UNIT I
FEEDBACK AMPLIFIER

1.1 Introduction

Feedback is taking a part of output back to the input either in phase or out of phase with the input signal.They are two types of feedback

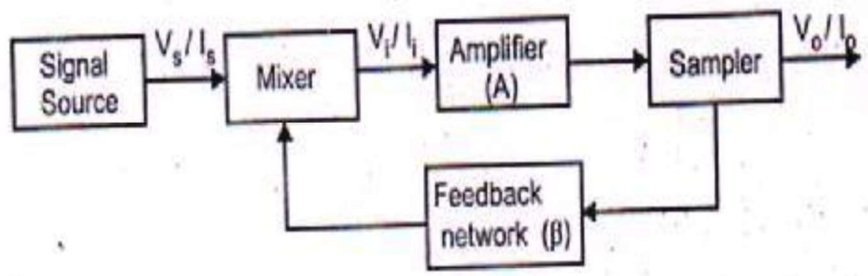
i. When input signal and part of output signal are in phase the feedback is **positive feedback.**
ii. When they are in out of phase then it is called as **negative feedback.**

Note: positive feedback used for oscillation and not for amplification

Feedback Amplifier

An amplifier which involves negative feedback is generally defined as a feedback amplifier.

1.2 Block Diagram of a Feedback Amplifier



1.2.1 Amplifier

The third functional block of a feedback system is the amplifier. The amplifier is basically classified into four types based on the given input and output obtained.

i. Voltage amplifier.
ii. Current amplifier.
iii. Transconductance amplifier.
iv. Transresistance amplifier.

Voltage amplifier

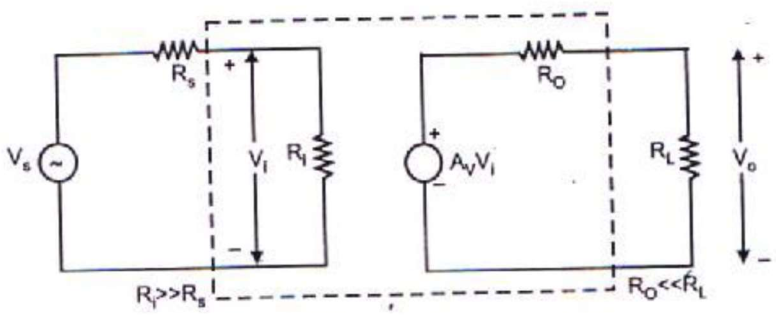


Figure shows a Thevenin's equivalent circuit of an amplifier.

If the amplifier input resistance R_i is large compared to source resistance R_s. if the external load resistance R_L is large compared to output resistance R_0 such amplifier circuit provides aoutput voltage proportional to the input voltage.

An ideal voltage amplifier must have infinite input resistance R_i and zero output resistance R_0

For practical case $R_i >> R_s \& R_L >> R_0$

Current amplifier

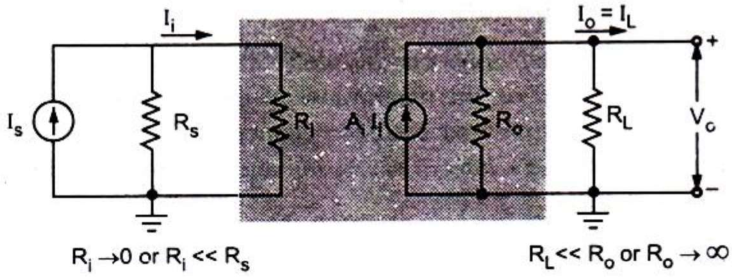


Figure shows a Norton's equivalent circuit of an amplifier.

If the amplifier input resistance $R_i \to 0$ then $I_i = I_s$ if output resistance $R_0 \to \infty$ then $I_L = A_i I_i$ such amplifier circuit provides a output current proportional to the input current.

An ideal voltage amplifier must have zero input resistance R_i and infinite output resistance R_0

For practical case $R_i << R_s \& R_0 >> R_L$

Transconductance amplifier

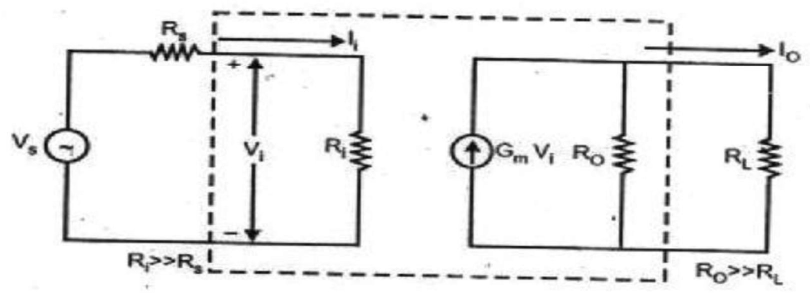


Figure shows Transconductance amplifier with a Thevenin's equivalent circuit in the input circuit and Norton's equivalent output circuit.

Here output current is proportional to the input signal voltage.

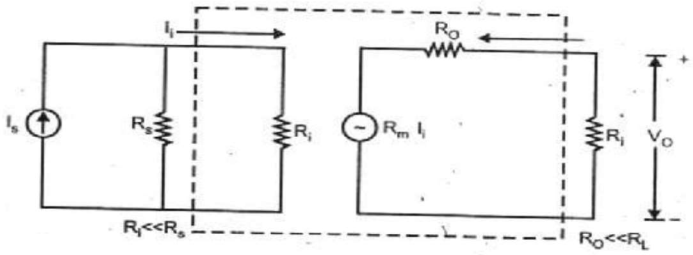
An ideal voltage amplifier must infinite input resistance R_i and infinite output resistance R_0

For practical case $R_i >> R_s \& R_0 >> R_L$

Transresistance amplifier

Figure shows Transresistance amplifier with a Norton's equivalent circuit at input circuit and Thevenin's equivalent at output circuit.

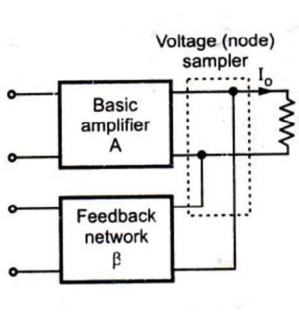
Here output voltage is proportional to the input signal current.



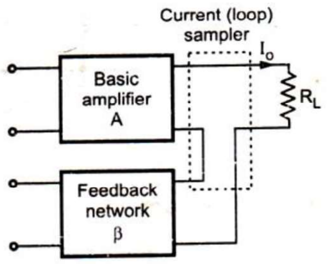
An ideal voltage amplifier must zero input resistance $R_i$and zero output resistance R_0
For practical case $R_i << R_s \& R_L >> R_0$

1.2.2 Sampler Network

There are two types of sampled output according to the sampling parameter either voltage or current.



(a) Voltage or node sampling



(b) Current or loop sampling

- The output voltage is sampled by connecting the feedback network in shunt with output **(voltage or node sampling).**
- The output voltage is sampled by connecting the feedback network in series with output **(current or loop sampling).**

1.2.3 Feedback network

It provides reduced portion of output as feedback to input mixer network. It may consist of resistor, capacitor & inductors. Most often it is simply a resistor configuration.It is give as,

$$V_f = \beta V_0$$

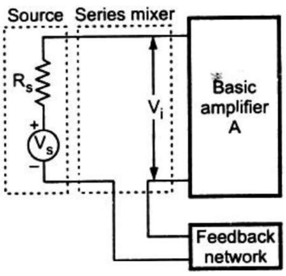
Where,

β feedback factor or feedback ratio (0,1)

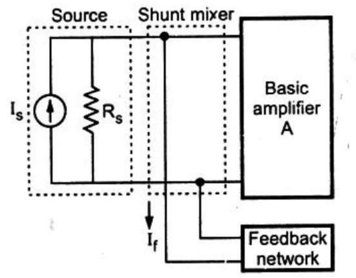
1.2.4 Mixer Network

There are two ways of mixing feedback signal with the input signal.

- Series mixing (loop)
- Shunt mixing (node)



(a) Series mixing



(b) Shunt mixing

1.3 Transfer Ratio or Gain

Block diagram of amplifier with feedback the ratio of output signal to input signal of the basic amplifier is represented by symbol A. suffix of A next represents the different transfer ratios.

$$A_V = \frac{V}{V_i} \qquad (Voltage\ Amplifier)$$

$$A_i = \frac{I}{I_i} \qquad (Current\ Amplifier)$$

$$G_m = \frac{I}{V_i} \qquad (Transconductance\ Amplifier)$$

$$R_m = \frac{V}{I_i} \qquad (Transresistance\ Amplifier)$$

The above gains are referred to a transfer gain of amplifier without feedback.

The transfer gain with feedback is represented by the symbol A_f. It is defined as the ratio of output signal to the input signal of the feedback amplifier.

$$A_{Vf} = \frac{V_0}{V_i} \qquad (Voltage\ Amplifier\ with\ feedback)$$

$$A_{if} = \frac{I_0}{I_i} \qquad (Current\ Amplifier\ with\ feedback)$$

$$G_{mf} = \frac{I_0}{V_i} \qquad (Transconductance\ Amplifier\ with\ feedback)$$

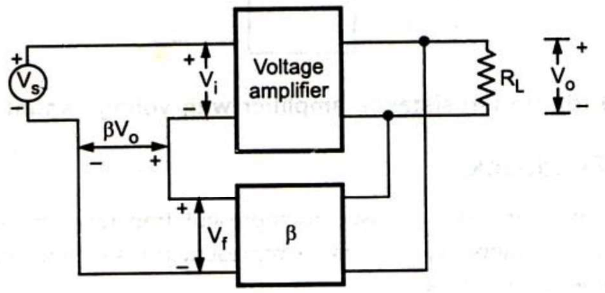
$$R_{mf} = \frac{V_0}{I_i} \qquad (Transresistance\ Amplifier\ with\ feedback)$$

1.4 Classification of Feedback Amplifier or Four Feedback Topology

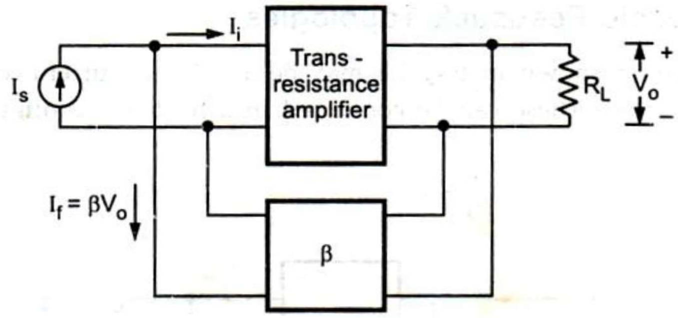
Based on the sampled signal and feedback signal the feedback amplifiers are classified into four types. There are,

i. Voltage Series Feedback Amplifier (Series Shunt feedback)
ii. Voltage Shunt Feedback Amplifier (Shunt Shunt feedback)
iii. Current Series Feedback Amplifier (Series Series feedback)
iv. Current Shunt Feedback Amplifier (Shunt Series feedback)

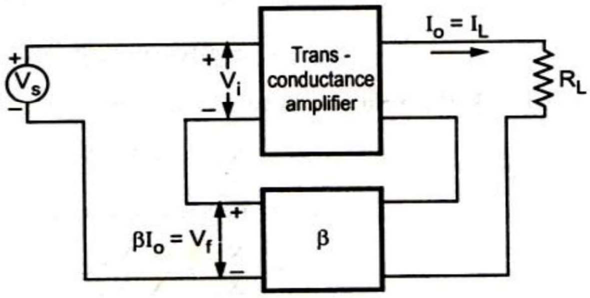
Voltage Series Feedback Amplifier



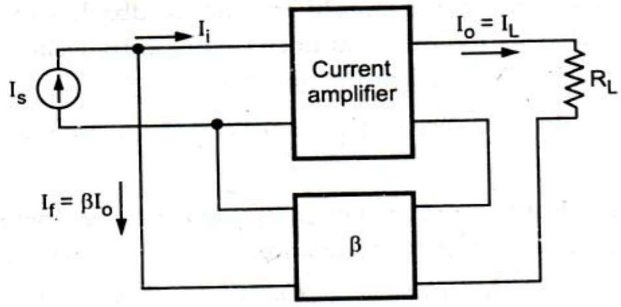
Voltage Shunt Feedback Amplifier



Current Series Feedback Amplifier



Current Shunt Feedback Amplifier



1.5 Properties of Negative Feedback

The basic properties of negative feedback amplifiers are

1. Transfer ratio
2. Input impedance
3. Stability
4. Sensitivity factor
5. Bandwidth
6. Noise and distortion

1.5.1 Gain with Feedback

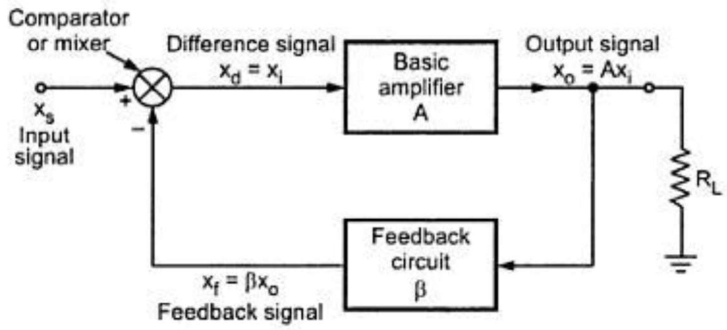
The symbol A is transfer gain of the basic amplifier without feedback and A_f is transfer gain of the basic amplifier with feedback.

$$A = \frac{X_0}{X_i}\ and\ A_f = \frac{X_0}{X_s}$$

Where, X_0= Output voltage or output current

X_i= Input voltage or output current

X_s= Source voltage or output current



As it is a negative feedback the relation between X_i and X_s is give as

$$X_i = X_s + (-X_f) \qquad X_s = X_i + X_f$$

Where X_f=Feedback voltage or output current

$$A_f = \frac{X_o}{X_s} = \frac{X_o}{X_i + X_f}$$

From block diagram,

$$X_f = \beta X_o\ ,\quad X_o = AX_i$$

$$A_f = \frac{AX_i}{X_i + \beta X_o}$$

Dividing by X_i to numarator and denominator we get,

$$\boldsymbol{A_f = \frac{A}{1+\beta A}} \ldots\ldots\ldots\ldots..(1)$$

Where,

β is a feedback factor

From the above equation we can say that gain without feedback (A) is always greater than gain with feedback $(A/1+\beta A)$ and it decreases with increase in β.

For voltage amplifier

$$\boldsymbol{A_{vf}=\frac{A_v}{1+\beta A_v}}$$

1.5.2 Input impedance

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

$$R_{if}=\frac{V_S}{I_i}=\frac{V_i+V_f}{I_i}=\frac{V_i+\beta V_o}{I_i}=\frac{V_i+\beta A_i V_i}{I_i}$$

$$R_{if}=\frac{V_i(1+\beta A_i)}{I_i}=R_i(1+\beta A_i)$$

Since R_i is multiplied by desensitivity factor, the input impedance with feedback increases, provided the feedback signal is a voltage.

1.5.3 Sensitivity factor

Sensitivity of transfer gain is defined as the ratio of fractional change in gain with feedback factor A_f to the fractional change in gain without feedback A.

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

Differentiate equation with respect to A

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

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

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

Divide both sides by A_f and substitute equation

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

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

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

Desensitivity factor

The reciprocal of sensitivity is defined as desensitivity D which equal to $1+\beta A$.

1.5.3 Cutoff Frequencies with Feedback

We know that,

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

Using this equation we can write,

$$A_{fmid} = \frac{A_{mid}}{1+\beta A_{mid}} \dots\dots\dots\dots (1)$$

$$A_{flow} = \frac{A_{low}}{1+\beta A_{low}} \dots\dots\dots\dots (2)$$

$$A_{fhigh} = \frac{A_{high}}{1+\beta A_{high}} \dots\dots\dots\dots (3)$$

Lower cutoff frequency

We know that the relation between gain at low and mid frequency is given as,

$$\frac{A_{low}}{A_{mid}} = \frac{1}{1-j\left(\frac{f_L}{f}\right)} \dots\dots\dots\dots (4)$$

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

Substituting value of A_{low} in equation (2) we get,

$$A_{flow} = \frac{\frac{A_{mid}}{1-j\left(\frac{f_L}{f}\right)}}{1+\beta\frac{A_{mid}}{1-j\left(\frac{f_L}{f}\right)}}$$

Taking LCM and simplify

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

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

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

$$A_{flow} = \frac{\frac{A_{mid}}{(1+\beta A_{mid})}}{1-j\left(\frac{f_L}{f(1+\beta A_{mid})}\right)}$$

$$A_{flow} = \frac{A_{fmid}}{1-j\left(\frac{f_{Lf}}{f}\right)}$$

$$\frac{A_{flow}}{A_{fmid}} = \frac{1}{1-j\left(\frac{f_{Lf}}{f}\right)} \dots\dots\dots\dots (5)$$

Where,

Lower cutoff frequency with feedback=$\boldsymbol{f_{Lf}} = \frac{f_L}{(1+\beta A_{mid})}$

Upper cut of frequency

We know that the relation between gain at high and mid frequency is given as,

$$\frac{A_{high}}{A_{mid}} = \frac{1}{1 - j\left(\frac{f}{f_H}\right)} \dots\dots\dots\dots(6)$$

$$A_{high} = \frac{A_{mid}}{1 - j\left(\frac{f}{f_H}\right)}$$

Substituting value of A_{high} in equation (3) we get,

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

Taking LCM and simplify

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

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

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

$$A_{fhigh} = \frac{A_{fmid}}{1 - j\left(\frac{f}{f_{Hf}}\right)} \dots\dots\dots\dots..(7)$$

Where,

Upper cutoff frequency with feedback=$\boldsymbol{f_{Hf} = f_H(1 + \beta A_{mid})}$

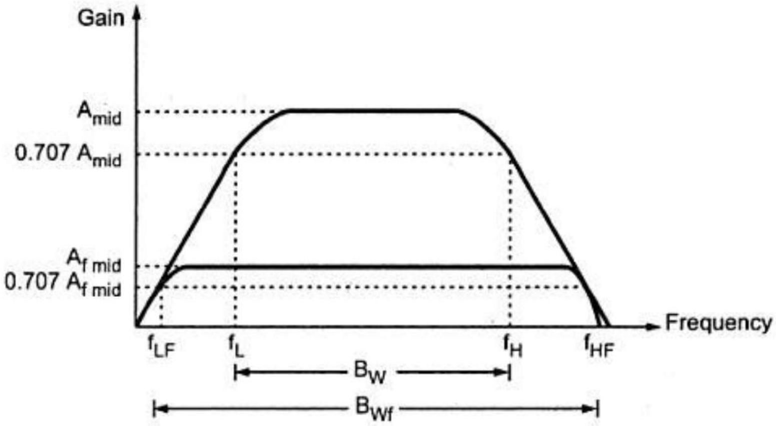
Bandwidth

Bandwidth of the amplifier is give as

BW= Upper cutoff frequency- Lower cutoff frequency

Bandwidth of the amplifier with feedback is give as

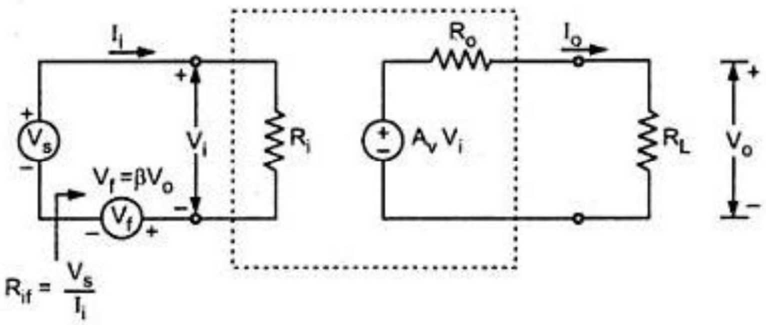
$$\boldsymbol{BW_f = f_{Hf} - f_{Lf} = f_H(1 + \beta A_{mid}) - \frac{f_L}{(1 + \beta A_{mid})}}$$



1.6Input and Output Impedance

Voltage Series Feedback

1.6.1 Input



The input resistance with feedback is given as,

$$R_{if} = \frac{V_s}{I_i} \ldots\ldots\ldots\ldots\ldots..(1)$$

Applying KVL to the input side,

$$V_s - I_i R_i - V_f = 0$$

$$V_s = I_i R_i + V_f$$

$$= I_i R_i + \beta V_0 \ldots\ldots\ldots.(2)$$

Output voltage $V_0$is give as,

$$V_0 = \frac{A_v V_i R_L}{R_0 + R_L}$$

$$V_0 = A_V V_i = A_V I_i R_i \ldots\ldots\ldots..(3)$$

Where,

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

Substituting values of V_0 in eqn (2)

$$V_s = I_i R_i + \beta A_V I_i R_i$$

$$\frac{V_s}{I_i} = R_i + \beta A_V R_i$$

Using eqn (1)

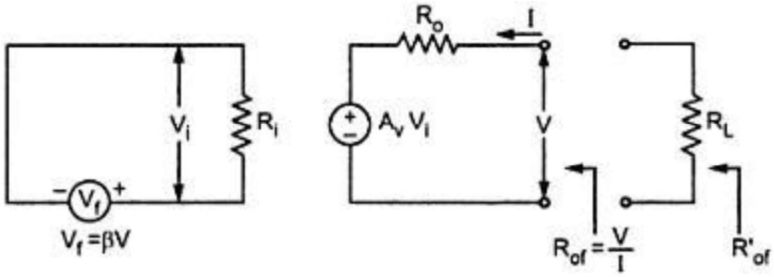
$$\boldsymbol{R_{if}} = \frac{\boldsymbol{V_s}}{\boldsymbol{I_i}} = \boldsymbol{R_i(1+\beta A_V)} \dots\dots\dots\dots(4)$$

1.6.2 Output

Applying KVL to the output side,

$$A_v V_i + I R_0 - V = 0$$

$$I = \frac{V - A_v V_i}{R_0} \dots\dots\dots\dots(1)$$



Input voltage is given as

$$V_i = -V_f = -\beta V \dots\dots\dots(2)$$

Substituting values of V_i in eqn (1)

$$I = \frac{V + A_v \beta V}{R_0} = \frac{V(1 + A_v\beta)}{R_0}$$

$$R_{0f} = \frac{V}{I} = \frac{R_0}{(1 + A_v\beta)} \dots\dots\dots(3)$$

Here A_v is open loop voltage gain without taking R_L

$$R'_{of} = R_{of} || R_L = \frac{R_{0f} \times R_L}{R_{0f} + R_L} = \frac{\frac{R_0}{(1+A_v\beta)} \times R_L}{\frac{R_0}{(1+A_v\beta)} + R_L}$$

Taking LCM and simplify

$$R'_{of} = \frac{R_0 R_L}{R_0 + R_L(1 + A_v\beta)} = \frac{R_0 R_L}{R_0 + R_L + A_v\beta R_L}$$

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

$$R'_{of} = \frac{\frac{R_0 R_L}{R_0 + R_L}}{1 + \frac{A_v \beta R_L}{R_0 + R_L}} = \frac{R'_0}{1 + \beta A_V}$$

$$\boldsymbol{R'_{of}} = \frac{\boldsymbol{R'_0}}{\boldsymbol{1 + \beta A_V}}$$

Where,

$$R'_0 = \frac{R_0 R_L}{R_0 + R_L} and A_V = \frac{A_v R_L}{R_0 + R_L}$$

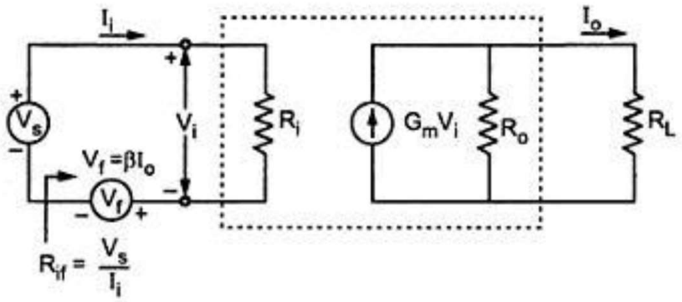
Here A_V is the open loop gain taking R_L into account.

Current Series Feedback

1.6.3 Input

The input resistance with feedback is given as,

$$R_{if} = \frac{V_s}{I_i} \ldots\ldots\ldots\ldots\ldots (1)$$



Applying KVL to the input side,

$$V_s - I_i R_i - V_f = 0$$

$$V_s = I_i R_i + V_f$$

$$= I_i R_i + \beta I_0 \ldots\ldots\ldots. (2)$$

Output current I_0 is give as,

$$I_0 = \frac{G_m V_i R_0}{R_0 + R_L}$$

$$V_0 = G_M V_i = G_M I_i R_i \ldots\ldots\ldots.. (3)$$

Where,

$$G_M = \frac{G_m R_0}{R_0 + R_L}$$

Substituting values of V_0in eqn (2)

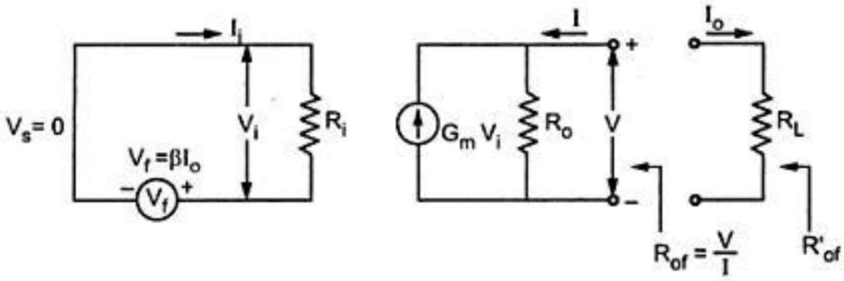
$$V_s = I_i R_i + \beta G_M I_i R_i$$

$$\frac{V_s}{I_i} = R_i + \beta G_M R_i$$

Using eqn (1)

$$\boldsymbol{R_{if}} = \frac{\boldsymbol{V_s}}{\boldsymbol{I_i}} = \boldsymbol{R_i(1 + \beta G_M)} \ldots\ldots\ldots\ldots.. (4)$$

1.6.4 Output



Applying KCL to the output node we get,

$$I = \frac{V}{R_0} - G_m V_i \ldots\ldots\ldots\ldots..(1)$$

Input voltage is give as

$$V_i = -V_f = -\beta I_0 \ldots\ldots\ldots..(2)$$

$$= \beta I$$

Where

$$I_0 = -I$$

Substituting values of $V_i$in eqn (1)

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

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

$$R_{0f} = \frac{V}{I} = R_0(1 + G_m \beta) \ldots\ldots\ldots.(3)$$

Here R_m is open loop transconductance without taking $R_L$in account.

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

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

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

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

$$\boldsymbol{R'_{of} = \frac{R'_0(1 + G_m\beta)}{1 + G_M\beta}}$$

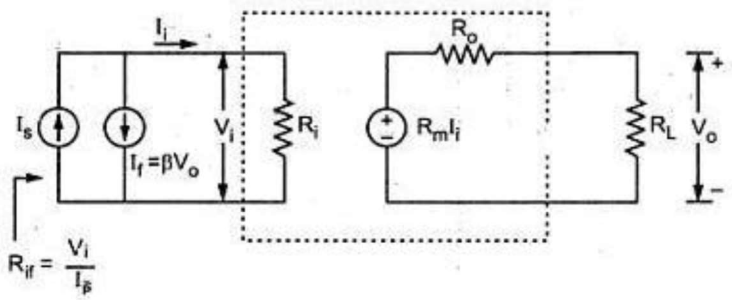
Where

$$R'_0 = \frac{R_0 R_L}{R_0 + R_L} and G_M = \frac{G_m R_0}{R_0 + R_L}$$

Here G_M is the open loop gain taking R_L into account.

Voltage Shunt Feedback

1.6.5 Input



The input resistance with feedback is given as,

$$R_{if} = \frac{V_i}{I_s} \ldots\ldots\ldots\ldots\ldots..(1)$$

Applying KCL to the input side we get,

$$I_s = I_i + I_f$$
$$= I_i + \beta V_0 \ldots\ldots\ldots\ldots\ldots(2)$$

Output voltage $V_0$is give as,

$$V_0 = \frac{R_m I_i R_L}{R_0 + R_L}$$
$$V_0 = R_M I_i \ldots\ldots\ldots\ldots..(3)$$

Where,

$$R_M = \frac{R_m R_L}{R_0 + R_L}$$

Substituting values of V_0in eqn (2)

$$I_s = I_i + \beta R_M I_i$$
$$I_s = I_i(1 + \beta R_M)$$
$$\frac{V_i}{I_s} = \frac{V_i}{I_i(1 + \beta R_M)}$$

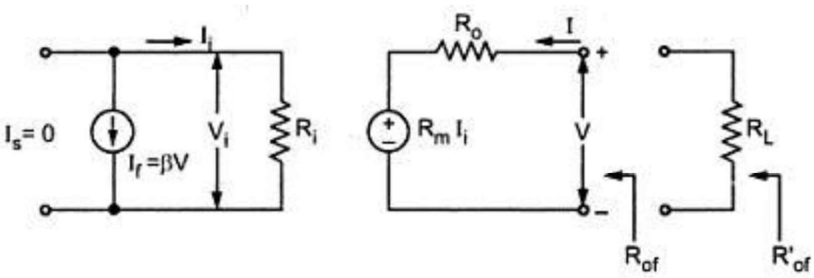
Using eqn (1)

$$R_{if} = \frac{V_i}{I_s} = \frac{V_i}{I_i(1 + \beta R_M)}$$
$$\boldsymbol{R_{if} = \frac{V_i}{I_s} = \frac{R_i}{(1 + \beta R_M)}} \ldots\ldots\ldots\ldots..(4)$$

Where

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

1.6.6 Output



Applying KVL to the output side,

$$R_m I_i + IR_0 - V = 0$$

$$I = \frac{V - R_m I_i}{R_0} \ldots\ldots\ldots\ldots..(1)$$

Input current is given as

$$I_i = -I_f = -\beta V \ldots\ldots\ldots..(2)$$

Substituting values of $V_i$in eqn (1)

$$I = \frac{V + R_m \beta V}{R_0} = \frac{V(1 + R_m \beta)}{R_0}$$

$$R_{0f} = \frac{V}{I} = \frac{R_0}{(1 + R_m \beta)} \ldots\ldots\ldots.(3)$$

Here R_m is open loop transresistance without taking $R_L$in account.

$$R'_{of} = R_{of} || R_L = \frac{R_{0f} \times R_L}{R_{0f} + R_L} = \frac{\frac{R_0}{(1+R_m\beta)} \times R_L}{\frac{R_0}{(1+R_m\beta)} + R_L}$$

Taking LCM and simplify

$$R'_{of} = \frac{R_0 R_L}{R_0 + R_L(1 + R_m \beta)} = \frac{R_0 R_L}{R_0 + R_L + R_m \beta R_L}$$

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

$$R'_{of} = \frac{\frac{R_0 R_L}{R_0 + R_L}}{1 + \frac{R_m \beta R_L}{R_0 + R_L}}$$

$$\boldsymbol{R'_{of} = \frac{R'_0}{1 + \beta R_M}}$$

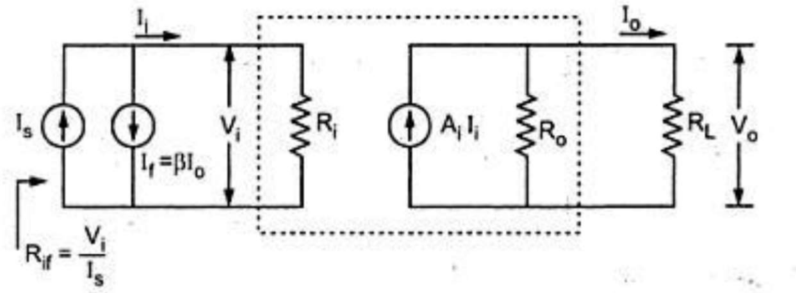
Where,

$$R'_0 = \frac{R_0 R_L}{R_0 + R_L} and R_M = \frac{R_m R_L}{R_0 + R_L}$$

Here R_M is the open loop gain taking R_L into account.

Current Shunt Feedback Amplifier

1.6.7 Input



The input resistance with feedback is given as,

$$R_{if} = \frac{V_i}{I_s} \ldots\ldots\ldots\ldots\ldots (1)$$

Applying KCL to the input side we get,

$$I_s = I_i + I_f$$

$$= I_i + \beta I_0 \ldots\ldots\ldots\ldots\ldots (2)$$

Output current I_0 is give as,

$$I_0 = \frac{A_i I_i R_0}{R_0 + R_L}$$

$$I_0 = A_I I_i \ldots\ldots\ldots\ldots (3)$$

Where,

$$A_I = \frac{A_i R_0}{R_0 + R_L}$$

Substituting values of I_0in eqn (2)

$$I_s = I_i + \beta A_I I_i$$

$$I_s = I_i(1 + \beta A_I)$$

$$\frac{V_i}{I_s} = \frac{V_i}{I_i(1 + \beta A_I)}$$

Using eqn (1)

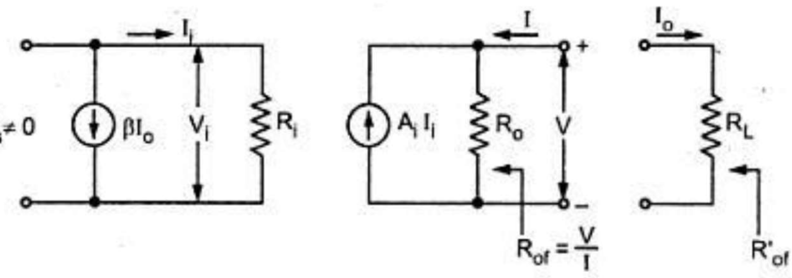
$$R_{if} = \frac{V_i}{I_s} = \frac{V_i}{I_i(1 + \beta A_I)}$$

$$\boldsymbol{R_{if} = \frac{R_i}{(1 + \beta A_I)} \ldots\ldots\ldots\ldots (4)}$$

Where

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

1.6.8 Output



Applying KCL to the output node we get,

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

Input current is give as

$$I_i = -I_f = -\beta I_0 \dots\dots\dots..(2)$$
$$= \beta I$$

Where

$$I_0 = -I$$

Substituting values of I_i in eqn (1)

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

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

$$R_{0f} = \frac{V}{I} = R_0(1 + A_i\beta) \dots\dots\dots.(3)$$

Here A_i is open loop current gain without taking $R_L$in account.

$$R'_{of} = R_{of}||R_L = \frac{R_{0f} \times R_L}{R_{0f} + R_L} = \frac{R_0(1 + A_i\beta) \times R_L}{R_0(1 + A_i\beta) + R_L}$$

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

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

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

$$\boldsymbol{R'_{of} = \frac{R'_0(1 + A_i\beta)}{1 + A_I\beta}}$$

Where,

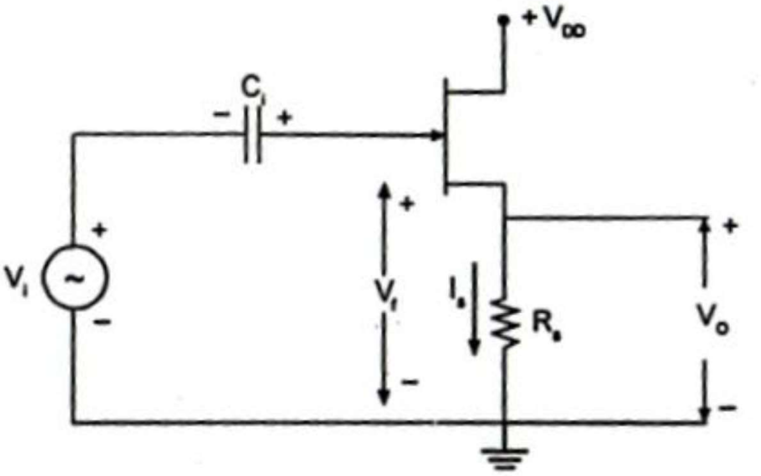
$$R'_0 = \frac{R_0 R_L}{R_0 + R_L} \; and A_I = \frac{A_i R_0}{R_0 + R_L}$$

Here A_I is the open loop gain taking R_L into account.

1.7Voltage series Feedback Amplifier

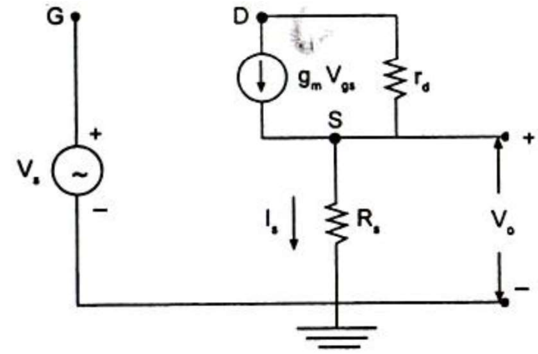
The emitter follower using BJT and source follower using FET are the commonly used Voltage series Feedback Amplifier.

1.7.1 FET Source Follower

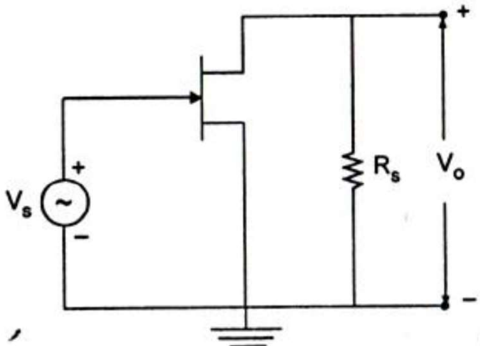


AC Analysis using the small signal low frequency model for FET

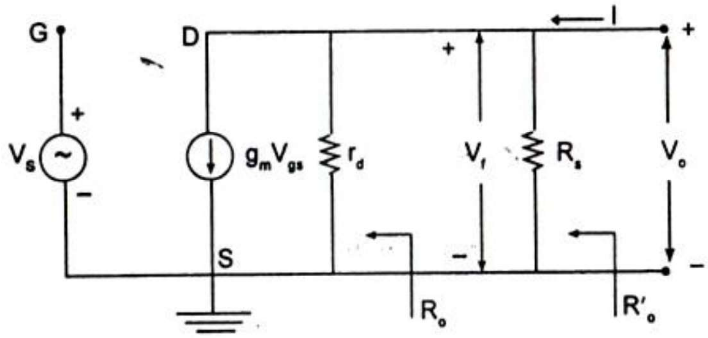
This circuit said to be voltage series feedback amplifier because the sampled signal is a voltage measured across source resistance R_S and the feedback signal is also a voltage measured across R_S. Now for analysis let us draw the circuit without feedback following given rules.



To find the input circuit since it is voltage sampling short circuit the output terminal. Hence the source resistance R_S is replaced by a short circuit at the input terminal.



To find the output circuit since it is series mixing open circuit the input terminal, which makes the input current as zero and so only output current flows through source resistance R_S. This makes R_S appear in the output circuit.



Voltage gain A_V

$$A_V = \frac{V_0}{V_S} = \frac{I(R_S \parallel r_d)}{V_S} = \frac{g_m V_{gs}(R_S \parallel r_d)}{V_S}$$

Where $V_{gs} = V_S$

$$A_V = \frac{g_m r_d R_S}{r_d + R_S} = \frac{\mu R_S}{r_d + R_S}$$

Where $\mu = g_m r_d$is an amplification factor.

Feedback Factor β

Feedback factor is given by,

$$\beta = \frac{V_0}{V_f}$$

Since $V_0 = V_f$ in this equivalent circuit

$$\beta = 1$$

Desenstivity factor D

Desenstivity factor is given by,

$$D = 1 + \beta A_V$$

$$= 1 + \frac{\mu R_S}{r_d + R_S}$$

$$D = \frac{r_d + R_S(1+\mu)R_S}{r_d + R_S}$$

Voltage gain with feedback A_{Vf}

$$A_{Vf} = \frac{A_V}{D} = \frac{\frac{\mu R_S}{r_d + R_S}}{\frac{r_d + R_S(1+\mu)}{r_d + R_S}}$$

$$A_{Vf} = \frac{\mu R_S}{r_d + (1+\mu)R_S}$$

If $(1+\mu)R_S \gg r_d \; and \; \mu \gg 1$

$$A_{Vf} \approx \frac{\mu R_S}{\mu R_S} = 1$$

Input Resistance R_i

$$R_i = \frac{V_S}{I_i} = \frac{V_S}{I_G}$$

Since gate current $I_G = 0 \; for \; a \; FET$

$$R_i = \propto$$

Input Resistance with feedback R_{if}

$$R_{if} = R_i \times D = \propto$$

Output Resistance R_0

$$R_0 = r_d$$

Output Resistance with feedback R_{0f}

$$R_{0f} = \frac{R_0}{D} = \frac{r_d}{\frac{r_d + R_S(1+\mu)}{r_d + R_S}}$$

If $R_S \gg r_d$ then

$$R_{0f} = \frac{r_d}{1+\mu}$$

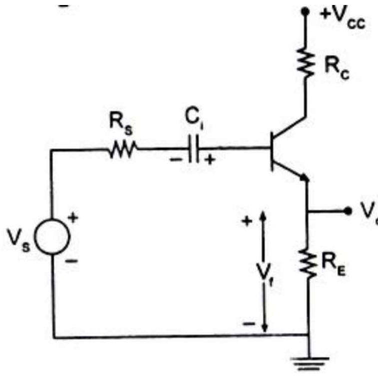
The output resistance with load R_S

$$R_0' = r_d \parallel R_S = \frac{r_d R_S}{r_d + R_S}$$

$$R_{0f}' = \frac{R_0'}{D} = \frac{r_d R_S}{r_d + R_S} \times \frac{r_d + R_S}{r_d + R_S(1+\mu)}$$

$$R_{0f}' = \frac{r_d R_S}{r_d + R_S(1+\mu)}$$

1.7.2 Emitter follower



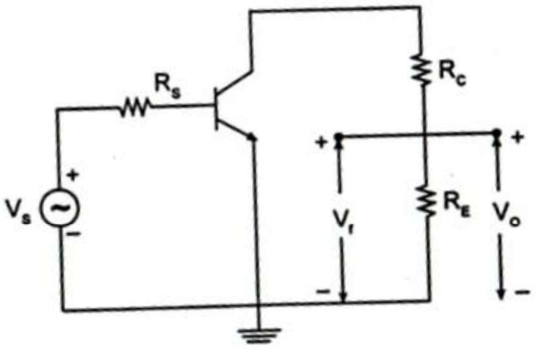
Here the sampled signal is the voltage across emitter resistance R_E and the feedback signal is also the voltage across emitter resistance R_E.

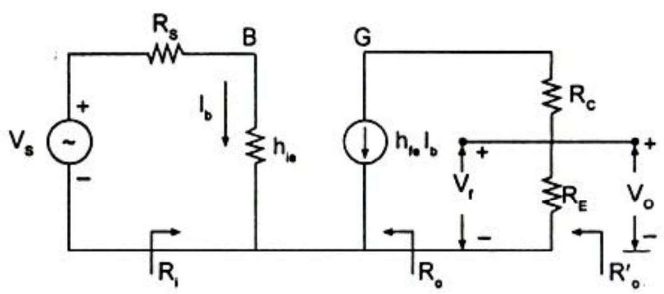
AC Analysis using the small signal low frequency model for BJT

Now for analysis let us draw the circuit without feedback following given rules.

To find the input circuit since it is voltage sampling short circuit the output terminal. Hence the emitter resistance R_E is replaced by a short circuit at the input terminal.

To find the output circuit since it is series mixing open circuit the input terminal, which makes the input current as zero and so only output current flows through emitter resistance R_E. This makes R_E appear in the output circuit.





Voltage gain A_V

$$A_V = \frac{V_0}{V_S} = \frac{h_{fe} I_b R_E}{V_S} \ldots\ldots\ldots\ldots(1)$$

The current flowing through the base of the transistor is given by,

$$I_b = \frac{V_S}{R_S + h_{ie}}$$

Substitute in above equation

$$A_V = \frac{h_{fe} R_E}{V_S} \times \frac{V_S}{R_S + h_{ie}} = \frac{h_{fe} R_E}{R_S + h_{ie}}$$

Feedback Factor β

Feedback factor is given by,

$$\beta = \frac{V_0}{V_f}$$

Since $V_0 = V_f$ in this equivalent circuit

$$\beta = 1$$

Desenstivity factor D

Desenstivity factor is given by,

$$D = 1 + \beta A_V$$

$$= 1 + \frac{h_{fe} R_E}{R_S + h_{ie}}$$

$$D = \frac{R_S + h_{ie} + h_{fe} R_E}{R_S + h_{ie}}$$

Voltage gain with feedback A_{Vf}

$$A_{Vf} = \frac{A_V}{D} = \frac{\frac{h_{fe} R_E}{R_S + h_{ie}}}{\frac{R_S + h_{ie} + h_{fe} R_E}{R_S + h_{ie}}}$$

$$A_{Vf} = \frac{h_{fe} R_E}{R_S + h_{ie} + h_{fe} R_E}$$

If $(R_S + h_{ie}) \gg h_{fe} R_E \; then$

$$A_{Vf} \approx 1$$

Input Resistance R_i

$$R_i = R_S + h_{ie}$$

Input Resistance with feedback R_{if}

$$R_{if} = R_i \times D = (R_S + h_{ie}) \left(\frac{R_S + h_{ie} + h_{fe} R_E}{R_S + h_{ie}} \right)$$

$$R_{if} = R_S + h_{ie} + h_{fe} R_E$$

Output Resistance R_0

$$R_0 = \propto$$

Output Resistance with feedback R_{0f}

$$R_{0f} = \frac{R_0}{D} = \propto$$

The output resistance with load R_E

$$R_0^{'} = R_E$$

$$R_{0f}^{'} = \frac{R_0^{'}}{D} = \frac{R_E(R_S + h_{ie})}{R_S + h_{ie} + h_{fe}R_E}$$

Divide numerator and denominator by R_E

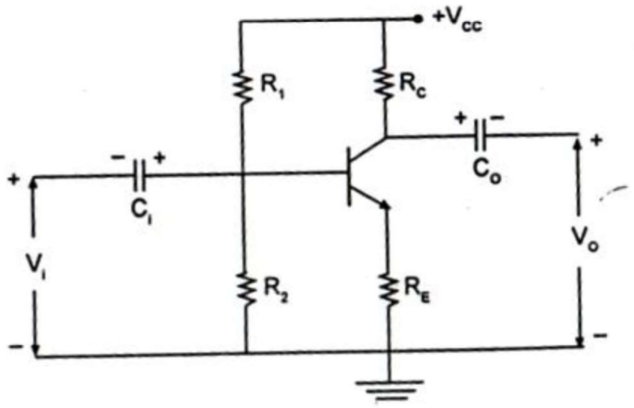
$$R_{0f}^{'} = \frac{(R_S + h_{ie})}{\frac{R_S + h_{ie} + h_{fe}R_E}{R_E}} = \frac{(R_S + h_{ie})}{\frac{R_S + h_{ie}}{R_E} + h_{fe}}$$

$$R_{0f} = \lim_{R_E \to \propto} R_{0f}^{'} = \lim_{R_E \to \propto} \left(\frac{(R_S + h_{ie})}{\frac{R_S + h_{ie}}{R_E} + h_{fe}} \right)$$

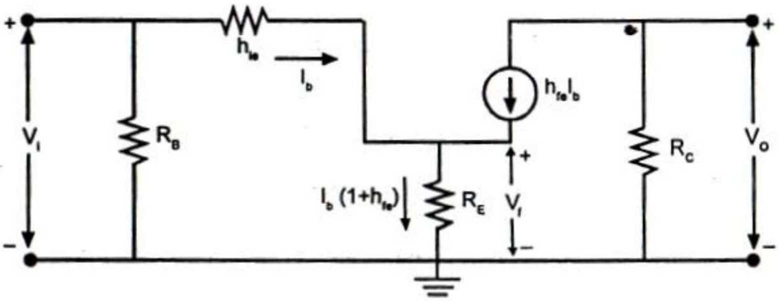
$$R_{0f} = \frac{R_S + h_{ie}}{h_{fe}}$$

1.8Current series Feedback Amplifier

1.8.1 Common emitter amplifier

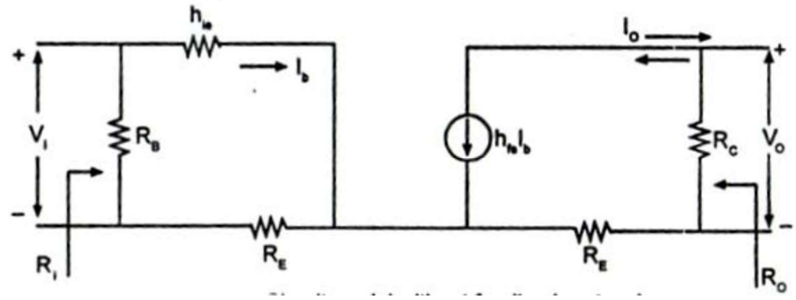


For current series feedback amplifier the sampling parameter is current flowing through emitter resistance R_E and the mixing parameter is voltage which is emitter voltage drop V_f appearing across emitter resistanceR_E.



To find the input circuit since it is current sampling open circuit the output terminal. When output current is set zero the current through R_E is I_b and hence R_E appears in series with h_{ie}.

To find the output circuit since it is series mixing open circuit the input terminal, When input current is set zero the current through R_E is I_C and hence it in series with R_C.



AC Analysis : without feedback network

Voltage gain A_V

$$A_V = \frac{V_0}{V_i} = \frac{-I_0 R_C}{I_b(h_{ie} + R_E)} = \frac{-h_{fe} I_b R_C}{I_b(h_{ie} + R_E)} = \frac{-h_{fe} R_C}{h_{ie} + R_E}$$

TranconductanceG_m

$$G_m = \frac{I_0}{V_i} = \frac{-h_{fe} I_b}{I_b(h_{ie} + R_E)}$$

$$G_m = \frac{-h_{fe}}{h_{ie} + R_E}$$

Feedback Factor β

Feedback factor is given by,

$$\beta = \frac{V_f}{V_0} = \frac{-I_0 R_E}{I_0}$$

$$\beta = -R_E$$

Desenstivity factor D

Desenstivity factor is given by,

$$D = 1 + \beta G_m = 1 + \frac{R_E h_{fe}}{h_{ie} + R_E}$$

$$D = \frac{h_{ie} + R_E(1 + h_{fe})}{h_{ie} + R_E}$$

Input Resistance R_i

$$R_i = R_B \parallel (h_{ie} + R_E)$$

$$R_i = \frac{R_B(h_{ie} + R_E)}{R_B + h_{ie} + R_E}$$

Ignoring the effect of biasing resistor

$$R_i = h_{ie} + R_E$$

Output Resistance R_0

$$R_0 = R_C + R_E$$

AC Analysis : with feedback network

TranconductanceG_{mf}

$$G_{mf} = \frac{G_m}{D} = \frac{\frac{-h_{fe}}{h_{ie}+R_E}}{\frac{h_{ie}+R_E(1+h_{fe})}{h_{ie}+R_E}}$$

$$G_{mf} = \frac{-h_{fe}}{h_{ie} + R_E(1 + h_{fe})}$$

Input Resistance R_{if}

$$R_{if} = R_i \times D = (h_{ie} + R_E)\left(\frac{h_{ie} + R_E(1 + h_{fe})}{h_{ie} + R_E}\right)$$

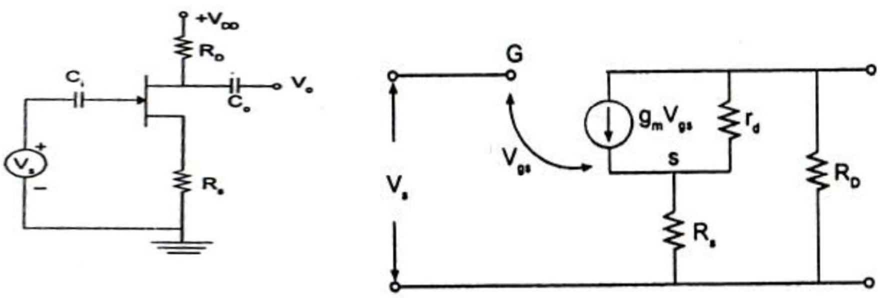
$$R_{if} = h_{ie} + R_E(1 + h_{fe})$$

Output Resistance R_{0f}

$$R_{0f} = R_0 \times D$$

$$= (R_C + R_E)\left(\frac{h_{ie} + R_E(1 + h_{fe})}{h_{ie} + R_E}\right)$$

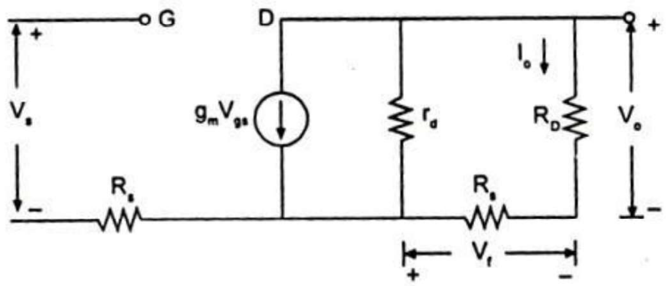
1.8.2 Common Source amplifier



In a current series feedback circuit, the sampling parameter is current I_D through R_S and mixing parameter is voltage V_f which is drop across R_S.

To find the input circuit $I_0 = 0$ (Open Circuit)

To find output circuit $I_i = 0$ to obtain the output circuit and hence R_S appear in series with $R_D$at the output.



TranconductanceG_m

$$G_m = \frac{I_0}{V_S} = \frac{\frac{-g_m V_{gs} r_d}{r_d+R_D+R_S}}{V_S}$$

Since $V_{gs} = V_S$

$$G_m = \frac{-g_m r_d}{r_d + R_D + R_S} = \frac{-\mu}{r_d + R_D + R_S}$$

Feedback Factor β

Feedback factor is given by,

$$\beta = \frac{V_f}{I_0} = \frac{-I_0 R_S}{I_0} = -R_S$$

$$\beta = -R_S$$

Desenstivity factor D

Desenstivity factor is given by,

$$D = 1 + \beta G_m = 1 + (-R_S)\left(\frac{-\mu}{r_d + R_D + R_S}\right)$$

$$D = \frac{r_d + R_D + R_S(1+\mu)}{r_d + R_D + R_S}$$

Input Resistance R_i

$$R_i = \infty$$

Output Resistance R_0

$$R_0 = r_d + R_S + R_D$$

AC Analysis : with feedback network

TranconductanceG_{mf}

$$G_{mf} = \frac{G_m}{D} = \frac{\frac{-\mu}{r_d+R_D+R_S}}{\frac{r_d+R_D+R_S(1+\mu)}{r_d+R_D+R_S}}$$

$$G_{mf} = \frac{-\mu}{r_d + R_D + R_S(1+\mu)}$$

Input Resistance R_{if}

$$R_{if} = R_i \times D = \infty$$

Output Resistance R_{0f}

$$R_{0f} = R_0 \times D$$

When

$$G_m = \lim_{R_0 \to \propto} G_M$$

Now

$$(1+\beta G_m) = \lim_{R_0 \to \propto} G_m(1+\beta G_m) = \frac{r_d + R_S(1+\mu)}{r_d + R_S}$$

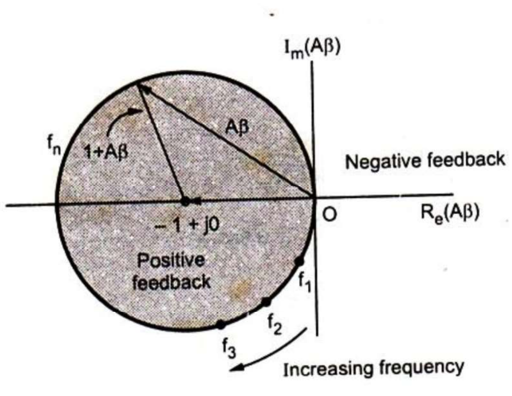
$$R_{0f} = R_0(1+\beta G_m) = (r_d + R_S)\left(\frac{r_d + R_S(1+\mu)}{r_d + R_S}\right) = r_d + R_S(1+\mu)$$

$$R_0^{'} = R_D \parallel R_{Of} = \frac{R_D\left(r_d + R_S(1+\mu)\right)}{R_D + r_d + R_S(1+\mu)}$$

1.9Nyquist Criterion for Feedback Amplifier

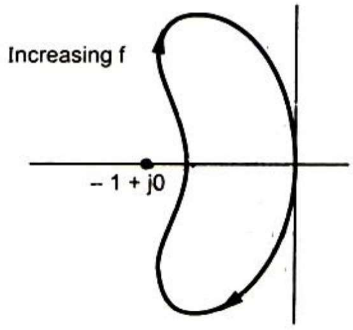
A negative feedback amplifier designed for a particular frequency range may break out into oscillation some high or low frequency. This stability problem arises a feedback amplifier when loop gain has more than two real poles. The existence of pole with a positive real part results in a disturbance increasing exponentially with time. When such transient disturbance persists indefinitely or increases the system becomes unstable.

Hence, the condition which must be satisfied, if a system is to be stable, is that the poles of the transfer function must all lie in the left hand of the complex frequency plane. If the system without feedback is stable, the poles of A do lie in left hand half plane. Therefore from equation $A_f = A/1+\beta A$ we can say that the stability condition requires that the zeros of $1+\beta A$ all lie in the left hand half of the complex frequency plane.

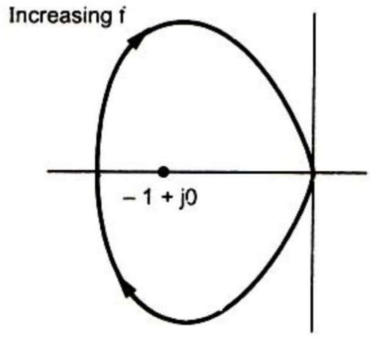


The Nyquist criterion forms the basis of a steady state method of determining whether or not an amplifier is stable.

The product of βA is a complex number, it may be represented as a point in the complex plane where the real component being plotted along X axis and the j component along the Y axis. We know that the βA is a function of frequency. Consequently points in the complex plane are obtained for the values of βA corresponding to all values of f from -∞ to +∞. The locus of all these point forms a close curve. The criterion of Nyquist is that the amplifier is unstable if this curve encloses the point -1+j0, and the amplifier is stable if the curve does not enclose this point.



(a) Stable



(b) Unstable

An example of the Nyquist criterion is illustrated in fig. the locus in fig (a) is stable since it does not enclose -1+j0 point, whereas the locus shown in fig (b) is unstable since the curve does enclose the -1+j0 point.

1.10Frequency compensation

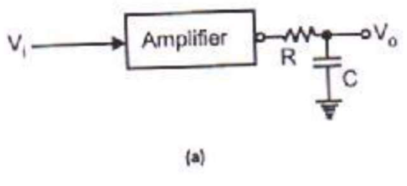
A suitable compensation technique is used when the application demands larger bandwidth and lower closed loop gain. This is possible by connecting a compensating network external to the amplfier to alter the loop gain so that the roll off rate is -20dB/decade over a wide range of frequency.

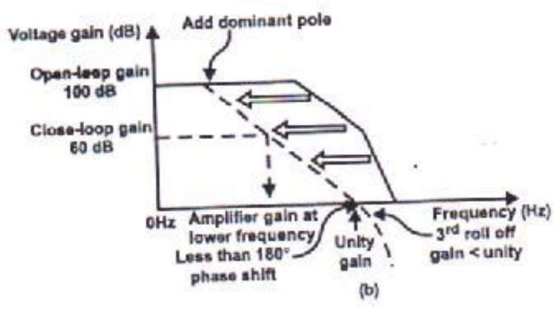
There are two common frequency compensation technique are in use. They are,

1. Dominant pole compensation technique
2. Pole zero (Lag) compensation technique

Dominant pole compensation technique

In case of Dominant pole compensation technique, a suitable RC network is connected to the output of the amplifier as shown in fig. or simply connecting a capacitor C from a suitable high resistance point to ground. Here the uncompensated transfer function A_{OL} is altered by adding a pole.





The compensated transfer is given by,

$$|A| = \frac{V_0}{V_i} = A_{0L} \frac{1/_{j\omega C}}{R + 1/_{j\omega C}}$$

$$= \frac{A_{0L}}{R + 1/_{j\omega C}}$$

$$= \frac{A_{0L}}{R + j\frac{f}{fc}}$$

A practical amplifier has number of stages and each stage produces a capacitive component. Thus due to a number of RC pole pairs, there will be a number of different break frequencies. The transfer function of an amplifier with three break frequencies can be written as,

$$|A| = \frac{A_{0L}}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}, \qquad 0 < f_1 < f_2 < f_3$$

A capacitor is connected at the output of the amplifier to make the modified gain to 0dB with a slope of -20dB/decade at a frequency where the pole of uncompensated transfer function A contribute negligible phase shift. Cutoff frequency is selected such that the compensated transfer A passes through 0dB at the pole $f_1$of the uncompensated A_{0L}

The frequency can be found graphically by having A pass through 0dB at the frequency f_1 with a slope of -20dB/decade as shown in fig.

The value of the capacitor can be calculated from the relation

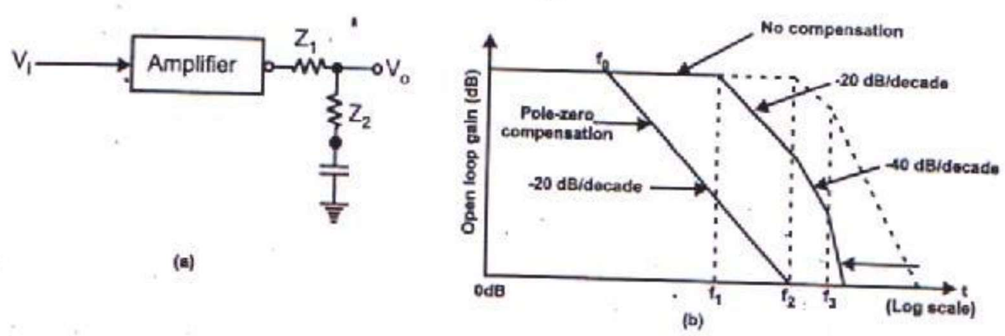
$$f_C = \frac{1}{2\pi RC}$$

Advantages

1. It reduce the open loop bandwidth
2. Improve noise immunity.

Pole-Zero compensation technique

In case of Pole- Zero compensation technique, a suitable RC network is connected to the output of an amplifier as shown in fig. or simply connected a capacitor C from a suitable high resistance point to ground. Here the uncompensated transfer function A_{0L} is altered by adding both pole and zero as shown in fig. the selection of zero should be at higher frequency then pole.



The compensated transfer is given by,

$$|A| = \frac{V_0}{V_i} = \frac{Z_2}{Z_1 + Z_2}$$

Where $Z_1 = R_1, Z_2 = R_2 + \frac{1}{j\omega C_2}, f_1 = \frac{1}{2\pi R_2 C_2}, f_0 = \frac{1}{2\pi(R_1+R_2)C_2}$

$$= \frac{R_2}{R_1 + R_2}\left(\frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_0}}\right)$$

The compensating network is designed to produce a zero at the first corner frequency f_1 of the uncompensated transfer functionA_{0L}. This zero will cancel the effect of the pole at f_1. The pole of the compensating network at f_0 is selected so that the compensated transfer function A passes through a 0 dB at the second corner frequency f_2 of the uncompensated transfer function A. the frequency can be found graphically by having A pass through 0dB at the frequency f_1 with a slope of 20 dB/decade as shown in fig. To avoid the loading of amplifier due to compensating network, it is always to consider$R_1 \ll R_2\ so\ that\ \frac{R_2}{R_1+R_2} \approx 1$.

A practical amplifier has number of stages and each stage produces a capacitive components. Thus due to number of RC pole pair, there will be a number of different break frequencies. The transfer function of an amplifier with three break frequencies can be written as,

$$|A| = \frac{V_0}{V_i} = \frac{V_0}{V_2}\frac{V_2}{V_i} = A_{0L}\frac{R_2}{R_1 + R_2}\left(\frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_0}}\right)$$

$$|A| = \frac{A_{0L}}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}\frac{R_2}{R_1 + R_2}\left(\frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_0}}\right)$$

$$|A| = \frac{A_{0L}}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}, \qquad 0 < f_0 < f_1 < f_2 < f_3$$

The value of $R_2\ and\ C_2$ are selected such that the zero of the compensating network is equal to the pole at the frequencyf_1. If there had been no pole added by the compensating network, the response of the amplifier would have changed to that of the dotted curve. However, because of the predominance of the pole of the compensating network atf_0, the rate of closure will be -20 dB/decade throughout as shown in fig. The pole of $f_0$should be selected so that -20 dB/decade fall should meet the 0dB line at f_2 which is the second pole of A_{0L}.

1.11 Example with Solutions

Example 1: A feedback amplifier has an open loop gain of 600 and feedback factor $\beta = 0.01$. Find the closed loop gain with negative feedback.

Solution:

$$A_{Vf} = \frac{A}{1+\beta A} = \frac{600}{1+600\times 0.01}$$

$$= 85.714$$

Example 2: If an amplifier has a bandwidth of 300 KHz and voltage gain of 100, what will be the new bandwidth and gain if 70% 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 800KHZ?

Solution:

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

$$A_{Vf} = \frac{A}{1+\beta A}\ where\ \beta = 0.1\ and\ A = 100$$

$$A_{Vf} = \frac{100}{1+100\times 0.1}$$

$$= 9.09$$

The bandwidth of an amplifier with feedback is given by,

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

Assuming $f_H \gg f_L$ we have,

$$B_W = f_H\ and\ B_{Wf} = (1+A_{mid}\beta)B_W$$

$$B_{Wf} = (1+100\times 0.1)\times 300kHz$$

$$= 3300KHz$$

The gain bandwidth product before feedback is,

Gain bandwith product = $A_V B_W$

$$= 100\times 300K = 30\times 10^6$$

The gain bandwidth product after feedback is,

$$= A_{Vf}\times B_{Wf}$$

$$= 9.09\times 3300KHz$$

$$= 30\times 10^6$$

If bandwidth is to be limited to 600 kHz we have $f_{Hf} = 800KHz$ assuming $f_{Hf} \gg f_{Lf}$

We know that,

$$B_{Wf} = (1+A_{Vmid}\beta)f_H$$

$$800K = (1+100\beta)300K$$

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