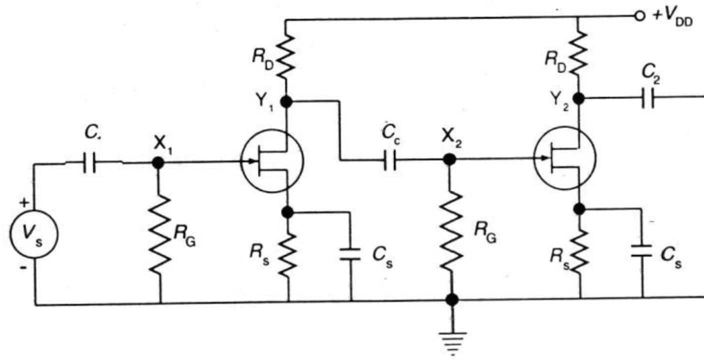


Fig 2 **Two-stage *RC* coupled amplifier with FETs**

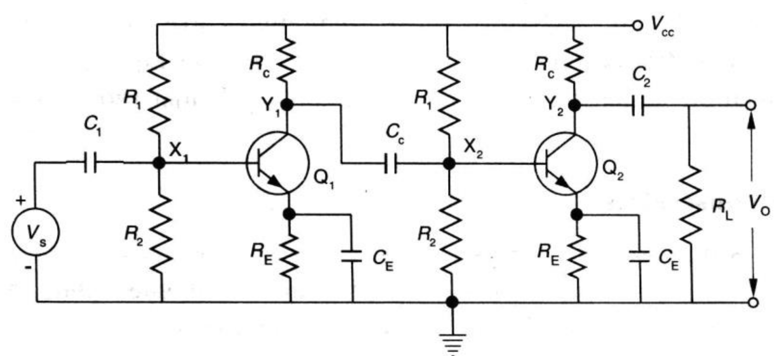


Fig 1 **Two-stage *RC* coupled amplifier with BJTs**

Fig. (1) above shows a two stage RC coupled CE amplifier using BJTs where as fig.(2) shows the FET version. The resistors R_C & R_B (= R_1R_2 / (R_1 + R_2) and capacitors C_C form the coupling network. Because of this, the arrangement is called as RC coupled amplifier. The bypass capacitors C_E (= C_S) are used to prevent loss of amplification due to –ve feedback. The junction capacitance C_j should be taken into account when high frequency operation is considered.

When an ac signal is applied to the input of the I stage, it is amplified by the active device (BJT or FET) and appears across the collector resistor R_C / drain resistor $R_{D.}$ this output signal is connected to the input of the second stage through a coupling capacitor C_C. The second stage doesn't further amplification of the signal.

In this way, the cascaded stages give a large output & the overall gain is equal to the product of this individual stage gains.

ANALYSIS OF TWO STAGE RC COUPLED AMPLIFIER:

This analysis is done using h parameter model. Assuming all capacitors are arbitrarily large and act as ac short circuits across $R_{E.}$ The dc power supply is also replaced by a short circuit. Their h parameter approximate models replace the transistors.

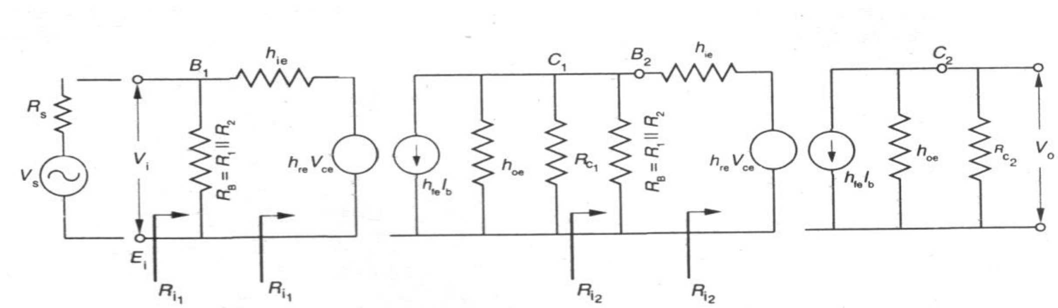


Fig. 5.6 *h*-parameter equivalent circuit for *RC* coupled amplifier

The parallel combination of resistors R_1 and R_2 is replaced by a single stage resistor R_B.

$$R_B = R_1 \parallel R_2 = R_1R_2/ (R_1 + R_2)$$

For finding the overall gain of the two stage amplifier, we must know the gains of the individual stages.

Current gain (A_{i2}):

$$A_i = - h_{fe} / (1 + h_{oe} R_L)$$

Neglecting h_{oe} as it is very small, $A_i = -h_{fe}$

Input resistance (R_{i2}):

We know that $R_i = h_{ie} + h_{re} A_i R_L$

Hence, $R_i = h_{ie}$ and $R_{i2} = h_{ie}$

Voltage gain (A_{v2}):

We know that $A_v = A_i R_L / R_i$

$$A_{v2} = - h_{fe} R_{C2} / R_{i2}$$

Current gain (A_{i1}):

$$A_{i1} = -h_{fe}$$

Input resistance (R_{i1}):

$$R_{i1} = h_{ie}$$

Voltage gain (Av1):

$$A_V = A_i R_L / R_{i1}$$

Here $R_L = R_{C1} \| R_B \| R_{i2}$

$$A_{V1} = - h_{fe} (R_{C1} \| R_B \| R_{i2}) / R_{i1}$$

Overall gain (A_v):

$$A_V = A_{V1} X A_{V2}$$

Session 2(b) FEEDBACK AMPLIFIERS:

Feedback is a common phenomenon in nature. It plays an important role in electronics & control systems. Feedback is a process whereby a portion of the output signal of the amplifier is feedback to the input of the amplifier. The feedback signal can be either a voltage or a current, being applied in series or shunt respectively with the input signal. The path over which the feedback is applied is the feedback loop. There are two types of feedback used in electronic circuits. (i) If the feedback voltage or current is in phase with the input signal and adds to its magnitude, the feedback is called positive or regenerative feedback.(ii) If the feedback voltage or current is opposite in phase to the input signal and opposes it , the feedback is called negative or regenerative feedback.

We will be more interested to see how the characteristics of the amplifier get modified with feedback.

CLASSIFICATION OF AMPLIFIERS:

Before analyzing the concept of feedback, it is useful to classify amplifiers based on the magnitudes of the input & output impedances of an amplifier relative to the sources & load impedances respectively as (i) voltage (ii) current (iii) Tran conductance (iv) Tran resistance amplifiers.

1. VOLTAGE AMPLIFIER:

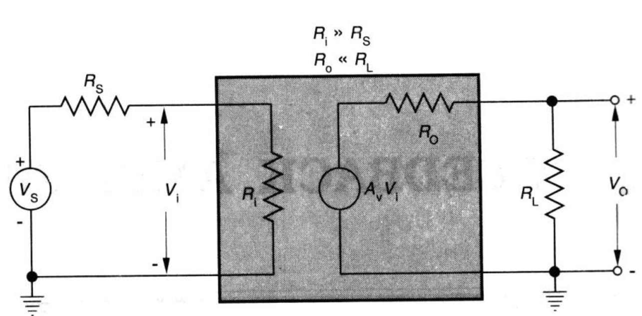


Fig. 4 **Thevenin's equivalent circuit of a voltage amplifier**

The above figure shows a Thevenin's equivalent circuit of an amplifier. If the input resistance of the amplifier R_i is large compared with the source resistance Rs, then

$V_i = V_{s.}$ If the external load R_L is large compared with the output resistance R_0 of the amplifier, then $V_0 = A_V V_S$ .This type of amplifier provides a voltage output proportional to the input voltage & the proportionality factor doesn't depend on the magnitudes of the source and load resistances. Hence, this amplifier is known as voltage amplifier.

An ideal voltage amplifier must have infinite resistance R_i and zero output resistance.

2. CURRENT AMPLIFIER:

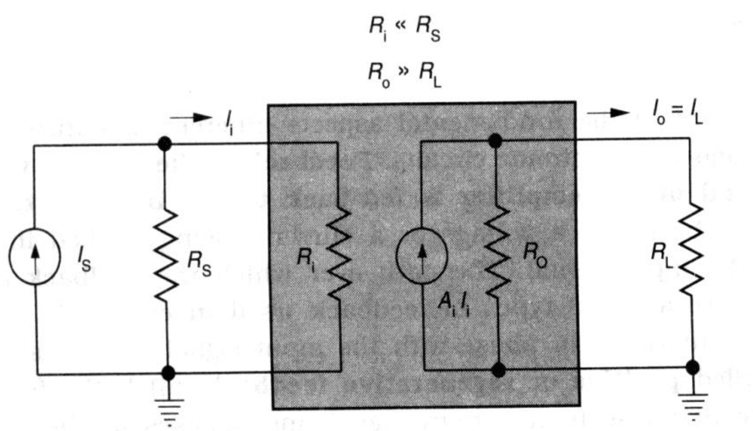


Fig. 5 Norton's equivalent circuit of a current amplifier

Above figure shows a Norton's equivalent circuit of a current amplifier. If the input resistance of the amplifier R_i is very low compared to the source resistance R_S, then $I_i = I_S$. If the output resistance of the amplifier R_0 is very large compared to external load R_L, then $I_L = A_iI_i = A_i I_S$ .This amplifier provides an output current proportional to the signal current and the proportionally is dependent of the source and load resistance. Hence, this amplifier is called a current amplifier.

An ideal current amplifier must have zero input resistance & infinite output resistance.

3. **TRANSCONDUCTANCE AMPLIFIER:**

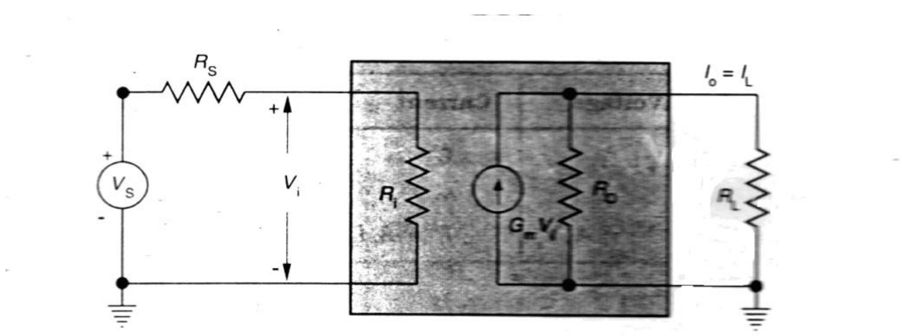


Fig. 6 Equivalent circuit of a transconductance amplifier

The above figure shows the equivalent circuit of a transconductance amplifier. In this circuit, the output current I_0 is proportional to the signal voltage V_S and the proportionality factor is independent of the magnitudes of source and load resistances.

An ideal transconductance amplifier must have an infinite resistance R_i & infinite output resistance R_0.

4. TRANSRESISTANCE AMPLIFIER:

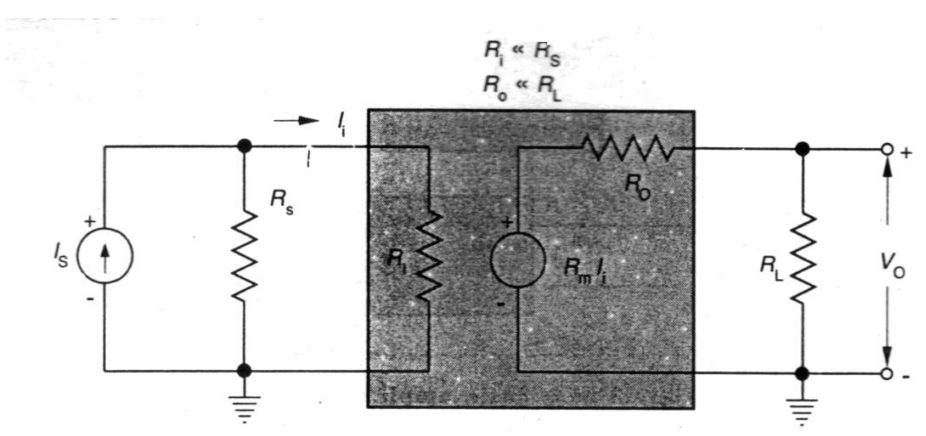


Fig. 7 Equivalent circuit of a transresistance amplifier

Figure above shows the equivalent circuit of a transconductance amplifier. Here, the output voltage V_0 is proportional to the signal current I_S and the proportionality factor is independent of magnitudes of source and loads resistances. If $R_S >> R_i$, then $I_i = I_S$, Output voltage $V_0 = R_m I_S$.

An ideal transconductance amplifier must have zero input resistance and zero output resistance.

THE FEEDBACK CONCEPT:

In each of the above discussed amplifiers, we can sample the output voltage or current by means of a suitable sampling network & this sampled portion is feedback to the input through a feedback network as shown below.

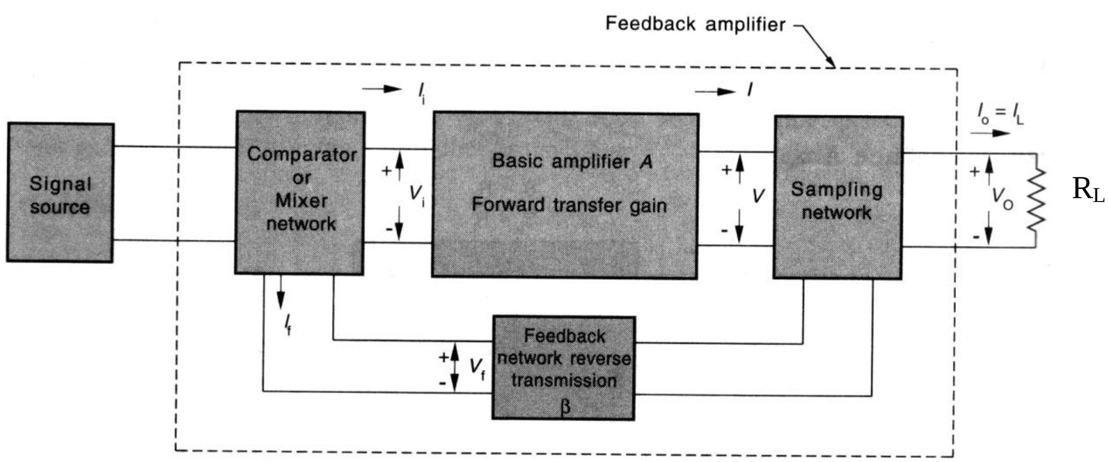


Fig. 1 Block diagram of a basic amplifier with feedback connection

All the input of the amplifier, the feedback signal is combined with the source signal through a unit called mixer.

The signal source shown in the above figure can be either a voltage source V_S or a current source.

The feedback connection has three networks.

(i) Sampling network

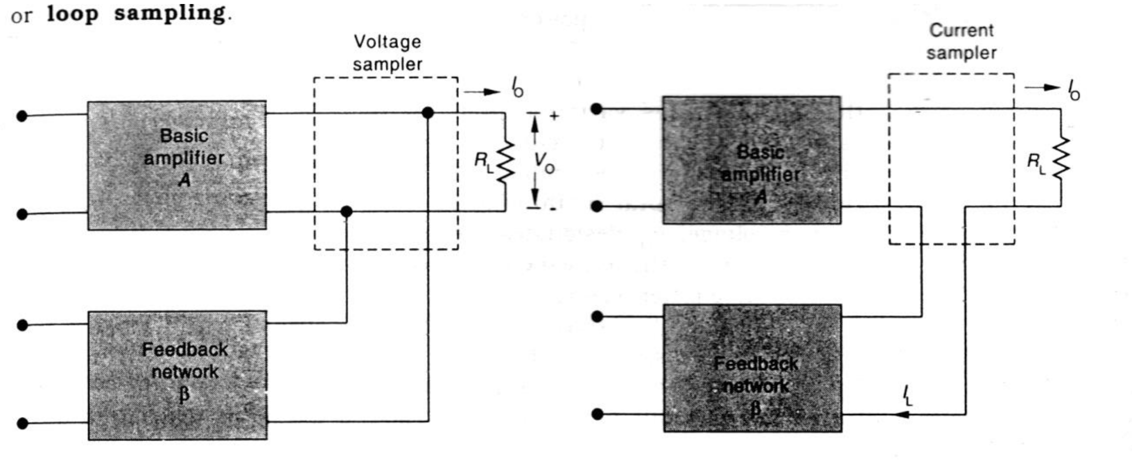
(ii) Feedback network

(iii) Mixer network

SAMPLING NETWORK:

There are two ways to sample the output, depending on the required feedback parameter. The output voltage is sampled by connecting the feedback network in shunt with the output as shown in fig6.6 (a) below.

or **loop sampling**.



(a) Voltage or node sampling **Fig. 2** **(b) Current or loop sampling**

This is called as voltage sampling. If the output current is sampled by connecting feedback network in series with the output (figure 6.6 (b)).

(ii) FEEDBACK NETWORK:

This is usually a passive two-port network consisting of resistors, capacitors and inductors. In case of a voltage shunt feedback, it provides a fraction of the output voltage as feedback signal V_f to the input of the mixer. The feedback voltage is given by

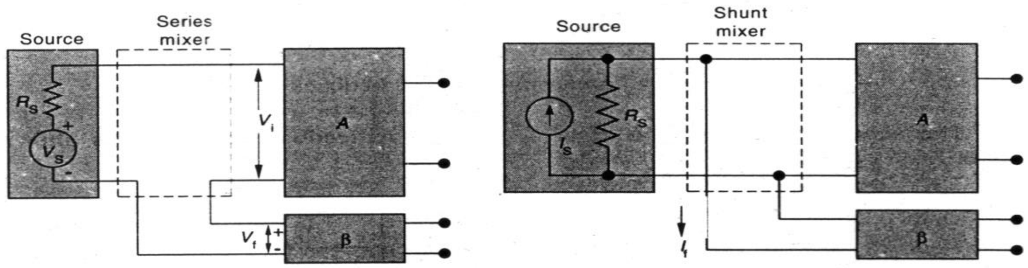
$$V_f = \beta V_0$$

Where β is called feedback factor. It lies between 0 & 1.

(iii) MIXER:

There are two ways of mixing the feedback signal with the input signal with the input signal as shown in figure . below.

(iii) Mixer Network



(a) Series mixing **(b) Shunt mixing**

Fig. 3 'eedback connections of the input of a basic amplifier

When the feedback voltage is applied in series with the input voltage through the feedback network as shown in figure 6.7 (a) above, it is called series mixing.

Otherwise, when the feedback voltage is applied in parallel to the input of the amplifier as shown in figure (b) above, it is called shunt feedback.

GAIN OR TRANSFER RATIO:

The ratio of the output signal to the input signal of the basic amplifier is represented by the symbol A , with proper suffix representing the different quantities.

Transfer ratio $\frac{V_0}{Vi} = A_V$ = Voltage gain

Transfer ratio $\frac{I_0}{I_i} = A_I$ = Current gain

Ratio $\frac{I_0}{V_i} = G_m$ = Transconductance

Ratio $\frac{V_i}{I_0} = R_m$ = Transresistance

A suffix ‘f’ is added to the above transfer ratios to get the corresponding quantities with feedback.

$A_{Vf} = \frac{V_0}{V_S} =$ Voltage gain with feedback

$A_{If} = \frac{I_0}{I_S} =$ Current gain with feedback

$G_{Mf} = \frac{I_0}{V_S}$ = Transconductance with feedback

$R_{Mf} = \frac{V_0}{I_S}$ = Transresistance with feedback

TYPES OF FEEDBACK:

Feedback amplifiers can be classified as positive or negative feedback depending on how the feedback signal gets added to the incoming signal.

If the feedback signal is of the same sign as the incoming signal, they get added & this is called as positive feedback. On the other hand, if the feedback signal is in phase inverse with the incoming signal, they get subtracted from each other; it will be called as negative feedback amplifier.

Positive feedback is employed in oscillators whereas negative feedback is used in amplifiers.

FEATURE OF NEGATIVE FEEDBACK AMPLIFIERS:

1. Overall gain is reduced

2. Bandwidth is improved

3. Distortion is reduced

4. Stability is improved

5. Noise is reduced

ANALYSIS OF FEEDBACK AMPLIFIER:

The analysis of the feedback amplifier can be carried out by replacing each active element (BJT, FET) by its small signal model and by writing Kirchoff's loop or nodal equations.

Consider the schematic representation of the feedback amplifier as shown below.

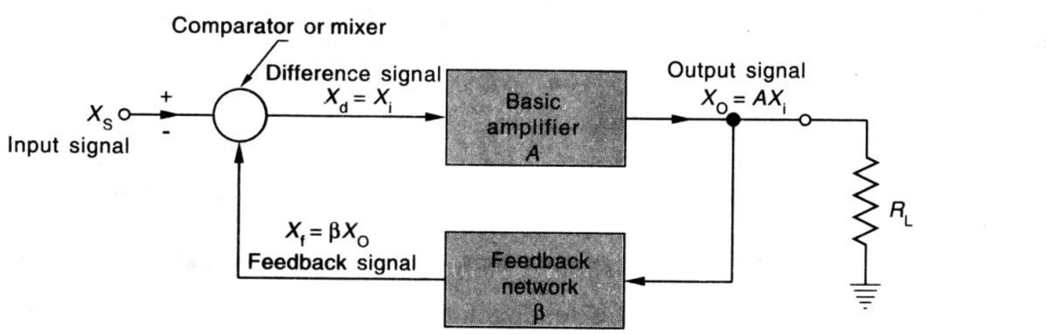
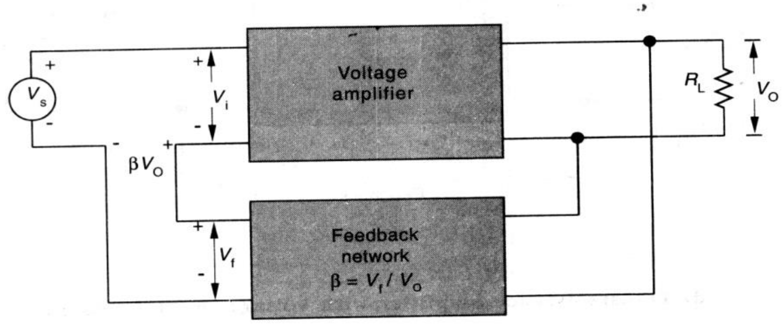


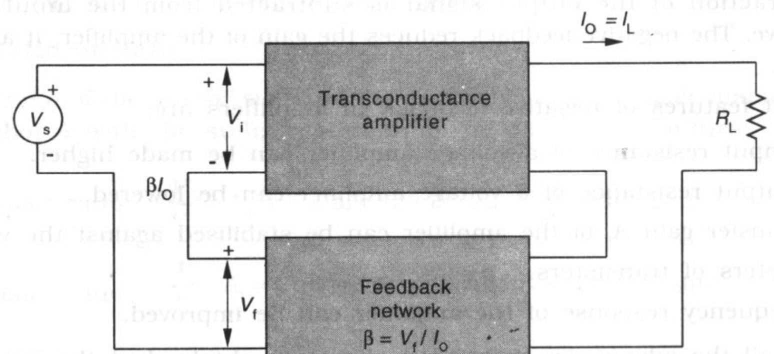
Fig. 4 Schematic representation of a single-loop feedback amplifier

The basic amplifier may be a voltage, transconductance, current or transresistance amplifier connected in a feedback configuration as shown in figures below.

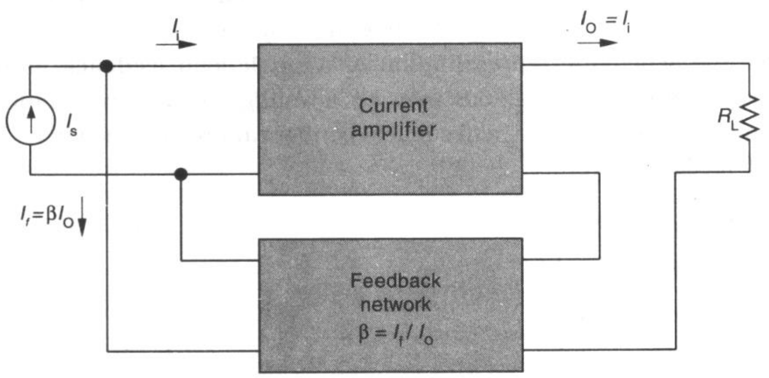


(a) Voltage amplifier with voltage-series feedback

Fig. 5 Types of amplifiers with negative feedback



(b) Transconductance amplifier with current-series feedback



(c) Current amplifier with current-shunt feedback

The four basic types of feedback are:

5. Voltage –Series feedback
6. Current – Series feedback
7. Current – Shunt feedback
8. Voltage – Shunt feedback

1. GAIN WITH FEEDBACK:

Consider the schematic representation of negative feedback amplifier as shown in fig.6.8.The source resistance R_S to be part of the amplifier & transfer gain A (A_V,A_i ,G_m ,

R_m) includes the effect of the loading of the β network upon the amplifier.The input signal X_S, the output signal X_0, the feedback signal X_f and the difference signal X_d , each represents either a voltage or a current and also the ratios A and β as summarized below.

Table 1. Voltage and Current signals in feedback amplifiers

Signal or ratio	**Type of feed back**			
	Voltage series	Current series	Current shunt	Voltage shunt
X_0	Voltage	Current series	Current	Voltage
X_S X_f X_d	Voltage	Voltage	Current	Current
A	A_V	G_m	A_1	R_m
β	V_f / V_o	V_f / I_o	I_f/I_o	I_f / V_o

The gain, $A = X_0 / X_S$ --(1)

The output of the mixer,

$X_d = X_s + (-X_f) = Xi$ ----------------------------------- (2)

The feedback ratio , $\beta = X_f / X_0$ ----------------------------------- (3)

The overall gain (including the feedback)

$A_f = X_0 / X_S$ -------------------------------------(4)

From equation (2), $X_S = X_i + X_f$

$A_f = X_0 / (X_i + X_f)$

Dividing both numerator and denominator by X_i and simplifying, we get

$A_f = A / (1 + \beta A)$ -- (5)

Equation (5) indicates that the overall gain A_f is less the open loop gain.

The denominator term $(1 + \beta A)$ in equation (5) is called the loop gain.

The forward path consists only of the basic amplifier, whereas the feedback is in the return path.

2.GAIN STABILITY:

Gain of an amplifier depends on the factors such as temperature, operating point

aging etc. It can be shown that the negative feedback tends to stabilize the gain.

The ratio of fractional change in amplification with feedback to the fractional change in without feedback is called the sensitivity of the gain

$$\text{Sensitivity of the gain} = \left|\frac{dA_f}{dA}\right| \quad \text{------- (1)}$$

$$A_f = \frac{A}{1+A\beta} \quad \text{--------(2)}$$

Differentiating equation (2) wrt A,

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

Dividing both sides by A_f , we get

$$\frac{dA_f}{A_f} = \frac{1}{(1+A\beta)^2} \cdot \frac{dA}{A_f} = \frac{1}{(1+A\beta)^2} \frac{dA}{(A/(1+A\beta)} = \frac{dA}{A} \cdot \frac{1}{(1+A\beta)} \quad \text{--------------- (3)}$$

i.e $\left|\frac{dA_f}{A_f}\right| = \left|\frac{dA}{A}\right| \frac{1}{|1+A\beta|}$ ---------------------------- (4)

Where

$\frac{dA_f}{A_f}$ = Fractional change in gain with feedback

$\frac{dA}{A}$ = Fractional change in gain without feedback.

Here $\frac{1}{1+A\beta}$ is sensitivity. The reciprocal of the sensitivity is called the desensitivity D.

The term desensitivity indicate the factor by which the gain has been reduced due to feedback.

Desensitivity, D = 1 + A β ------------------------ (5)

$$A_f = \frac{A}{1+A\beta} = \frac{A}{D} \quad \text{-------------- (6)}$$

If $|A\beta| >> 1$, then $A_f = \frac{1}{\beta}$ ------------------------(7)

Hence the gain may be made to depend entirely on the feedback network. If the feedback network contains only stable passive elements, it is evident that the overall gain is stabilized.

The same thing can be said about all other type of feedback amplifiers.

3. REDUCTION IN FREQUENCY DISTORTION:

If the feedback network is purely resistive, the overall gain is then not a function of frequency even though the basic amplifier gain is frequency dependent. Under such conditions a substantial reduction in frequency & phase distortion is obtained.

4. NONLINEAR DISTORTION:

Negative feedback tends to reduce the amount of noise and non-linear distortion.

Suppose that a large amplitude signal is applied to an amplifier, so that the operation of the device extends slightly beyond its range of linear operation and as a consequence the output signal is distorted. Negative feedback is now introduced and the input signal is increased by the same amount by which the gain is reduced, so that the output signal amplitude remains the same.

Assume that the second harmonic component, in the absence of feedback is B_2. Because of feedback, a component B_{2f} actually appears in the output. To find the relationship that exists between B_{2f}& B_2, it is noted that the output will contain the term $-A\beta B_{2f}$, which arises from the component $-\beta B_{2f}$ that is feedback to the input. Thus the output contains two terms: B_2, generated in the transistor and $-A\beta B_2 f$, which represents the effect of the feedback.

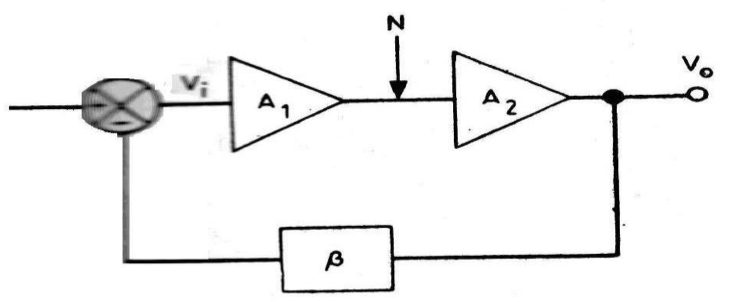
Hence $$B_2 - A\beta B_{2f} = B_{2f}$$

$$B_{2f} = \frac{B_2}{1+\beta A} = \frac{B_2}{D}$$

Thus, it is seen that, the negative feedback tends to reduce the second harmonic distortion by the factor (1+βA).

5. NOISE:

Noise or hum components introduced into an amplifier inside the feedback loop are reduced by the feedback loop. Suppose there are two stages of amplifier with gains A_1 & A_2 and noise or hum pick-up is introduced after the amplifier with gain A_1 as shown in the fig. below



The output voltage can be expressed as

$$V_0 = A_1 A_2 V_S + A_2 N - A_1 A_2 V_f$$

$$= A_1 A_2 V_S + A_2 N - A_1 A_2 \beta V_0$$

Hence $$V_0 = \frac{1}{1 + A_1 A_2 \beta}((A_1 A_2 V_S + A_2 N)$$

Therefore $$V_0 = \frac{A_1 A_2}{1 + A_1 A_2 \beta}\left(V_S + \frac{N}{A_1}\right)$$

The overall gain of the two stage amplifier is reduced by the factor $1 + A_1 A_2 \beta$. In addition the noise output is reduced by the additional factor A_1 which is the gain that precedes the introduction of noise.

In a single stage amplifier, noise will be reduced by the factor 1/(1 + Aβ) just like distortion. But if signal-to-noise ratio has to improve, we have to increase the signal level at the input by the factor $(1 + A\beta)$ to bring back the signal level to the same value as obtained without feedback. If we can assume that noise does not further increase when we increase the signal input, we can conclude that noise is reduced by the factor $1/(1+A\beta)$ due to feedback while the signal level is maintained constant.

1.EFFECT ON BANDWIDTH:

The gain of the amplifier at high frequencies can be represented by the function

$$A = \frac{A_{mid}}{\left(1 + \frac{jf}{f_H}\right)} \quad \text{---} \ (1)$$

Where A_{mid} is the mid and gain without feedback. Gain with feedback is given by

$$A_f = \frac{\frac{A_{mid}}{\left(1 + \frac{jf}{f_H}\right)}}{1 + \beta \frac{A_{mid}}{\left(1 + \frac{jf}{f_H}\right)}} = \frac{A_{mid}}{1 + \beta A_{mid} + \frac{jf}{f_H}} \quad \text{---------------} \ (2)$$

Dividing both numerator and denominator by $(1+\beta A_{mid})$, we get

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

$$= \frac{A_{midf}}{1 + \frac{jf}{f_{Hf}}} \quad \text{------------------------------------} \ (3)$$

Where A_{midf} = mid band gain

$$= \frac{A_{mid}}{1 + \beta A_{mid}} \quad \text{---------------------------------} \ (4)$$

And f_{Hf} = upper 3 dB frequency with feedback

$$= f_H(1+\beta A_{mid}) \quad \text{---------------------------------------} \ (5)$$

By a similar reasoning, we can show that the lower 3 dB frequency with feedback is given by

$$f_{Lf} = \frac{f_L}{1+\beta A_{mid}} \quad \text{---(6)}$$

Thus f_H is multiplied by (1+Aβ) and f_L is divided by (1+Aβ).Hence the bandwidth is improved by the factor (1+Aβ). Therefore negative feedback reduces the gain and increases the bandwidth by the same factor (1+Aβ) resulting in a constant gain-bandwidth product. Thus one can employ negative feedback to trade gain for bandwidth.

2. **INPUT RESISTANCE:**

The introduction of feedback can greatly modify the impedance levels within a circuit. If feedback signal is added to the input in series with the applied voltage (regardless of whether the feedback signal is obtained by sampling output current or voltage) it increases the input resistance. Since the feedback voltage V_f opposes V_S, input current I_i is less than it would have been without feedback.

On the other hand, if the feedback signal is added to the input in shunt with the applied voltage, it decreases the input resistance. Since $I_S = I_i + I_f$, then the current I_i is decreased from what it would be if thare was no feedback current. Hence

$R_{if} = \frac{V_i}{I_S} = \frac{I_i R_i}{I_S}$ is decreased because of feedback.

(A) VOLTAGE SERIES FEEDBACK

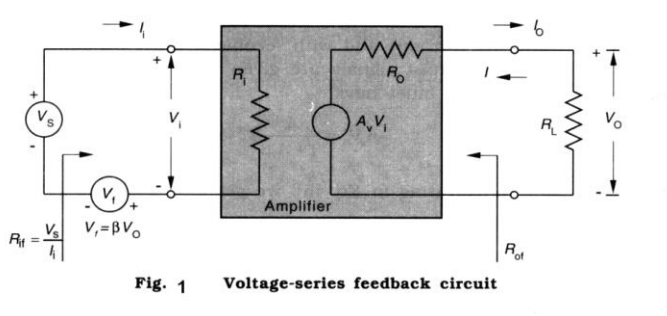


Fig. 1 **Voltage-series feedback circuit**

The topology of voltage series feedback is shown above, with the amplifier replaced by Thevenin's model. Let A_V be the open circuit voltage gain taking R_S into account.

From the above figure, the input resistance with feedback is given as

$$R_{if} = \frac{V_S}{I_i} \quad \text{-- --- (1)}$$

Applying KVL to the input circuit, we get

$$V_S = I_i R_i + V_f$$

Since $V_f = \beta V_0$, $V_S = I_i R_i + \beta V_0$ ---------------------------- (2)

But from the output circuit

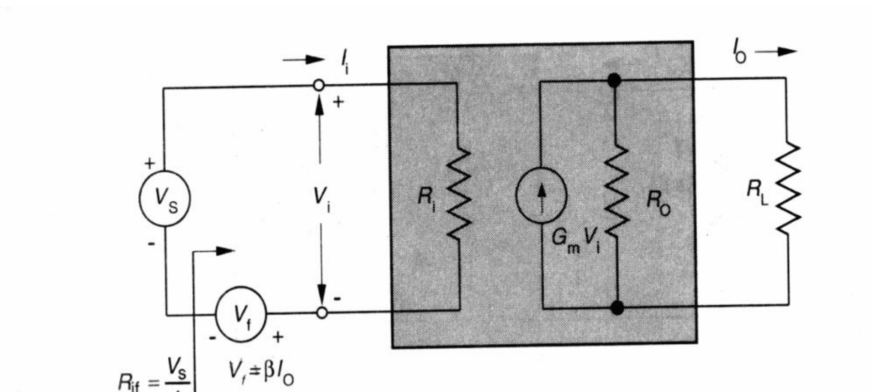


Fig. 2 Current-series feedback circuit

,

$$V_0 = \frac{A_V V_i R_L}{R_0 + R_L} = A_V I_i R_i \quad \text{---------------------------------- -- (3)}$$

$$= A_V V_i$$

Where $A_V = \frac{V_0}{V_i} = \frac{A_V R_L}{R_0 + R_L}$ ---------------------------------- (4)

Where A_V is the voltage gain without feedback taking the load R_L into account.

Input resistance with feedback is

$$R_{if} = \frac{V_S}{I_i} \quad \text{-- ------------(5)}$$

Substituting the value of V_S from equation (2)

$$R_{if} = \frac{I_i R_i + \beta V_O}{I_i}$$

Since $V_O = A_V V_i$

$$R_{if} = \frac{I_i R_i + \beta A_V V_i}{I_i} = R_i + \beta A_V R_i \quad \text{------------------ (6)}$$

Thus the negative feedback increases the R_i by a factor $(1+\beta A_V)$.

(B)CURRENT SERIES FEEDBACK:

The topology for this amplifier is shown above. The input resistance for this circuit is given by

$$R_{if} = \frac{V_S}{I_i} \quad \text{------------------------------------ (1)}$$

Applying KVL to the input circuit

$$V_S = I_i R_i + V_f = I_i R_i + \beta I_0 \quad \text{---------------------- (2)}$$

The output current is given by,

$$I_0 = \frac{G_m V_i R_0}{R_0 + R_L} = G_M V_i \quad \text{--------------------- (3)}$$

Where $G_M = \dfrac{G_m R_0}{R_0 + R_L} = \dfrac{I_0}{V_i}$ --------------------- (4)

Note that G_m is the short transconductance without feedback taking the load R_L into account.

Input resistance with feedback is given by

$$R_{if} = \frac{V_S}{I_i} \quad \text{-------------------------------------} \ (5)$$

Substituting the value of V_S from equation (2), we gat

$$R_{if} = \frac{I_i R_i + \beta I_0}{I_i}$$

Since $I_0 = G_M V_i$

$$R_{if} = \frac{I_i R_i + \beta G_M V_i}{I_i} = R_i + \beta G_M R_i$$

$$R_{if} = R_i(1+\beta G_M) \quad \text{-------------------------------} (6)$$

Hence for series mixing $R_{if} > R_i$

(C) CURRENT SHUNT FEEDBACK:

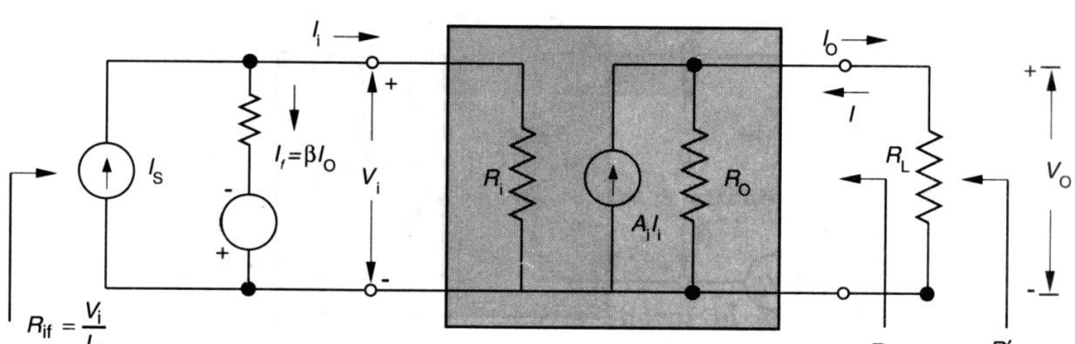


Fig. 3 **Current-shunt feedback circuit**

The topology for this amplifier is shown above. Here the amplifier is replaced by by Norton's model .Let A_i represent the short-circuit current gain taking R_S into account.

Applying KCL to the input node

$$I_S = I_i + I_f = I_i + \beta I_0 \quad \text{---} \ (1)$$

Output voltage, $V_0 = \dfrac{A_i I_i R_0}{R_0 + R_L} = A_I I_i$ ---------------- (2)

Where $A_I = \dfrac{A_i R_0}{R_0 + R_L} = \dfrac{I_0}{I_i}$ ------------------------- (3)

Note that A_I represents the current gain without feedback taking the load R_L into account.

Input resistance with feedback is given by,

$$R_{if} = \frac{V_i}{I_S} \quad \text{-------------------------------------- (4)}$$

Substituting the value of I_S from equation (1)

$$R_{if} = \frac{V_i}{I_i + \beta I_0}$$

Since $I_0 = A_I I_i$ $R_{if} = \dfrac{R_i}{1 + \beta A_I}$ ------------------------ (5)

(D) VOLTAGE- SHUNT FEEDBACK:

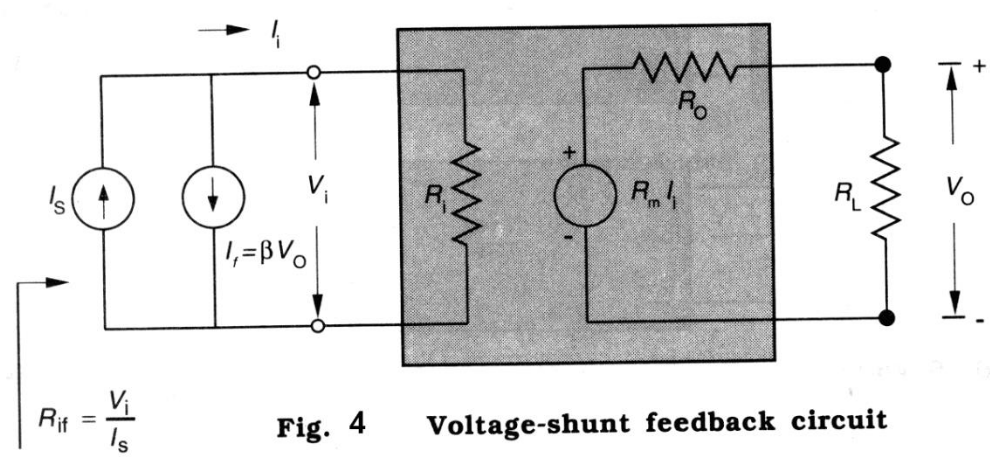


Fig. 4 Voltage-shunt feedback circuit

The topology for this configuration is shown above, in which the amplifier input circuit replaced by Norton's model and output circuit replaced by Thevenin's model. Here R_m is the open circuit transresistance.

Applying KCL to the input node, we get

$I_S = I_i + I_f = I_i + \beta I_0$ -------------------------------- (1)

By voltage divider rule , the output voltage is given by

$$V_0 = \frac{R_m I_i R_0}{R_0 + R_L} \text{ ------------------------------------- (2)}$$

$$= R_M I_i \text{ -- (3)}$$

$$\text{Where } R_M = \frac{R_m R_0}{R_0 + R_L} = \frac{I_0}{I_i} \text{----------- ----------- (4)}$$

is the transresistance without feedback ,taking the load R_L into account.

Input resistance with feedback is given by

$$R_{if} = \frac{V_i}{I_S} \text{ -- (5)}$$

Substituting the value of I_S from equation (1)

$$R_{if} = \frac{V_i}{I_i + \beta I_0} = \frac{V_i}{I_i + \beta R_M I_i}$$

$(I_0 = R_M I_i)$

$$R_{if} = \frac{V_i}{I_i (I + \beta R_M)}$$

$$\text{Thus } R_{if} = \frac{R_i}{1 + \beta R_M} \text{ ---------------------------------- (6)}$$

Thus, it is evident from the above analysis that, for series configuration, the input resistance gets multiplied by (1+ β A), whereas for shunt configurations, the input resistance gets divided by (1+βA).

3. OUTPUT RESISTANCE:

It will be shown that the voltage feedback tends to decrease the output resistance whereas current feedback tends to increase the output resistance.

(A) VOLTAGE-SERIES FEEDBACK:

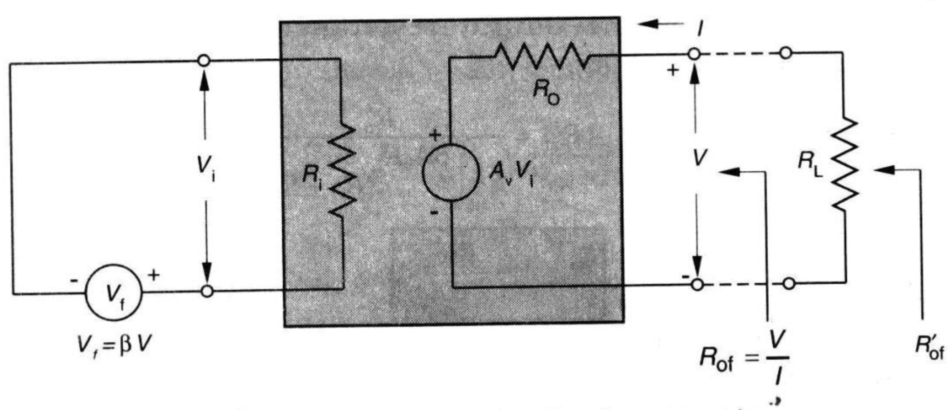


Fig. 5 Voltage-series feedback connection

In this topology, the output resistance can be measured by shorting the input source (i.e $V_S = 0$) and looking into the output terminals with R_L disconnected as shown above.

Applying KVL to the output circuit,

$$A_V V_i + IR_0 - V = 0$$

Or $$I = \frac{V - A_V V_i}{R_0} \text{ -- (1)}$$

Since the input is shorted,

$$V_i = -V_f = -\beta V \text{ -- (2)}$$

Substituting the value of $V_i = \beta V$ in equation (1), we get

$$I = \frac{V - A_V(-\beta V)}{R_0} = \frac{V + \beta A_V V}{R_0} = \frac{V(1+\beta A_V)}{R_0} \text{ ------------------- (3)}$$

The the output resistance with feedback is given by

$$R_{0f} = \frac{V}{I}$$

From equation (3) ,

$$R_{0f} = \frac{R_0}{(1+\beta A_V)} \text{ ------------------------- (4)}$$

Where A_V is the open-circuit voltage gain.

The output resistance with feedback which includes R_L as part of the amplifier is given by,

$$R'_{0f} = R_{0f} \text{ I I } R_L = \frac{R_{of} R_L}{R_{0f} + R_L}$$

Substituting for R_{of} and simplifying we get,

$$R'_{0f} \frac{R'_0}{1+\beta A_V} \text{ ------------------------------ (5)}$$

Where $A_V = \frac{A_V R_L}{R_0 + R_L}$

OUTPUT RESISTANCE WITH FEEDBACK

(B) VOLTAGE SHUNT FEEDBACK:

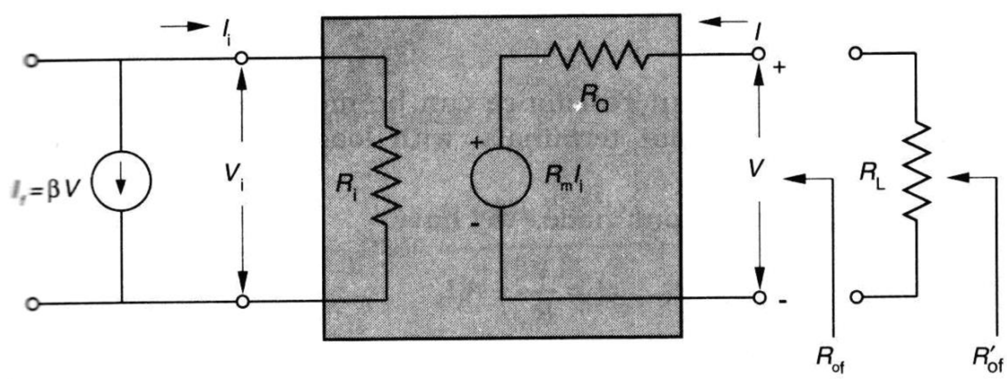


Fig. 1 Voltage-shunt feedback connection

In this topology, the output resistance can be measured by opening the input source (i.e. $I_0 = 0$) and looking into the output terminals with R_L disconnected as shown above.

Applying KVL to the output circuit, we have

$R_m I_i + IR_0 = 0$

$$\therefore I = \frac{V - R_m I_i}{R_0} \quad \text{----------------------------------- (1)}$$

Since the input is shorted

$$Ii = -I_f = -\beta V \quad \text{-------------------------------- (2)}$$

Substituting the value of I_i in equation (1),we get

$$I = \frac{V - R_m(-\beta V)}{R_0} = \frac{V + R_m \beta V}{R_0} = \frac{V(1 + \beta R_m)}{R_0} \quad \text{--------- (3)}$$

The output resistance with feedback is given by

$$R = \frac{V}{I}$$

From equation (3) ,

$$R_{of} = \frac{R_0}{1+\beta R_m} \quad \text{--------------------------- (4)}$$

R_m is the open loop transresistance without taking R_L into account.

The output resistance with feedback which includes R_L as part of the amplifier is given by,

$$R'_{0f} = R_{of} \text{ I I } R_L = \frac{R_{0f} R_L}{R_{0f} + R_L} \quad \text{--------(5)}$$

From equation (4),

$$R'_{0f} = \frac{\left(\frac{R_0}{(1+\beta R_m)}\right)}{\left(\frac{R_0}{(1+\beta R_m)}\right) + R_L} R_L = \frac{R_0 R_L}{R_0 + R_L(1+\beta R_m)}$$

Dividing Numerator and Denominator by (R_0 +R_L), we get

$$R'_{0f} = \frac{\frac{R_0 R_L}{(R_0 + R_L)}}{1+\left(\frac{\beta R_m R_L}{R_0 + R_L}\right)}$$

Since $R'_{of} = R_0$ I I R_L is the output resistance without feedback

$$R'_{0f} = \frac{R'_0}{\left(1+\frac{\beta R_m R_L}{R_0 + R_L}\right)} = \frac{R'_0}{1+\beta R_M} \quad \text{------------------------------ (6)}$$

Where $R_M = \frac{R_m R_L}{R_0 + R_L}$ is the transresistance without feedback taking the load into account.

(C). CURRENT SHUNT FEEDBACK:

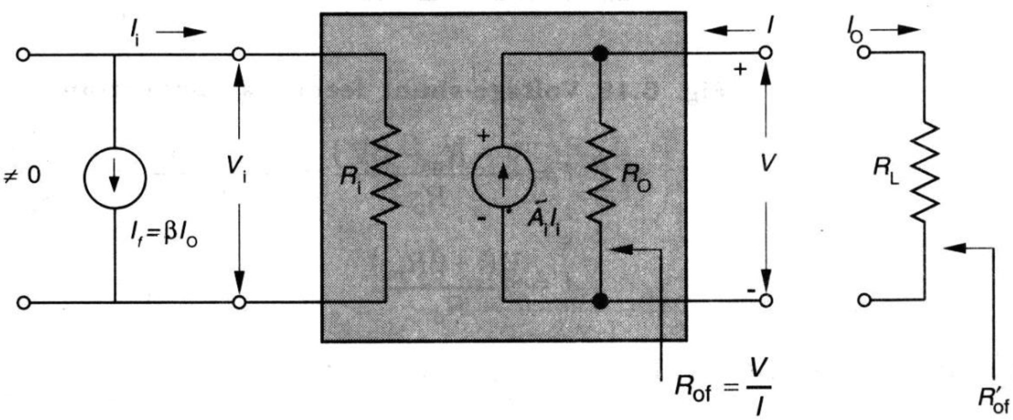


Fig. 2 Current-shunt feedback connection

In this topology, the output resistance can be measured by opening the input source .i.e. $I_S = 0$ and looking into the output terminals, with load R_L disconnected as shown in the above figure.

Applying KCL to the output node,

$I = \frac{V}{R_0} - A_i I_i$ ------------------------------ (1)

The input current is given by

$I_i = -I_f = -\beta I_0 \quad (\because I_S = 0)$

But $I = -I_0$, $I_i = \beta I$ ------------------------(2)

Substituting the value of I_i in equation (1), we get

$I = \frac{V}{R_0} - A_i \beta I$

$$I(1+\beta A_i) = \frac{V}{R_0} \text{ ----------------------------(3)}$$

Output resistance with feedback is given by ,

$$R_{0f} = \frac{V}{I}$$

From equation (3)

$$R_{of} = R_0 \left(1+\beta A\right) \text{ ---------------------------- (4)}$$

A_i is the short circuit gain without taking load R_L into account.

The output resistance accounting for R_L, is given by

$$R'_{of} = R_{0f} \text{ I I } R_L = \frac{R_{of} R_L}{R_{of} + R_L} \text{ -----------(5)}$$

From equation (4),

$$R'_{0f} = \frac{R_0\left(1+\beta A_i\right)R_L}{R_0\left(1+\beta A_i\right)+R_L} = \frac{R_0 R_L (1+\beta A_i)}{R_0 + R_L + \beta A_i R_o}$$

Dividing Numerator and Denominator by (R_0 + R_L) , we get

$$R'_{of} = \frac{\dfrac{\left(1+\beta A_i\right)R_0 R_L}{R_0 + R_L}}{1+\dfrac{\left(\beta A_i R_0\right)}{R_0 + R_L}}$$

Since R'_0 = R_0 I I R_L is the output resistance without feedback.

$$R'_{of} = \frac{R'_0 (1+\beta A_i)}{1+\left(\dfrac{\beta A_i R_0}{R_0 + R_L}\right)}$$

$= \dfrac{R'_0(1+\beta A_i)}{1+\beta A_I}$ ---------------------------------(6)

Where $A_I = \dfrac{A_i R_0}{R_0 + R_L}$ is the current gain without feedback taking the load R_L into account.

(D) CURRENT SERIES FEEDBACK:

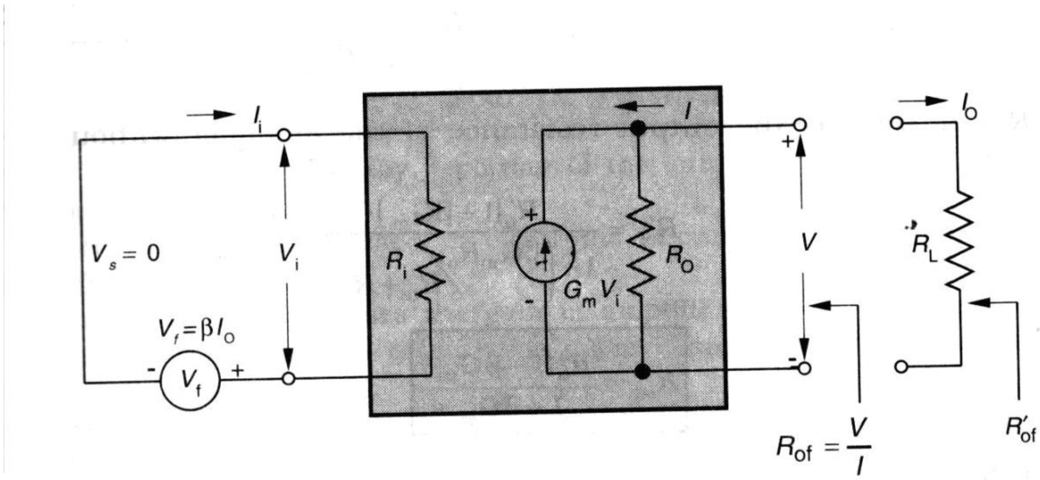


Fig. 3 Current-series feedback connection

In this topology, the output resistance can be measured by shorting the input source (i.e V_S = 0) and looking into the output terminals with R_L disconnected. As shown above.

Applying KCL to the output node

$I = \dfrac{V}{R_0} - G_m V_i$ -------------------------- (1)

The input voltage is given by

$V_i = -V_f = -\beta I_0$

Since $I = -I_0, V_i = \beta I$ ------------------------------ (2)

Substituting the value of V_i from equation (2) in equation (1), we get

$$I = \frac{V}{R_0} - G_m \beta I$$

or $I(1+G_m \beta) = \frac{V}{R_0}$ ------------------(3)

The output resistance with feedback given by

$$R_{0f} = \frac{V}{I}$$

From equation (3), $R_{of} = R_o(1+ \beta G_m)$ -----------------------(4)

Where G_m is the short circuit transconductance without taking R_L into account.

The output resistance R'_{of} which includes R_L as part of the amplifier is given by

$$R'_{of} = R_{of} \parallel R_L = \frac{R_{0f} R_L}{R_{0f} + R_L}$$ ---------------------(5)

From equation (4)

$$R'_{0f} = \frac{R_0(1+\beta G_m)R_L}{R_0(1+\beta G_m) + R_L}$$

$$= \frac{(1+\beta G_m)R_0 R_L}{R_0 + R_L + \beta G_m R_0}$$

Dividing numerator and denominator by $(R_0 + R_L)$, we get

$$R'_{0f} = \frac{\frac{(1+\beta G_m)R_0 R_L}{(R_0+R_L)}}{1+\frac{\beta G_m R_0}{R_0+R_L}}$$

Since $R'_{0f} = R_0 \, I \, I \, R_L$ is the output resistance of the amplifier without feedback

$$R'_{0f} = \frac{R_0^{'}(1+\beta G_m)}{1+\frac{\beta G_m R_0}{R_0+R_L}}$$

$$= \frac{R'_0(1+\beta G_m)}{1+\beta G_M} \quad \text{--} \quad (6)$$

Where $G_M = \frac{G_m R_0}{R_0+R_L}$ is the transconductance without feedback taking the load R_L into account.

PROBLEMS

P1. An amplifier has an open loop gain of 500 and a feedback of 0.1.If open loop gain changes by 20% due to change in the temperature, find the %change in the closed loop gain .

SOLN: Given A = 500, β= 0.1 & $\frac{dA}{A} = 20$

Change in closed loop gain $\frac{dA_f}{A_f} = \frac{dA}{A}\frac{1}{(1+\beta A)}$

$$= 20 \text{ X } \frac{1}{1+500X0.1} = 0.3921 \text{ or } 39.21\%$$

P2. An amplifier has a voltage gain of 200.The gain is reduced to 50, when negative feedback is applied. Determine the reverse transmission factor and express the amount of feedback in dB.

SOLN: Given A = 200, $A_f = 50$

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

i.e. $50 = \frac{200}{1+\beta(200)}$

$\therefore \beta = 0.015$

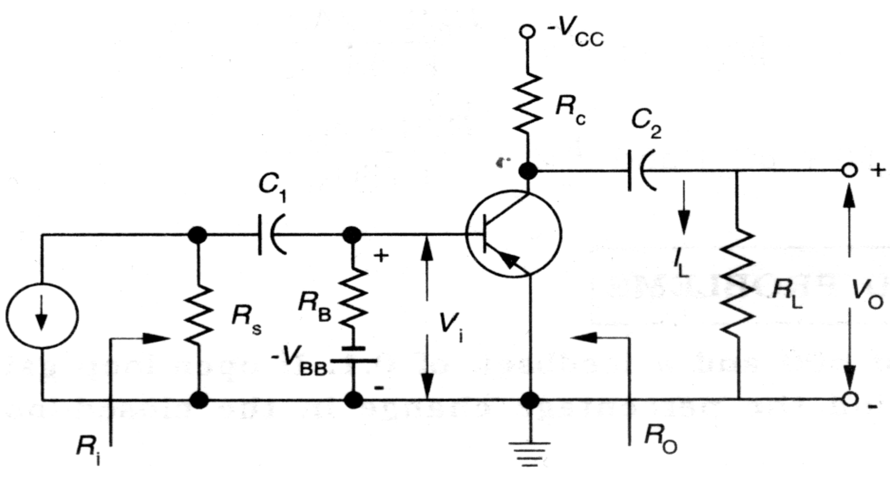
Feedback factor in dB

$N = 20 \log_{10} \frac{A_f}{A} = 20 \log_{10} \left(\frac{1}{1+\beta A}\right)$

$= 20 \log_{10} \left(\frac{1}{1+200 X 0.015}\right)$

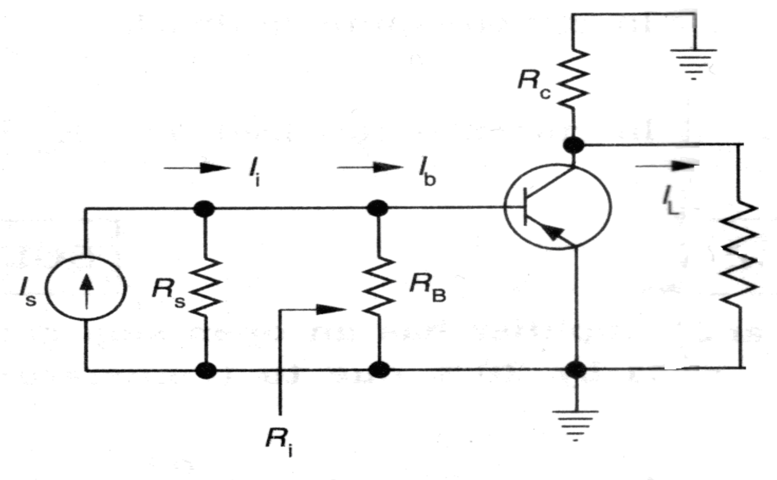
$= -12.042$ dB.

P3.



For the circuit shown above with R_C = 4KΩ, R_L = 4KΩ, R_B = 20KΩ, R_S = 1KΩ and the transistor parameters are h_{ie} = 1.1 KΩ, h_{fe} = 50, h_{re} = 2.5 X 10^{-4} and h_{oe} = 24 µS. Find the (a) current gain (b) voltage gain (c) transconductance (d) transresistance. (e) the input resistance seen by the source and (f) the output resistance seen by the load. Neglect all capacitive effects.

SOLN: The ac equivalent circuit is shown below.



RL

(a) From the above circuit,

$$\text{Current gain } A_i = \frac{I_L}{I_S} = \frac{I_i}{I_S} \cdot \frac{I_b}{I_i} \cdot \frac{I_L}{I_b}$$

$$\text{Where } \frac{I_i}{I_S} = \frac{R_S}{R_S + R_i}$$

And input resistance

$R_i = R_b$ I I h_{ie} = 20K I I 1.1 K

$$= \frac{20X1.1}{20+1.1} = 1.04\ \text{K}\Omega$$

Then $\frac{I_i}{I_S} = \frac{1K}{1K + 1.04K} = \frac{1}{2.04}$

$\frac{I_b}{I_i} = \frac{R_B}{R_B + h_{ie}} = 0.95$

$\frac{I_L}{I_b} = -h_{fe}\frac{R_C}{R_C + R_L} = -50 \text{ X } \frac{4}{4+4} = -25$

$A_i = \frac{I_L}{I_S} = \frac{1}{2.04} X(0.95) X(-25) = -11.65$

(b)Voltage gain, $A_V = \frac{V_0}{V_S} = \frac{I_L R_L}{I_S R_S} = A_i \frac{R_L}{R_S} = (-11.65)\frac{4K}{1K} = -46.6$

(c) Transconductance:

$G_m = \frac{I_L}{V_S} = \frac{V_0}{R_L}.\frac{1}{V_S} = \frac{V_0}{V_S} X \frac{1}{R_L}$

$= A_V \text{ X } \frac{1}{R_S} = (-46.6) X \frac{1}{4K}$

= -11.65 mA/V

(.d) Transresistance:

$R_m = \frac{V_0}{I_S} = \frac{R_S}{V_S}.V_0 = R_S.\frac{V_0}{V_S}$

= 1K X (-46.6) = -46.6KΩ

(e).Input resistance:

$R_i = R_B \text{ I I } h_{ie}$ = 20K I I 1.4K = 1.04KΩ

(f) Output resistance:

$$R_0 = R_C \; II \; \frac{1}{h_{0e}} = 4K \; II \; 40K = 3.64 \; K\Omega$$

P4. An amplifier with open loop voltage gain, $A_V = 1000 \pm 100$ is available .It is necessary to have an amplifier where voltage gain varies by no more than $\pm 0.1\%$.

Find the (a) feedback ratio and (b) the gain with feedback.

SOLN: Given $A_V = 1000 \pm 100$, $\frac{dA_f}{A_f} = 0.1\%$

(a) $\frac{dA_f}{A_f} = \frac{1}{(1+\beta A)} \frac{dA}{A}$

Substituting the values

$$\frac{0.1}{100} = \frac{1}{(1+\beta A)} X \frac{100}{1000} = \frac{1}{1+\beta A} X \frac{1}{10}$$

$$\therefore 1+\beta A = 100 \quad \text{and} \quad \beta = \frac{99}{1000} = 0.099$$

(b) Voltage gain with feedback

$$A_f = \frac{A}{1+\beta A} = \frac{1000}{1+0.099X1000} = 10$$

P5. An amplifier without feedback gives a fundamental output of 36 V with 7% second harmonic distortion when the input is 0.028 V.

9. If 1.2% of the output is fedback to the input in a negative series feedback circuit , what is the output voltage?

10. If the fundamental output is maintained at 36 V but the second harmonic distortion is reduced to 1%, what is the input voltage?

SOLN: Given V_0 = 36V, V_i = 0.028V

V_f = 1.2% , $\frac{D}{D_{0f}} = 7$

(a) Voltage gain, A = $\frac{V_0}{V_i} = \frac{36}{0.028} = 1285$

Feedback ratio, β = $\frac{V_f}{V_0} = \frac{1.2}{100} = 0.012$

A_f = $\frac{A}{1+\beta A} = \frac{1285}{1+0.012X1285} = 78.2$

Output voltage, V_{0f} = $A_f V_S$ = 78.2 X 0.028 = 2.19V

(b)If the output is maintained constant at 36 V, then the distortion generated by

The device is unchanged. The reduction in the total distortion is due to feedback.

D_{0f} = $\frac{D}{1+\beta A}$

$$\therefore 1+\beta A = \frac{D}{D_{0f}} = 7$$

$$\beta A = 6$$

A_f = $\frac{A}{1+\beta A} = \frac{1285}{7}$

$$V_S = \frac{V_0}{V_f} = \frac{36}{\frac{1285}{7}} = 0.196 \text{ V}$$

P.6 The output resistance of a voltage series feedback amplifier is 10 Ω.If the gain of the basic amplifier is 100 and the feedback fraction is 0.01, what is the output resistance of the amplifier with out feedback ?.

SOLN: Given R_{0f} = 10ΩA = 100, β = 0.01.

$$R_{0f} = \frac{R_0}{1+\beta A}$$

With out feedback, $R_0 = R_{0f}$ (1+βA) = 10 (1+0.01 X 100) = 20 Ω.

P7. The input and output voltages of an amplifier are 1mV& 1V respectively. If the gain with negative feedback is 100 and input resistance without feedback (Voltage series feedback) is 2 KΩ.Find the feedback fraction and input resistance with feedback.

SOLN: Given V_S = 1mV, V_0=1V, A_f = 100, R_i = 2KΩ.

Open circuit voltage gain, $A = \frac{V_0}{V_S} = \frac{1V}{1mV} = 1000$

Gain with feedback, $A_f = \frac{A}{1+\beta A}$

$$(1+\beta A) = \frac{A}{A_f} = \frac{1000}{100} = 10$$

$\beta = 0.009$

Input resistance with feedback, $R_{if} = R_i(1+\beta A)$

$= 2K\Omega \times 10 = 20\Omega$

P8. If an amplifier has a bandwidth of 200 KHz and voltage gain of 80.What will be the new bandwidth and gain if 5% negative feedback is introduced ?.

SOLN: Given BW = 200 KHz, A = 80, β = 5% = 0.05.

$$A_f = \frac{A}{1+\beta A} = \frac{80}{1+0.05X80} = 16$$

$$BW_f = (1+\beta A)\, BW = (1+80X0.05)200 \times 10^3 = 1MHz.$$

P9. An amplifier has a normal gain of 1000 and harmonic distortion of 10%. If 1% inverse feedback is applied, find the gain with feedback and the distortion in the presence of feedback.

SOLN: Feedback factor, $\beta = \frac{1}{100} = 0.01$

Gain with feedback, $A_f = \frac{A}{1+\beta A} = \frac{1000}{1+1000X0.01} = 90.9$

Distortion with feedback, $D_f = \frac{D}{1+\beta A}$

$$= \frac{10}{1+0.01X1000} = 0.909\%$$

P10. An amplifier gain changes by $\pm 10\%$.Using negative feedback, the amplifier is to be modified to yield a gain of 100 with $\pm 0.1\%$ variation. Find the required open loop gain of the amplifier and the amount of negative feedback.

SOLN: We have $\frac{dA_f}{A_f} = \frac{dA}{A} X \frac{1}{(1+\beta A)}$

Improvement in gain stability = 1+βA = $\frac{\frac{dA}{A}}{\frac{dA_f}{A_f}} = \frac{10\%}{0.1\%} = 100$

Hence, Open loop gain = (Closed loop gain)(1+βA)

= (100)100 = 10^4

Amount of negative feedback required $\beta = \frac{A\beta}{A} = \frac{(100-1)}{10^4} = 0.0099.$

P11. An amplifier with an open loop voltage gain of 2000 delivers 20 W of power at 10% second harmonic distortion when input signal is 10 mV. If 40 dB negative voltage series feedback is applied and the out power is to remain at 10W, determine the (a) required input signal (b) percentage harmonic distortion.

SOLN: (a) -40 $dB = 20\log_{10}\frac{1}{|1+\beta A|}$

= -20$\log_{10}|1+\beta A|$

$|1+\beta A| = 100$

$$|A_f| = \frac{|A|}{|1+\beta A|} = \frac{200}{100} = 20$$

When the amplifier delivers 20W, it's output voltage is'

V_0 = A X V_S = 2000 X (10 X 10^{-3}) = 20 W.

If the output power is to remain at 10W, then the output voltage also must remain at 10W. Hence the input signal required when feedback is applied will be'

$$V_S = \frac{V_0}{A_f} = \frac{20}{20} = 1V$$

(b)The distortion of the amplifier with feedback will be reduced by the factor $(1+\beta A)$.

$$D_f = \frac{10\%}{100} = 0.1\%$$