1

Feedback Amplifiers

1.1 INTRODUCTION

An amplifier is a device that increases the magnitude of a signal for use by a load. Amplifiers are complicated arrangements of transistors, resistors and other component. A practical amplifier has a gain of nearly one million i.e. its output is one million times the input.

Ideally an amplifier should reproduce the input signal, with change in magnitude and with or without change in phase.

Drawbacks of amplifier circuits

1. Change in the value of the gain due to variation in supplying voltage, temperature or due to components.
2. Distortion in wave-form due to non-linearities in the operating characteristics of the amplifying device.
3. The amplifier may introduce noise (undesired signals).

The above drawbacks can be minimizing if we introduce feedback.

1.2 FEEDBACK CONCEPT

The process of injecting a fraction of output energy of some device back to the input is known as feedback.

Part of output signal is sampled and feedback one of the input to amplifier is called as *feedback amplifier*. It is very useful in reducing noise in amplifiers and making amplifier operation stable.

1.2.1 Types of Feedback

Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers.

1) Positive feedback and 2) Negative feedback

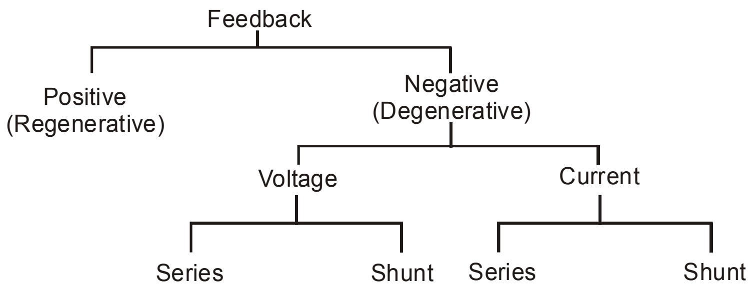


Figure 1.1: Feedback Classification

i) Positive feedback

When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called *positive feedback.*

Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around theloop, causing the feedback voltage V_f to be in phase with the input signal V_{in}.

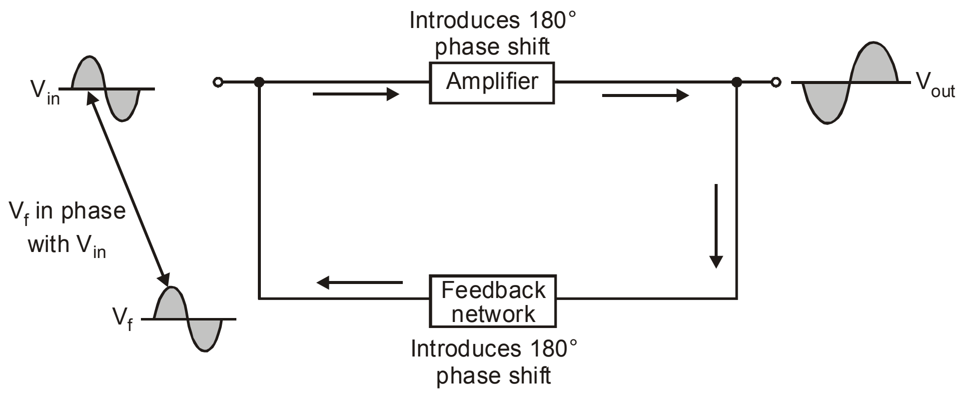


Figure 1.2: Positive Feedback

ii) Negative feedback

When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*.

Amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (i.e., 0° phase shift). The result is that the feedback voltageV_f is 180° out of phase with the input signal V_{in}.

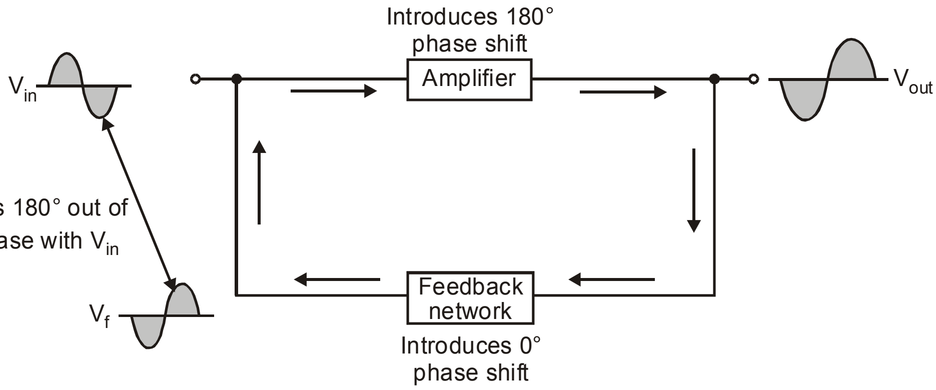


Figure 1.3: Negative Feedback

*Negative feedback is also called as **degenerative feedback**. Because in negative feedback, the feedback signal opposes the input signal. So it is called as **degenerative feedback.***

Table 1.1: Positive and Negative feedback comparison

S.No.	*Parameters*	*Positive Feedback*	*Negative Feedback*
1.	Phase shift between input signal and feedback signal	0 or 360°	180°
2.	Phase structure	In-phase	Out-phase
3.	Input Voltage	Increases	Decreases
4.	Output Voltage	Increases	Decreases
5.	Voltage Gain	Increases	Decreases
6.	Stability	Decreases	Increases
7.	Distortion	Increases	Decreases
8.	Bandwidth	Decreases	Increases
9.	Application	Important use of positive feedback is oscillators. If positive feedback is sufficiently large, it leads to oscillations.	Used in amplifiers

1.3 CLASSIFICATION OF AMPLIFIER

Amplifier can be classified as,

1. Voltage amplifier
2. Current amplifier
3. Transconductance amplifier
4. Transresistance amplifier

1.3.1 Voltage Amplifier

Figure 1.4 shows Thevenin's equivalent circuit of a two-port network, which represents amplifier. Suppose $R_i >> R_s$, drop across R_s is very small. Then $V_i = V_s$.

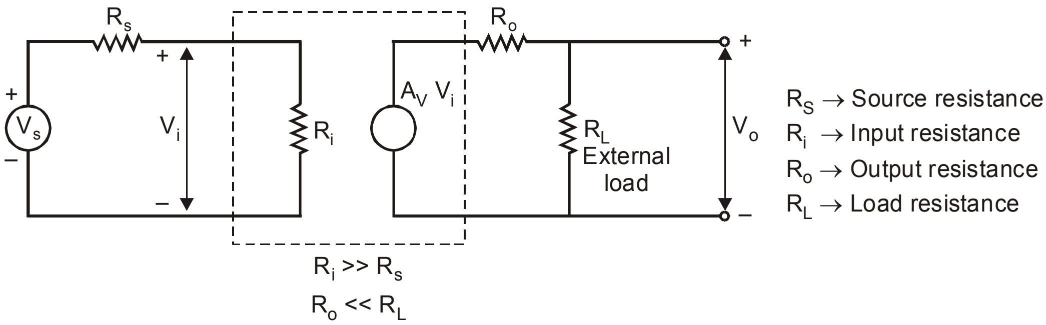


Figure 1.4: Thevenin's Equivalent circuits for voltage Amplifier

Similarly, If $R_L >> R_O$; then $V_o = A_v \times V_i$

But, $V_i \approx V_s$

So, $V_o \approx A_v V_s$

Therefore output voltage is proportional to input. Voltage the constant of proportionally A_v does not depend on the impedence (source or load). Such a circuit is *voltage amplifier.*

For ideal voltage amplifier,

$$R_i = \infty,\ R_o = 0\ ,\ A_V = \frac{V_o}{V_i}\ \text{and}\ R_L = \infty$$

where,

$A_V \rightarrow$ Open circuit voltage gain

For ideal voltage amplifier, output voltage is proportional to input voltage and constant of proportionality is independent of R_S or R_L.

1.3.2 Current Amplifier

An ideal current amplifier is one which gives output current proportional to input current and the proportionality factor is independent of R_S and R_L.

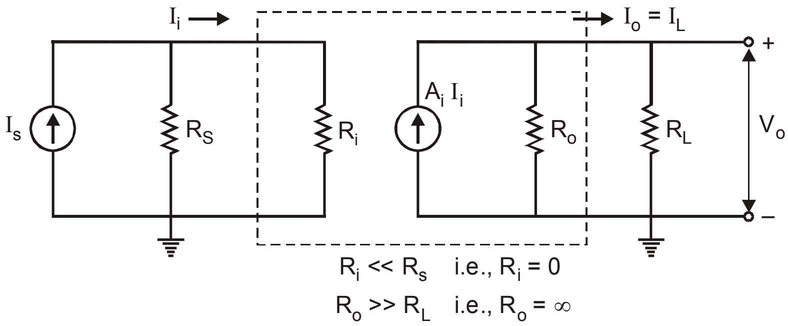


Figure 1.5: Norton equivalent circuits of a current amplifier

For ideal current amplifier $R_i = 0$ and $R_0 = \infty$.

If $\quad R_i = 0,\ I_s \approx I_i$

$\therefore\ R_0 = \infty$

$$I_L = I_0 = A_i\, I_i = A_i I_S$$

$$A_I = \frac{I_L}{I_i} \text{ with } R_L = 0$$

where, A_I – short circuit current amplification

1.3.3 Transconductance Amplifier

An ideal transconductance amplifier supplies output current which is proportional to input voltage independently of magnitude of R_S and R_L..

Figure 1.6 shows transconductance amplifier with the various equivalant in input circuit and Norton's equivalant in its output circuit.

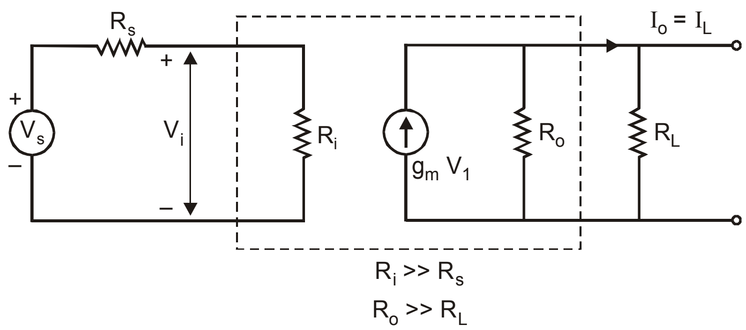


Figure 1.6: Equivalent circuit of transconductance amplifier

Ideal transconductance amplifier will have

$$R_i = \infty \text{ and } R_0 = \infty.$$

Practical transconductance amplifier must have

$$R_i >> R_S \text{ and } R_0 >> R_L$$

Since $R_i >> R_S$, $V_i \approx V_S$

$R_0 >> R_L$, $I_L = G_m V_i$

$$\therefore \; I_L = G_m V_S$$

where,

$$G_m = \frac{I_L}{V_S} \rightarrow \text{Transfer (or) Mutual conductance}$$

1.3.4 Transresistance Amplifier

It gives output voltage V_0 proportional to I_S independent of R_S and R_L.

Figure 1.7 shows transresistance amplifier with Norton's equivalant in its input and thevenin's equivalant in its output circuit.

For ideal amplifier,

$$R_i = 0 \; ; R_o = 0$$

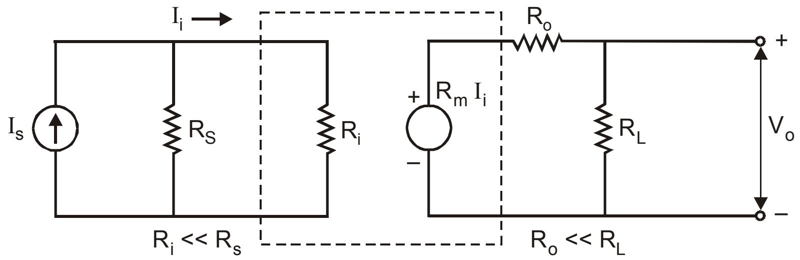


Figure 1.7: Transresistance Amplifier

For practical transresistance amplifier

$$R_i << R_S \quad \text{and} \quad R_o << R_L$$

Since $R_i << R_S$; $I_i = I_S$

$R_o << R_L$; $V_o = R_m I_i$

$$V_o = R_m I_s$$

where $R_m = \frac{V_o}{I_s}$ is transfer (or) mutual resistance.

Table 1.2: Ideal Amplifier Characteristics

Parameter	***Amplifier Type***			
	Voltage	***Current***	***Tranconductance***	***Transresistance***
R_i	∞	0	∞	0
R_0	0	∞	∞	0
Transfer	$A_V = \frac{V_o}{V_s}$	$A_i = \frac{I_L}{I_s}$	$G_m = \frac{I_L}{V_S}$	$R_m = \frac{V_o}{I_S}$

1.4 FEEDBACK BLOCK DIAGRAM

As of now we studied about four types of amplifier with their characteristics. In each circuit, we have sampling network which samples the output voltage or current and this signal is applied to the input through a feedback two port network. The block diagram representation is as shown in Figure 1.8.

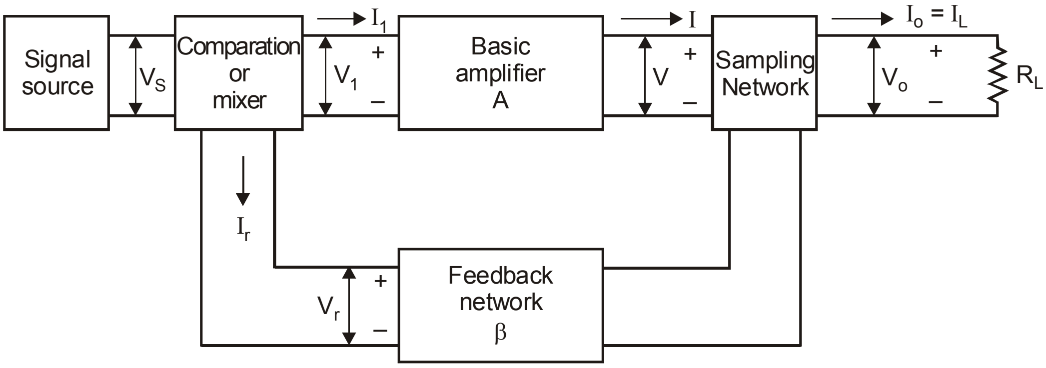


Figure 1.8: Feedback block diagram

Feedback network consists of following:

1. Signal source
2. Sampling network
3. Feedback network
4. Mixer network.

1. Signal Source

It can be a voltage source V_s or a current source I_s.

2. Feedback Network

It is a passive two port network. It may contain *resistors, capacitors or inductors*. But usually a resistance is used as the *feedback element*. Here the output current is *sampled and feedback.*

It takes a part of output as feedback signal to input mixer network.

$$V_f = \beta V_{out}.$$

Where $\beta \rightarrow$ Reverse Transmission Factor or Feedback factor or Feedback Ratio. $0 < \beta < 1$

3. Sampling network

There are two types to sample the output.

a) Voltage or Node sampling.

b) Current or Loop sampling.

A voltage feedback is distinguished in this way from current feedback.

Output voltage is sampled by connecting the feedback network in shunt across the output. In this case, it is desirable that input impedance of the feedback network should be much greater than R_L so as not to load the output of amplifier. *For voltage feedback, the feedback element (resistor) will be in parallel with the output.*

Output current is sampled by connecting the feedback network in series with output. In this case, it is desirable that input impedance of the feedback network should be much smaller than RL in order not to reduce the current gain(without feedback). *For current feedback the element will be in series.*

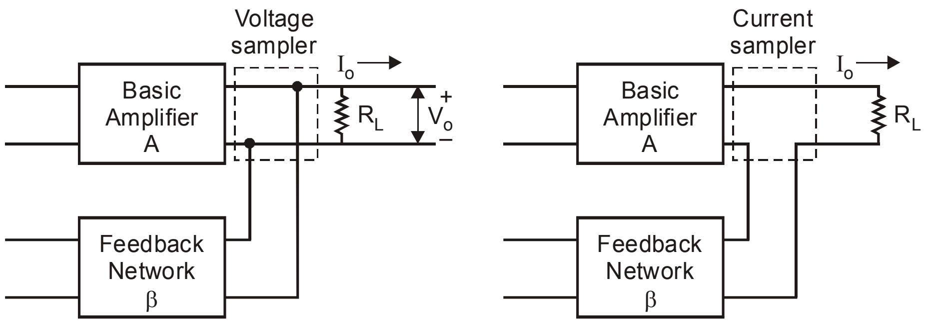


Figure 1.9: Output feedback connection, sampling output a) Voltage b) Current

4. Comparator or Mixer Network

There are two types of mixing network like sampling.

1) Series Input connection.

2) Shunt Input connection.

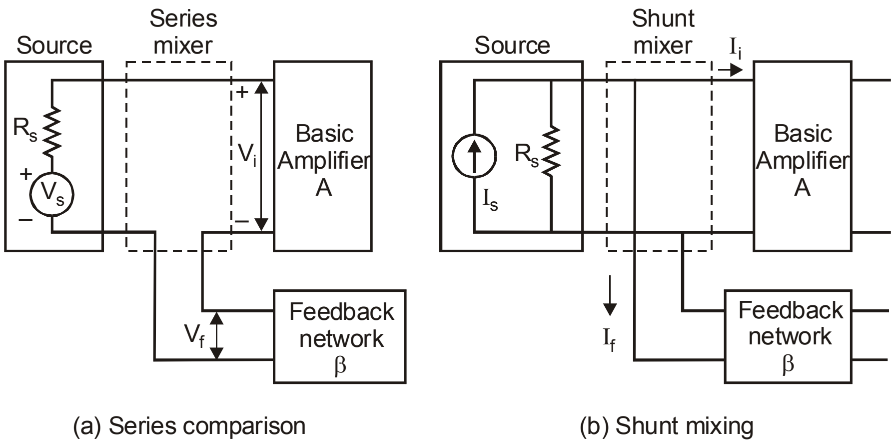


Figure 1.10: Input feedback connection a) series comparison b) Shunt mixing

1.4.1 Transfer Gain

The symbol A in Figure 1.10 represents *ratio of output signal to input signal of basic amplifier*

For an Ideal Amplifier,

Voltage Gain $= A_V = \dfrac{V}{V_i}$

Current Gain $= A_i = \dfrac{I}{I_i}$

Transconductance $= G_m = \dfrac{I}{V_i}$

Trans resistance $= R_m = \dfrac{V}{I_i}$

The above four quantities A_v, A_i, G_m, R_m are called as *transfer gain of basic amplifier.*

1.4.2 Transfer gain with feedback

The symbol A_f is defined as *ratio of output signal to input signal of Amplifier Configuration.*

Hence A_f is used to reperesent any one of four ratios

$$\text{Voltage gain with feedback} = A_{vf} = \frac{V_o}{V_S}$$

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

$$\text{Transconductance with feedback} = G_{mf} = \frac{I_o}{V_S}$$

$$\text{Transresistance with feedback} = R_{mf} = \frac{V_o}{I_S}$$

1.5 ANALYSIS OF IDEAL FEEDBACK AMPLIFIER

Figure 1.11 shows Ideal feedback Amplifier. The basic amplifier of Figure 1.11 may be Ideal Voltage transconducatance, current or transresistance amplifier connected in feedback configuration.

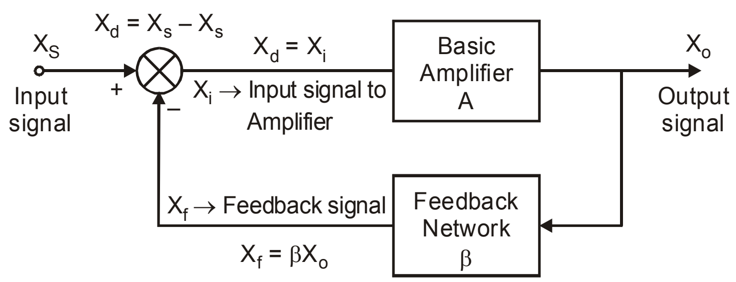


Figure 1.11: Ideal Single - loop Feedback Amplifier

Mixing network whose output is sum of inputs, taking the sign shown at each input, then

$$X_d = X_S - X_f \Rightarrow X_S = X_d + X_f \quad \text{... (1.1)}$$

Where $X_d \rightarrow$ Difference Signal

Difference Signal or error signal represents the difference between applied signal and that of feedback to input

$$X_d = X_i \quad \text{... (1.2)}$$

Reverse Transmission Factor

The Reverse transmission or feedback factor β of feedback network is defined by

$$\beta = \frac{X_o}{X_f} \qquad \text{... (1.3)}$$

$$X_f = \beta X_o$$

Factor β is + or – Real Number

Output signal

For Ideal Amplifier Output Signal is proportional to input and that this proportionality factor A is independent of magnitude of source and load impedences. Then

$$X_o = AX_i \Rightarrow AX_d$$

Then $$A = \frac{X_o}{X_d} \qquad \text{... (1.4)}$$

We know that gain with feedback is expressed as follows

$$A_f = \frac{V_o}{V_S} = \frac{X_o}{X_S} \qquad \text{... (1.5)}$$

Sub equation (1.1) in equation (1.5), So

$$A_f = \frac{X_o}{X_d + X_f} = \frac{X_o}{X_d + \beta X_o} \quad \text{(from equation 1.3)}$$

Divide numerator and Denominator by X_o

$$= \frac{X_o / X_o}{(X_d / X_o) + (\beta X_o / X_o)} = \frac{1}{X_d / X_o + \beta}$$

$$\text{Since } A = \frac{X_o}{X_d}\ ;\ \text{Then } \frac{1}{A} = \frac{X_d}{X_o}$$

So $$A_f = \frac{1}{(1/A) + \beta} = \frac{A}{1+\beta A} \qquad \text{... (1.6)}$$

If $|A_f| <$ A ; The feedback is Negative of Degenerative.

If $|A_f| <$ A ; The feedback is Positive of Regenerative.

From equation (1.6) we come to know that gain of basic amplifier with feedback is divided by the factor $|1+\beta A|$ which exceeds unity.

1.5.1 Loop Gain

The signal X_d is multiplied by A in passing through the amplifier, is multiplied by β in transmission through the feedback network and it is multiplied by -1 in the mixing or differenicng network. A path takes from Input terminals around the loop consisting of the amplifier and feedback network back to input forms a loop. The product - $A\beta$ is loop gain (-1) is due to phase shift of 180°C between input and output in CE amplifier. Since sin(180°) = -1

Return Difference D = 1 – Loop gain negative is because it is the difference

$$= 1 - (-\beta A)$$

$$D = 1 + \beta A$$

Amount of feedback introduced into an Amplifier is expressed in decibels by

$$N = \text{dB of feedback} = 20 \log \left| \frac{A_f}{A} \right| = 20 \log \left| \frac{1}{1+A\beta} \right| \quad ...(1.7)$$

If negative feedback is under consideration, N will be negative number.

1.5.2 Advantages of Negative Feedback Amplifier

1) Input impedance can be increased.
2) Output impedance can be decreased.
3) Transfer gain A_f can be stabilized against variations in It-parameter of the transistor with temperature etc. i.e. stability is improved.
4) Bandwidth is increased.
5) Linearity of operation is improved.
6) Distortiion is reduced.
7) Noise reduces.

1.6 CLASSIFICATION OF FEEDBACK AMPLIFIERS

Feedback amplifiers are classified as follows

1) Voltage series feedback. 2) Voltage shunt feedback.
3) Current series feedback. 4) Current shunt feedback.

- If the feedback signal is proportional to voltage, it is *Voltage Feedback.*
- If the feedback signal is proportional to current, it is *Current Feedback.*

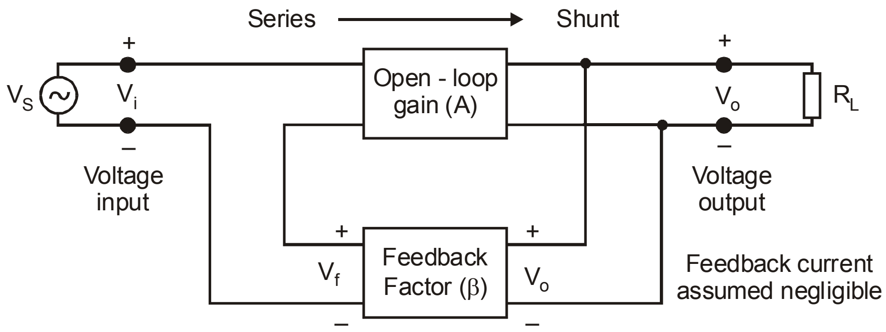


Figure 1.12: Voltage series feedback

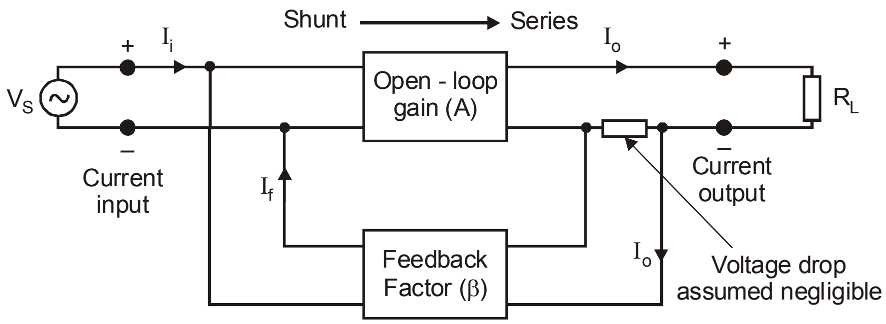


Figure 1.13: Current shunt Feedback

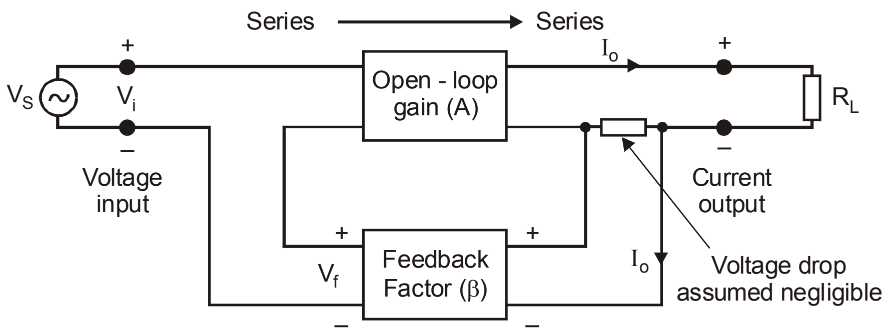


Figure 1.14: Current series feedback.

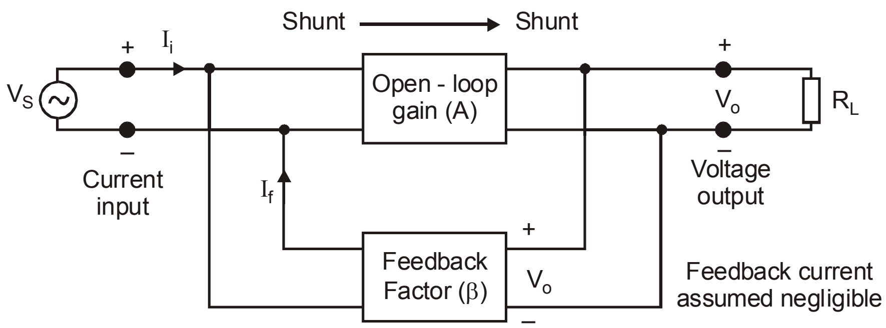


Figure 1.15: Voltage shunt feedback

1.7 PROPERTIES FO NEGATIVE FEEDBACK

1.7.1 Desensitivity of Transfer Amplification

The variation due to aging, temperature, replacement of cirucuit components and transistor is reflected in corresponding lack of stability of Amplifier transfer gain in amplification is related Fractional Change to fractional change wihout feedback is given by $\frac{dA_f}{A_f}$ ... (1.8)

Differntiating equation with respect to A, we get

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

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

Dividing both sides by A_f, we get

$$\frac{dA_f}{A_f} = \frac{dA}{(1+\beta A)^2} \times \frac{1}{A_f} \qquad \text{... (1.9)}$$

Since $A_f = \frac{A}{1+\beta A}$ (From equation 1.6)

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

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

$\left|\frac{dA_f}{A_f}\right|$ = Fractional change in amplification with feedback

$\left|\frac{dA}{A}\right|$ = Fractional change in amplification without feedback

$\frac{1}{|(1+\beta A)|}$ = Sensitivity ... (1.10)

If the feedback is –ve , so that $|(1 + \beta A)| > 1$, the feedback will have served to improve the gain stability of the amplifier.

For example, For an amplifier with 20 db of –ve feedback sensitivity is 0.1 and a 1% change in the gain wihtout feedback is reduced to 0.1% change after feedback is introduced.

The Reciprocal of sensitivity is called Desensitivity (D)

Then $D = 1 + \beta A$ ... (1.11)

Therefore, stability of Amplifier increases with increase in densitivity

In particular,

If $|\beta A| \gg 1$ Then,

$$A_f = \frac{A}{1+\beta A} \approx \frac{A}{\beta A} = \frac{1}{\beta} \quad \text{... (1.12)}$$

and the gain may be made to depend entirely on feedback network.

Since a represents either A_v, G_m, A_I or R_m then A_f represents corresponding transfer gains with feedback either A_{vf}, G_{mf}, A_{If} or R_{mf}.

For voltage series feedback $A_{vf} = \frac{1}{\beta}$ Voltage gain is stabilized.

For Current series feedback $G_{mf} = \frac{1}{\beta}$ Transconductance gain is stabilized.

For voltage shunt feedback $R_{mf.} = \frac{1}{\beta}$ Transresistance gain is stabilized.

For Current shunt feedback $A_{vf} = \frac{1}{\beta}$ Current gain is stabilized.

1.7.2 Reduction in Gain

For positive Feedback	*For Negative feedback*
β is positive	β is negative
Gain with feedback $A_f = \frac{A}{1-\beta A}$	Gain with feedback $A_f = \frac{A}{1-(-\beta A)} = \frac{A}{1+\beta A}$
Here Denominator is < 1 $A_f > A$	Here Denominatr is > 1 $A_f < A$
Gain of positive feedback is infinite. *Thus the +ve feedback amplifier is act as oscillator.*	There is reduction in gain

1.7.3 Increase in Bandwidth

If f_H is upper cut off frequency

f_L is Lower cut off frequency

f is any frequency

$$BW_f = f_{Hf} - f_{Lf}$$

Expression for A_v(Voltage gain at any frequency) is

$$A = \frac{A(\text{mid})}{1 + j\frac{f}{f_H}} \quad \text{where A (mid)} \Rightarrow \text{mid frequency gain} \qquad \text{... (1.13)}$$

$$A = \frac{A}{1+\beta A} \quad \text{For negative feedback} \qquad \text{... (1.14)}$$

Sub equation (1.13) in equation (1.14)

$$A = \frac{\dfrac{A(\text{mid})}{1+j\dfrac{f}{f_H}}}{1+\beta\left[\dfrac{A(\text{mid})}{1+j\dfrac{f}{f_H}}\right]} \quad \text{For negative feedback}$$

Simplifying
$$A = \frac{\dfrac{A(\text{mid})}{1+j\left(\dfrac{f}{f_H}\right)} \times \left[1+\dfrac{jf}{f_H}\right]}{1+\dfrac{jf}{f_H}\,\beta(\text{mid})} = \frac{A(\text{mid})}{f_H + j.f + \beta A(\text{mid}) \times f_H}$$

$$A_f = \frac{A(\text{mid})/[1+\beta a\, A_v(\text{mid})]}{1+\dfrac{j.f}{f_H[1+\beta A(\text{mid})]}} \qquad \text{... (1.15)}$$

Above equation can be rewrite as

$$A_f = \frac{A_f(\text{mid})}{1+\dfrac{j.f}{f_H'}}$$

$$A_f(\text{mid}) = \frac{A_V(\text{mid})}{1+\beta A_V(\text{mid})} \quad \text{... (1.16)}$$

and $$f^1_H = f_H(1 + \beta \times A_V(\text{mid}))$$

$\therefore$ β is positive for negative feedback $f'_H > f_H$

Negative feedback increases bandwidth.

Similarly $$f^1_L = \frac{f_L}{1+\beta \times A(\text{mid})}$$

$$A = \frac{A(\text{mid})}{1 - j\left(\frac{f_L}{f}\right)}$$

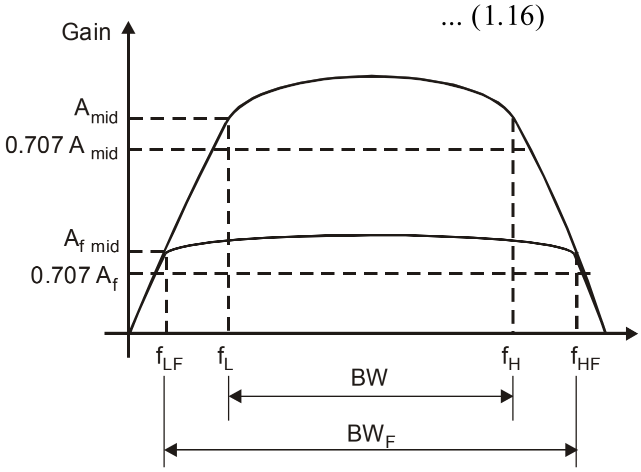


Figure 1.16: Bandwidth

(or) $$A_f = \frac{A(\text{mid})/1+\beta A(\text{mid})}{1+j\frac{f_L}{f(1+\beta A)}} = \frac{A}{1 - j\left(\frac{f'_L}{f}\right)} \quad \text{... (1.17)}$$

$$\beta w = f_{Hf} - f_{Lf}$$

1.7.4 Reduction in Distortion

Suppose, the Amplifier, in addition to voltage amplification is also producing distortion D.

$$V_0 = AV_i + D$$

Where $V_i = V_s - \beta V_o$ (for negative feedback)

So $V_o = A[V_s - \beta V_o] + D$

$$V_o + A\beta V_o = AV_s + D$$

$$V_o[1 + A\beta] = AV_s + D$$

$$V_o = \frac{AV_s}{1+A\beta} + \frac{D}{1+A\beta}$$

For -ve feedback, β is negative i.e., Denominator is >1

$\therefore$ The Distortion in output is reduced

$$V_o = \frac{D}{1+\beta A} \text{ is} < D \quad \text{... (1.18)}$$

1.7.5 Feedback to Improve Sensitivity

Suppose an amplifier of gain A_l is required. Build an amplifier of gain $A_2 = DA$, in which D is large. Feedback is now introduced to divide the gain by D. Sensitivity is improved by the same factor D, because both gain and instability are divided by D, The stability will be improved by the same factor.

1.7.6 Frequency Distortion

If the feedback network does not contain reactive elements, The overall gain is not a function of frequency. So frequency duration is less, If β depends upon frequency, with negative feedback, Q factor will be high. i.e., $A_f = \frac{1}{1+A\beta}$.

1.7.7 Reduction of Nonlinear Distortion

Suppose the input signal contains second harmonic and its value is B_2 before feedback. Because of feedback. B_{2f} appears at the output. So positive βB_{2f} is fed to the input. It is amplified to $-A\beta B_{2f}$.

Output with two terms $B_2 - A\beta B_{2f} = B_{2f}$

Or $$B_{2f} = \frac{B_2}{1+A\beta} = \frac{B_2}{D} \quad \text{(Since D = 1 + AB)}$$

$$B_{2f} = \frac{B_2}{1+A\beta} \quad B_{2f} < B_2 \qquad \text{... (1.19)}$$

So it is reduced.

1.7.8 Reduction of Noise

Let N be constant without feedback and N_F with feedback. N_F is fed to the input and its value is βn_F. It is amplificed to $-\beta AN_F$.

$$N_F = N - \beta AN_F$$

$$N_F(1+\beta A) = N$$

$$N_F = \frac{N}{(1+\beta A)} \qquad \text{... (1.20)}$$

$N_F < N$ So Noise is reduced with negative feedback.

1.7.9 Increase in Input Impedence

An amplifier should have high input impedence so that will not load the preceding stage Input Impedence with feedback

$$Z_{1f} = Z_i(1 + A\beta) \qquad \text{... (1.21)}$$

1.7.10 Decrease in Output Impedence

An amplifier with low output Impedence is capable of delivering power to load without much loss. Output Impedence with feedback

$$Z_{of} = \frac{Z_o}{1+A\beta} \quad \text{... (1.22)}$$

1.8 INPUT RESISTANCE AND OUTPUT RESISTANCE

Input Resistance

If the feedback Signal is returned to input in series to oppose the applied voltagte regardless of whether it is obtained by sampling the output voltage or current, it tends to increase the input resistance.

Since the V_f opposes the V_s (figure 1.17) the current is less than it could be if V_f were absent.

Hence $R_{if} = \frac{V_s}{i_s} - R_s \Rightarrow R_{if} = \frac{V_s}{I_s}$ is » R_i

Where R_i = Input Resistance without feedback.

Negative feedback in which output signal is feedback to input in parallel tends to decrease the input resistance.

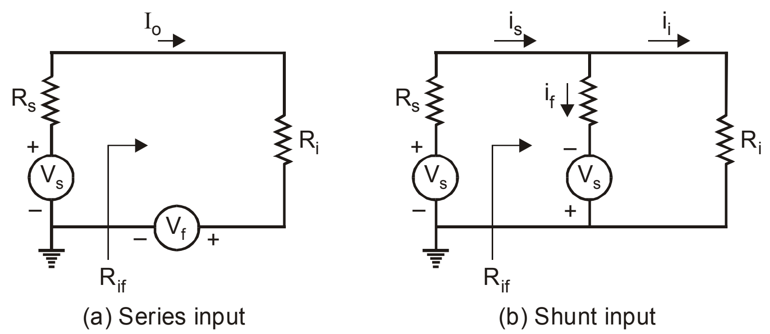


Figure 1.17: Mixer Connection

Since $I_s = I_i + I_f$

Then the current I_i is decreased from what it would be if there were no I_f.

Hence R_{if} is decreased.

$$R_{if} = R_i/(1 + \beta A) \Rightarrow R_i/D \quad \text{... (1.23)}$$

Output Resistance

Negative feedback which samples the output voltage regardless of how this output signal is returned to input, *tends to decrease the output resistance.*

If $R_L\uparrow$, $V_o\uparrow$, the effect of feeding this voltage back to input in a degenerative manner is to cause V_o to increase less than it would if there were no feedback.Hence the output voltage bends to remain constant as R_L changes which means that $R_{of} \ll R_L$. This leads to reduce output resistance.

1.8.1 Voltage series Feedback Amplifier

Input Resistance

In figure 1.18 shows Thevenin's model of Voltage series feedback. In this circuit voltage gain taking R_s in account. Throughout the feedback Amplifier, we shall consider R_s to be part of amplifier and drop the subscript S on transfer gain and input impedance (A_V for A_{VS}, R_i for R_{is}, R_{is} for R_{ifs}, G_m for G_{ms} etc)

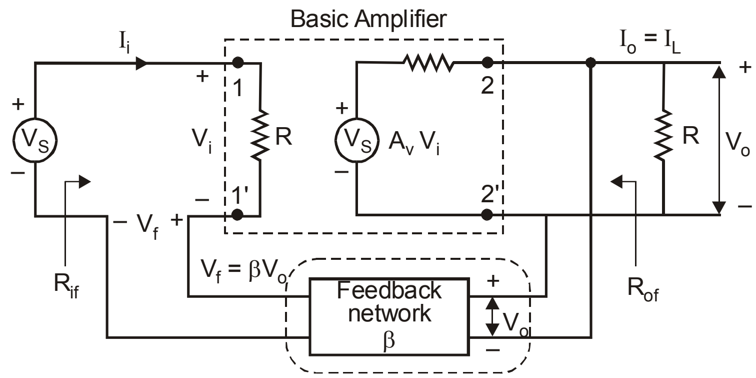


Figure 1.18: Input Resistance Calculation

Input resistance with feedback R_{if} is

$$R_{if} = \frac{V_s}{I_s} \qquad \text{... (1.24)}$$

Where $\qquad I_i \rightarrow$ Input current

Apply KVL to Input Loop

$$V_s - I_iR_i - V_f = 0$$

$$V_s = V_f + I_i R_i$$

$$= \beta V_o + I_iR_i \quad \text{Since} \quad V_f = \beta V_o \qquad \text{... (1.25)}$$

The output voltage V_o is expressed as

$$V_o = \frac{A_v V_i \times R_L}{R_o + R_L} = \frac{A_V R_L}{R_o + R_L} = A_V V_i \qquad \text{... (1.26)}$$

Where $\quad A_V = \dfrac{A_v R_L}{R_o + R_L}$

$A_v \rightarrow$ Open loop voltage gain without feedback

$A_V \rightarrow$ Voltage gain without feedback taking R_L in account

$$V_o = A_V V_i = A_V I_i R_i \quad \text{Since } V_i = I_v R_i \qquad \text{... (1.27)}$$

Sub equation (1.25) in (1.24), we get

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

Sub equation (1.27) in above equation we get.

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

$$R_{if} = R_i [1 + \beta A_V] \qquad \text{... (1.28)}$$

Where $\quad R_i$ = Input resistance wihtout feedback.

Output Resistance

To find output resistance (R_{of}), we must remove the external signal (set $V_s = 0$ or $I_S = 0$) R_{of} can be obtained by looking in to output terminals with R_L disconnected.

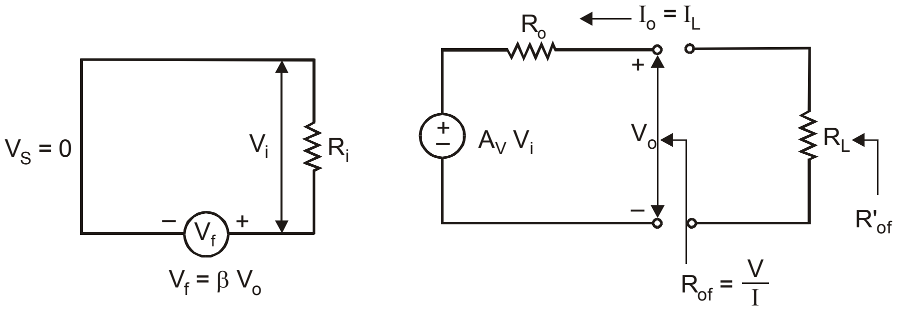


Figure 1.19: Output resistance calculation

Apply KVL to output side

$$A_v V_i + I_L R_O - V_O = 0$$

$$I_L = \frac{V_o - A_v V_i}{R_o} \qquad ...(1.29)$$

Since $V_s = 0$; So $V_i = -V_f = -\beta V_o$ ...(1.30)

$$I_L = \frac{V_o - A_v \beta V_o}{R_o} = \frac{V_o [1 + A_v \beta]}{R_o}$$

Since output resistance with feedback is

$$R_{of} = \frac{V_o}{I_L} \text{; Then } R_{of} = \frac{V_o \times R_o}{V_o [1 + A_v \beta]}$$

$$R_{of} = \frac{R_o}{[1 + A_v \beta]} \qquad ... (1.31)$$

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

$$R'_{of} = R_{of} \| R_L$$

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

From equation 1.31

$$= \frac{\left[\frac{R_o}{1 + \beta A_v}\right] \times R_L}{\left[\frac{R_o}{1 + \beta A_v}\right] + R_L}$$

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

$$R'_{of} = \frac{R_o R_L / R_O + R_L}{1 + \frac{\beta A_V R_L}{R_o + R_L}} = \frac{R'o}{1 + \beta A_v}; \qquad ... (1.32)$$

Where $R'o = \frac{R_o R_L}{R_o + R_L}$ and $A_V = \frac{A_v R_L}{R_o + R_L}$

$R'o$ is now divided by densitivity factor $1 + \beta A_V$

which contains the voltage gain A_v that takes R_L into account.

1.8.2 Current series Feedback Amplifier

Input Resistance

Figure 1.20 shows Thevenin's equivalent circuit for input circuit of current seires feedback and output circuit by Norton equivalent.

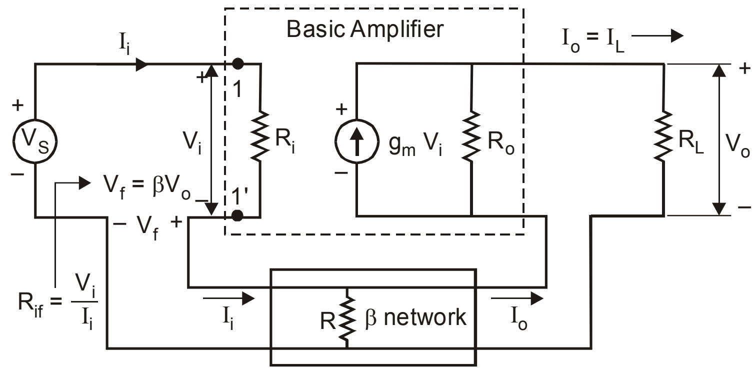


Figure 1.20: Transconductance Amplifier

From figure 1.20 we come to know that input resistance with feedback is

$$R_{if} = \frac{V_s}{I_s} \qquad \text{...(1.33)}$$

Apply KVL to input Loop

$$V_s - I_iR_i - V_f = 0$$

$$V_s = I_iR_i + V_f = I_iR_i - \beta I_o \qquad \therefore \quad V_f = \beta I_o \qquad \text{... (1.34)}$$

The ouput current I_o is expressed as

$$I_o = \frac{G_m V_i \times R_o}{R_o + R_L} = G_M v_i \qquad \text{... (1.35)}$$

Where $G_M = \dfrac{G_m R_o}{R_o + R_L}$

Where $G_m \rightarrow$ Open loop transconductation without feedback

$G_M \rightarrow$ Transconductance without feedback takin R_L in account

Sub equation (1.35) in equation (1.34) we get

$$V_s = I_iR_i + V_f + \beta G_M v_i = I_iR_i + \beta G_M I_iR_i \qquad \therefore \; V_i = I_iR_i$$

From equation (1.33)

$$R_{if} = \frac{V_s}{I_s} = \frac{I_i\ R_i + \beta G_M\ I_i\ R_i}{R_i} = R_i[1+\beta G_M] \quad \text{... (1.36)}$$

Output Resistence

Output Resistence can be obtained by shorting input source is $V_s = 0$, with looking into output terminal with R_L disconnected as shown in figure 1.21

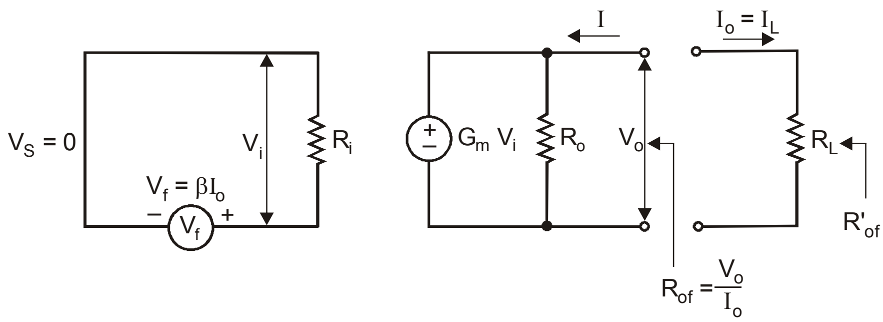


Figure 1.21: Output resistance with V_s = 0 and R_L disconnected

Apply KCL to output Node

$$G_m V_i + I = \frac{V_o}{R_o} = \Rightarrow I = \frac{V_o}{R_o} - G_m V_i \quad \text{... (1.37)}$$

The input Voltage can be expressed as

$$V_i = -V_f = -\beta I = \beta I_o \qquad \text{Since } I_o = -I \quad \text{... (1.38)}$$

Sub Equation (1.38) in (1.37), we get

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

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

So $$V_o = R_o\, I\, (1 + G_m B) \quad \text{... (1.39)}$$

Since $$R_{of} = \frac{V_o}{I} = R_o \frac{I(1+G_m\beta)}{I} = R_o\,(1 + G_m\beta) \quad \text{... (1.40)}$$

Where $G_m \rightarrow$ Open loop Tansconductance without taking R_L in account.

$$R'_{of} = R_{of} \| R_L = \frac{R_{of} \times R_L}{R_{of} + R_L}$$

$$R'_{of} = \frac{R_o(1+\beta G_m)\times R_L}{R_o(1+\beta G_m)+R_L} = \frac{R_oR_L(1+\beta G_m)}{R_o+R_L+\beta G_mR_o}$$

Divide Numberator and denominator by $R_o + R_L$

$$R'_{of} = \frac{\dfrac{R_oR_L(1+\beta G_m)}{R_o+R_L}}{1+\dfrac{\beta G_mR_o}{R_o+R_L}} = \frac{R'_o(1+\beta G_m)}{1+\beta G_m} \qquad \text{... (1.41)}$$

Since $R'_o = \dfrac{R_oR_L}{R_o+R_L}$ and $G_m = \dfrac{G_mR_o}{R_o+R_L}$

Where $G_M \rightarrow$ Open loop current gain taking R_L in account.

1.8.3 Current shunt feedback

Input Resistance

Figure 1.22 shows Norton equivalent circuit for current shunt feedback input and output circuit

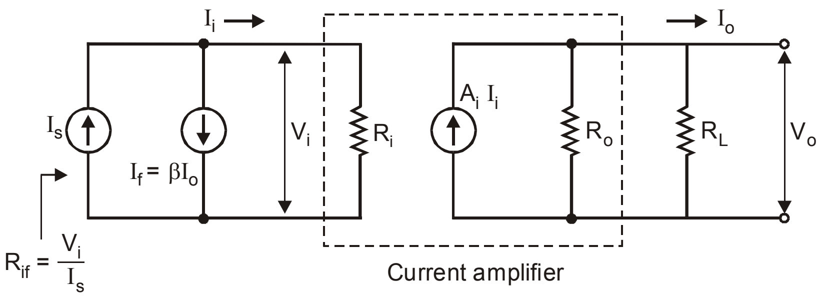


Figure 1.22: Current Amplifier

Apply KCL to input Node

$$I_s = I_l + I_f = I_l + \beta I_o \qquad \text{Since } I_f = \beta I_o \qquad \text{......(1.42)}$$

The output I_o current can be expressed as

$$I_o = \frac{A_iI_i\times R_o}{R_o+R_L} = A_II_i \qquad \text{... (1.43)}$$

where $A_I = \dfrac{A_i\times R_o}{R_o+R_L}$

$A_i \rightarrow$ Open loop current gain without feedback

$A_I \rightarrow$ Open loop current gain without feedback taking R_L in account.

Sub equation (1.43) in (1.42) we get

$$I_s = I_i + \beta I_o = I_I + \beta A_I I_i \Rightarrow I_i(1 + \beta A_I)$$

Input resistance with feedback is

$$R_{if} = \frac{V_i}{I_S} = \frac{V_i}{I_I(1+\beta A_I)}$$

Since $R_i = \frac{V_i}{I_S}$

Then $$R_{if} = \frac{V_i}{(1+\beta A_I)} = \frac{R_i}{(1+\beta A_I)} \qquad ... (1.44)$$

Output Resistance

Output Resistance can be obtained by open circuiting the Input source $I_S = 0$ and looking into output terminal, with R_L disconnected as shown below

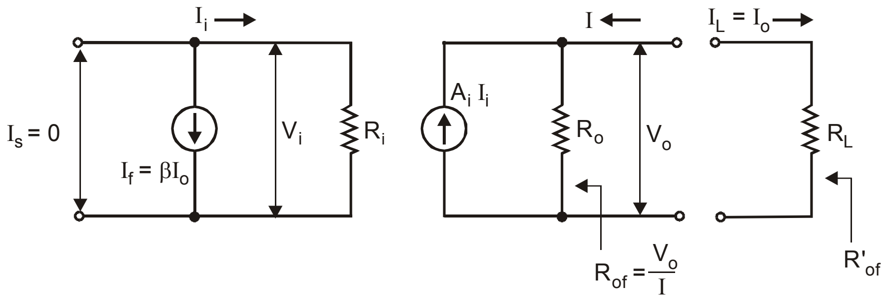


Figure 1.23: Output resistance calculation

Apply KCL to output Node

$$A_i I_i + I = \frac{V_o}{R_o} = \Rightarrow I = \frac{V_o}{R_o} = A_i I_i \qquad ... (1.45)$$

The input Voltage can be expressed as

$$I_i = -I_f = -\beta I_o \qquad \text{Since } I_s = 0$$

$$I_i = \beta I \qquad \text{Since } I = -I_0 \qquad ... (1.46)$$

Sub Equation (1.40) in (1.45), we get

$$I = \frac{V_o}{R_o} - A_i \beta I$$

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

Then $\quad V_o = IR_o(1 + \beta A_i)$ ... (1.47)

Output resistance with feedback is

Since $\quad R_{of} = \dfrac{V_o}{I} = \dfrac{IR_o(1+\beta A_i)}{I} = R_o(1 + \beta A_t)$ ... (1.48)

where $\quad A_i \rightarrow$ Open loop Tansconductance without taking R_L in account.

$$R'_{of} = R_{of} \parallel R_L \quad = \frac{R_{of} \times R_L}{R_{of} + R_L}$$

$$R'_{of} = \frac{R_o(1+\beta A_i) \times R_L}{R_o(1+\beta A_i) + R_L} = \frac{R_o R_L(1+\beta A_i)}{R_o + R_L + \beta A_i I_o}$$

Divide Numberator and denominator by $R_o + R_L$

$$R'_{of} = \frac{\dfrac{R_o R_L(1+\beta A_i)}{R_o + R_L}}{1+\dfrac{\beta A_i R_o}{R_o + R_L}} = \frac{R_o(1+\beta A_i)}{(1+\beta A_i)} \quad \text{... (1.49)}$$

Since $R'_o = \dfrac{R_o R_L}{R_o + R_L}$ and $A_I = \dfrac{A_i R_o}{R_o + R_L}$

where $\quad A_I \rightarrow$ open loop current gain with R_L in account.

1.8.4 Voltage Shunt Amplifier

Input Resistance

Figure 1.24 shows amplifier input circuit is represented by Norton's equivalant circuit and output circuit is represented by Thevenin's equivalant

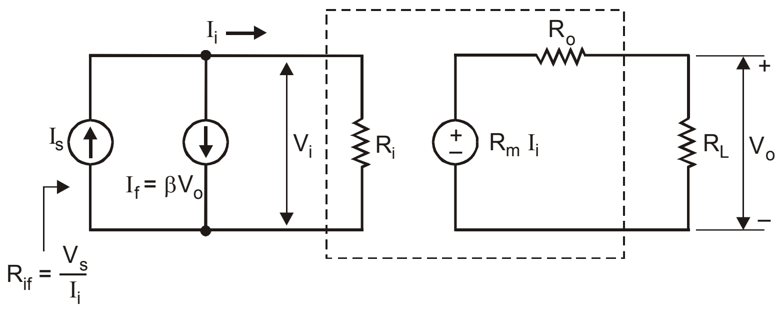


Figure 1.24: Transresistance Amplifier

Apply KCL to input Node

$$I_s = I_i + I_f = I_l + \beta V_o \quad \text{Since } I_f = \beta V_o \qquad \text{... (1.50)}$$

The output I_o current can be expressed as

$$V_o = \frac{R_m I_i \times R_o}{R_o + R_L} = R_M I_i \qquad \text{... (1.51)}$$

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

$R_m \rightarrow$ Open circuit transresistance without feedback

$R_M \rightarrow$ Open circuit transresistance without feedback with R_L into account.

Sub equation (1.51) in (1.50) we get

$$I_s = I_i + \beta R_M I_i \quad \Rightarrow I_i(1 + \beta R_M)$$

Input resistance with feedback R_{if} is

$$R_{if} = \frac{V_i}{I_S} = \frac{V_i}{I_I(1+\beta R_M)} \qquad \text{... (1.52)}$$

Since $$I_i = \frac{V_i}{R_i}$$

Then $$R_{if} = \frac{R_i}{(1+\beta R_M)}$$

Output Resistance

Output Resistance can be measured by setting $I_s = 0$ and looking into output terminal, with R_L disconnected as shown below

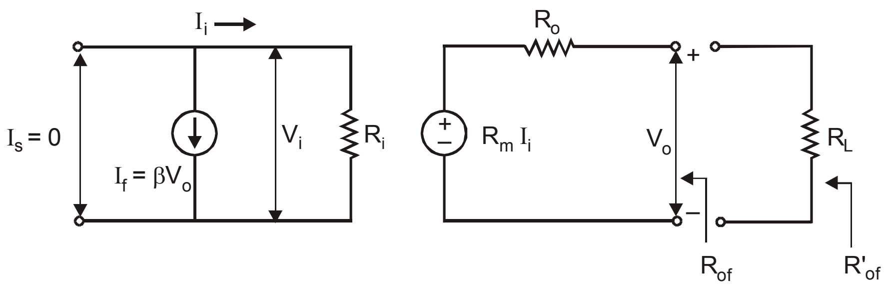


Figure 1.25: Output Resistance Calaculation

Apply KVL to output Node

$$R_M I_i + IR_o - V = 0$$

$$\Rightarrow \qquad I = \frac{V - R_m I_i}{R_o} \qquad \text{... (1.53)}$$

The input Current is givern as

$$I_i = -I_f = -\beta V \qquad \text{... (1.54)}$$

Sub equation (1.54) in (1.53), we get

$$I = \frac{V - R_m \beta V}{R_o} = \frac{V(1 + R_m\beta)}{R_o} \qquad \text{... (1.55)}$$

Output resistance with feedback is $R_{of} = \dfrac{V}{I}$

Sub equation (1.55) in above equation

Since $\qquad R_{of} = \dfrac{V R_o}{V(1+R_m\beta)} = \dfrac{R_o}{(1+R_m\beta)}$

where $\qquad R_m \rightarrow$ Open loop Tansresistance without taking R_L in account.

$$R'_{of} = R_{of} \,||\, R_L = \frac{R_o \times R_L}{R_o + R_L}$$

$$= \frac{\dfrac{R_o R_L}{1 + R_m\beta}}{\dfrac{R_o}{1 + R_m\beta} + R_L} = \frac{R_o \times R_L}{R_o + R_L(1 + R_m\beta)} \qquad \text{... (1.56)}$$

Dividing Numberator and denominator by $R_o + R_L$

$$R'_{of} = \frac{\dfrac{R_o R_L}{R_o + R_L}}{1 + \dfrac{\beta R_m R_L}{R_o + R_L}} = \frac{R'_o}{(1 + \beta R_m)} \qquad \text{... (1.57)}$$

where $\qquad R'_o = \dfrac{R_L \times R_{of}}{R_L + R_{of}}$ and $\quad R_M = \dfrac{R_m \times R_L}{R_o + R_L}$

where $\qquad R_M \rightarrow$ Open loop transresistance taking R_L in account.

1.9 SUMMARY OF NEGATIVE FEEDBACK AMPLIFIER

Following table depicts overall summary of negative feedback amplifier

Parameter	Type of feedback			
	Current series	**Voltage series**	**Voltage shunt**	**Current shunt**
Voltage Gain with Feedback	$A_{vf} = \frac{A}{1+A\beta}$ Decreases	$G_{mf} = \frac{G_m}{1+\beta G_m}$ Decreases	$A_{if} = \frac{A}{1+A\beta}$ Decreases	$R_{mf} = \frac{R_m}{1+\beta R_m}$ Decreases
Bandwidth	Increases	Increases	Increases	Increases
Stability	Improves	Improves	Improves	Improves
Harmonic distortion	Decreases	Decreases	Decreases	Decreases
Frequency response	Improves	Improves	Improves	Improves
Noise	Decreases	Decreases	Decreases	Decreases
Frequency distortion	Reduces	Reduces	Reduces	Reduces
Input Resistance	Increases	Increases	Decreases	Decreases
Output Resistance	Increases	Decreases	Decreases	Increases

1.10 METHOD OF ANALYSIS OF FEEDBACK AMPLIFIER

Following steps are necessary to analyse Feedback Amplifier

Step 1: Identify Topology (Type of Topology)

a) To find the type of sampling network

1) By shorting the output i.e., $V_o = 0$, if feedback signal (x_f) becomes zero, then it is called "Voltage sampling".
2) By opening the output loop i.e., $I_o = 0$, if feedback signal (x_f) becomes zero, then it is called "Current sampling".

b) To find the type of mixing network

1) If the feedback signal is subtracted from the externally supplied signal as a current in input loop it is called "shunt mixing".

Thus by finding the type of sampling network and mixing network, type of feedback amplifier can be determined. For Example, if amplifier uses a voltage sampling and series mixing uses a voltage sampling and series mixing, then it is called a voltage series Amplifier.

Step 2: To find the input circuit

1) For voltage sampling, output voltage is to set output voltage $V_o = 0$ by shorting output.
2) For current sampling, set output current $I_o = 0$ by opening the output loop.

Step 3: To find the output circuit

1) For series mixing, set input current $I_i = 0$ by opening input loop.

2) For shunt mixing, set input voltage $V_i = 0$ by shorting the input.

In step 2 and 3, Ensure that feed back is reduced to zero without altering the loading on basic amplifier.

Step 4: Replace each device by its h - parameter at low frequency

Step 5: Find the open loop gain (without feedback) A of Amplifier.

Step 6: Indicate x_f (feedback voltage or feedback current) and x_o (output voltage output current) on the circuit and evaluate $\beta = x_f x_o$

Step 7: From A and B, Find D, A_f, R_{if}, R_{of} and $R^1{}_{of}$.

1.10.1 Comparisn of Negative Feedback Amplifier

Sl.No	Characteristic	Voltage Series	Current Series	Current Shunt	Voltage Shunt
1.	Feedback Signal x_f	Voltage	Voltage	Current	Current
2.	Sampled Signal x_o	Voltage	Current	Current	Voltage
3.	To find input Loop set	$V_o = 0$	$I_o = 0$	$I_o = 0$	$V_o = 0$
4.	To find output Loop set	$I_i = 0$	$I_i = 0$	$V_i = 0$	$V_i = 0$
5.	Signal Source	Thevenin	Thevenin	Norton	Norton
6.	$\beta = \frac{X_f}{X_o}$	$\frac{V_f}{V_o}$	$\frac{V_f}{I_o}$	$\frac{I_f}{I_o}$	$\frac{I_f}{V_o}$
7.	$A = \frac{X_o}{X_i}$	$A_V = \frac{V_o}{V_i}$	$G_m = \frac{I_o}{V_i}$	$A_I = \frac{I_o}{I_i}$	$R_M = \frac{V_o}{I_i}$
8.	$D = 1 + \beta A$	$1 + \beta A_V$	$1 + \beta G_M$	$1 + \beta A_I$	$1 + \beta R_M$
9.	A_f	$\frac{A_v}{D}$	$\frac{G_M}{D}$	$\frac{A_I}{D}$	$\frac{R_M}{D}$
10.	R_{if}	$R_i D$	$R_i D$	$\frac{R_i}{D}$	$\frac{R_i}{D}$
11.	R_{of}	$\frac{R_o}{1+\beta AV_o}$	$R_o(1 + \beta G_M)$	$R_o(1 + \beta A_I)$	$\frac{R_o}{1+\beta R_M}$
12	$R'_{of} = R_{of} \parallel R_L$	$\frac{R'_o}{D}$	$R'_o \frac{(1+\beta G_m)}{D}$	$R'_o \frac{(1+\beta A_I)}{D}$	$\frac{R'_o}{D}$

1.11 ANALYSIS OF FEEDBACK AMPLIFIERS

1.11.1 Voltage Series Feedback

Voltage Series feedback can be implemented by using BJT and FET.

a) Transistor Emitter Follower:

The Feedback signed is voltage V_f across R_e and the sampled signal is V_o across R_e.

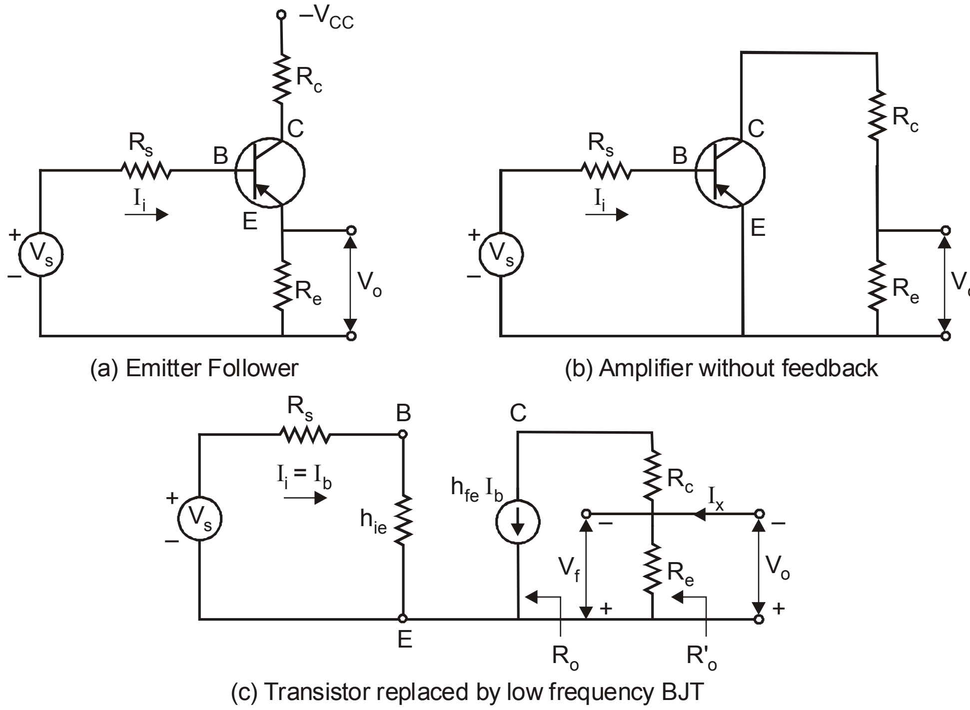


Figure 1.26: Voltage Series feedback

1. **Identify Topology:** By shorting V_o = 0, feedback signal becomes zero.So it is voltage sampling We can see that V_f is subtracted from externally applied signal V_s. Hence it is series mixing. So we come to know that it voltage series feedback amplifier.
2. **Input Circuit:** To find Input Circuit set $V_0 = 0$, So $V_f = V_o$, because feedback signal is proportional to output voltage.

Now the drop across R_e. ie, V_f opposes the input voltage. It reverse biases the feedback in V_f coining in series with V_{BE} and it opposes it. So it is negative series voltage feedback.

3. **Output Circuit:** To find output circuit set $I_i = I_b = 0$. So R_e appears only in output loop.
4. **Open Loop Voltage gain:** This topology stabilizes the voltage gain.

$$\text{Open Loop Voltage Gain } A_V = \frac{V_o}{V_s} = \frac{h_{fe} I_b R_e}{V_s} \quad \text{... (1.58)}$$

Since R_s is considered as part of amplifier, Then $V_i = V_s$.

Apply KVL to input loop in figure $V_s = I_b(R_S + h_{ie})$

$$\text{then} \quad A_V = \frac{V_o}{V_s} = \frac{h_{fe} I_b R_e}{I_b (R_S + h_{ie})} = \frac{h_{fe} R_e}{R_S + h_{ie}} \qquad \text{... (1.59)}$$

5. Feedback Factor (β):

$$\text{Since } V_o = V_f \,; \quad \beta = \frac{V_f}{V_o} = \frac{V_f}{V_f} = 1 \qquad \text{... (1.60)}$$

6. Densitivity

$$D = 1 + \beta A_v = 1 + \beta \frac{h_{fe} R_e}{R_S + h_{ie}} = \frac{R_s + h_{ie} + \beta h_{fe} R_e}{R_S + h_{ie}} \qquad \text{... (1.61)}$$

7. Voltage Gain with Feedback:

$$A_{vf} = \frac{A_V}{D} \Rightarrow \frac{A_V}{1 + \beta A_V} = \frac{h_{fe} R_e}{R_S + h_{ie} + \beta h_{fe} R_e} \qquad \text{... (1.62)}$$

For Emitter Follower, $h_{fe} R_e \gg R_e + h_{ie}$; $A_{vf} \approx 1$

8. Input Resistance

Input Resistance without feedback is $R_i = R_S + h_{ie}$ ... (1.63)

Hence $R_{if} = R_i[1+\beta A_v] \Rightarrow R_i D$ ... (1.64)

$$R_{if} = R_i D = (R_S + h_{ie}) \frac{R_s + h_{ie} + \beta h_{fe} R_e}{R_S + h_{ie}} = R_S + h_{ie} + \beta h_{fe} R_e \qquad \text{... (1.65)}$$

where R_{if} = Input Resistance with feedback

9. Output Resistance:

It can be calculated by setting

$V_s = 0$, So $I_b = 0$, Hence $h_{fe} I_b = 0$.

R_e is considered as external Load.

$$R_{of} = \frac{R_o}{1 + \beta A_V} = \frac{\infty}{\infty} \qquad \text{... (1.66)}$$

From figure 1.26 we are looking into current Source, $R_o = \infty$.

The interterminancy $R_e = \infty$, $R_{of} = \infty$ is resolved by calcualting R'_{of} and then going to limit $R_e = \infty$.

$$R_o' = \frac{V_o}{I_x} = \frac{I_x R_e}{I_x} = R_e$$

$$R_{of} = \lim_{R_e \to \infty} R'_{of}$$

Where $$R_{of}' = \frac{R_o}{D} = \frac{R_e(R_s + h_{ie})}{R_S + h_{ie} + h_{fe}R_e}$$

Then $$R_{of} = \frac{R_s + h_{ie}}{h_{fe}} \quad \text{... (1.67)}$$

This feedback desensitizes voltage gain with respect to changes in h_{fe} and that it increases the input resistance and decreases the output resistance.

b) FET Source Follower

Feedback signal is voltage V_f across R and sampled signal is output voltage V_o and R.

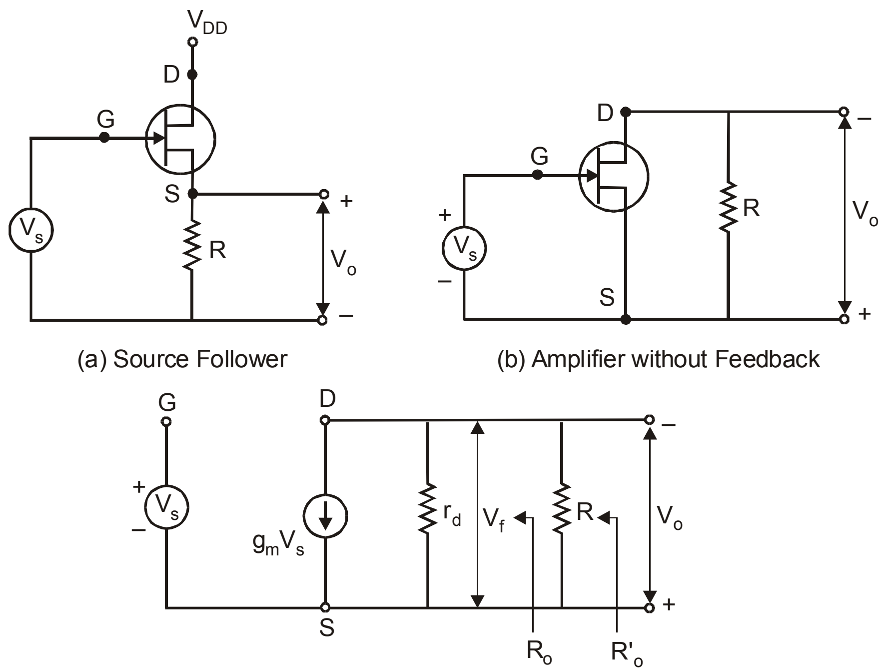


Figure 1.27: FET voltage series feedback amplifier

1. Identify Topology

By shorting $V_o = 0$, V_f becomes feedback signal 0, hence it is voltage sampling, We can see that V_f is subtracted from V_s, hence it is series mixing. So we come to know that it is voltage series feedback amplifier.

2. Input Circuit

To find Input Circuit set $V_o = 0$. Hence V_s appears directly between G and S.

3. Output Circuit

To find output circuit , set $I_i = I_b = 0$. Hence R appears only in output loop.

4. Open Loop Voltage Gain

This topology stabilizes voltage gain

$$A_v = \frac{V_o}{V_i} = \frac{V_o}{V_S} = \frac{g_m V_s r_d R}{(r_d + R)\, V_s} \qquad \text{... (1.68)}$$

$$\text{Since} \quad \mu = g_m r_d; \text{ then } A_v = \frac{\mu R}{r_d + R}$$

5. Feedback Factor

$$\text{Since} \quad V_f = V_o; \text{Then } \beta = \frac{V_f}{V_o} = 1 \qquad \text{... (1.69)}$$

6. Densitivity

$$D = 1 + \beta A_v = \frac{1 + \mu R}{r_d + R} = \frac{r_d + (1+\mu)R}{r_d + R} \qquad \text{... (1.70)}$$

7. Voltage Gain with Feedback

$$A_{vf} = \frac{A_v}{D} = \frac{A_v}{1 + \beta A_v} = \frac{\mu R}{r_d + (1+\mu)R} \qquad \text{... (1.71)}$$

8. Input Resistance

Input Resistance of FET is infinite, $R_i = \infty$

$$\text{Hence} \quad R_{if} = R_i(1+\beta A_v) = R_i D = \infty \qquad \text{... (1.72)}$$

9. Output Resistance

Here R is considered as external load R_L.

$$R_{of} = \frac{R_o}{1 + \beta A_V} \qquad \text{... (1.73)}$$

Since $R_o = r_d;\ \beta = 1$ and $A_v = \lim_{R \to \infty}$

$$A_v = \lim_{R \to \infty} \frac{\mu R}{rd + R} = \mu$$

Then $R_{of} = \dfrac{r_d}{1+\mu}$

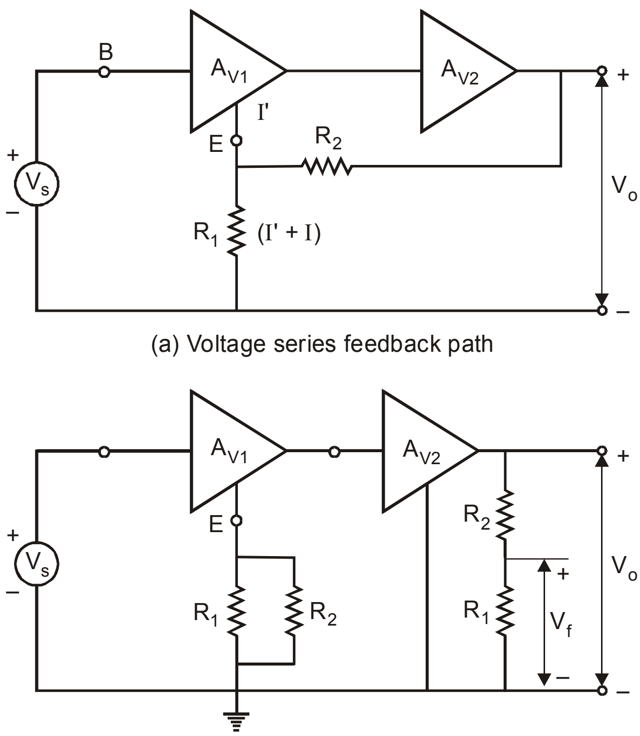
$$R'_{of} = \frac{R'_o}{D} \quad \text{where } R'_o = R||r_d$$

$$R'_{of} = \frac{Rr_d}{R+r_d} \frac{r_d + R}{r_d + (\mu+1)R} = \frac{R\ r_d}{r_d + (\mu+1)R} \qquad ...(1.74)$$

$$R_{of} = \lim_{R \to \infty} R'_{of}$$

$$R'_{of} = \frac{r_d}{\mu+1}$$

c) Voltage Series Feedback Pair



(b) Equivalent circuit without external feedback

Figure 1.28: Voltage series feedback path

Figure 1.28 shows two cascaded stages whose voltage gains are AV_1 ans AV_2 respectively. The output of second stage is returned through R_1R_2 in opposition to input signal V_s.

Identify Topology

To find input circuit, set $V_o = 0$ in figure 1.28 hence R_2 appears in parallel with R_1 at first emitter.

To find output circuit, set $I_i = 0$ in figure 1.28 hence I'= 0 and R_1 appears in series with R_2 across output.

Feedback Factor

$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2} \qquad \text{... (1.75)}$$

1.11.2 Current Series Feedback

1. Transistor Configuration

Consider the circuit as shown in figure output is taken between collector and ground. The drop across Re is feedback signal V_f The sampled signal is the load current I_o and not V_o. This is *current series Feedback* Because V_f is in series with V_i.

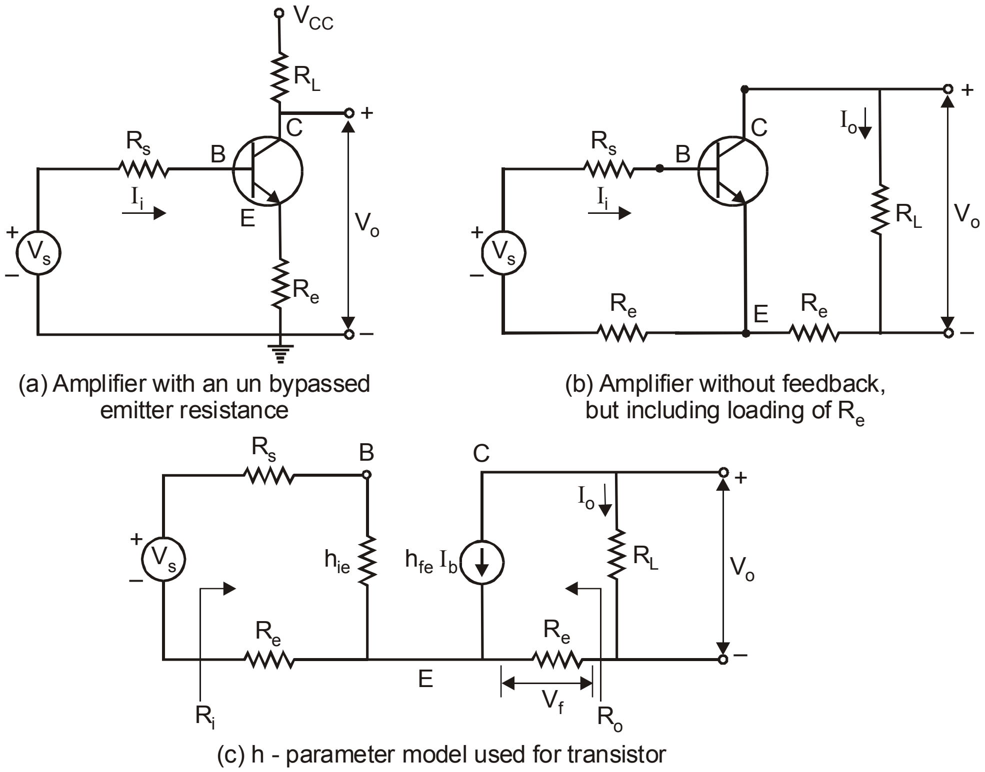


Figure 1.29: Current series feedback using BJT

a) Identify Topology

By opening output loop, $I_o = 0$, feedback signal becomes zero, hence it is current sampling. We can see that feedback signal V_f is subtracted from externally applied signal V_s hence it is series mixing. From this we come to know that it is *current series feedback amplifier.*

b) Input Circuit

Input circuit of amplifier without feedback is obtained by opening output loop. Hence R_e must appear in input side.

c) Output Circuit

Output circuit is obtained by opening input loop and this places R_e also in input side.

d) Open Loop Transfer Gain

$$G_M = \frac{I_o}{V_i} = -\frac{h_{fe}I_b}{V_i} \qquad \text{Since} \quad I_o = h_{fe}I_b \qquad \text{... (1.76)}$$

Input signal V_i without feedback is V_s.

$$V_i = I_b (R_s + R_e + h_{ie})$$

So $$G_M = -\frac{h_{fe}I_b}{V_i} = -\frac{h_{fe}I_b}{I_b(R_s + R_e + h_{ie})} = -\frac{h_{fe}}{R_s + R_e + h_{ie}} \qquad \text{... (1.77)}$$

e) Feedback Factor

Since V_f appears across Re in output circuit, then

$$\beta = \frac{V_f}{I_o} = -\frac{I_eR_e}{I_o} = -R_e \qquad \text{... (1.78)}$$

f) Densitivity

$$D = 1+\beta G_M = 1 + \frac{h_{fe}R_e}{R_s + h_{ie} + R_e} = \frac{R_s + h_{ie} + (1+h_{fe})R_e}{R_s + h_{ie} + R_e} \qquad \text{... (1.79)}$$

g) Voltage gain with Feedback

$$G_{mf} = \frac{G_m}{D} = \frac{-h_{fe}}{R_s + h_{ie} + (1+h_{fe})R_e} \qquad \text{... (1.80)}$$

If R_e is a stable Resistor, the transconductance gain with feedback is stabilized the load current is $I_o = G_{mf}V_s = \frac{-h_{fe}}{R_s + h_{ie} + (1+h_{fe})R_e} = \frac{-V_s}{R_e}$ ... (1.81)

$I_o \propto V_s$ and $I_o \propto R_e$ and not upon any other transistor parameter

Voltage gain is given by

$$A_{vf} = \frac{I_o R_L}{V_s} = G_{mf} R_L = \frac{-h_{fe} R_L}{R_s + h_{ie} + (1+h_{fe})R_e} \quad \text{... (1.81)}$$

h) Input Resistance

$$R_{if} = R_i D$$

Since $R_i = R_i + h_{ie} + R_e$ ......(1.82)

$$R_{if} = R_i D = R_s + h_{ie} + (1 + h_{fe})R_e$$

i) Output Resistance

$R_o = \infty$, Then $R_{of} = R_o (1 + \beta G_M) = \infty$

$$R'_{of} = R_L || R_{of}$$

$$R'_{of} = \frac{R'_o 1+\beta G_m}{1+\beta g_M} \quad \text{... (1.83)}$$

Where G_m = short circuit tranconductance.

Then $G_m = \lim_{R_L \to 0} G_M$ Hence $G_m = G_M$

$$R'_{of} = R'_o = R.$$

If the Amplifier is deactivated ($h_{fe} = 0$), then $I_o = 0$ which means that none of the input signal appears at output via feedback block.

2. FET common source stage with a Source

Here the feedback signal is voltage across R and the sampled signal is load current I_o.

a) Identify Topology

By setting, $V_o = 0$,drain current does not become zero; So feedback does not become zero, hence it is not voltage sampling, By setting $I_o = 0$, V_f becomes zero, Hence it is currents sampling. V_f is mixed in series with input source. So it is current series feedback.

b) Input and Output Circuit

To find Input Circuit, set $I_o = 0$. Then R appears at input side.

To find output circuit, set $I_i = 0$. Then R appears at output circuit.

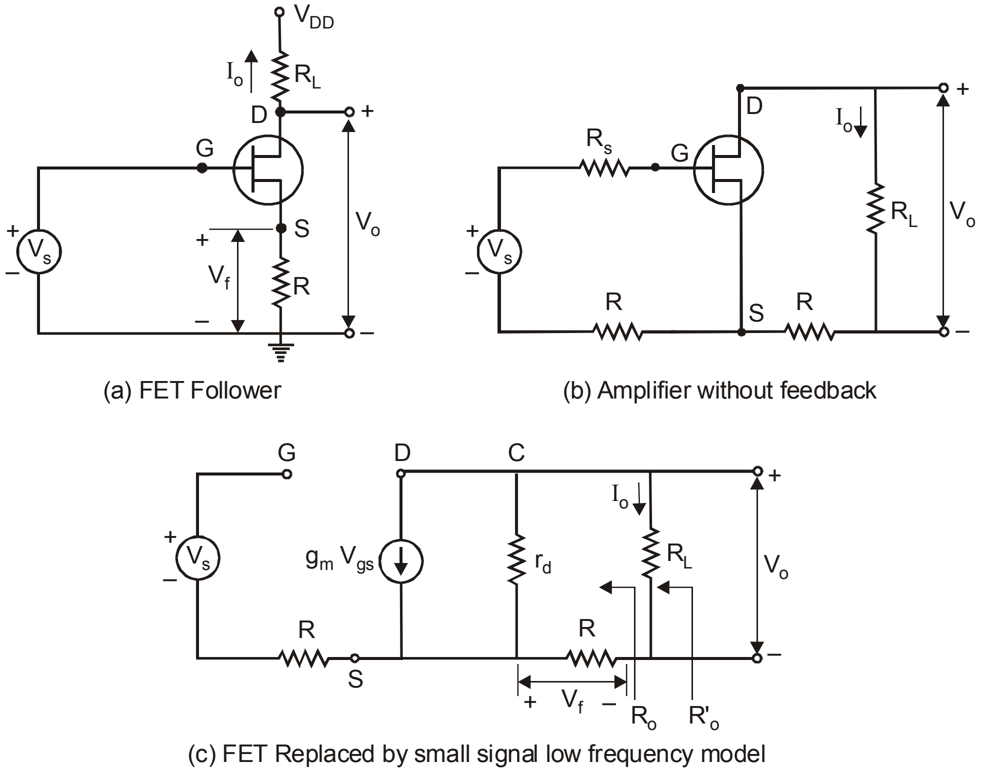


Figure 1.30: FET Current series feedback

c) Open Loop Voltage Gain

$$G_M = \frac{I_o}{V_i} = \frac{I_o}{V_S} = \frac{-g_m V_{gs} r_d}{(r_d + R_L + R) V_s}$$

Without feedback $V_i = V_S$, Then

$$G_M = \frac{-g_m V_s r_d}{(r_d + R_L + R) V_s} = \frac{-g_m r_d}{r_d + R_L + R} \qquad \text{... (1.84)}$$

Since $\mu = g_m r_d$; then $G_M = \dfrac{-\mu}{r_d + R_L + R}$.

d) Feedback Factor

$$\beta = \frac{V_f}{I_o} = \frac{-I_o R}{I_o} = -R. \qquad \text{... (1.85)}$$

e) Densitivity

$$D = 1 + \beta G_M = \frac{1+\mu R}{r_d + R_L + R} = \frac{r_d + R_L + (1+\mu)R}{r_d + R_L + R}$$

$$G_{mf} = \frac{G_M}{D} = \frac{-\mu}{r_d + R_L + (\mu+1)R} \qquad \text{... (1.86)}$$

f) Input Resistance

Since $R_i = \infty$ Then $R_{if} = R_i D = \infty$ ... (1.87)

g) Output Resistance

If R_L is considered as external load then $R_o = r_d + R$.

Then $R_{of} = R_o(1 + \beta G_m)$

Where $G_m = \lim\limits_{R_L \to 0} G_M = \lim\limits_{R_L \to 0} \frac{-\mu}{r_d + R_L + R} = \frac{-\mu}{r_d + R}$

$$1 + \beta G_m = 1 + \frac{(-R)(-\mu)}{r_d + R} = 1 + \frac{\mu R}{r_d + R} = \frac{r_d + R + \mu R}{r_d + R}$$

$$1 + \beta G_m = \frac{r_d + (1+\mu)R}{r_d + R}$$

Then $R_{of} = R_o(1 + \beta G_m)$

$$R_{of} = (r_d + R)\frac{r_d + R + \mu R}{r_d + R}$$

$$R_{of} = r_d + (1+\mu)R \qquad \text{... (1.88)}$$

$$R'_{of} = R_L || R_{of}$$

Another way to calculate R'_{of} is

$$R'_{of} = R'_o \frac{1+\beta G_m}{D} = R'_o \times 1 + \beta G_m \times \frac{1}{D}$$

Where $R_o' = R_o || R_L$

$$R_o' = \frac{R_o \times R_L}{R_o + R_L} = \frac{(r_d + R)R_L}{r_d + R + R_L} \qquad \text{... (1.89)}$$

Then $R'_{of} = \dfrac{(r_d + R)R_L}{r_d + R + R_L} \times \dfrac{r_d + (\mu+1)R}{r_d + R} \times \dfrac{1}{D}$

$$= \frac{(r_d + R)R_L}{r_d + R + R_L} \times \frac{r_d + (\mu+1)R}{r_d + R} \times \frac{r_d + R_L + R}{r_d + R_L + (\mu+1)R}$$

$$R'_{of} = \frac{R_L[r_d + (\mu+1)R]}{r_d + R_L + (\mu+1)R} \qquad \text{... (1.90)}$$

Above equation is equivalent to $R_L \,||\, R_{of}$.

1.11.3 Current shunt Feedback

Figure 1.31 shows two transistors Q_1 and Q_2 in casacade. Feedback is provided from emitter of Q_2 to base of Q_1.

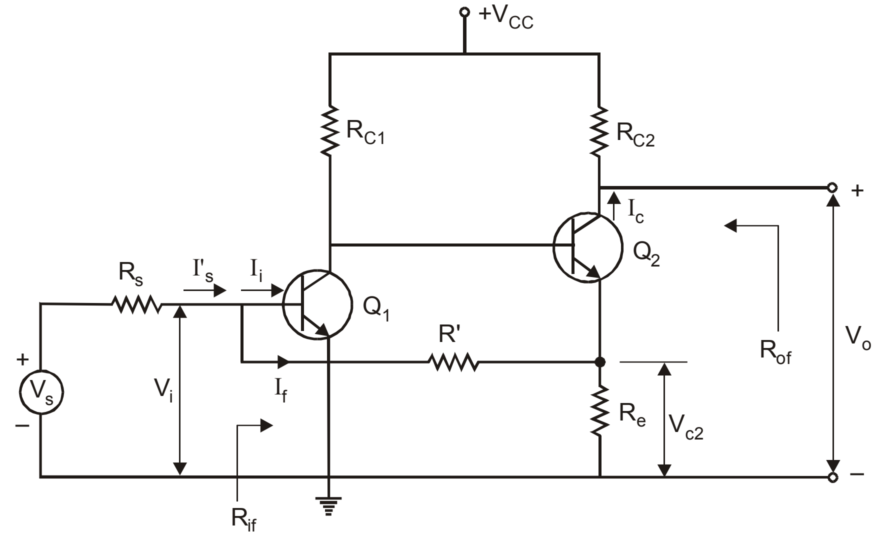


Figure 1.31: Second Emitter with First base Feedback path

This is negative feedback because, V_{i2} the input voltage to Q_2 is >> V_{i1}. V_{i2} is out of fashion with V_{i1}. V_{i2} >> V_{i1} because Q_1 is always large also V_{i2} is 180° out of phase with V_{i1}. Q_2 is emitter follower because emitter is not at ground potential. Voltage is taken across R_e (This Voltage follows the collector voltage. suit is emitter follower). So $A_v < 1 = 0.99$

V_{e2} is slightly «V_{i2} and no phase shifts (Because emitter follows action)

V_{i2} is out of phase with V_{i1}.

V_{e2} is out of phase with V_{i1}(180°) so it is negative feedback.

$V_{i2} >> V_{i1}$; $V_{e2} = V_{i2}$ and $V_{e2} >> V_{i1}$.

If the input signal V_s increases, the input curren I_s from source also increases.

If I_s increases, I_f also increases (Since V_{e2} increases as I_s' increases)

$I_i = I's - I_f$ (It is the base current for transistor Q_1, it is the negative feedback)

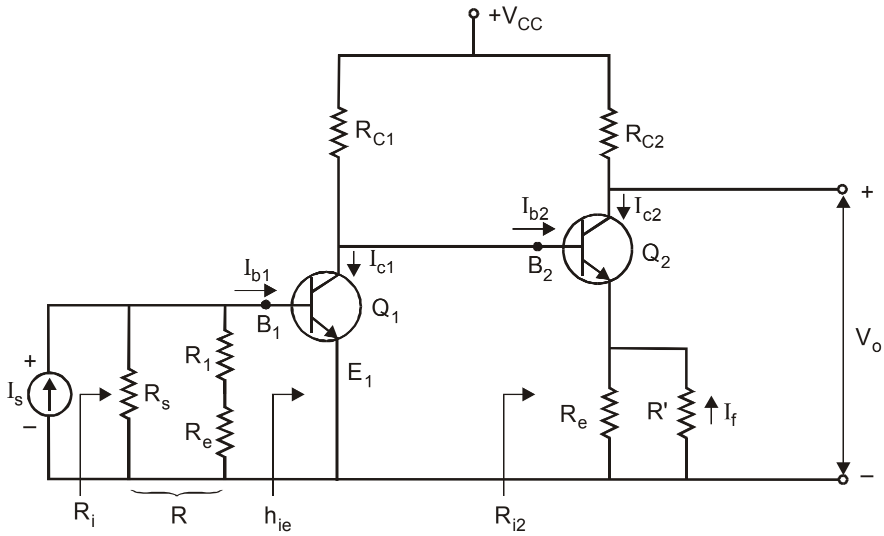


Figure 1.32: Amplifier of without feedback but including the loading of R'

a) Identify Topology

By shorting output Voltage $V_0 = 0$, feedback signal does not become zero hence it is not voltage sampling. By opening the output loop ($I_0 = 0$), feedback signal becomes zero, hence it is current feedback, the feedback signal appears in shunt with input

($I_i = I_s - I_f$), hence it is *current shunt feedback Amplifier.*

b) Input Circuit

Input circuit of Amplifier without feedback is obtained by opening the output loop at the emitter Q_2 ($I_o = 0$). This places R' in series with R_e from base to emitter of Q.

c) Output Circuit

It is obtained by shorting the input node, ie, $V_i = 0$. This places R' in parallel with R_e.

d) Open Loop Current Gain (A_I)

Feedback current $$I_f = \frac{V_{i1} - V_{e2}}{R'} \qquad \text{... (1.91)}$$

Since $v_{e2} >> v_{i1}$; Then $$I_f = \frac{-V_{e2}}{R'} = \frac{(I_o - I_f)R_e}{R'}$$

Where I_o = Collector current of Q_2.

I_o = Collector current of $Q_2 \approx$ Emitter current of Q_2.

$$I_f = \frac{-V_{e2}}{R'} = \frac{(I_o - I_f)R_e}{R'}$$

$$= \frac{I_o R_e}{R'} - \frac{I_f R_e}{R'}$$

$$I_f + \frac{I_f R_e}{R'} = \frac{I_o R_e}{R'} \Rightarrow I_f\left[1 + \frac{R_e}{R'}\right] = \frac{I_o R_e}{R'}$$

$$I_f = \frac{I_o R_e}{R'} \times \frac{R'}{R' + R_e} \Rightarrow \left(\frac{R_e}{R' + R_e}\right) I_o \qquad \text{... (1.92)}$$

$$I_f \propto I_o$$

This is current feedback.

$$A_I = \frac{I_{c2}}{I_{b2}} \cdot \frac{I_{b2}}{I_{c1}} \cdot \frac{I_{c1}}{I_{b1}} \cdot \frac{I_{b1}}{I_s}$$

Where $\frac{-I_{c2}}{I_{b2}} = -h_{fe} = -50;$ $\frac{-I_{c1}}{I_{b1}} = +h_{fe} = 50;$

$$\frac{I_{b1}}{I_{c1}} = \frac{-R_{c1}}{R_{c1} + R_{i2}}; \quad \frac{I_{b1}}{I_s} = \frac{R}{R + h_{ie}}$$

e) Feedback Factor (β)

$$\beta = \frac{I_f}{I_o} = \frac{R_e}{R' + R_e}$$

$$I_f = \beta I_o \qquad \text{... (1.93)}$$

f) Current gain with Feedback (A_{if})

$$A_{If} = \frac{I_o}{I_S'}$$

Since $I_s' = I_i + I_f$ (small value which is MA) so $I_i = I_b$

So $I_s' = I_f$ negleting I_i

$$A_{If} = \frac{I_o}{I_f} = \frac{I_o}{\beta I_o} = \frac{1}{\beta} \quad \text{Since } I_f = \beta I_o$$

$$A_{If} = \frac{1}{\beta} = \frac{R' + R_e}{R_e} \qquad \text{... (1.94)}$$

A_{If} is desensitized provided that R' and R_e are stable resistance.

g) Voltage gain with feedback (A_{Vf})

$$A_{Vf} = \frac{V_o}{V_s}$$

$$V_o = I_o R_{c2} \text{ and } V_s = I_s R_s$$

Then $A_{Vf} = \dfrac{V_o}{V_s} = \dfrac{I_o R_{c2}}{I_s R_s}$

Since $I_s = I_f$; Then $A_{Vf} = \dfrac{I_o}{I_f} \times \dfrac{R_{c2}}{R_s}$

$A_{Vf} = \dfrac{1}{\beta} \times \dfrac{R_{c2}}{R_s}$ Since $\dfrac{I_o}{I_f} = \dfrac{1}{\beta}$

$$A_{Vf} = \frac{R' + R_e}{R_e} \times \frac{R_{c2}}{R_s} \qquad \text{... (1.95)}$$

h) Densitivity $D = 1 + \beta A_I$ ... (1.96)

i) Input resistance

$$R_{if} = \frac{R_i}{D} \qquad R_i = R_i \parallel h_{ie} \qquad \text{... (1.97)}$$

j) Output Resistance

$$R_o = 0$$

So $R_{of} = R_{oD} = \infty$

$$R'_{of} = R'_o \frac{1+\beta A_i}{1+\beta A_i}$$

$$A_i = \lim_{R_{c2} \to 0} A_I \qquad \text{... (1.98)}$$

1.11.4 Voltage Shunt Feedback

a) Identify Topology

By shorting V_o= 0 feedback reduces to zero hence it is voltage sampling. As $I_i = I_s - I_f$ the mixing is shunt type and topology is voltage shunt.

Feedback current through R_B is proportional to output voltage or it is in shunt with the input. So it is *voltage shunt feedback.* The feedback signal is proportional to output voltage. So it is *Voltage feedback.*

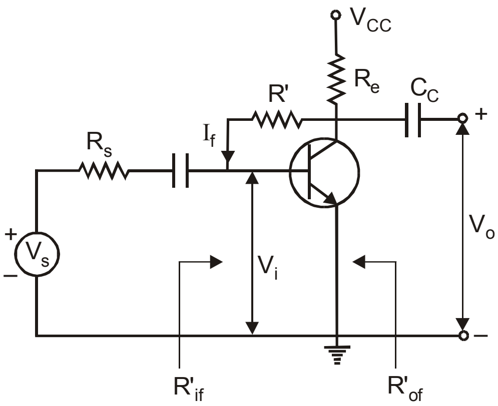


Figure 1.33: Voltage Shunt Feedback

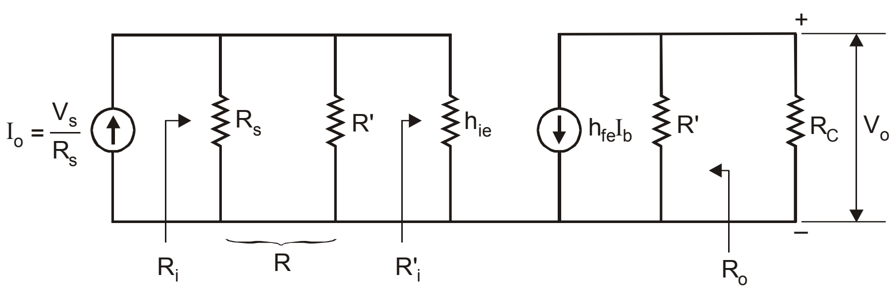


Figure 1.34: h - parameter equivalant circuit

b) Find input and output circuit

To find input circuit set V_o = 0, this places R′ between base and ground.

To find output circuit set V_i= 0, this places R′ between collector and ground.

The output voltage V_o is >> input voltage v_i and it is 180° out of phase with V_i

$$I_f = \frac{V_i - V_o}{R'} = \frac{-V_o}{R'} \qquad \text{... (1.99)}$$

c) Feedback Factor (β)

$$\beta = \frac{I_f}{V_o} \Rightarrow \frac{\frac{-V_o}{R'}}{V_o} \Rightarrow \frac{-1}{R'} \quad \text{... (1.100)}$$

So $I_f = -\beta V_o$

d) Transresistance

$$R_{Mf} = \frac{V_o}{I_s}$$

$I_s = I_f + I_b$ $\qquad I_b$ = is negligible

So $I_s = I_f$

$$R_{Mf} = \frac{V_0}{I_S} \Rightarrow \frac{V_o}{-\beta V_o} = \frac{-1}{\beta} \Rightarrow -R' \quad \text{... (1.101)}$$

Transresistance equals to negative of feedback resistance from output to input of the transistor and it is stable if R′ is a stable resistence.

e) Desensitivity

$$D = 1 + \beta R_M \quad \text{... (1.102)}$$

f) Voltage gain with Feedback

$$A_{Vf} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s}$$

Since $I_s = I_f$

Then $A_{Vf} = \dfrac{V_o}{I_f\, R_S}$

Using equation (1.101) $A_{Vf} = \dfrac{R_{Mf}}{R_s}$

g) Input Resistance

$$R_{if} = \frac{R_i}{D} \Rightarrow \frac{Rh_{ie}}{R + h_{ie}} \times \frac{1}{D} \quad \text{Since } R_i = R \parallel h_{ie} \text{ ......(1.103)}$$

h) Input resistance

$$R_{of} = \frac{R_o}{1 + \beta R_m} \quad \text{... (1.104)}$$

where $R_m = \lim_{R_C \to \infty} R_M$ and $R_M = \dfrac{V_o}{I_S}$

Then $R_M = \left.\frac{V_o}{I_S}\right|_{R_C \to \infty}$

$$R_m = \left.\frac{I_o R'}{I_s}\right|_{R_C = \infty} \quad (\because V_0 = I_0 R')$$

$$R_m = \frac{I_o R'}{I_s}$$

$$R'_{of} = R_{of} \parallel R_C \quad \text{(or)} \quad R'_{of} = \frac{R'_0}{D} \qquad \dots (1.105)$$

where $R_o' = R' \parallel R_C$

1.12 DETERMINING THE LOOP GAIN

Generally, "Open-loop analysis with equivalent loading" method is used to *Finding Loop Gain*.

Open-loop analysis with equivalent loading

1) Remove the external source
2) Break the loop with equivalent loading.
3) Provide test signal V_t.
4) Loop gain: $A\beta = -\frac{V_r}{-V_t}$

Equivalent method for determining loop gain

1) Usually convenient to employ in simulation
2) Remove the external source.
3) Break the loop.
4) Provide test signal V_t
5) Find the open-circuit voltage transfer function T_{oc}
6) Find the short-circuit current transfer function T_{sc}
7) Loop gain: $A\beta = -\frac{V_r}{-V_t}$ From figure 1.35(c), $A\beta$ is obtained by,

$$A\beta = \frac{-\left\{R_L \parallel \left[R_2 + R_1 \parallel (R_{id} + R)\right]\right\}}{\left\{R_L \parallel \left[R_2 + R_1 \parallel (R_{id} + R)\right]\right\} + r_0} \; \frac{R_1 \parallel (R_{id} + R)}{R_1 \parallel (R_{id} + R) + R_2} \; \frac{R_{id}}{R_{id} + R}$$

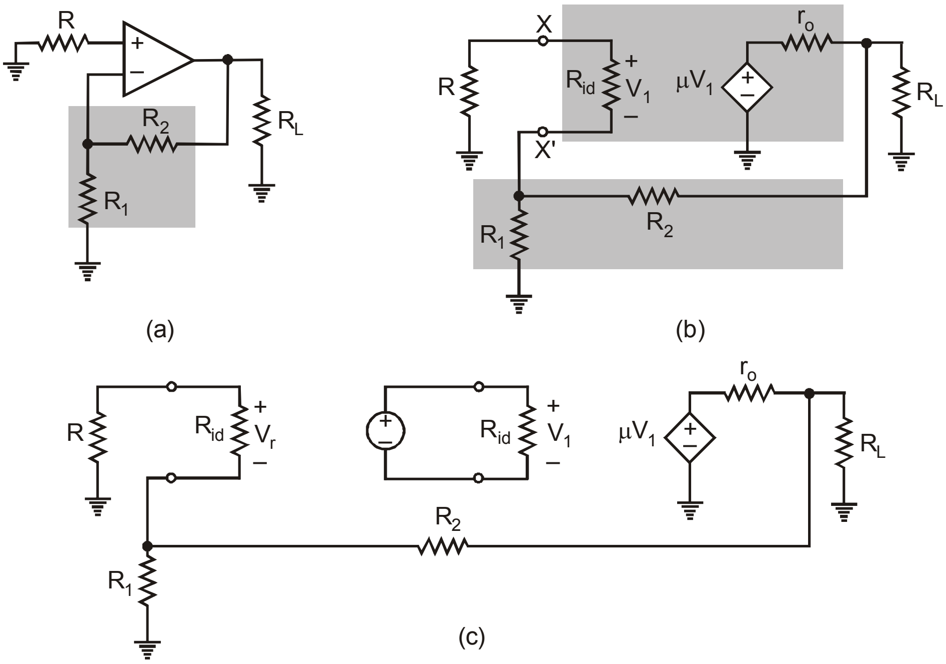


Figure 1.35: Equivalance of circuits from feedback-loop point of view

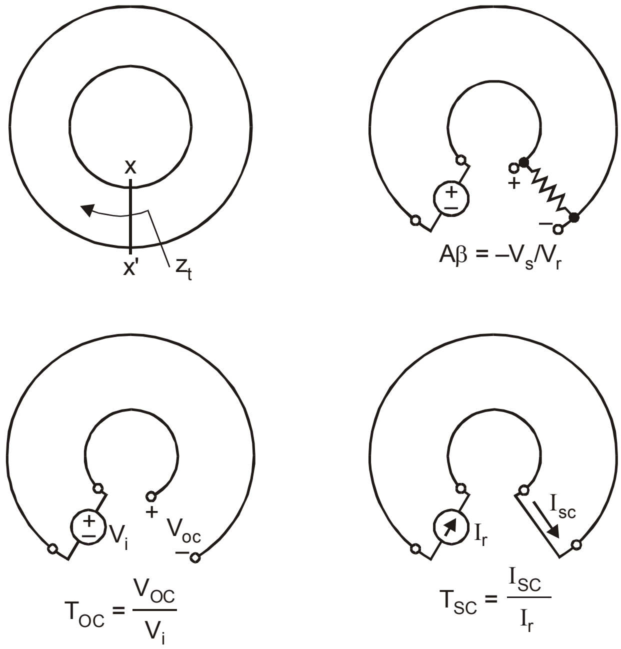


Figure 1.36: Alternative approach of finding loop gain

1.12.1 Characteristic Equation

- The gain of a feedback amplifier can be expressed as a transfer function (function of s) by taking the frequency-dependent properties into consideration.
- The denominator determines the poles of the system and the numerator defines the zeros.
- From the study of circuit theory that the poles of a circuit are independent of the external excitation.
- The poles or the natural modes can be determined by setting the external excitation to zero.
- The characteristic equation and the poles are completely determined by the loop gain.
- A given feedback loop may be used to general a number of circuits having the same poles but different transmission zero's.
- The closed-loop gain and the transmission zero's depend on how and where the input signal is injected intothe loop.

1.13 THE STABILITY PROBLEM

For positive feedback amplifier ($|1+A\beta| < 1$), the resultant transfer function $A_f > A$, the nominal gain without feedback, since $|A_f| = |A|/|1+A\beta| > |A|$.Regeneration as an effective means of increasing amplification of amplifier reduces the stability of positive feedback amplifier.

In negative feedback amplifier ($|1+A\beta| > 1$), the feedback signal was opposite to the input signal in the mid frequency range of operation. The gain A and phase shift of an amplifier change with frequency. The gain gets decreased at low and high frequencies from the mid frequency value. When the phase shift changes at high frequencies, the some of feedback adds to the input signal. Due to positive feedback, breaks out into oscillation at some high or low frequencies.

Positive feedback amplifier reduces the stability of amplifier while negative feedback Amplifier increases the stability of amplifier.

1.13.1 Condition for stability

If the amplifier is designed to have negative amplifier in a particular frequency range and oscillates at some high or low frequency, it is no longer useful as an amplifier. Hence , the feedback amplifier should designed properly in such a way that the circuit is stable at all frequencies and not merely over the frequency range of intrest.

- A system is stable, if a transient disturbance results in a response which dies out.
- A system is unstable, if a transient disturbance persists indefinitely or increases until it is limited only by some nonlinearity in the circuit.

If a pole exists with positive real part, this will result in a disturbance increasing exponentially with time. Hence condition must be satisfied ,

- If a system is to be stable, the poles of transfer function must all lie in the left-hand half of the complex frequency plane.
- If a system without feedback is stable, the poles of A do lie in the left-hand half plane.

Therefore the stability condition requires that the zeros of $1+A\beta$ all lie in the left-hand half of the complex-frequency plane.

1.13.2 Transfer function of Feedback Amplifier

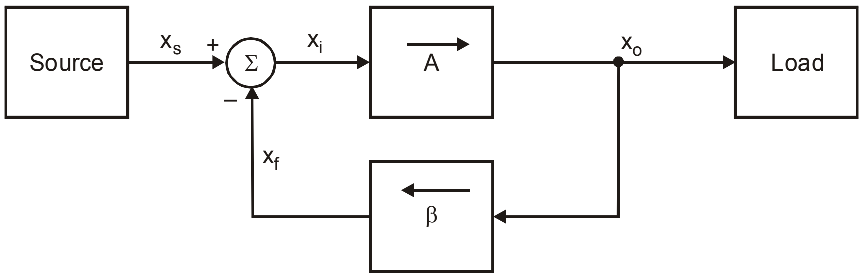


Figure 1.37: Feedback block

Consider open-loop transfer function is A(s) and feedback transfer function is β(s) and closed-loop transfer function A_f (s) as shown in figure 1.37.

$$A_f(s) = \frac{A(s)}{1 + A(s)\beta(s)} \qquad \text{... (1.106)}$$

Since $s = j\omega$ $\quad A_f(j\omega) = \dfrac{A(j\omega)}{1 + A(j\omega)\beta(j\omega)}$ ... (1.107)

Then the Loop Gain is $L(j\omega) = A(j\omega)\beta(j\omega) = |A(j\omega)\beta(j\omega)|e^{j\phi(\omega)}$

Suppose that there is a frequency, ω_{180}, for which

Then $\phi(\omega_{180}) = 180° \Rightarrow e^{j\phi(\omega_{180})} = e^{j180°} = -1$

$$A_f(j\omega) = \frac{A(j\omega)}{1-|A(j\omega)\beta(j\omega)|} \quad \text{... (1.108)}$$

❒ If $|A(j\omega)\beta(j\omega)| < 1$ then $|A_f(j\omega)| > |A(j\omega)|$

- It becomes positive feedback
- The feedback amplifier is still stable

❒ If $|A(j\omega)\beta(j\omega)| \rightarrow 1$ Then $|A_f(j\omega)| \rightarrow \infty$

- The amplifier will have an output for zero input (oscillation)

❒ If $|A(j\omega)\beta(j\omega)| \rightarrow 1$ Then $|A_f(j\omega)| \rightarrow \infty$

Oscillation with a growing amplitude at the output.

1.13.3 Nyquist criterion

Nyquist method is used to investigate stability.Nyquist diagram is used to plot gain and phase shift as a function of frequency on complex plane. Since the product $A\beta$ is a complex number and function of frequency in complex plane are obtained for the values of $A\beta$ corresponding to values of f from $-\infty$ to $+\infty$.The locus of all these poles forms a closed curve.

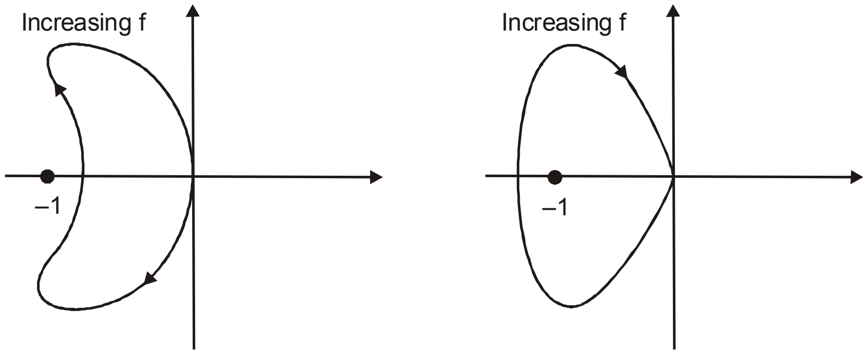
Nyquist criterion for the stability states that an amplifier is unstable if the Nyquist curve encloses the $-1+j0$ point, and the amplifier is stable if the curve does not enclose this point as shown below.

Nyquist criterion also represents in the complex plane for positive and negative feedback. As shown in figure 1.38, $|1+A\beta|=1$ represnts a circle of unit radius, with the center at $-1 + j0$ point.

For any frequency, if $A\beta$ extends outside the circle, the feedback is negative i.e., $|1 + A\beta| > 1$. If $A\beta$ lies within this circle, then $|1 + A\beta| < 1$, and the feedback is positive.

If the locus $A\beta$ does not encloses the point $-1 + j0$, i.e, $|1 + A\beta| > 1$, then the amplifier is stable and the feedback is negative for all frequencies.

Feedback amplifier is stable if the loop gain $A\beta$ is less than unity (0 dB) when its phase angle is 180°.



(a) Stable (b) Unstable

Nyquist plot showing stability conditions

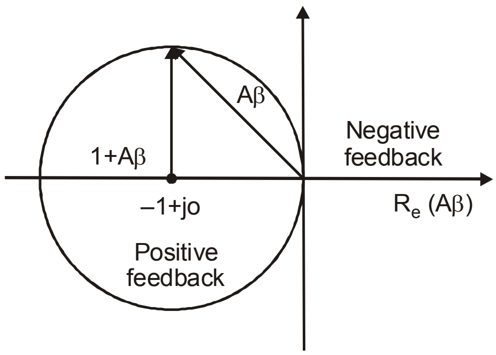


Figure 1.38: The locus of |1+Aβ| = 1 representing the type of Amplifier

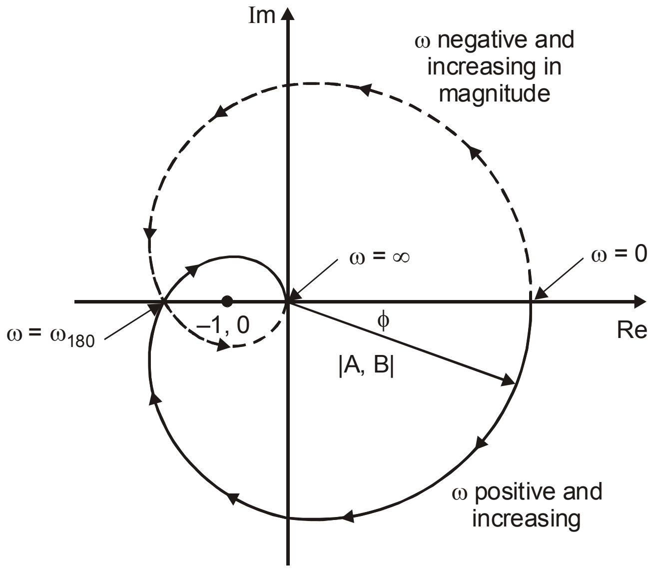


Figure 1.39: The plot does not encircle the point (–1, 0)

1.14 EFFECT OF FEEDBACK ON AMPLIFIER BANDWIDTH

The transfer gain of Amplifier employing feedback is

$$A_f = \frac{A}{1+\beta A}, \quad \text{If } |\beta A| >> 1, \quad \text{then } A_f = \frac{A}{1+\beta A} = \frac{1}{\beta} \qquad \text{... (1.109)}$$

From equation (1.109), we come to know that the transfer gain may be made to depend entirely on feedback network β.

Stability and pole Location

Consider an amplifier with a pole pair at $S = \sigma_o \pm jw_o$. The transient response contains the terms of the form

$$V(t) = e^{\sigma_0 t}[e^{j\omega_n t} + e^{-j\omega_n t}] = 2e^{\sigma_0 t}\cos(\omega_n t)$$

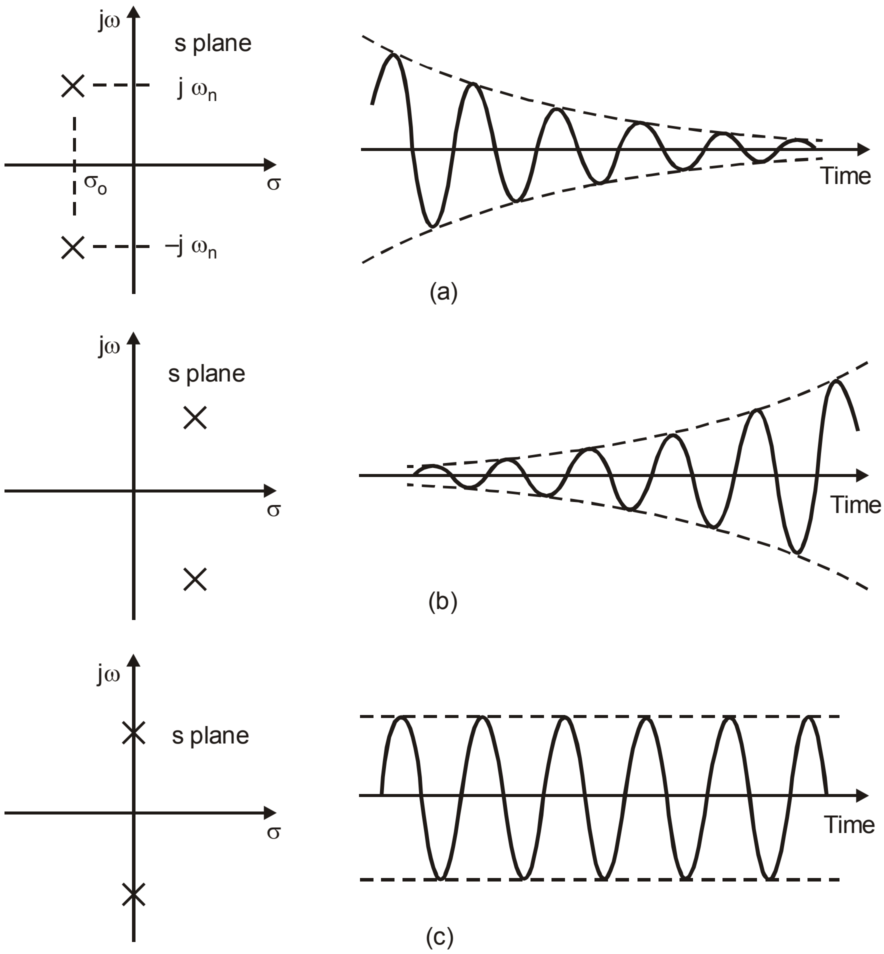


Figure 1.40: Relationship between pole location and transient response

1.14.1 Pole of Feedback Amplifier

Transfer function of feedback amplifier is

$$A_f(s) = \frac{A(S)}{1+A(S)\beta(S)} \quad \text{... (1.110)}$$

Feedback amplifier poles are obtained by solving characterisitic equation, that

$$1 + A(S)\beta(S) = 0 \quad \text{... (1.111)}$$

1.14.2 Amplifier with Single Response

Gain A of single pole amplifier is

$$A = \frac{A_o}{1+j\left(\frac{f}{f_H}\right)} \quad \text{... (1.112)}$$

where A_o is midband gain without feedback (real and negative)

$$f_H = \text{High 3-dB frequency}$$

Substitute equation (1.112) in equation (1.109), then the gain with feedback is,

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

$$\Rightarrow \quad \frac{\dfrac{A_o}{1+j\left(\frac{f}{f_H}\right)}}{1+\beta\left(\dfrac{A_o}{1+j\left(\frac{f}{f_H}\right)}\right)} = \frac{\dfrac{A_o}{1+j\left(\frac{f}{f_H}\right)}}{\dfrac{1+j\left(\frac{f}{f_H}\right)+A_o\beta}{1+j\left(\frac{f}{f_H}\right)}}$$

$$= \frac{A_o}{1+A_o\beta+j\left(\frac{f}{f_H}\right)} \quad \text{... (1.113)}$$

Divide equation by numerator and denominator by $1+A_o\beta$,

$$A_f = \frac{\dfrac{A_o}{1+A_o\beta}}{\dfrac{1+A_o\beta+j\left(\frac{f}{f_H}\right)}{1+A_o\beta}} \Rightarrow \frac{A_{of}}{1+j\left(\frac{f}{f_{Hf}}\right)} \quad \text{... (1.114)}$$

where $A_{of} = \dfrac{A_o}{1+\beta A_o}$ and $f_{Hf} = f_H(1+\beta A_o)$ ... (1.115)

Midband amplification with feedback A_{of} equals the midband amplification without feedback A_o divided by $(1+A\beta_o)$.

The low 3dB frequency with feedback f_{Lf} is decreased by same factor as,

$$f_{Lf} = \frac{f_L}{1+\beta A_o} \quad \text{... (1.116)}$$

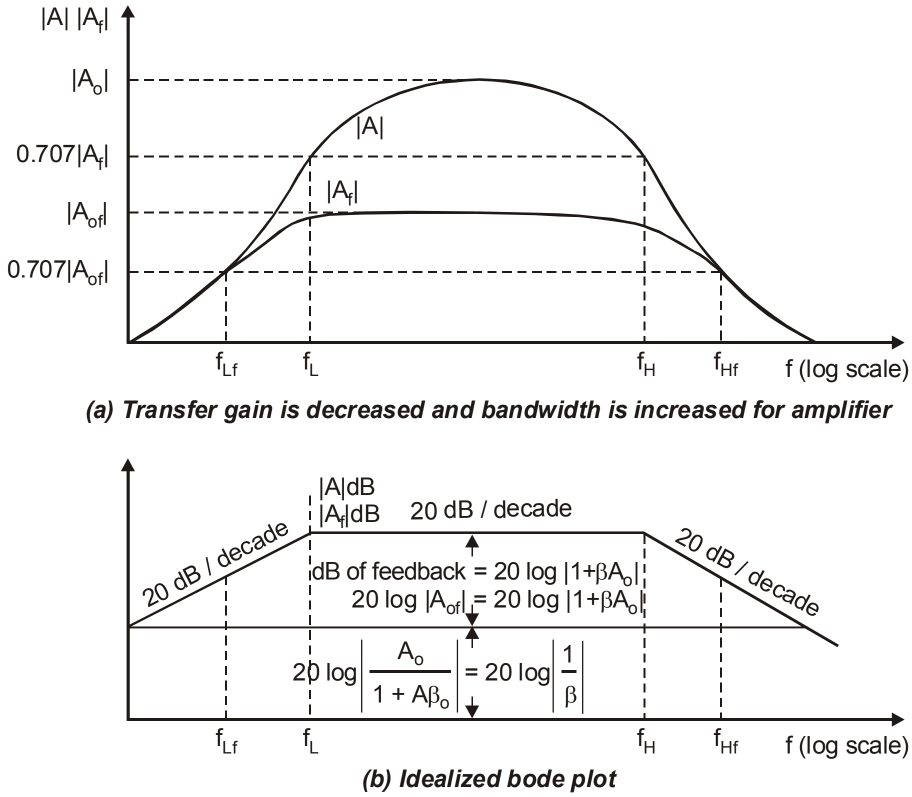


Figure 1.41

The gain frequency product has not been changed by feedback because

$$A_{of} f_{Hf} = A_o f_H \quad \text{... (1.117)}$$

Pole moves away from origin in the S- plane as feedback (β) increases. Bandwidth is extended by feedback at cost of reduction in gain.

1.14.3 Amplifier with two - pole response

Let us consider the circuit where the basic amplifier without feedback has two poles on negative real axis at $s_1 = -\omega_1$, and $s_2 = -\omega_2$ where ω_1 and ω_2 are positive.

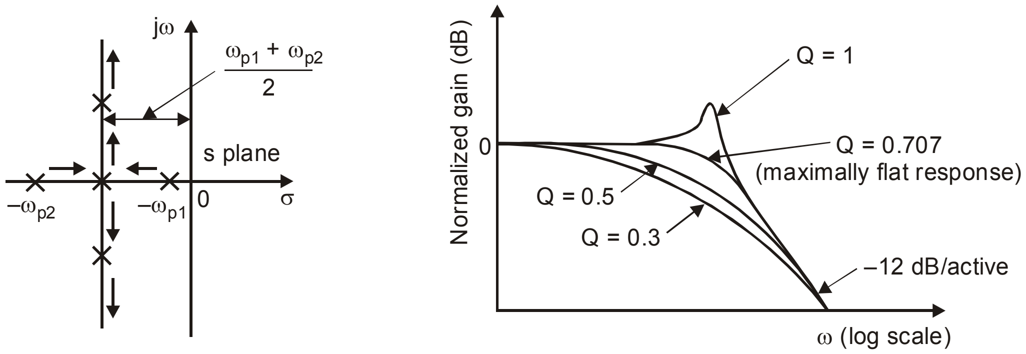


Figure 1.42: Amplifier without feedback with 2 poles on –ve real axis

If the midband gain is A_o, the transfer gain is

$$A = \frac{A_o}{\left(1-\frac{S}{S_1}\right)\left(1-\frac{S}{S_2}\right)} \Rightarrow \frac{A_o}{\left(1+\frac{S}{\omega_1}\right)\left(1+\frac{S}{\omega_2}\right)}$$

Substitute above equation in equation (1.109) the gain with feedback is given by,

$$A_f = \frac{A}{1+\beta A} = \frac{\dfrac{A_o}{\left(1+\frac{S}{\omega_1}\right)\left(1+\frac{S}{\omega_2}\right)}}{1+\beta\left[\dfrac{A_o}{\left(1+\frac{S}{\omega_1}\right)\left(1+\frac{S}{\omega_2}\right)}\right]} \Rightarrow \frac{A_o}{\left(1+\frac{S}{\omega_1}\right)\left(1+\frac{S}{\omega_2}\right)+A_o\beta}$$

$$\Rightarrow \frac{A_o}{\dfrac{S^2+S(\omega_1+\omega_2)+\omega_1\omega_2}{\omega_1\omega_2}+A_o\beta}$$

$$= \frac{A_o\omega_1\omega_2}{S^2+S(\omega_1+\omega_2)+\omega_1\omega_2+A_o\beta\omega_1\omega_2}$$

$$= \frac{A_o\omega_1\omega_2}{S^2+S(\omega_1+\omega_2)+\omega_1\omega_2(1+A_o\beta)}$$

Consider the part

$$= \left(1+\frac{S}{\omega_1}\right)\left(1+\frac{S}{\omega_2}\right)$$

$$= 1+\frac{S}{\omega_1}+\frac{S}{\omega_2}+\frac{S^2}{\omega_1\omega_2}$$

$$= \frac{S^2+S(\omega_1+\omega_2)+\omega_1\omega_2}{\omega_1\omega_2}$$

The characteristic equation

$$S^2 + S(\omega_1 + \omega_2) + \omega_1\omega_2 (1 + A_o\beta) = 0 \qquad \text{... (1.118)}$$

The closed loop poles are given by

$$S = -\frac{1}{2}(\omega_1 + \omega_2) \pm \frac{1}{2}\sqrt{(\omega_1 + \omega_2)^2 - 4(1 + A_o)\beta\omega_1\omega_2} \qquad \text{... (1.119)}$$

Plot of pols verses β is called *Root - Locus diagram.*

Note for all positive values of $A\beta_o$, the transfer function has poles which remain in left hand s plane. Therefore the negative feedback amplifier is stable; independent of amount of feedback.

1.14.4 Amplifier with three or more poles

In previous section, we verified that the feedback amplifier transfer function always has poles which lie in the left - hand plane. *In 3 pole transfer function, if the loop gain is sufficiently large, the poles of feedback amplifier move into right hand place and thus circuit become unstable.*

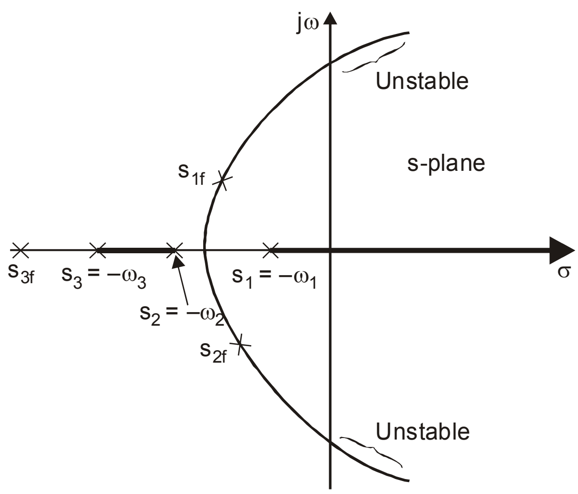


Figure 1.43: Root locus of 3-pole transfer function in S-plane

Let us consider the 3 pole $S_1 = -\omega_1$, $S_2 = -\omega_2$, $S_3 = -\omega_3$.

If the midband gain is A_o, the open loop transfer gain is

$$A(S) = \frac{A_o}{\left(1-\frac{S}{S_1}\right)\left(1-\frac{S}{S_2}\right)\left(1-\frac{S}{S_3}\right)} \Rightarrow \frac{A_o}{\left(1+\frac{S}{\omega_1}\right)\left(1+\frac{S}{\omega_2}\right)\left(1+\frac{S}{\omega_3}\right)}$$

Substitute above equation in equation (1.109), the gain with feedback is given by,

$$A_{f(S)} = \frac{A_{(S)}}{1+\beta A_{(S)}} = \frac{\dfrac{A_o}{\left(1+\dfrac{S}{\omega_1}\right)\left(1+\dfrac{S}{\omega_2}\right)\left(1+\dfrac{S}{\omega_3}\right)}}{1+\beta\left[\dfrac{A_o}{\left(1+\dfrac{S}{\omega_1}\right)\left(1+\dfrac{S}{\omega_2}\right)\left(1+\dfrac{S}{\omega_3}\right)}\right]}$$

$$\Rightarrow \frac{A_o}{\left(1+\dfrac{S}{\omega_o}\right)^3 + a_2\left(1+\dfrac{S}{\omega_o}\right)^2 + a_1\left(1+\dfrac{S}{\omega_o}\right)+1} \qquad \text{... (1.120)}$$

where A_{of} = midband gain with feedback.

$$\omega_{o3} = \omega_1\omega_2\omega_3(1+A\beta_o)$$

$$= \frac{(\omega_1+\omega_2)+\omega_2\omega_3+\omega_1\omega_3}{\omega_0^{\;2}}$$

$$a_2 = \frac{\omega_1+\omega_2+\omega_3}{\omega_0}$$

The stability of feedback amlifier is determined by poles its transfer function.

The characteristics equation

$$\left(\frac{S}{\omega_o}\right)^3 + a_2\left(\frac{S}{\omega_o}\right)^2 + a_1\left(\frac{S}{\omega_o}\right)+1 = 0 \qquad \text{... (1.121)}$$

Feedback amplifier is stable only if β does not exceed a maximum value.

1.15 FREQUENCY COMPENSATION

Frequency compensation modifies the open-loop transfer function A(s) of an amplifier (with three or more poles) so that the closed-loop transfer function $A_f(s)$ is stable for any value chosen for the closed-loop gain. Compensation techniques reduce the amplifier gain A at those frequencies for which phase shift is high.

The essential idea of compensation is to reshape the magnitude and phase plots of $A\beta$ so that $|A\beta| < 1$ when the angle of $A\beta$ is 180°.

Key points of Frequency compensation

- The simplest method of frequency compensation modifies the original open-loop transfer function, $A(j\omega)$, by introducing a new low frequency pole at ω_D to form a new open-loop transfer function, $A'(j\omega)$, which has a slope of -20 dB/decade at the intersection of the 20 $\log_{10}|A'(j\omega)|$curve and the 20 $\log_{10}(1/\beta)$ curve.

Disadvantages of Adding New poles

The disadvantage of introducing a new pole at lower frequency is the significant bandwidth reduction.

Alternatively, the dominant pole can be shifted to a lower frequency f'_D such that the amplifier is compensated without introducing a new pole.

1.15.1 Types of compensation

In applications where one desires large bandwidth and lower closer loop gain, suitable compensation techniques are used.

1. Dominant-pole or lag compensation

This method inserts an extra pole into the transfer function at a lower frequency than the existing poles. Such a circuit introduces a phase lag into the amplifier.

2. Lead compensation

Amplifier or feedback network is modified so as to add a zero to the transfer function, thereby increasing the phase.

3. Pole-zero, or lag-lead compensation

It adds both a pole(a lag) and a zero (a lead) to the transfer gain. The zero is chosen so as to cancel the lowest pole.

1.15.2 Dominant Pole Compensation

Suppose A is the uncompensated trasfer function feedback amplifier in open loop condition. Introduce a dominant pole by adding RC network in series with feedback amplifier, or by connecting capacitor C from suitable high resistance to ground function. Then the compensated transfer function becomes A′.

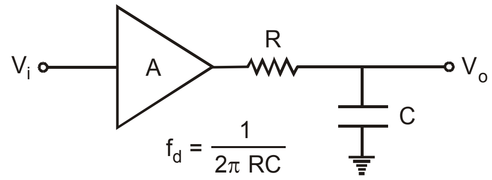


Figure 1.44: Domain Pole Compensation

$$A' = \frac{V_o}{V_i}$$

$$A = \frac{\frac{-j}{\omega c}}{1-\frac{j}{\omega c}} = \frac{A}{1+j\left(\frac{f}{f_d}\right)}$$

where $f_d = \frac{1}{2\pi Rc} < 1$ MHz

$$A = \frac{A_{oL}\omega_1\omega_2}{(S+\omega_1)(S+\omega_2)} = 0 < f_1 < f_2$$

The capitance C is choosen so that the modified loop gain drops to 0dB with a slop of 20dB/ decade at a frequency where poles of uncompensated transfer function A contributes negligible phase shift usually $f_d = \frac{\omega_d}{2\pi}$ is selected so that the compensated transfer function A^1 passes through 0dB at the f_1 of uncompensated A.

Disadvantage of Domain Pole Compensation

- It reduces open - loop bond width drastically.

Advantage of Domain Pole Compensation

- Noise immunity is improved since noise frequency component outside the bandwidth are eliminated.

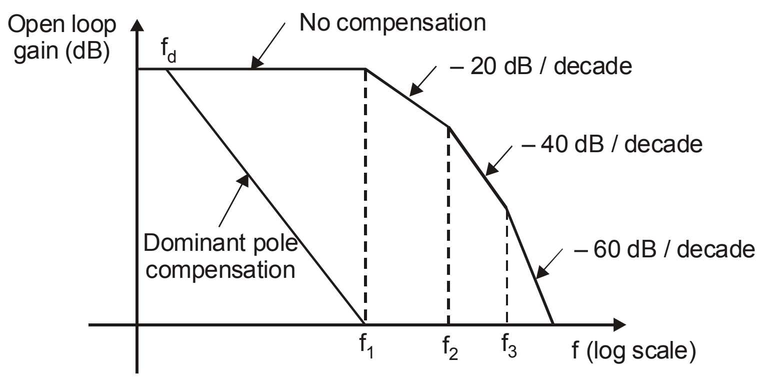


Figure 1.45: Dominant pole compensation

1.15.3 Pole Zero compensation

Here uncompensated transfer function A is altered by adding both pole and a zero shown in figure 1.46. The zero should be at high frequency than pole.

The transfer function of compensatory network alone.

$$\frac{V_o}{V_2} = \frac{Z_2}{Z_1 + Z_2} = \frac{R_2}{R_1 + R_2}\frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_o}}$$

where $Z_1 = R_1$, $Z_2 = R_2 + \frac{1}{jwC_2}$, $f_1 = \frac{1}{2\pi R_2 C_2}$ and $f_o = \frac{1}{2\pi(R_1 + R_2)C_2}$

The compensating network is designed to produce a zero at the first corner frequency f_1 of the uncompensated transfer function A. This zero will cancel effect of pole at F_1.

The pole of compensating network at $f_o = \frac{w_o}{2\pi}$ is selected so that the compensated transfer function A^1 passes through 0dB at 2nd corner frequency f_2 of the uncompensated transfer function A.

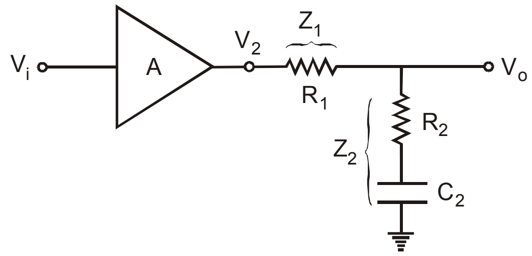


Figure 1.46: Pole zero compensation

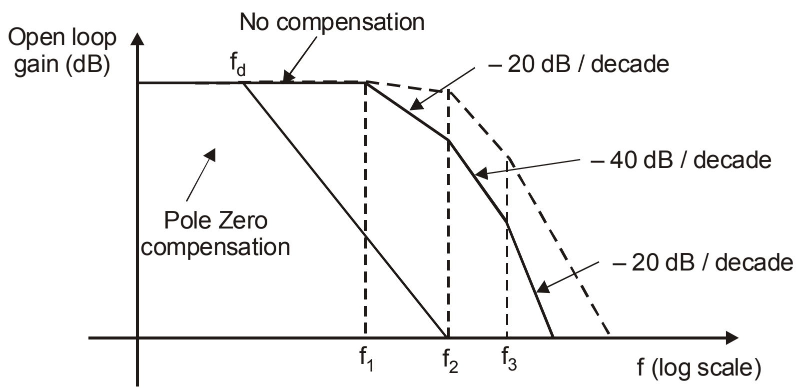


Figure 1.47: Zero compensation

Assuming that the compensating network does not load the amplifier i.e. $R_2 >> R_1$, then the overall transfer function becomes,

$$A' = \frac{V_o}{V_i} = \frac{V_o}{V_2} = \frac{V_2}{V_i}$$

$$= A\frac{R_2}{R_1+R_2}\frac{1+j\frac{f}{f_1}}{1+j\frac{f}{f_o}} \qquad \therefore \frac{V_2}{V_i} = A$$

$$= \frac{A}{\left(1+j\frac{f}{f_1}\right)\left(1+j\frac{f}{f_2}\right)\left(1+j\frac{f}{f_3}\right)}\frac{R_2}{R_1+R_2}\frac{1+j\frac{f}{f_1}}{1+j\frac{f}{f_o}}$$

$$A' = \frac{A}{\left(1+j\frac{f}{f_0}\right)\left(1+j\frac{f}{f_2}\right)\left(1+j\frac{f}{f_3}\right)} \quad 0 < f_0 < f_1 < f_2 < f_3 \quad \text{... (1.126)}$$

Since $R_2 >> R_1$.

$$\text{So} \quad \frac{R_2}{R_1+R_2} = 1. \quad \text{... (1.127)}$$

1.15.4 Miller compensation and pole splitting

The feedback connection between output and input causes it to appear to the amplifier like a large capacitor has been inserted between the output and input terminals. This phenomenon is called the **Miller effect.**

The Miller effect allows shifting to f_{p1} and shifting f_D to a higher frequency. Stability and high open-loop gain can be obtained for $f < 10^3$Hz.

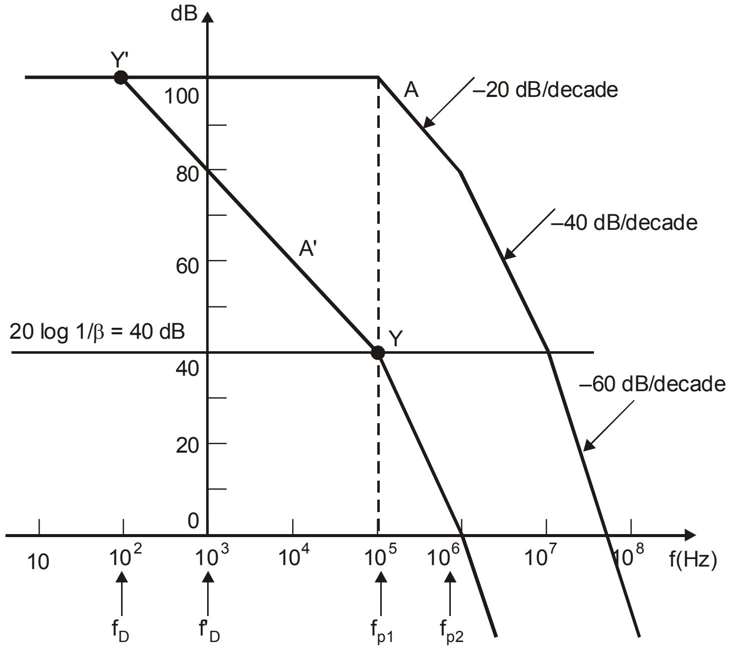


Figure 1.48: Stability for closed-loop gains of 40 dB or higher by adding a new pole at ω_D

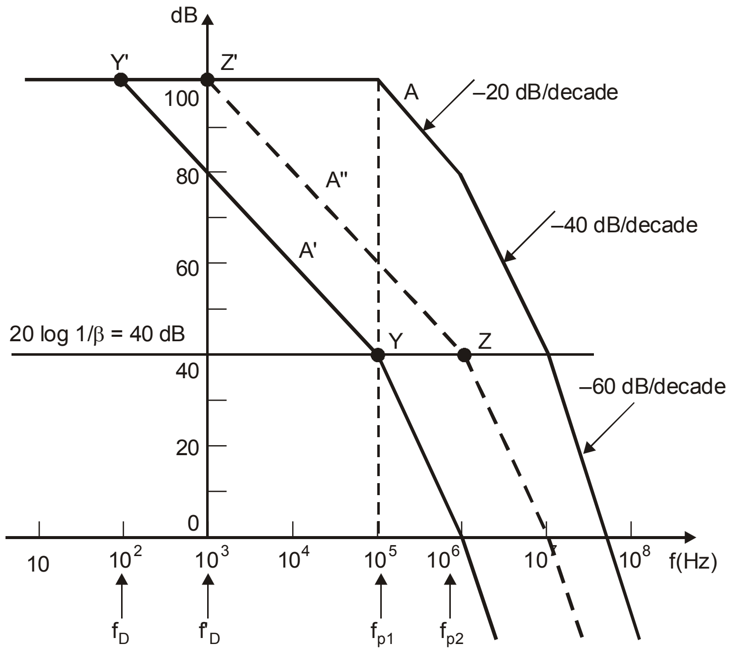


Figure 1.49: Frequency compensation for f = 10^{-2}. The response labeled A' is obtained by introducing an additional pole at fD. The A" response is obtained by moving the original low-frequency pole to f'D.

Increase the time-constant of the dominant pole by adding additional capacitance

Add external capacitance C_C at the node which contributes to a dominant pole.

The required value of C_C is usually quite large, making it unsuitable for IC implementation.

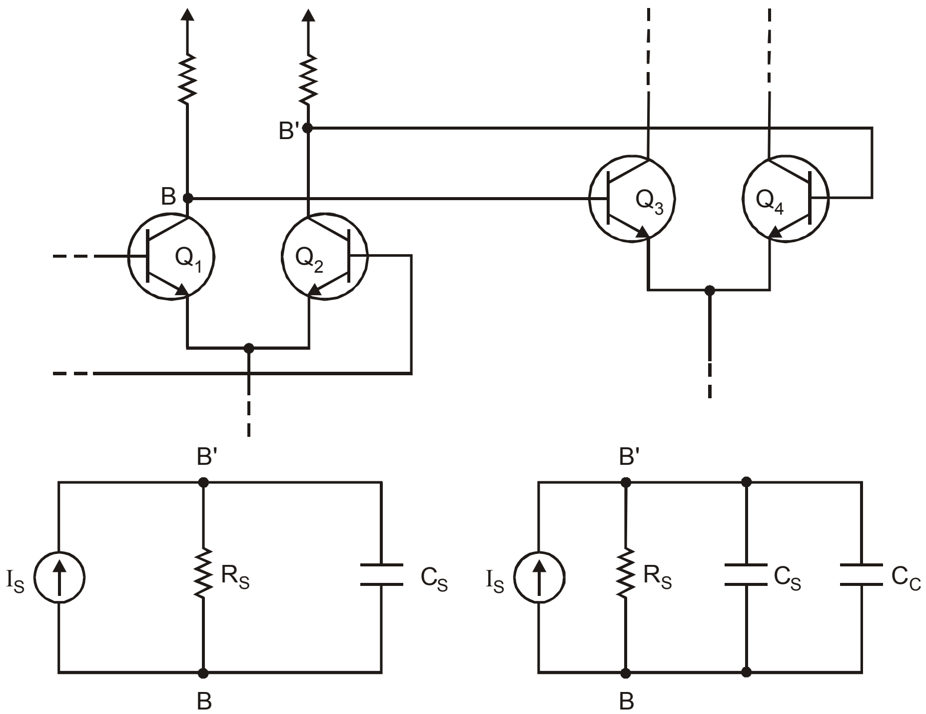


Figure 1.50: Differential Amplifier

$$f_{p1} = \frac{1}{2\pi R_x C_x} \quad \text{and} \quad f_D = \frac{1}{2\pi R_x (C_x + C_C)} \qquad \text{... (1.128)}$$

Needs of Miller

- Miller effect equivalently increase the capacitance by a factor of voltage gain.
- Use miller capacitance for compensation can reduce the need for large capacitance.

Miller effect for Two stage Amplifier

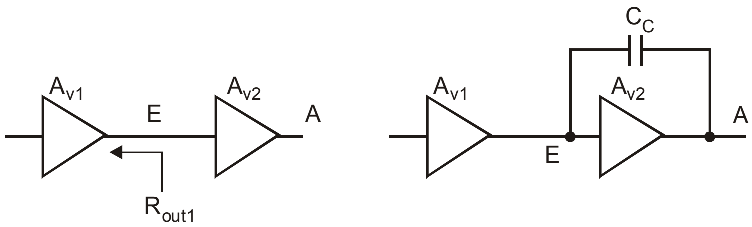


Figure 1.51: (a) Two stage Amplifier (b) Miller effect

In a two-stage amplifier as shown in figure 1.51(a), the first stage exhibits a high output impedance and the second stage provides a moderate gain, thereby providing a suitable environment for Miller multiplication of capacitors.

In figure 1.51(b), we create a large capacitance at E, the pole is As a result, a low-frequency pole can be established with a moderate capacitor value, saving considerable chip area.

$$\omega_{p,E} = \frac{1}{R_{out1}\left[C_E + (1 + A_{V2})C_C\right]} \qquad \text{... (1.129)}$$

Pole splitting:

In addition to lowering the required capacitor value, Miller compensation entails a very important property: it moves the output pole away from the origin. Pole splitting is a result of Miller compensation.

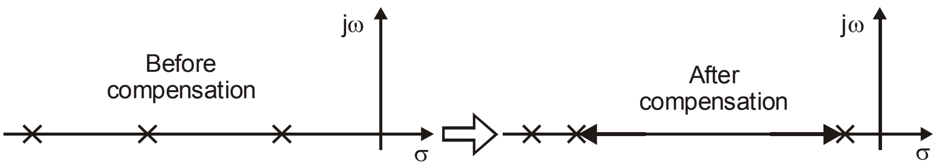


Figure 1.52: Pole splitting

Miller compensation moves the interstage pole toward the origin and the output pole away from the origin, allowing a much greater bandwidth than that obtained by merely connect the compensation capacitor from one node to ground.

Miller effect for Multistage Amplifier

The small-signal equivalent circuit of our two-stage amplifier is shown below.

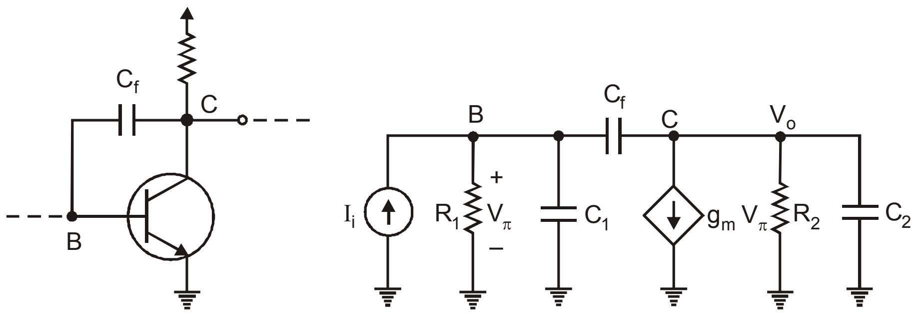


Figure 1.53: (a) A gain stage in a multistage amplifier with a compensating capacitor connected in the feedback path and (b)Equivalent circuit for tranresistance amplifier

where R_1 and R_2 represent the total small-signal output resistances of stage 1 and 2, respectively - drain source resistances of the MOSFETS, bias current sources etc.

C_1 and C_2 represent the total parasitic capacitances on the input and output.

Using the small-signal equivalent circuit above, we can examine the effect of C_f on the poles of the two-stage amplifier circuit.

The pole frequencies in the absence of C_f

In the absence of the compensating capacitor C_f, there are two poles - one at the input and one at the output. Two poles are ω_{p1} and ω_{p2}:

$$\omega_{p1} = \frac{1}{R_1C_1} \text{ (or) } f_{p1} = \frac{1}{2\pi R_1C_1} \text{ and } \omega_{p2} = \frac{1}{R_2C_2} \text{ (or) } f_{p1} = \frac{1}{2\pi R_2C_2} \quad \text{... (1.130)}$$

The new pole frequencies including C_f

Applying Kirchoff's current law to the input and output node in the figure 1.53 with C_f present, then the expression for the voltage gain:

At Base B:

$$-I_i + \frac{V_B}{R_1} + sC_1V_B + sC_f\left(V_B - V_C\right) = 0$$

At Collector C:

$$sC_f\left(V_C - V_B\right) + g_m V_B + \frac{V_C}{R_2} + sC_2V_C = 0$$

Collect Terms:

$$V_B\left[-s\,C_f + g_m\right] + V_C\left[s\,C_f + \frac{1}{R_2} + s\,C_2\right] = 0$$

$$V_B\left[\frac{1}{R_1} + s\,C_1 + s\,C_f\right] + V_C\left[-s\,C_f\right] = I_i$$

Then

$$\frac{V_0}{I_i} = \frac{\left(s\,C_f - g_m\right)R_1\,R_2}{1 + s\left[C_1\,R_1 + C_2\,R_2 + C_f\left(g_m\,R_1\,R_2 + R_1 + R_2\right)\right] + s^2\left[C_1\,C_2 + C_f\left(C_1 + C_2\right)\right]R_1\,R_2}$$

... (1.131)

The characteristics equation are

$$D(s) = 1 + s\left[C_1\,R_1 + C_2\,R_2 + C_f\left(g_m\,R_1\,R_2 + R_1 + R_2\right)\right] + s^2\left[C_1\,C_2 + C_f\left(C_1 + C_2\right)\right]R_1\,R_2$$

... (1.132)

$$\mathrm{D(s)} = \left(1 + \frac{\mathrm{s}}{\omega'_{\mathrm{P1}}}\right)\left(1 + \frac{\mathrm{s}}{\omega'_{\mathrm{P2}}}\right) = 1 + \mathrm{s}\left(\frac{1}{\omega'_{\mathrm{P1}}} + \frac{1}{\omega'_{\mathrm{P2}}}\right) + \frac{\mathrm{s}^2}{\omega'_{\mathrm{P1}}\,\omega'_{\mathrm{P2}}} \qquad \text{... (1.133)}$$

Suppose one pole is dominant $\omega'_{P1} << \omega'_{P2}$

Then $D(s) \approx 1 + \dfrac{s}{\omega'_{P1}} + \dfrac{s^2}{\omega'_{P1}\,\omega'_{P2}}$ ... (1.134)

Calculation of ω'_{P1}:

By comparing equation (1.32) and (1.34),

$$\omega'_{P1} = \frac{1}{C_1\,R_1 + C_2\,R_2 + C_f\left(g_m\,R_1\,R_2 + R_1 + R_2\right)}$$

Logarithmic differentiation is,

$$\ln\left(\omega'_{P1}\right) = -\ln\left(C_1\,R_1 + C_2\,R_2 + C_f\left(g_m\,R_1\,R_2 + R_1 + R_2\right)\right)$$

$$\frac{1}{\omega'_{P1}}\frac{d\omega'_{P1}}{dC_f} = -\frac{g_m\,R_1\,R_2 + R_1 + R_2}{C_1\,R_1 + C_2\,R_2 + C_f\left(g_m\,R_1\,R_2 + R_1 + R_2\right)} < 0 \qquad \text{.. (1.135)}$$

Thus, $\dfrac{d\omega'_{P1}}{dC_f} < 0$, so the Miller capacitor lowers the frequency of the lower frequency pole.

Calculation of ω'_{P2}:

By comparing equation (1.132) and (1.134), we get

$$\frac{1}{\omega'_{P1}\,\omega'_{P2}} = \left[C_1 C_2 + C_f\left(C_1 + C_2\right)\right] R_1 R_2$$

$$\omega'_{P2} = \frac{1}{\omega'_{P1}\left[C_1 C_2 + C_f\left(C_1 + C_2\right)\right] R_1 R_2} \qquad \text{... (1.136)}$$

Then the logarithmic differentiation is

$$\ln\left(\omega'_{P2}\right) = -\ln\left(\omega'_{P1}\right) - \ln\left(C_1 C_2 + C_f\left(C_1 + C_2\right)\right) - \ln\left(R_1 R_2\right)$$

$$\frac{1}{\omega'_{P2}}\frac{d\omega'_{P2}}{dC_f} = -\frac{1}{\omega'_{P2}}\frac{d\omega'_{P1}}{dC_f} - \frac{C_1 + C_2}{C_1 C_2 + C_f\left(C_1 + C_2\right)}$$

$$\frac{1}{\omega'_{P2}}\frac{d\omega'_{P2}}{dC_f} = -\left(-\frac{g_m R_1 R_2 + R_1 + R_2}{C_1 R_1 + C_2 R_2 + C_f\left(g_m R_1 R_2 + R_1 + R_2\right)}\right) - \frac{C_1 + C_2}{C_1 C_2 + C_f\left(C_1 + C_2\right)}$$

$$\frac{C_f}{\omega'_{P2}}\frac{d\omega'_{P2}}{dC_f} = \frac{C_f\left(g_m R_1 R_2 + R_1 + R_2\right)}{C_1 R_1 + C_2 R_2 + C_f\left(g_m R_1 R_2 + R_1 + R_2\right)} - \frac{C_f\left(C_1 + C_2\right)}{C_1 C_2 + C_f\left(C_1 + C_2\right)}$$

Note: $\dfrac{C_f\left(g_m R_1 R_2 + R_1 + R_2\right)}{C_1 R_1 + C_2 R_2 + C_f\left(g_m R_1 R_2 + R_1 + R_2\right)} < 1$ and $\dfrac{C_f\left(C_1 + C_2\right)}{C_1 C_2 + C_f\left(C_1 + C_2\right)} = \dfrac{1}{\dfrac{1}{C_f}\dfrac{C_1 C_2}{C_1 + C_2} + 1} < 1$

For the Miller effect to be large $g_m R_2 \to \infty$.

$$\frac{C_f}{\omega'_{P2}}\frac{d\omega'_{P2}}{dC_f} = 1 - \frac{C_f\left(C_1 + C_2\right)}{C_1 C_2 + C_f\left(C_1 + C_2\right)} > 0 \qquad \text{... (1.137)}$$

The Miller effect can split the two poles, pushing the frequency of the lower one lower and pushing the higher frequency higher.

Shifting the lower frequency pole gives stability without the addition of an extra pole.

Equation 1.37 shows that increasing C_f reduces ω'_{P1} and increases ω'_{P2}. This is referred to as *pole splitting*.

Comments

1. Pole splitting is very useful: increasing C_f forces the second pole ω'_{P2} to the right, increasing the compensated open-loop gain and improving the amp's high-frequency performance.
2. In the modified expression for ω'_{P1} the effect of C_f is multiplied by the gain of stage 2:

$$A_2 = -g_{m3}R_2$$

to give the new value of ω'_{P1}, as Miller's theorem predicts. This means that the required value for C_f is much smaller than the C_C required for simple pole-shifting compensation.

Effect of C_f on slew rate

1. One drawback of adding a compensating capacitor in this way is that it slows the slew rate.
2. The slew rate of an amplifier is the maximum rate of change of vout in response to vin.
3. The slower slew rate is especially noticeable when we apply widely-swinging input voltages that are changing rapidly (high frequency).

SOLVED PROBLEMS

Based on Negative Feedback

EXAMPLE 1

Determine the gain with feedback for the amplifier with open loop gain of 300 and feedfack factor of 0.1. (NOV / DEC - 2009)

Solution:

$$A_{vf} = \frac{A_v}{1+\beta A_v} = \frac{300}{1+0.1\times 300} = 9.677$$

EXAMPLE 2

An amplifier has an open-loop gain of 1000 and a feedback ratio of 0.04. If the open loop gain changes by 10% due to temperature, find the percentage change in gain of the amplifier with feedback.

Solution:

Given:

$$A = 1000,\ \beta = 0.04 \text{ and } \frac{dA}{A} = 10$$

We know that the percentage change in gain of the amplifier with feedback is,

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

$$= 10 \times \frac{1}{1 + 1000 \times 0.04} = 0.25\%$$

EXAMPLE 3

A voltage series feedback amplifier has a voltage gain with feedback as 83.33 and feedback ratio as 0.01. Calculate the voltage gain of the amplifier without feedback.

(NOV / DEC - 2006)

Solution:

Given:

$$A_{vf} = 83.33, \quad \beta = 0.01$$

We know that, $$A_{vf} = \frac{A}{1 + A\beta}$$

$$\therefore \quad 83.33 = \frac{A}{1 + 0.01A}$$

$$\therefore \quad 83.33 + 0.8333\ A = A$$

$$\therefore \quad A = \mathbf{500}$$

The voltage gain of the amplifier without feedback is 500.

EXAMPLE 4

An amplifier has a voltage gain of 1000. With negative feedback, the voltage gain reduces to 10. Calculate the fraction of the output, that is feedback to the input.
(MAY / JUNE - 2007)

Solution:

Given:

$$A_v = \frac{A}{1 + A\beta}$$

$$10 = \frac{1000}{1 + 1000 \times \beta}$$

$$\beta = \mathbf{0.099}$$

EXAMPLE 5

The distortion in an amplifier is found to be 3%, when the feedback ratio of feedback amplifier is 0.05. When the feedback is removed, the distortion becomes 15%. Find the open loop and closed loop gain. (APR / MAY - 2005)

Solution:

$$D = 1 + A\beta = \frac{15}{3} = 5$$

$$\therefore \quad A_v = 100 \qquad \because \quad b = 0.04$$

$$A_{vf} = \frac{A_v}{D} = \frac{100}{5} = 20$$

EXAMPLE 6

The gain and distortion of an amplifier are 100 and 4% respectively. If a negative feedback with β = 0.3 is applied, find the new distortion in the system.

(NOV / DEC - 2004)

Solution:

$$D = 1 + \beta\ A_v = 1 + 0.3 \times 100 = 31$$

$$\text{Distortion} = \frac{4\%}{31} = 0.129\%$$

EXAMPLE 7

An amplifier has a midband gain of 125 and a bandwidth of 250 KHz.

1) If 4% negative feedback is introduced, find the new bandwidth and gain.

2) If the bandwidth is to be restricted to 1 MHz find the feedback ratio.

(NOV / DEC - 2006, 2011)

Solution:

Given:

A_v = 125, BW = 250 KHz and β = 0.04

1)
$$A_{vf} = \frac{A_v}{1+\beta A_v} = \frac{125}{1+0.04\times 125} = \mathbf{20.83}$$

$$BW_f = BW \times (1 + \beta A_v)$$

$$= 250 \times 10^3 \times (1 + 0.04 \times 125) = \mathbf{1.5\ MHz}$$

2) If $BW_f = \mathbf{1\ MHz}$

$$1 \times 10^6 = BW \times (1 + \beta A_v)$$

$$= 250 \times 10^3 \times (1 + \beta \times 125)$$

$$\therefore \quad \beta = \mathbf{0.024}$$

EXAMPLE 8

An amplifier has voltage gain with feedback of 100. If the gain without feedback changes by 20% and the gain with feedback should not vary more than 2%, determine the values of open loop gain A and feedback ratio β.

Solution:

Given:

$$A_f = 100, \ \frac{dA_f}{A_f} = 2\% = 0.02 \text{ and } \frac{dA}{A} = 20\% = 0.2$$

We know that $$\frac{dA_f}{A_f} = \frac{d_A}{A}\frac{1}{(1 + A\beta)}$$

$$0.02 = 0.2 \times \frac{1}{1 + A\beta}$$

Therefore, $$(1 + A\beta) = \frac{0.2}{0.02} = 10$$

Also, we know that the gain with feedback is,

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

i.e., $$100 = \frac{A}{10}$$

Therefore, $$A = 1000$$

$$1 + A\beta = 10, \text{ i.e. } A\beta = 9$$

Therefore, $$\beta = \frac{9}{1000} = 0.009$$

EXAMPLE 9

Calculate the closed loop gain of a negative feedback amplifier if its open loop gain is 100,000 and feedback factor is 0.01. (MAY - 2013)

Solution:

Given:

$$A = 100000 \text{ and } \beta = 0.01$$

$$A_{vf} = \frac{A_v}{1+A\beta} = \frac{100000}{1+100000\times 0.01} = \mathbf{99.9}$$

EXAMPLE 10

An amplifier has a midband gain of 125 and a bandwidth of 250 KHz.

(a) If 4% negative feedback is introduced, find the new bandwidth and gain.

(b) If the bandwidth is to be restricted to 1 MHz, find the feedback ratio.

Solution:

Given:

$A = 125$, $BW = 250$ kHz and $\beta = 4\% = 0.04$

a) We know that $BW_f = (1 + A\beta)BW$

$$= (1 + 125 \times 0.04) \times 250 \times 10^3$$

$$= 1.5 \text{ MHz}$$

Gain with feedback, $A_f = \frac{A}{1+A\beta} = \frac{125}{1+125\times 0.04}$

$$= \frac{125}{6} = 20.83$$

b) $BW_f = (1 + A\beta)BW$

$$1 \times 10^6 = (1 + 125\,\beta') \times 250 \times 10^3$$

Therefore, $(1 + 125\,\beta') = \frac{1\times 10^6}{250\times 10^3} = 4$

i.e. $\beta' = \frac{3}{125} = 0.024$

$$= 2.4\%$$

EXAMPLE 11

An amplifier, without feedback, has a voltage gain of 400, lower cut-off frequency f_1 = 50 Hz, upper cut-off frequency f_2 = 200 KHz and a distortion of 10%. Determine the amplifier voltage, gain, lower cut-off frequency and upper cut-off frequency and distortion, when a negative feedback is applied with feedback ratio of 0.01.

(APR / MAY - 2011, DEC - 12)

Solution:

Given:

$$\beta = 0.01,\ f_1 = 50\text{ Hz},\ f_2 = 200\text{ KHz},\ \text{distortion} = 10\%,\ \text{and } A_v = 400$$

1) $$A_{vf} = \frac{1}{1+\beta A_v} = \frac{400}{1+0.01\times 400} = \mathbf{80}$$

2) $$f_{1f} = \frac{f_1}{1+\beta A_v} = \frac{50}{1+0.01\times 400} = \mathbf{10}$$

3) $$f_{2f} = f_2 \times (1 + \beta A_v)$$
$$= 200 \times 10^3 \times (1 + 0.01 \times 400) = \mathbf{1MHz}$$

4) Distortion with feedback $$= \frac{\text{Distortion}}{1+\beta A_v} = \frac{0.1}{1+0.01\times 400}$$
$$= 0.02 = \mathbf{2\%}$$

EXAMPLE 12

Addition negative feedback to an amplifier reduces its voltage gain from 300 to 60. Determine the feedback factor. **(NOV / DEC - 2007)**

Solution:

Given:

$$A_{vf} = 60 \qquad A_v = 300$$

We have, $$A_{vf} = \frac{A_v}{1+A_v\beta}$$

$$\therefore \quad 60 = \frac{300}{1+300\times\beta}$$

$$\therefore \quad \beta = 0.01333$$

$$\therefore \quad \text{Feedback factor } (\beta) = 0.01333$$

EXAMPLE 12

An amplifier has a mid frequency gain of 100 and a bandwidth of 200 KHz.

1) What will be the new bandwidth and gain, if 5% negative feedback is introduced?

2) What should be the amount of feedback, if the bandwidth is to be restricted to 1 MHz? (APR / MAY - 2010)

Solution:

Given:

$A_v = 100$, BW = 200 KHz and $\beta = 0.05$

1) $$A_{vf} = \frac{A_v}{1+\beta A_v} = \frac{100}{1+0.05\times 100} = \mathbf{16.67}$$

$$BW_f = BW \times (1 + \beta A_v)$$
$$= 200 \times 10^3 \times (1 + 0.05 \times 100) = \mathbf{1.2\ MHz}$$

2) Given $BW_f = 1$ MHz

$$1 \times 10^6 = BW \times (1 + \beta A_v)$$
$$= 200 \times 10^3 \times (1 + \beta \times 100)$$
$$\therefore \quad \beta = \mathbf{0.04}$$

EXAMPLE 13

If an amplifier has a bandwidth of 300 KHz and voltage gain of 100, what will be the new bandwidth and gain if 10% negative feedback is introduced? What will be the gain bandwidth product before and after feedback? What should be the amount of feedback if the bandwidth is to be limited to 800 KHz. (MAY - 2011, 12)

Solution:

The voltage gain of the amplifier with feedback is given as,

$$A_{vf} = \frac{A}{1+A\beta} \qquad \text{Where } \beta = 0.1 \text{ and } A = 100$$

$$\therefore \quad A_{vf} = \frac{100}{1+100\times 0.1} = \mathbf{9.09}$$

The bandwidth of an amplifier with feedback is given as,

$$BW_f = (1 + A_{mid}\beta) f_H - \frac{f_L}{(1 + A_{mid}\beta)}$$

Assuming $f_H >> f_L$ we have,

$$BW = f_H \text{ and } BW_f = (1 + A_{mid}\beta)\ BW$$

$$\therefore \quad BW_f = (1 + 100 \times 0.1) \times 300 \text{ KHz} = \mathbf{3300\ KHz}$$

The gain bandwidth product before feedback can be given as,

$$\text{Gain bandwidth product} = A_v\ BW = 100 \times 300 \text{ KHz} = \mathbf{30 \times 10^6}$$

Gain bandwidth product after feedback,

$$= A_{vf}\ BW_f = 9.09 \times 3300 \text{ KHz} = \mathbf{30 \times 10^6}$$

If bandwidth is to be limited to 800 KHz we have f_{Hf} = 800 KHz assuming $f_{Hf} >> f_{Lf}$.

We know that,

$$BW_f = (1 + A_{vmid}\ \beta)f_H$$

$$\therefore \quad 800 \text{ K} = (1 + 100\beta)\ 300 \text{ K}$$

$$\therefore \quad \beta = \frac{\frac{800}{300} - 1}{100} = \mathbf{0.01667}$$

EXAMPLE 14

An amplifier with feedback has a voltage gain of 100. When the gain without feedback changes by 20% and the gain with feedback should not vary more than 2%. If so, determine the values of open loop gain A and feedback ratio β.

(APR / MAY - 2011, DEC - 12)

Solution:

Given:

$$A_{vf} = 100$$

$$\frac{1}{D} = \frac{\text{Change in gain with feedback}}{\text{Change in gain without feedback}} = \frac{2}{20} = 0.1$$

$$\therefore \quad D = 1 + \beta A_v = 10$$

$$A_{vf} = \frac{A_v}{D} \quad \therefore A_v = A_{vf} \times D = 100 \times 10 = \mathbf{1000}$$

$$1 + \beta A_v = 10$$

$$\beta = \frac{10 - 1}{A_v} = \frac{9}{1000} = \mathbf{0.009}$$

EXAMPLE 15

A negative feedback amplifier has an open loop gain of 60,000 and closed loop gain of 300. If the open loop upper cut off frequency is 15 KHz, estimate the closed loop upper cut off frequency. Also, calculate the total harmonic distortion with feedback if there is 10% harmonic distortion without feedback. (MAY - 2013)

Solution:

Given:

$$A = 60000,\ A_f = 300,\ f_H = 15 \text{ KHz and Distortion} = 10\%$$

$$A_f = \frac{A_v}{1 + A\beta} \quad \therefore 1 + A\beta = D = \frac{A}{A_f} = \frac{60000}{300} = \mathbf{200}$$

$$f_{Hf} = f_H \times D = 15 \text{ KHz} \times 200 = \mathbf{3\ MHz}$$

$$\text{Distortion with feedback} = \frac{10\%}{1 + A\beta} = \frac{10\%}{200} = \mathbf{0.05\%}$$

EXAMPLE 16

An amplifier with negative feedback give an output of 12.5 V with an input of 1.5 V. When feedback is removed, it requires 0.25 V input for the same output. Find, (1) The value of voltage gain without feedback, (2) Value of feedback β**, if the input and output are in phase and β is real.**

Solution:

Given:

$$V_{of} = 125 \text{ V},\ V_{in} = 1.5 \text{ V}$$

$$A_{vf} = \frac{V_{of}}{V_{in}} = \frac{12.5}{1.5} = 8.333$$

1) $$A_v = \frac{V_o}{V_{in}} = \frac{12.5}{0.25} = 50$$

2) $$A_{vf} = \frac{A}{1 + A\beta}$$

$$8.333 = \frac{50}{1 + 50\beta}$$

EXAMPLE 17

An amplifier as a voltage gain of 400, f_1 = 50 Hz, f_2 = 200 KHz and a distortion of 10% without feedback. Determine the amplifier voltage gain f_{1f}, f_{2f} and D_f when a negative feedback is applied with feedback ratio of 0.01.

Solution:

Given:

$A = 400$, $f_1 = 50$ Hz, $f_2 = 200$ KHz, $D = 10\%$ and $\beta = 0.01$

We know that voltage gain with feedback,

New lower 3dB frequency, $f_{1f} = \dfrac{f_1}{1 + A\beta} = \dfrac{50}{1 + 400 \times 0.01} = 10$ Hz

New upper 3dB frequency, $f_{2f} = (1 + A\beta) \times f_2 = (1 + 400 \times 0.01) \times 200 \times 10^3$

$= 1$ MHz

Distortion with feedback, $D_f = \dfrac{D}{1 + A\beta} = \dfrac{10}{5} = 2\%$

Based on Voltage Series Feedback

EXAMPLE 18

Find the voltage gain, feedback factor, input resistance and output resistance of a series-shunt pair type two stage feedback amplifier using transistors with h_{fe} = 99 and h_{ic} = 2 kΩ, shown in Figure 1. (MAY / JUNE - 2007)

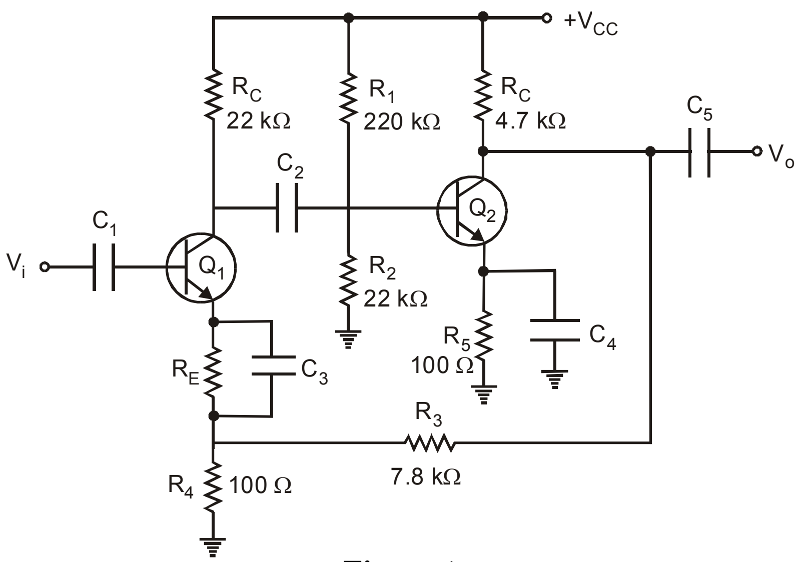


Figure 1

Solution:

Step 1: Identify topology

Feedback voltage is applied across the resistance R_4 and it is in series with input signal. So feedback is voltage series feedback.

Step 2 and Step 3: To find input circuit, set $V_{on} = 0$ which gives parallel combination of R_4 with R_3 at E_1.

To find output circuit, set $I_i = 0$, which gives series combination of R_3 and R_4 across the output as shown in the Figure 2.

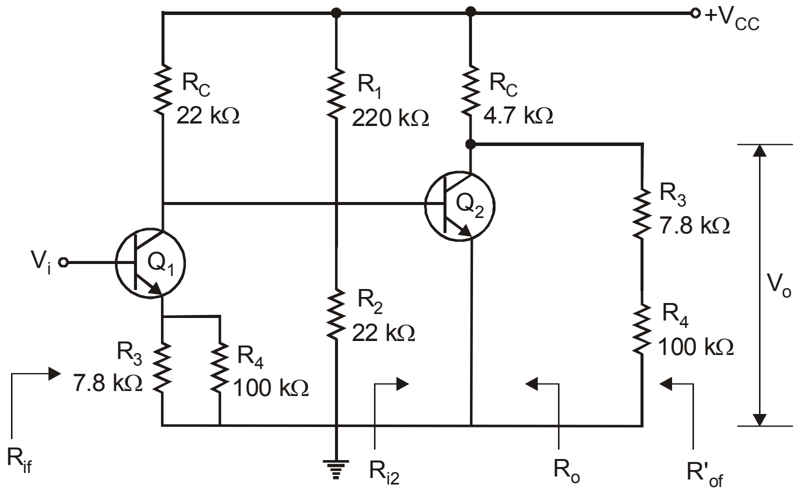


Figure 2

Step 4: Find open loop voltage gain (A_v)

$$R_{L2} = R_C \,||\, (R_4 + R_2) = 4.7\text{ K} \,||\, (100 + 7.8\text{ K}) = \mathbf{2.946\ K}$$

$$A_{i2} = -h_{fe} = -99$$

$$R_{i2} = h_{ie} = 2\text{ K}$$

$$A_{V2} = \frac{A_{i2}\,R_{L2}}{R_{i2}} = \frac{-99 \times 2.946\text{K}}{2\text{K}} = -145.827$$

$$A_{i1} = -h_{fe} = \mathbf{-99}$$

$$R_{L1} = R_{C1} \,||\, R_1 \,||\, R_2 \,||\, R_{i2} = 22\text{ K} \,||\, 220\text{ K} \,||\, 22\text{ K} \,||\, 2\text{ K}$$

$$= \mathbf{1.679\ k\Omega}$$

$$R_{i1} = h_{ie} + (1 + h_{fe})\, R_e = h_{ie} + (1 + h_{fe})\,(R_4 \,||\, R_3)$$

$$= 2\text{ K} + (1 + 99)\ (100 \parallel 7.8\text{ K})$$

$$= \mathbf{11.873\ k\Omega}$$

$$A_{V1} = \frac{A_{i1} R_{L1}}{R_{i1}}$$

$$= \frac{-99 \times 1.67 \times 10^3}{11.87 \times 10^3} = -14$$

Overall gain without feedback is,

$$A_V = A_{V1} \times A_{V2}$$

$$= -145.9 \times -14 = 2042$$

Calculation of B, D, A_{vf}, R_{if}, R'_{of}

$$\text{Feeback factor} \quad \beta = \frac{V_f}{V_o} = \frac{100}{100 + 7.8 \times 10^3} = 0.0127$$

$$D = 1 + \beta A_v$$

$$= 1 + (0.0127 + 2042)$$

$$= 27$$

$$A_{Vf} = \frac{A_V}{D} = \frac{2042}{27} = 75.6$$

$$R_{if} = R_{i1}\ D$$

$$= 11.8 \times 10^{-3} \times 27$$

$$= 319\ k\Omega$$

$$A_{Vf} = \frac{A_v}{D} = \frac{2042}{27} = 75.6$$

$$A_{Vf} = \frac{V_{of}}{V_{in}} = \frac{12.5}{1.5} = 8.333$$

$$R'_{of} = \frac{R'_o}{D} = \frac{R_{L2}}{D} = \frac{2.94}{27} = 110\ \Omega \quad (R_o' = R_{L2})$$

Based on Current Series Feedback

EXAMPLE 19

A current series feedback amplifier is shown in the figure 1 below.

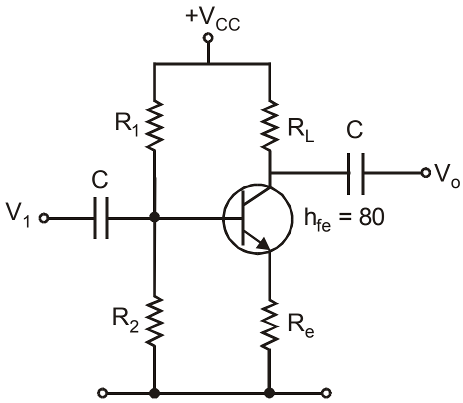


Figure 1

It has the following parameters:

R_1 = 20 kΩ, R_2 = 20 kΩ, h_{ie} = 2 kΩ, R_L = 1 kΩ, R_e = 100 kΩ, h_{fe} = 80; h_{re} = 0, h_{oe} = 0.

Calculate G_M, β, R_{if} and A_{vf}. **(MAY / JUNE - 2012)**

Solution:

The figure 2 shows the equivalent circuit for the given current series feedback amplifier.

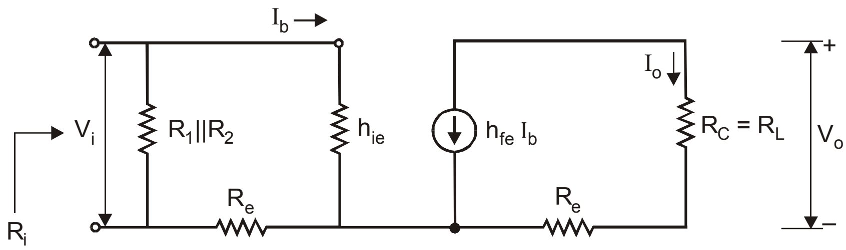


Figure 2: Equivalent circuit

The open loop transfer gainis given by,

$$G_M = \frac{I_o}{V_i} = \frac{-h_{fe}\, I_b}{V_i} \qquad I_o = -h_{fe}\, I_b$$

$$= \frac{-h_{fe} I_b}{V_i} = \frac{-h_{fe} I_b}{I_b(h_{ie} + R_e)} = \frac{-h_{fe}}{h_{ie} + R_e} = \frac{-80}{2000 + 100} = -0.038$$

$$\beta = \frac{V_f}{I_o} = \frac{I_e R_e}{I_o} = -R_e \qquad \because I_e = -I_o$$

$$\boxed{\beta = -100}$$

$$D = 1 + \beta G_M = 1 + (-100)\ (-0.038) = 4.81$$

$$G_{MF} = \frac{-0.038}{4.81} = -7.9 \times 10^{-3}$$

$$A_{Vf} = G_{MF} \times R_L = -7.9 \times 10^{-3} \times 1000 = -7.9$$

$$R_i = h_{ie} + R_e = 2000 + 100 = 2100\ \Omega$$

$$R_i' = R_1 \parallel R_2 \parallel R_i = 1.735\ k\Omega$$

$$R_{if} = R_i\ D = 2100 \times 4.81 = 10.1\ k\Omega$$

Based on Current Shunt Feedback

EXAMPLE 20

The circuit in figure has following parameters:

R_{c1}=3k$_1$, R_{c2}=500 Ω, R=R_s=1.2 k, h_{fe}=50, h_{ie}=1.1 K, and h_{ie}=h_{oe}=0

Find (a) A_{Vf}, (b) R_{if}, (c) Resistance seen by voltage source, (d) Output resistance.

Solution:

a) ∴ For V_o = 0, feedback does not become zero.

For I_o = 0, output loop feedback becomes zero. So it is current shunt feedback.

Open Loop current gain:

$$A_I = c = \frac{I_{c2}}{I_{b2}} \frac{I_{b2}}{I_{c1}} \frac{I_{c1}}{I_{b1}} \frac{I_{b1}}{I_s}$$

Using the low-frequency approximate h-parameter models for Q_1 and Q_2,

$$\frac{-I_{c2}}{I_{b2}} = -h_{fe} = -50 \qquad \frac{I_{c1}}{I_{b1}} = +h_{fe} = +50$$

$$\frac{I_{b2}}{I_{c1}} = \frac{-R_{c1}}{R_{c1} + R_{i2}} = \frac{-3}{3 + 3.55} = -0.458$$

Since $R_{i2} = h_{ie} + (1 + h_{fe})\,(R_e \parallel R') = 1.1 + (51)\left(\dfrac{0.05 \times 1.20}{1.25}\right) = 3.55\ \text{K}$

If R is defined by, $R \equiv R_s \parallel (R' \parallel R_e) = \dfrac{(1.2)(1.25)}{1.2 + 1.25} = 0.612\ \text{K}$

$$\frac{I_{b1}}{I_s} = \frac{R}{R + h_{ie}} = \frac{0.61}{0.61 + 1.1} = 0.358$$

Then $A_I = (-50)\,(-0.458)\,(50)\,(0.358) = +410$

$$\beta = \frac{R_e}{R' + R_e} = \frac{50}{1{,}250} = 0.040$$

$$D = 1 + \beta A_I = 1 + (0.040)\,(410) = 17.4$$

$$A_{If} = \frac{A_t}{D} = \frac{410}{17.4} = 23.6$$

$$A_{Vf} = \frac{V_o}{V_s} = \frac{-I_{c2}\,R_{c2}}{I_s\,R_s} = \frac{A_{If}\,R_{c2}}{R_s} = \frac{(23.6)(0.5)}{1.2} = 9.83$$

$$A_{Vf} = \frac{R_{c2}}{\beta R_s} \approx \frac{0.5}{(0.040)(1.2)} = 10.4$$

which is an error by 6 percent.

b) From figure 1.32 the input impedance without feedback seen by the current source is, using equation,

$$R_i = R \parallel h_{ie} = \frac{(0.61)(1.1)}{1.71} = 0.394\ \text{K}$$

$$R_{if} = \frac{R_i}{D} = \frac{394}{17.4} = 22.6\ \Omega$$

c) If the resistance looking to the right of R_s (from base to emitter of Q_1) in figure 1.32, is R'_{if}, then $R_{if} = R'_{if} \parallel R_s$, or

$$22.6 = \frac{1{,}200\,R'_{if}}{1{,}200 + R'_{if}}$$

By solving, $R'_{if} = 23.0\ \Omega$. Hence from Figure 1.32, the reistance with feedback seen by the voltage source V_s is $R_s + R'_{if} =$ 1,200 + 23.0 Ω = 1.22 K.

d) R'_{of} can also be calculated as the ratio of the open-circuit voltage V_c to the short-circuit output current I_o. Since for $h_{se} = 0$, $I_c = -I_{c2}$ is independent of R_{c2}, then

$$R'_{ef} = \frac{V_o}{V_s} = \frac{V_o}{V_s}\frac{V_s}{I_s}\frac{I_s}{I_o} = \frac{A_{Vf}\,R_s}{A_{If}} = \frac{(9.83)(1.25)}{23.6} = 0.50\ \text{K}$$

Based on Voltage Shunt Feedback

EXAMPLE 21

The circuit in Figure has following parameters, R_c = 4 K, R = 40 K, R_s = 10 L. h_{ie} = 1.1 K_1, h_{fe} = 50 K and h_{re} = h_{oe} = 0. Find (a) A_{Vf}, (b) R_{If}, (c) R'_{of}.

Solution:

Identify Topology

For $V_o = 0$, feedback reduces to zero

Since $T_i = I_s - I_f$, mixing is shunt type so it is voltage shunt feedback amplifier

Calculation of R_{Mf} from R_M

$$R_M = \frac{V_o}{I_s} = \frac{-I_c R'_c}{I_s} = \frac{-h_{fe} I_b R'_c}{I_s} = \frac{-h_{fe} R'_c}{R + h_{ie}}$$

where, $R'_c = R_c \,||\, R' = \frac{4 \times 40}{44} = 364$ K and $R = R_s \,||\, R' = \frac{10 \times 40}{50} = 8$ K

$$\therefore\ R_M = \frac{-50 \times 3.64 \times 8}{8 + 1.1} = -160\ \text{K}$$

$$\beta = \frac{-1}{R'} = \frac{-1}{40} = -0.025\ \text{mA/V}$$

$$D = 1 + \beta R_M = 1 + 0.025 \times 160 = 5$$

$$R_{Mf} = \frac{R_M}{D} = \frac{-160}{5.00} = -32.0\ \text{K}$$

$$A_{Vf} = \frac{V_o}{V_s} = \frac{V_o}{I_s R_s} = \frac{R_{Mf}}{R_s}$$

or $$A_{Vf} = \frac{-32.0}{10} = -3.20$$

From figure 1.34,

From equation (1.103)

$$R_i = \frac{Rh_{ie}}{R + h_{ie}} = \frac{(8)(1.1)}{9.1}$$

$$= 0.968 \text{ K} = 968 \ \Omega$$

$$R_i = \frac{R_i}{D} = \frac{968}{5.00} = 193 \ \Omega$$

If the input resistance looking to the right of R_s (from base to emitter in Figure 1.32 is R'_{if}, then $R_{if} = R'_{if} \| R_s$.

Solving, we find $R_{if} = 196 \ \Omega$.

The impedance seen by the voltage source V_s is

$$R_s + R'_{if} = 10.2 \text{ K.}$$

The output resistance, taking R_c into account but neglecting feedback is, from Figure 1.34,

$$R'_o = R_c \,\|\, R' = R'_c = 3.64 \text{ K.}$$

$$R'_{of} = \frac{R'_o}{D}$$

$$= \frac{3.64}{5.00} \text{K} = 728 \ \Omega$$

TWO MARKS QUESTIONS AND ANSWERS

1. What is meant by feedback?

A portion of the output signal is taken from the output of the amplifier and is combined with the normal input signal. This is known as feedback.

2. Name the different types of feedbacks used in amplifier circuits.

a) Positive feedback

b) Negative feedback

3. Define negative feedback. (Nov/Dec 2013)

When input signal and part of the output signal are in out of phase, the feedback is called negative feedback.

4. What type of feedback is used in oscillator?

Positive.

5. Give classification of amplifiers. (Nov/Dec 2012)

The amplifiers can be classified into four broad categories: voltage, current, Tranconductance and Tranresistance amplifiers.

6. Define feedback factor or feedback ratio. (Apr/May 2012)

The ratio of the feedback voltage to output voltage is known as feedback factor or feedback ratio.

7. What are the advantages of introducing negative feedback?

(Apr/May 2014, Nov/Dec 2004)

a) Input resistance is very high.

b) Output resistance is low.

c) It improves the frequency response of the amplifiers.

d) There is a significant improvement in the linearity of operation of the feedback.

8. List the four basic feedback topologies.

1. Voltage amplifier with voltage series feedback.
2. Transconductance amplifier with current-series feedback.
3. Current amplifier with current-shunt feedback
4. Transresistance amplifier with voltage shunt feedback

9. What is loop gain or return ratio? (Apr/May 2011, Nov/Dec 2011)

A path of a signal from input terminals through basic amplifier, through the feedback network and back to the input terminals forms a loop. The gain of this loop is the product $-A\beta$. This gain is known as loop gain or return ratio.

10. What is Sensitivity and desensitivity? (Apr/May 2010)

Sensitivity: Fractional change in amplification with feedback divided by fractional change without feedback is called sensitivity.

Desensitivity: The reciprocal of the sensitivity is called the desensitivity D. It is given as

$$D = 1 + A\beta$$

11. What is the effect of negative feedback on bandwidth?

Bandwidth of amplifier with feedback is greater than bandwidth of amplifier without feedback.

12. Why gain bandwidth product remains constant with the introduction of negative feedback?

Since bandwidth with negative feedback increases by factor $(1 + A\beta)$ and gain decreases by same factor, the gain-bandwidth product of an amplifier does not altered, when negative feedback is introduced.

13. What is the effect of negative feedback on feedback distortion?

The frequency distortion is reduced with the negative feedback.

14. What is the effect of negative feedback on noise? (Apr/May 2010)

The noise is reduced with the negative feedback.

15. What are the types of distortions in an amplifier?

1. Frequency
2. Noise and non linear

16. What type of feedback is employed in emitter follower amplifier?

Voltage series feedback.

17. The distortion in an amplifier is found to be 3%, when the feedback ratio of negative feedback amplifier is 0.04. When the feedback is removed, the distortion becomes 15%. Find the open and closed loop gain.

Solution: Given: $\beta = 0.04$, Distortion with feedback=3%, Distortion without feedback = 15%

$$D = 15/3 = 5.$$

where $D = 1 + A\beta = 5$

$$A = 100.$$

18. Which is the most commonly used feedback arrangement in cascaded amplifiers and why?

Voltage series feedback is the most commonly used feedback arrangement in cascaded amplifiers. Voltage series feedback increases input resistance and decreases output resistance. Increase in input resistance reduces the loading effect of previous stage and the decrease in output resistance reduces the loading effect of amplifier itself for driving the next stage.

18. Draw equivalent circuit of transconductance amplifier.

(Nov/Dec 2002, Apr/May 2005)

Refer figure 1.6

19. Draw equivalent circuit of voltage amplifier. (Nov/Dec 2004)

Refer figure 1.4

20. Draw a block diagram of voltage shunt feedback amplifier and give its input and output resistance. (May/June 2007, Nov/Dec 2011)

Refer figure 1.24 and 1.25

21. Compare the input and output resistance for a voltage and current shunt feedback amplifier. (Nov/Dec 2008)

Refer section 1.8.3 and 1.8.4

22. What are the steps to be carried out for complete analysis of a feedback amplifier.

(May/June 2009)

Refer section 1.10.

23. State the effect on output resistance and on input resistance of amplifier when current shunt feedback is employed. (Apr/May 2011, Nov/Dec 2012)

Refer section 1.8.3.

24. What is the effect on output resistance and on input resistance of amplifier if it employs voltage series negative feedback? (Apr/May 2013)

Refer section 1.8.1.

25. Give the expression for gain of an amplifier with feedback. (Nov/Dec 2013)

$$Avf = AV/\ 1 + AV\beta$$

where, Avf – feedback voltage gain

AV – Voltage gain

β – Feedback factor

30. State the nyquist criterion for stability of feedback amplifiers? (Nov/Dec 2010)

1. The amplifier is unstable if the curve encloses the point $-1 + j0$. The system is called as unstable system.
2. The amplifier is stable if the curve encloses the point $-1 + j0$. That system is called as stable system.

31. What is nyquist diagram?

The plot which shows the relationship between gain and phase-shift as a function of frequency is called as nyquist diagram.

32. Define Frequency compensation.

Frequency compensation modifies the open-loop transfer function A(s) of an amplifier (with three or more poles) so that the closed-loop transfer function $A_f(s)$ is stable for any value chosen for the closed-loop gain. Compensation techniques reduce the amplifier gain A at those frequencies for which phase shift is high.

33. List out the compensation techniques.

1. Dominant-pole or lag compensation.
2. Lead compensation
3. Pole-zero, or lag-lead compensation.

34. Define Miller effect.

The feedback connection between output and input causes it to appear to the amplifier like a large capacitor has been inserted between the output and input terminals. This phenomenon is called the Miller effect.

35. Draw a single stage amplifier with current series feedback. (May/June 2014)

Refer figure 1.26 and 1.27.

36. Negative feedback stabilizes the gain-Justify the statement.

Refer section 1.7.5

REVIEW QUESTIONS

1. Describe the effect of negative feedback on the bandwidth and harmonic distortion of a amplifier.
2. A negative feedback amplifier has an open loop gain of 60,000 and a closed loop gain of 300. If the open loop upper cut off frequency is 15 KHz, estimate the closed loop upper cut off frequency. Also, calculate the total harmonic distortion with feedback if there is 10% harmonic distortion without feedback.
3. With neat block diagrams explain the four possible topologies of a feedback amplifier.
4. Draw the circuit of a feedback pair with current shunt topology.
5. Draw the circuit of a current series feedback amplifier and explain how feedback is established. Derive expressions for voltage gain, input and output impedance. How does it improve the stability of the amplifier?
6. Draw the block diagram of voltage series amplifier and derive for A_{vf}, R_{if} and R_{of}. Draw a two stage amplifier with voltage series feedback.
7. Derive for Bandwidth with feeback BW_f.