

1.5 ANALYSIS OF FEEDBACK AMPLIFIER

CURRENT-SERIES (OR) SERIES-SERIES FEEDBACK AMPLIFIER

- Trans-conductance feedback amplifier provides an output current I_o which is proportional to the input voltage V_s . The feedback signal is the voltage V_f , Here added to V_s at the input of the amplifier.

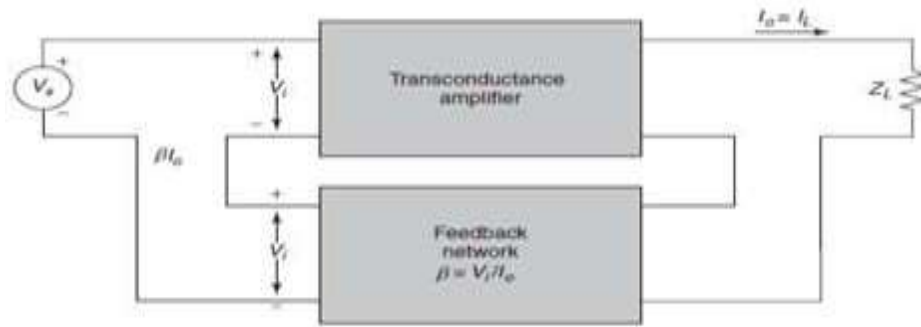


Fig.1.5.1 . Current – Series Amplifier

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-240)

Input & Output resistance:

Input resistance:

- Step 1: Draw the equivalent Circuit for Current Series amplifier

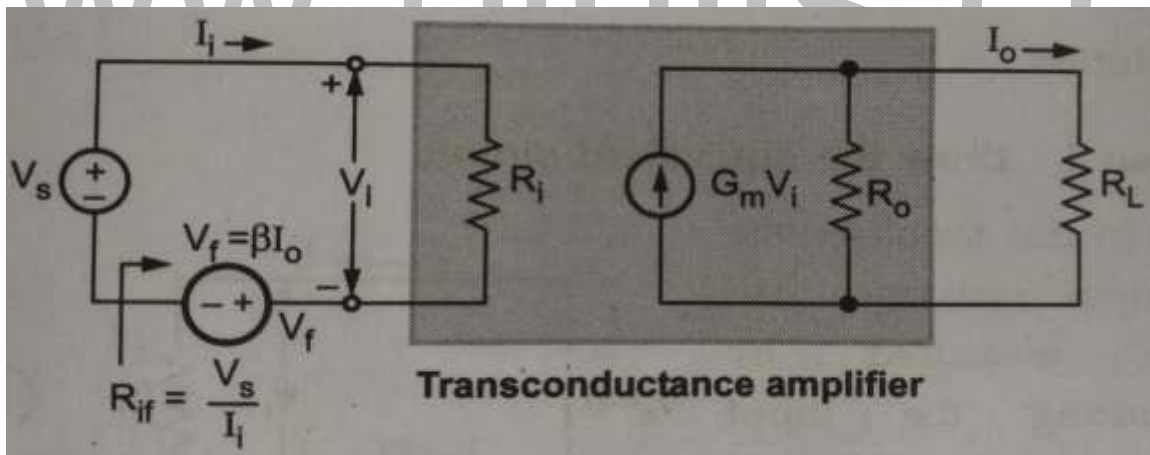


Fig.1.5.2 . Current – Series Amplifier-input resistance

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-240)

Looking in fig1.5.2 the input resistance with feedback is given $R_{if} = V_s / I_i$

- Step 2: Obtain expression for V_s

Applying KVL to the input side,

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

$$V_s = I_i R_i + V_f = I_i R_i + \beta I_o \text{ -----(1)}$$

- Step 3: Obtain expression for I_o in terms of V_i

Output Current I_o is given by

$$I_o = G_m V_i R_o / (R_o + R_L)$$

where $G_M = G_m R_o / (R_o + R_L)$

$$I_o = G_M V_i = G_M I_i R_i \text{ -----(2)}$$

G_m is open Circuit Transconductance gain without feedback and G_M is Transconductance without feedback taking the load R_L into account

- Step 4: Obtain expression for R_{if}

Sub value of I_o from eqn (2) in eqn (1)

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

$$R_{if} = V_s / I_i = R_i + \beta G_M R_i$$

Output resistance:

- Step 1: Draw the equivalent Circuit

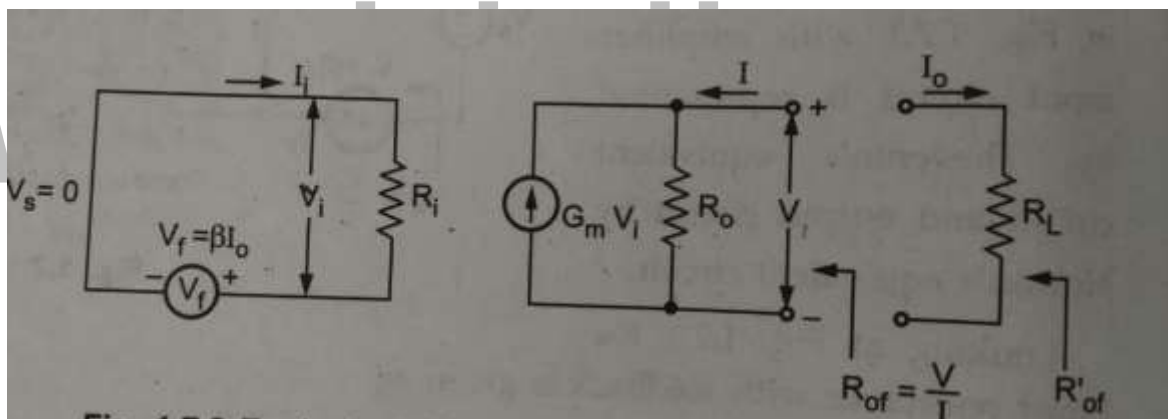


Fig.1.5.3 . Current – Series Amplifier-output resistance

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-241)

Output resistance can be measured by shorting the input source $V_s = 0$ and looking into the output terminals with R_L disconnected

- Step 2: Obtain expression for I in terms of V

Applying KCL to the output Node,

$$I = (V / R_o) - G_m V_i \text{ -----(1)}$$

Input voltage is given by

$$V_i = - V_f = - \beta I_o$$

$$V_i = \beta I$$

$$\therefore I_o = -I \text{ ----- (2)}$$

Sub value of V_i from eqn (2) in eqn (1)

$$I = (V / R_o) - G_m \beta I$$

$$V / R_o = I + G_m \beta I = I (1 + G_m \beta)$$

- Step 3: Obtain expression for R_{of}

$$R_{of} = V / I$$

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

- Step 4: Obtain expression for R'_{of}

$$R'_{of} = R_{of} \parallel R_L = R_o R_L / (R_o + R_L + \beta A_v R_L)$$

Dividing num and den by $(R_o + R_L)$

$$R'_{of} = R'_o (1 + \beta G_m) / (1 + \beta G_M)$$

$$R'_o = R_o R_L / (R_o + R_L)$$

$$G_M = G_m R_o / (R_o + R_L)$$

Transistorized Analysis of feedback amplifiers:

1. Identify the type of feedback
2. Find input circuit
3. Find output circuit
4. Replace transistor by its h-parameter equivalent circuit.
5. Find open loop voltage gain
6. Indicate v_o and v_f and calculate β
7. Calculate D , A_{vf} , R_{if} , R_{of} , and R'_{of}

VOLTAGE-SHUNT (OR) SHUNT-SHUNT FEEDBACK AMPLIFIER

- The voltage-shunt or shunt-shunt feedback amplifier provides an output voltage V_o in proportion to the input current I_s . The input current I_i of the basic amplifier is the algebraic sum of I_s and the feedback current I_f .

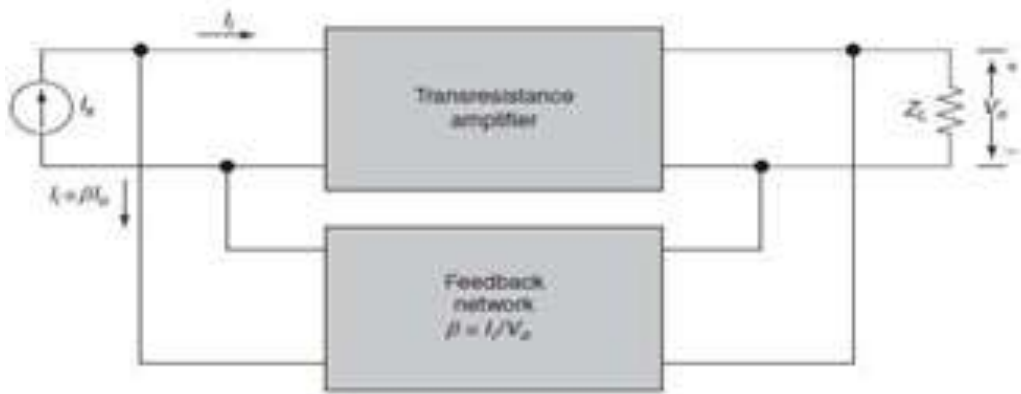


Fig 1.5.4. Voltage-Shunt Amplifier

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-252)

Input Resistance:

- Step 1: Draw the equivalent Circuit for Voltage Shunt amplifier

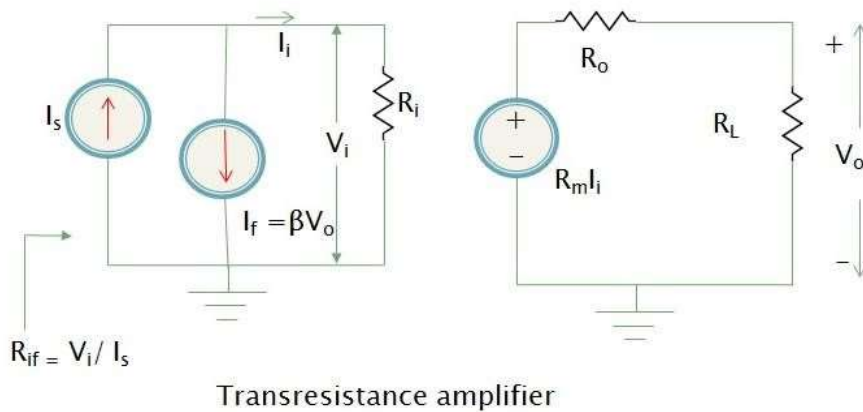


Fig 1.5.5. Voltage-Shunt Amplifier-input resistance

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-252)

Looking in fig 1.5.5 the input resistance with feedback is given $R_{if} = V_i / I_s$

- Step 2: Obtain expression for I_s

Applying KCL to the input node,

$$I_s = I_i + I_f = I_i + \beta V_o \text{----- (1)}$$

Expression for V_o in terms of I_i

Output Voltage V_o is given by

$$V_o = R_m I_i R_o / (R_o + R_L)$$

where $R_M = R_m R_o / (R_o + R_L)$

$$V_o = R_M I_i \text{----- (2)}$$

R_m is open Circuit Transresistance gain without feedback and R_M is Transresistance without feedback taking the load R_L into account

- Step 3: Obtain expression for R_{if}

Sub value of V_o from eqn (2) in eqn (1)

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

$$R_{if} = V_i / I_s = V_i / I_i (1 + \beta R_M)$$

Output resistance:

- Step 1: Draw the equivalent Circuit

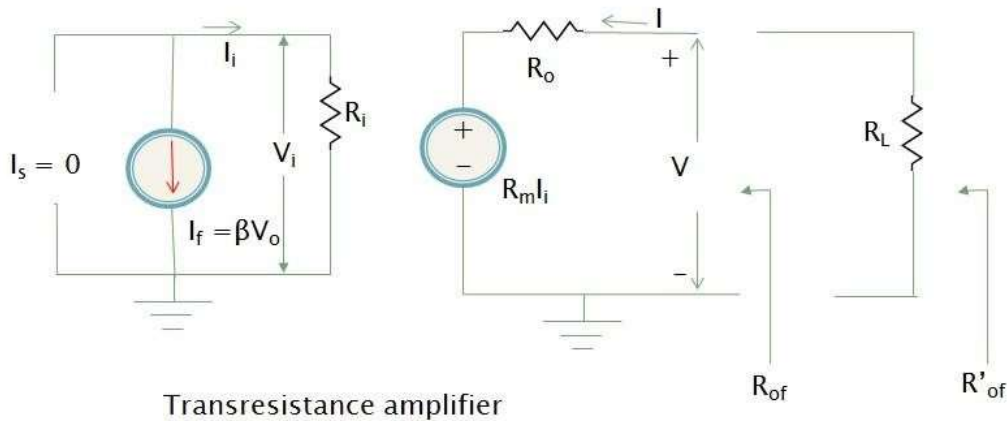


Fig 1.5.6. Voltage-Shunt Amplifier-output resistance

(Source: Microelectronics by J. Millman and A. Grabel, 2nd ed., Page-252)

Output resistance can be measured by opening the input source $I_s = 0$ and looking into the output terminals with R_L disconnected

- Step 2: Obtain expression for I in terms of V ,

Applying KVL to the output Side,

$$R_m I_i + I R_o - V = 0$$

$$I = (V - R_m I_i) / R_o \text{ ----- (1)}$$

Input Current is given by

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

Sub value of I_i from eqn (2) in eqn (1)

$$I = (V + R_m \beta V) / R_o$$

$$I = V (1 + R_m \beta) / R_o$$

- Step 3: Obtain expression for R_{of}

$$R_{of} = V / I$$

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

- Step 3: Obtain expression for R'_{of}

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

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

Dividing num and denominator by $(R_o + R_L)$

$$R'_o = \frac{R_{of} R_L}{R_{of} + R_L}$$

Transistorized Analysis of feedback amplifiers:

1. Identify the type of feedback
2. Find input circuit
3. Find output circuit
4. Replace transistor by its h-parameter equivalent circuit.
5. Find open loop voltage gain
6. Indicate v_o and v_f and calculate β
7. Calculate D , A_{vf} , R_{if} , R_{of} , and R'_{of}

SHUNT-SERIES (OR) CURRENT-SHUNT FEEDBACK AMPLIFIER

- The current-shunt feedback amplifier, supplies an output current I_o which is proportional to the input current I_i . This makes it a current amplifier.
- The feedback signal is the current if the input current of the basic amplifier is $I_i = I_s + I_f$ and the output current is $I_o = I$

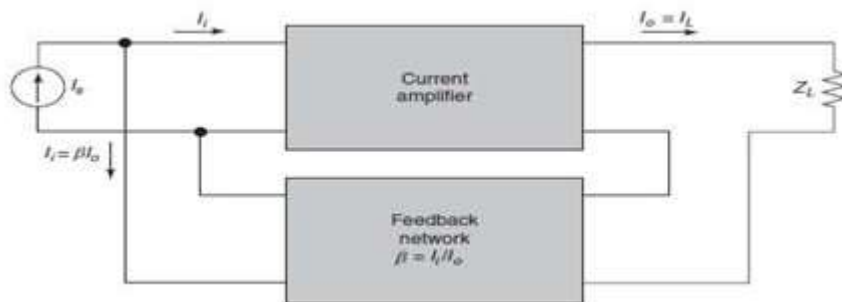


Fig: 1.5.7 Current -Shunt Amplifier

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-255)

Input & Output resistance:

Input resistance:

- Step 1: Draw the equivalent Ckt for Voltage Series Shunt amplifier

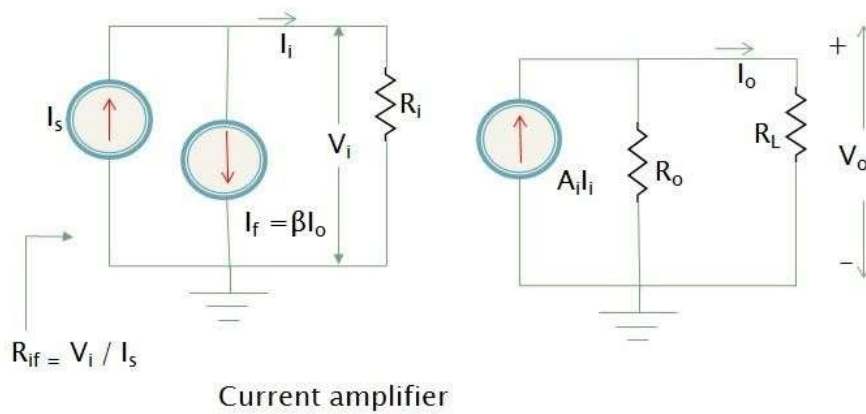


Fig: 1.5.8 Current -Shunt Amplifier-input resistance

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-256)

Looking in fig 1.5.8 the input resistance with feedback is given $R_{if} = V_i / I_s$

- Step 2: Obtain expression for I_s

Applying KCL to the input node ,

$$I_s = I_i + I_f = I_i + \beta I_o \text{ -----(1)}$$

- Step 3: Obtain expression for I_o in terms of I_i

Output Current I_o is given by

$$I_o = A_i I_i R_o / (R_o + R_L)$$

$$\text{Where } A_I = A_i R_o / (R_o + R_L)$$

$$I_o = A_I I_i \text{----- (2)}$$

A_i is open Circuit Current gain without feedback and A_I is Current gain without feedback taking the load R_L into account

- Step 3: Obtain expression for R_{if}

Sub value of I_o from eqn (2) in eqn (1)

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

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

Output resistance:

- Step 1: Draw the equivalent Ckt

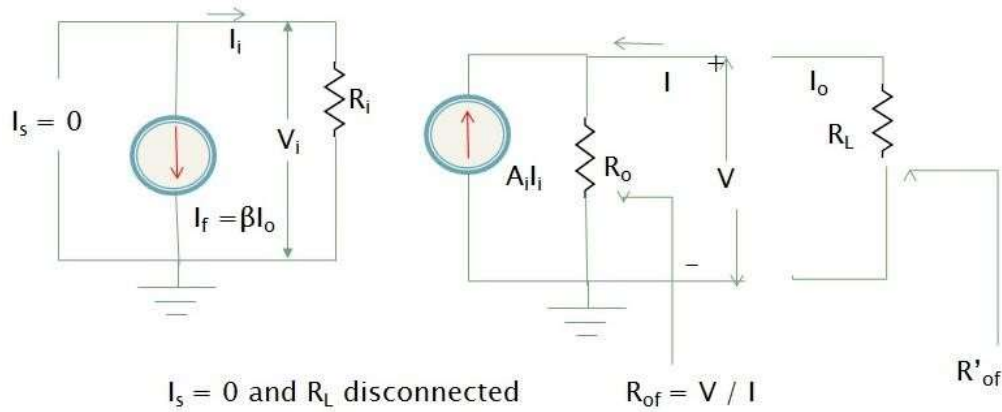


Fig: 1.5.9 Current -Shunt Amplifier-output resistance

(Source: Microelectronics by J. Millman and A. Grabel, 2nd ed., Page-256)

Output resistance can be measured by shorting the input source $I_s = 0$ and looking into the output terminals with R_L disconnected

- Step 2: Obtain expression for I in terms of V

Applying KCL to the output node,

$$I = (V / R_o) - A_i I_i \text{ ----- (1)}$$

Input Current is given by

$$I_i = - I_f = - \beta I_o = \beta I \text{ ----- (2)}$$

Sub value of I_i from eqn (2) in eqn (1)

$$I = (V / R_o) - A_i \beta I$$

$$V / R_o = I + A_i \beta I = I (1 + \beta A_i)$$

- Step 3: Obtain expression for R_{of}

$$R_{of} = V / I$$

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

- Step 4: Obtain expression for R'_{of}

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

$$R'_{of} = R_o (1 + \beta A_i) / (1 + \beta A_i)$$

Dividing num and den by $(R_o + R_L)$

$$R'_{of} = R_o R_L / (R_o + R_L)$$

Transistorized Analysis of feedback amplifiers:

1. Identify the type of feedback
2. Find input circuit

3. Find output circuit
4. Replace transistor by its h-parameter equivalent circuit.
5. Find open loop voltage gain
6. Indicate v_o and v_f and calculate β
7. Calculate D , A_{vf} , R_{if} , R_{of} , and R'_{of}

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1.3 EFFECTS OF FEEDBACK

Stabilization of Gain:

- The gain of the amplifier may change due to the changes in the parameters of the transistor or the supply voltage variation.
- The gain A_f of the feedback amplifier is independent of internal gain A and depends only on feedback fraction.

W.K.T,

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

Diff.w.r.t A

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

Dividing both sides by A_f we get

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

Where $\left| \frac{dA_f}{A_f} \right|$ = fractional change in gain with the feedback

$\left| \frac{dA}{A} \right|$ = fractional change in gain without the feedback.

- The sensitivity of transfer gain of the feedback amplifier A_f with respect to the variations in the internal amplifier gain A is defined as the ratio of the fractional change in gain with the feedback to the fractional change in gain without the feedback.

- $\frac{1}{|(1 + \beta A)|}$

- The sensitivity is

- The inverse or reciprocal of sensitivity is called De-Sensitivity.

$$D = 1 + \beta A$$

- The stability of the amplifier increases with increase in desensitivity

Reduction in distortion:

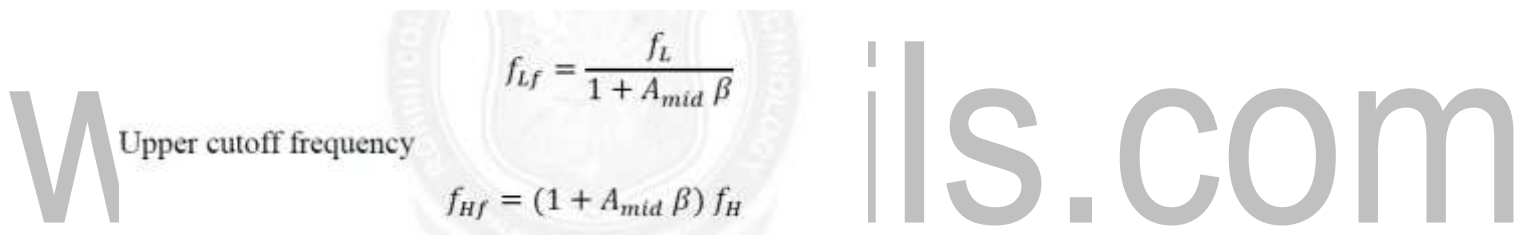
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- The negative feedback reduces the non-linear distortion in the output signal.
- Nonlinear distortion occurs when an active device in the amplifier has nonlinear transfer characteristics.
- The negative feedback reduces the nonlinear distortion by the factor

Increase in Bandwidth:

- The negative feedback decreases the lower cut off frequency f_L while increases the upper cut off frequency f_H i.e. it increases the bandwidth of the amplifier.
- This implies that if the band width of the gain A has certain values (say 1MHz), by applying negative feedback, it can be increased.
- The increase, happens by sacrificing the value of the gain A .
- It implies a mid-band gain of A_{Mf} and a high frequency band width of A_{Hf} .

Lower Cutoff frequency


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

Upper cutoff frequency

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

- It can be clearly seen that the new mid-band gain is $(1+A \beta)$ times smaller than the mid-band gain without feedback, but the high frequency band width is $(1+A\beta)$ times larger than the band width without feedback.
- Thus an extension of band width by the factor $(1+A\beta)$ has been achieved.
- Band width = Upper cut-off Frequency – Lower cut-off Frequency

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

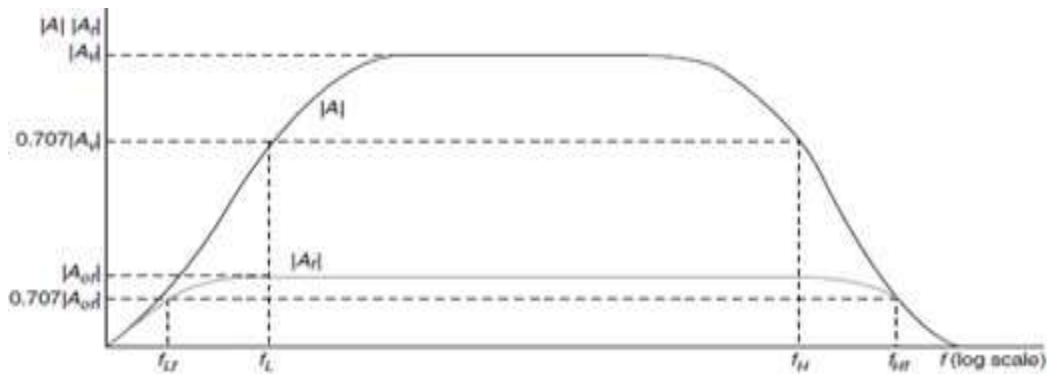


Fig.1.3.1 effect of negative feedback on gain and bandwidth

(Source: *Microelectronics* by J. Millman and A. Grabel, , 2nd ed., Page-212)

- 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

Reduction in Noise:

- Almost all amplifier circuit produces noise due to presence of active and passive components in it.
- The negative feedback can be used to reduce the noise in amplifiers.
- It is possible to improve signal to noise ration of an amplifier under certain conditions.
- A noisy amplifier is modified by a noiseless amplifier in series with noise source V_n .
- The output voltage of this noisy amplifier is given by,

$$V_o = A(V_s + V_n)$$

- The signal to noise ratio is given by

$$\frac{S}{N} = \frac{V_s}{V_n}$$

- It is possible to improve S/N ratio of this noisy amplifier by preceding a noise free preamplifier
- The signal to noise ratio at the output is given by

$$S/N = \frac{V_s A_p}{V_N}$$

- We can improve SNR of a noisy amplifier by factor of A_p if a noise-free preamplifier with a voltage gain A_p precedes a noisy amplifier.

Input impedance:

- If the feedback signal is added to the input in series with the applied voltage it increases the input resistance.
- Hence, the input resistance with feedback — is greater than the input resistance without feedback.
- Feedback signal is added to the input in shunt with applied voltage, it decreases the input resistance.
- Hence, the input resistance with feedback is decreased.

Output impedance:

- Negative Feedback which samples the output voltage, it decreases output resistance.
- Negative Feedback which samples the output Current, it Increases output resistance

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1.1 FEEDBACK CONCEPTS:

- Definition: The amplifier in which a part of output is sampled and fed back to the input of the amplifier is called feedback amplifier
- Feedback is used to make the operating point of a transistor insensitive to both manufacturing variations in as well as temperature.

TYPES:

- **Positive feedback:** the input and part of the output which fed back to the input are in phase, the feedback is called positive feedback.

If the net effect of the feedback is to increase the magnitude of the input signal, it is called as Positive.

- **Negative feedback:** both the signals are out of phase, the feedback is called negative feedback.

ADVANTAGES OF NEGATIVE FEEDBACK:

- ❖ Stabilization of Gain
- ❖ Reduction in Distortion
- ❖ Reduction in Noise
- ❖ Increase in Input Impedance
- ❖ Decrease in Output Impedance
- ❖ Increases the range of Uniform Amplification.

COMPARISON OF POSITIVE AND NEGATIVE FEEDBACK:

S.No	Parameter	Positive feedback	Negative feedback
1	Phase shift b/w f/b signal and input signal	0 or 360	180
2	F/B signal and I/P signal	In phase	Out of phase
3	I/P Voltage	Increases	Decreases
4	O/P Voltage	Increases	Decreases
5	Voltage Gain	Increases	Decreases

6	Distortion	Increases	Decreases
7	Stability	Decreases	Increases
8	Application	Oscillator & Schmitt trigger	Amplifiers

1.1.1 GENERAL FEEDBACK STRUCTURE

The general feedback structure of feedback amplifier is shown in figure 1.1.1. The basic feedback amplifier consists of five basic elements. These are: Input & Output signals, Basic Amplifier, Sampling Network, Comparison or Summing Network and feedback network.

Input Signal:

- The signal source is modeled either by a voltage source V_s in series with a resistance R_s , or by a current source I_s in parallel with a resistance R_s .

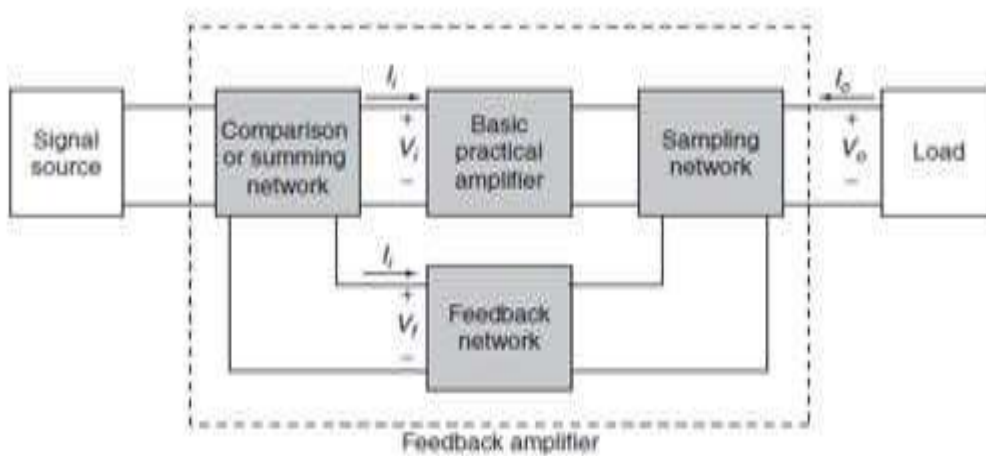


Fig1.1.1. Block diagram of a basic feedback amplifier

(Source: *Microelectronics by J. Millman and A. Grabel, 2nd ed., Page-203*)

Output Signal:

- The output can either be the voltage across the load resistance R_L or the current through it. It is the output signal that is desired to be independent of the load and insensitive to parameter variations in the basic amplifier.

Sampling Network:

- There are two ways to sample the output, according to the sampling parameter, either voltage or current.

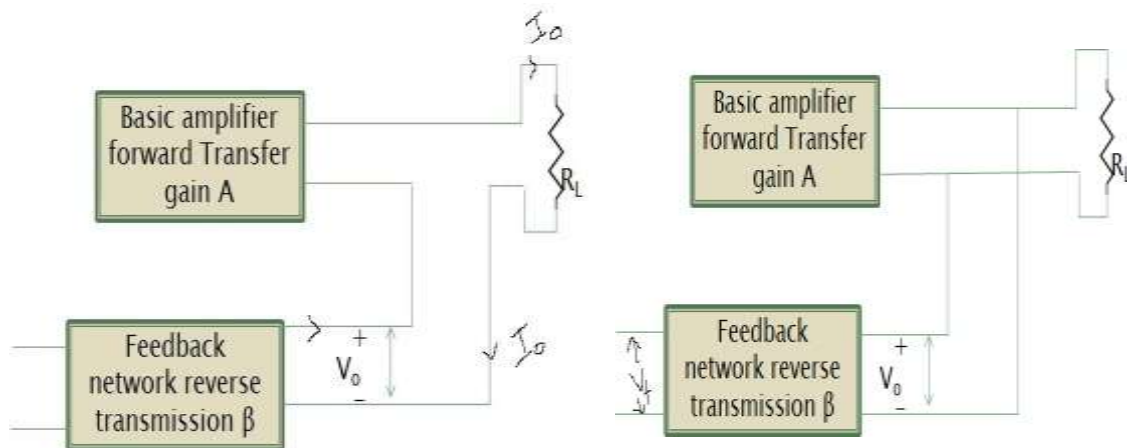


Fig1.1.2. (a) voltage (node) & (b) Current (loop) sampling

(Source: *Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-203*)

- The output voltage is sampled by connecting the feedback network in shunt across the output, as shown in 1.1.2 (a). This type of connection is referred to as voltage sampling.
- The output current is sampled by connecting the feedback network in series with the output, as shown in 1.1.2 (b). This type of connection is referred to as current sampling.

Feedback network:

- It may consists of resistor, Capacitors, inductors (resistive configuration)
- Provides reduced portion of the output as feedback signal to the input mixer network. $V_f = \beta V_o$
- β feedback factor or feedback ratio (lies b/w 0 to 1)

Mixer Network:

- There are two ways of mixing feedback signal with the input signal
- Series input mixing in fig 1.1.3 (a) shunt input mixing in fig 1.1.3 (b)

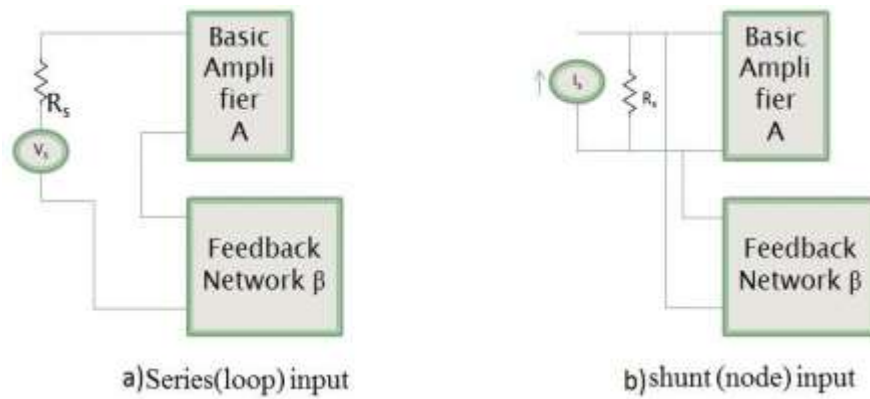


Fig.1.1.3. (a) series & (b) shunt mixing

(Source: Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-203)

TRANSFER RATIO OR GAIN

- the ratio of the output signal to the input signal of the basic amplifier is represented by the symbol A

$$\frac{V_o}{V_i} = A_v = \text{Voltage gain}$$

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

$$\frac{I_o}{I_i} = A_i = \text{Current gain}$$

$$\frac{I_o}{I_s} = A_{if} = \text{Current gain with feedback}$$

$$\frac{I_o}{V_i} = G_m = \text{Transconductance}$$

$$\frac{I_o}{V_s} = G_{Mf} = \text{Transconductance with feedback}$$

$$\frac{V_o}{I_i} = R_m = \text{Transresistance}$$

$$\frac{V_o}{I_s} = R_{Mf} = \text{Transresistance with feedback}$$

- The four quantities A_v , A_i , G_m , and R_m are referred to as a transfer gain of the basic amplifier without feedback
- The four quantities A_{vf} , A_{if} , G_{Mf} , and R_{Mf} are referred to as a transfer gain of the basic amplifier with feedback

1.2 GAIN WITH FEEDBACK

- Gain without feedback (A) is always greater than gain with feedback $\{A / (1 + \beta A)\}$ and it decreases with increases in β

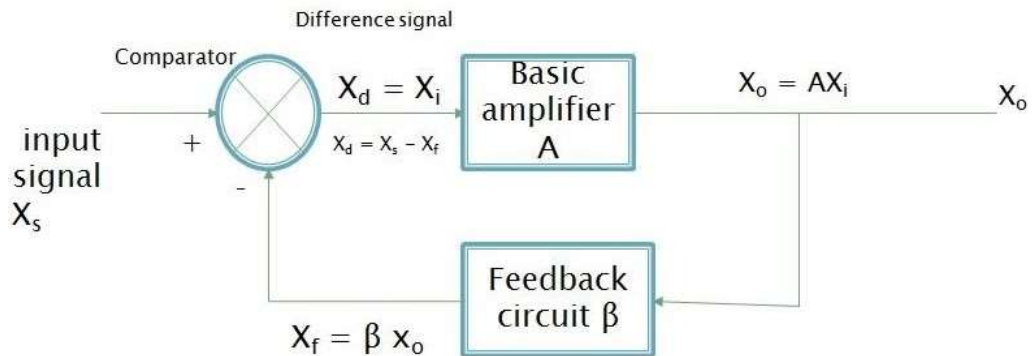


Fig.1.2.1. schematic representation of negative feedback amplifier

(Source: *Microelectronics by J. Millman and A. Grabel, , 2nd ed., Page-204*)

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

For voltage amplifier, gain with negative feedback is given by,

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

A_v = open loop gain

β = feedback factor

LOOP GAIN

- In fig 1.2.1 The difference signal, X_d is multiplied by A in passing through the amplifier, is multiplied by β in transmission through the feedback network, and is multiplied by -1 in the mixing or difference network.
- The gain of this loop is the product $-A \beta$. This gain is known as loop gain or return ratio

1.7 FREQUENCY COMPENSATION

Dominant pole compensation:

- The open-loop transfer function $A(s)$ of an amplifier having three or more poles so that the closed-loop amplifier is stable for a given desired value of closed-loop gain.

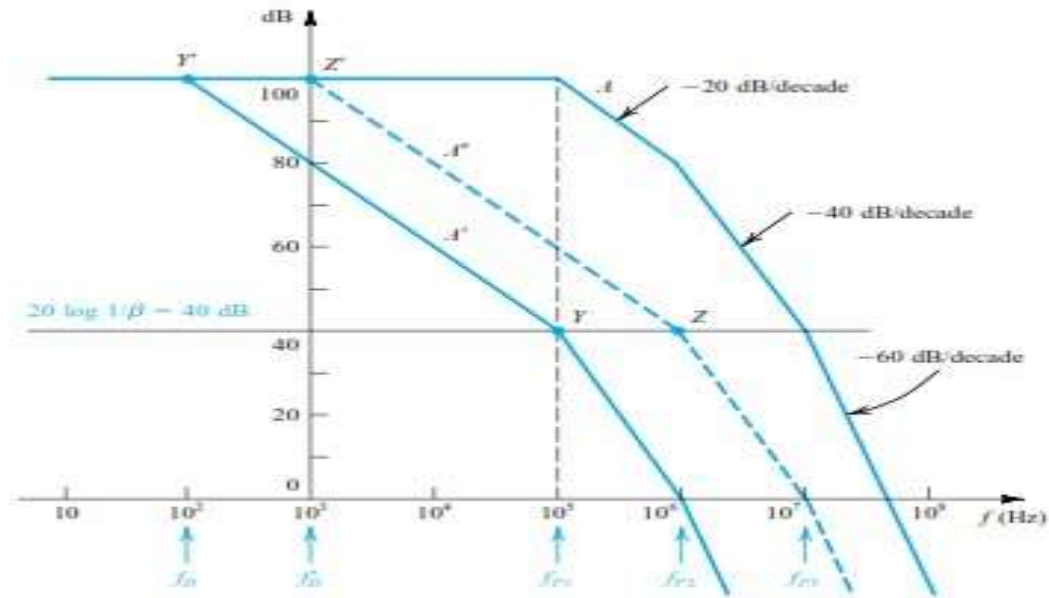


Figure 1.7.1 the frequency compensation

[Source: microelectronic circuits by sedra & smith, page no:884]

- The simplest method of frequency compensation consists of introducing a new pole in the function $A(s)$ at a sufficiently low frequency, f_D , such that the modified open-loop gain $A'(s)$, intersects the $20 \log(1/|\beta|)$ curve with a slope difference of 20 dB/decade.
- Let it be required to compensate the amplifier whose $A(s)$ is shown in Fig.1.7.1. such that closed-loop amplifiers with β as high as 10^{-2} will be stable
- First, we draw a horizontal straight line at the 40-dB level to represent $20 \log(1/|\beta|)$
- Then locate point Y on this line at the frequency of the first pole f_{p1}
- From Y we draw a line with -20-dB/decade slope and determine the point at which this line intersects the dc gain line, point Y' .

- This latter point gives the frequency f_D of the new pole that has to be introduced in the open-loop transfer function.
- The compensated open-loop response is indicated in Fig. 1.7.1.
- It has four poles: at f_D , f_{p1} , f_{p2} and f_{p3} .
- Thus $|A'|$ begins to roll off with a slope of -20dB/decade at f_D .
- At f_{p1} the slope changes to -40 dB/decade, at f_{p2} it changes to -60 dB/decade, and so on.
- Since the $20 \log (1/\beta)$ line intersects the $20 \log |A'|$ curve at point Y on the -20 dB/decade, the closed loop amplifier with this β value will be stable.

Disadvantage:

- Most frequencies the open loop gain has been drastically reduced.

Implementation of dominant pole compensation:

- The frequency compensation using dominant pole can be implemented by intersecting a capacitor C_x in such a way that it adds a break frequency to the basic amplifier.
- This approach is illustrated in fig 1.7.2

$$f_{p1} = \frac{1}{2\pi C_x R_x}$$

- In the above approach of implementation of dominant pole it is assumed that the intersection of ne pole does not affect the original poles of the amplifier.
- In another approach, the dominant pole is implemented by adding a capacitor to the amplifier in such a way that the original break frequency f_{p1} is reduced and it performs the compensation function.

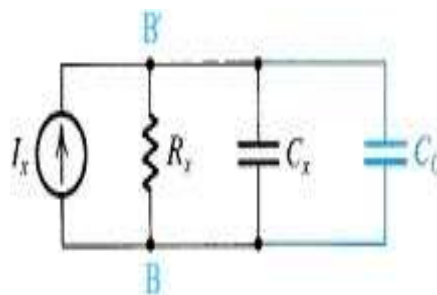


Figure 1.6.1 a compensating capacitor C_c added.

[source: microelectronic circuits by sedra & smith, page no:870]

- The break frequency is given by

$$f_D = \frac{1}{2\pi(C_x + C_c)R_x}$$

Advantages:

1. As the noise frequency components are outside the smaller bandwidth, the noise immunity of the system improves.
2. Adjusting vale of f_D adequate phase margin and the stability of the system is assured.

Disadvantages:

1. Bandwidth of an amplifier reduces significantly.
2. Requires large value of compensating capacitor.

Miller compensation:

- Miller compensation is implemented by connecting a capacitor between input and output of a gain stage of multistage amplifier.
- The fig 1.7.3 shows the gain stage of multistage amplifier with a miller capacitance connected as a feedback path.

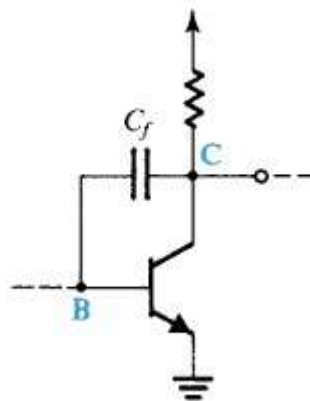


Figure 1.6.1 gain amplifier stage.

[Source: microelectronic circuits by sedra & smith,page no:887]

- Fig 1.7.4 shows a simplified equivalent circuit of the common emitter stage.

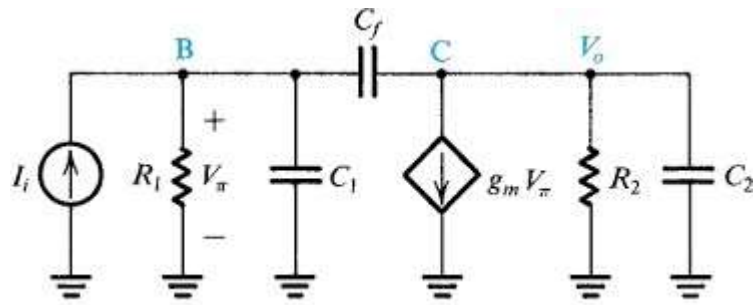


Figure 1.6.1 Equivalent circuit.

[Source: *microelectronic circuits by sedra & smith, page no:887*]

- Here R_i and C_i represent the total resistance and total capacitance, between node B and ground.
- R_o and C_o represent the total resistance and total capacitance between node C and the ground.
- In the absence of the compensating capacitor C_f , there are two poles—one at the input and one at the output. Let us assume that these two poles are f_{p1} and f_{p2}

$$f_{p1} = \frac{1}{2\pi C_1 R_1}$$

$$f_{p2} = \frac{1}{2\pi C_2 R_2}$$

If C_f present new frequency of the two poles

$$\omega'_{p1} = \frac{1}{g_m R_2 C_f R_1}$$

$$\omega'_{p2} = \frac{g_m C_f}{C_1 C_2 + C_f (C_1 + C_2)}$$

If C_f is increased f_{p1} is reduced and f_{p2} is increased. This action is referred to as pole splitting

1.8 GAIN AND PHASE MARGIN

- We know that whether a feedback amplifier is or is not stable can be determined by examining its loop gain $A\beta$ as a function of frequency.
- The simplest and most effective means for doing this is through the use of a Bode plot for $A\beta$ shown in Fig 1.8.1
- The feedback amplifier whose loop gain is plotted in will be stable.
- Once at the frequency of 180° phase shift, ω_{180} the magnitude of the loop gain is less than unity.
- The difference between the value of $|A\beta|$ at ω_{180} and unity, called the **gain margin**.
- The gain margin represents the amount by which the loop gain can be increased while stability is maintained.
- Another way to investigate the stability and to express its degree is to examine the Bode plot at the frequency for which $|A\beta| = 1$, which is the point at which the magnitude plot crosses the 0-dB line.
- If at this frequency the phase angle is less (in magnitude) than 180° , then the amplifier is stable.
- The difference between the phase angle at this frequency and 180° is termed the **phase margin**

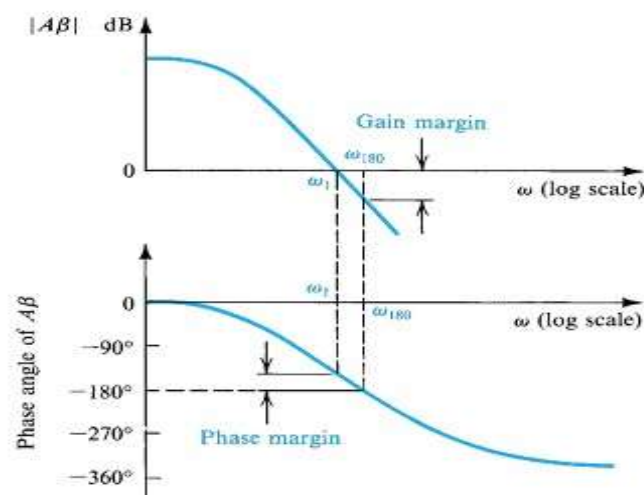


Figure 1.8.1 Bode plot for the loop gain $A\beta$ illustrating the definitions of the gain and phase margins.

[Source: microelectronic circuits by sedra & smith, page no: 880]

1.5 STABILITY PROBLEM

Transfer function of feedback amplifier

- The ideal closed loop transfer function for the feedback amplifier is given by,

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

Where A-is the open loop transfer function

β - is the feedback transfer function.

- Amplifier components and parameters change with frequency and hence its open-loop gain is a function of frequency.
- Closed-loop transfer function is given by

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

- Assume that the amplifier is direct coupled with constant dc gain A and with poles and zeros occurring in the high-frequency band.
- let us assume that at low frequencies $\beta(s)$ reduces to a constant value Thus at low frequencies the loop gain $A(s)\beta(s)$ becomes a constant, which should be a positive number.
- For physical frequencies $s=j\omega$

$$A_f(j\omega) = \frac{A(j\omega)}{1 + A(j\omega)\beta(j\omega)}$$

- Thus the loop gain $A(j\omega)\beta(j\omega)$ is a complex number that can be represented by its magnitude and phase,

$$L(j\omega) = A(j\omega)\beta(j\omega)$$

$$= |A(j\omega)\beta(j\omega)| e^{-i\phi\omega}$$

- It is the manner in which the loop gain varies with frequency that determines the stability or instability of the feedback amplifier.
- Consider the frequency at which the phase angle $\phi(\omega)$ becomes 180° .
- At this frequency ω_{180} , the loop gain will be a real number with a negative sign.

- Thus at this frequency the feedback will become positive. If at $\omega = \omega_{180}$, the magnitude of the loop gain is less than unity, then that the closed-loop gain $A_f(j\omega)$ will be greater than the open-loop gain $A(j\omega)$. the feedback amplifier will be stable.
- If at the frequency ω_{180} the magnitude of the loop gain is equal to unity, that $A_f(j\omega)$ will be infinite. That the amplifier will have an output for zero input (oscillator).

The nyquist plot:

- It can be used to test the stability of the feedback amplifier.
- The nyquist plot not only determines if a system is stable, it also indicates the degree of system stability.

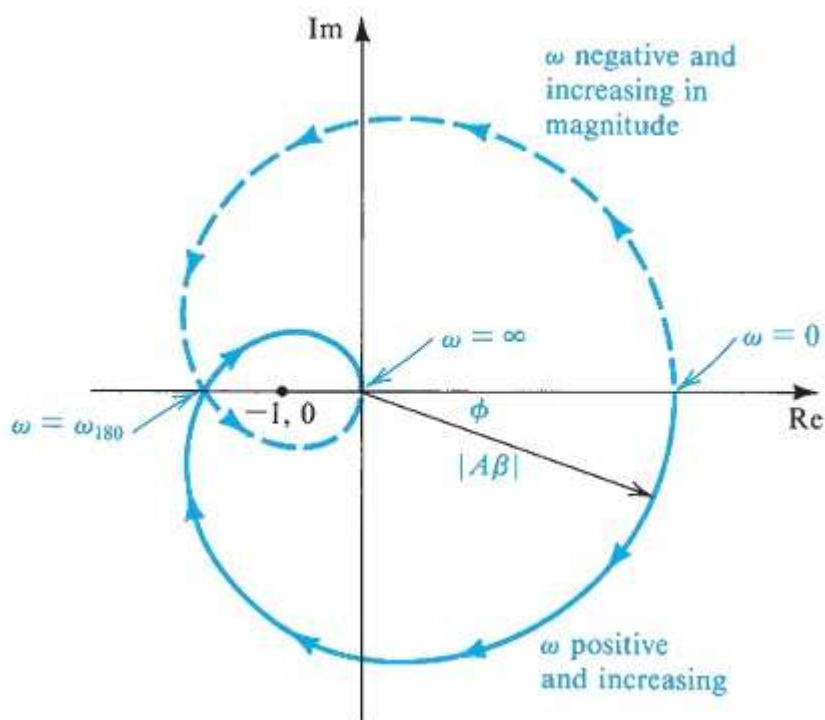


Figure 1.6.1 the nyquist plot of an unstable amplifier

[source: *microelectronic circuits by sedra & smith, page no:870*]

- The radial distance is $|A\beta|$ and the angle is the phase angle ϕ . the solid-line plot is for positive frequencies.
- The loop gain has a magnitude that is an even function of frequency and a phase that is an odd function of frequency, the A plot for negative frequencies can be drawn as a mirror image through the real axis.

- The Nyquist plot intersects the negative real axis at frequency ω_{180} . If this intersection occurs to the left of the point $(-1,0)$, then the magnitude of loop gain at this frequency is greater than unity and the amplifier will be unstable.
- If the intersection occurs to the right of the point $(-1,0)$ the amplifier will be stable.
- It follows that if the Nyquist plot encircles the point $(-1, 0)$ then the amplifier will be unstable.

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1.4 TOPOLOGIES OF FEEDBACK AMPLIFIER

Basic amplifiers are voltage, current, transconductance, transresistance amplifier.

These can be connected in a feedback configuration as shown in figure.

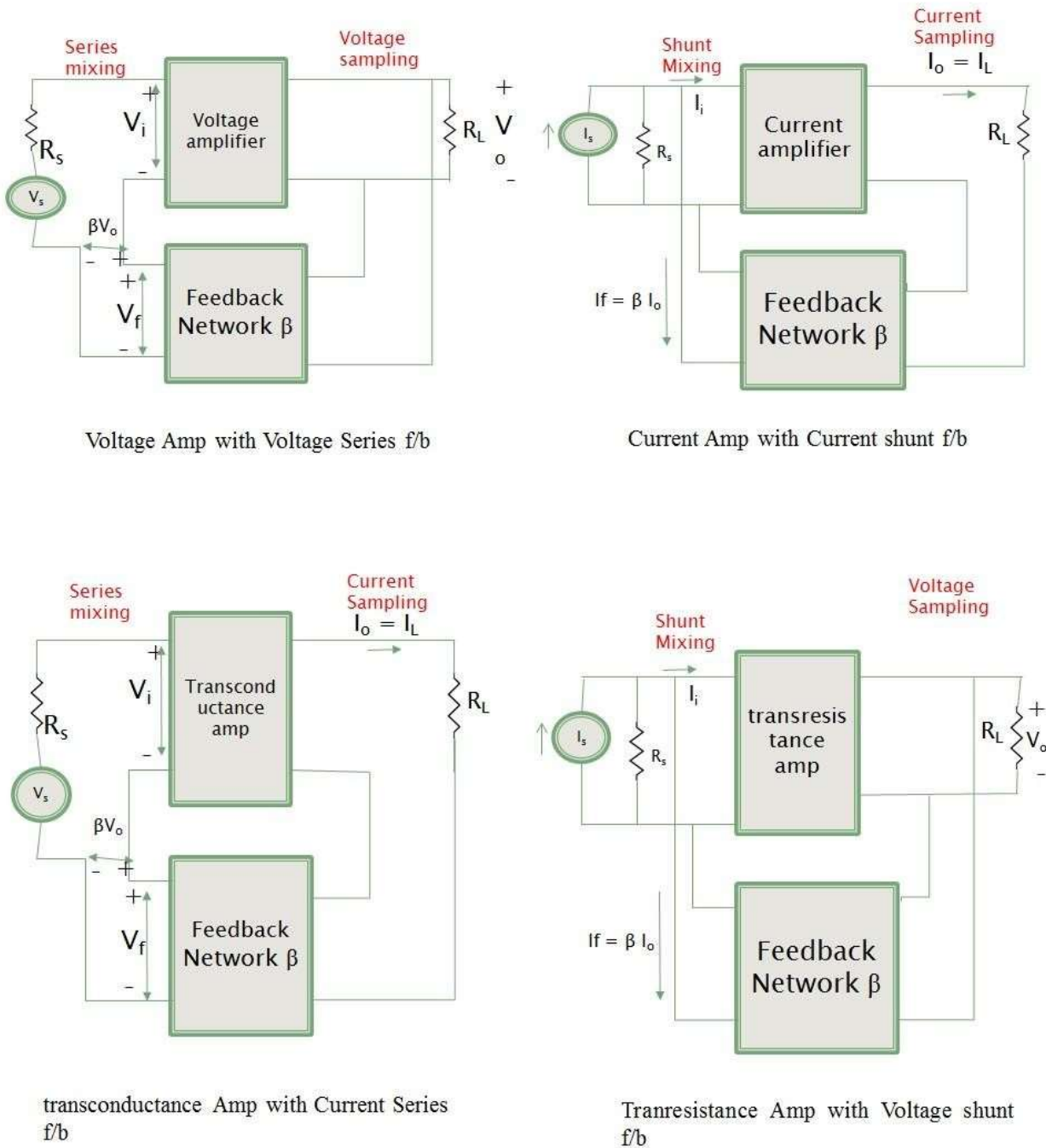


Fig 1.4.1. feedback configuration

(Source: *Microelectronics by J. Millman and A. Grabel, 2nd ed., Page-217*)

Voltage Amplifier:

- Voltage amplifier is used to amplify input voltage signal and provide amplified input voltage at the output.
- Signal source is a voltage signal hence it in thevenin's equivalent circuit.

- Feedback topology suitable for Voltage Amplifier is voltage sampling and series mixing.
- This topology is known as series-shunt feedback topology or voltage series feedback.

Current Amplifier:

- Current amplifier are used to amplify input current signal and provide amplified input Current at the output
- Signal source is a Current signal hence it in Norton's equivalent circuit
- Feedback topology suitable for Current Amplifier is Current sampling and Shunt mixing.
- This topology is known as shunt-series f/b topology or Current shunt f/b

Transconductance Amplifier:

- Transconductance amplifier with a thevenin's equivalent in its input circuit and Norton's equivalent in output circuit

$$R_i \gg R_s, V_i = V_s ; \quad R_o \gg R_L, I_L = G_m V_i$$

- Feedback topology suitable for Voltage Transconductance Amplifier is Current sampling and series mixing.
- This topology is known as series-series feedback topology or Current series feedback

Transresistance Amplifier:

- Transresistance amplifier with a Norton's equivalent in its input circuit and thevenin's equivalent in output circuit

$$R_i \ll R_s, I_i = I_s ; \quad R_o \ll R_L, V_o = R_m V_i$$

- Feedback topology suitable for transresistance Amplifier is Voltage sampling and shunt mixing.
- This topology is known as shunt-shunt feedback topology or voltage shunt feedback.

Voltage-Series Feedback

- In the voltage series feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit.

- This is also known as **shunt-driven series-fed** feedback, i.e., a parallel-series circuit.
- The following figure 1.4.2 shows the block diagram of voltage series feedback, by which it is evident that the feedback circuit is placed in shunt with the output but in series with the input.

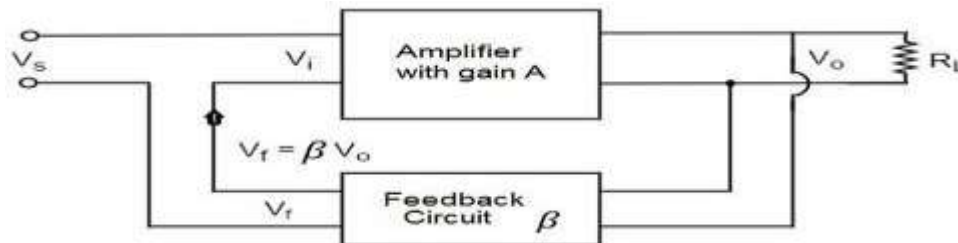


Fig.1.4.2. voltage series feedback circuit

(Source: *Microelectronics by J. Millman and A. Grabel, 2nd ed., Page-218*)

- As the feedback circuit is connected in shunt with the output, the output impedance is decreased and due to the series connection with the input, the input impedance is increased.

Voltage-Shunt Feedback

- In the voltage shunt feedback circuit, a fraction of the output voltage is applied in parallel with the input voltage through the feedback network.
- This is also known as **shunt-driven shunt-fed** feedback i.e., a parallel-parallel proto type.
- The below figure 1.4.3 shows the block diagram of voltage shunt feedback, by which it is evident that the feedback circuit is placed in shunt with the output and also with the input.

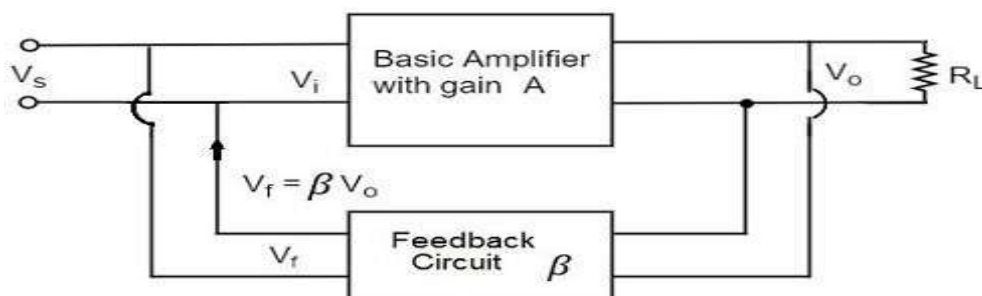


Fig1.4.3. voltage shunt feedback circuit

(Source: *Microelectronics by J. Millman and A. Grabel, 2nd ed., Page-219*)

- As the feedback circuit is connected in shunt with the output and the input as well, both the output impedance and the input impedance are decreased.

Current-Series Feedback

- In the current series feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit.
- This is also known as **series-driven series-fed** feedback i.e., a series-series circuit.
- The following figure 1.4.4 shows the block diagram of current series feedback, by which it is evident that the feedback circuit is placed in series with the output and also with the input.

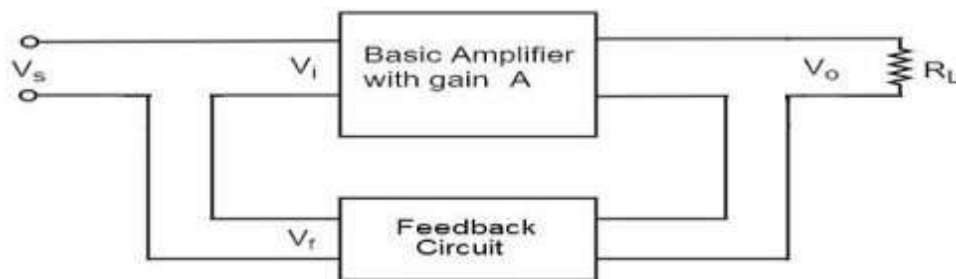


Fig 1.4.4. current series feedback circuit

(Source: "Microelectronics" by J. Millman and A. Grabel, 2nd ed., Page-220)

- As the feedback circuit is connected in series with the output and the input as well, both the output impedance and the input impedance are increased.

Current-Shunt Feedback

- In the current shunt feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit.
- This is also known as **series-driven shunt-fed** feedback i.e., a series-parallel circuit.
- The below figure 1.4.5 shows the block diagram of current shunt feedback, by which it is evident that the feedback circuit is placed in series with the output but in parallel with the input.
- As the feedback circuit is connected in series with the output, the output impedance is increased and due to the parallel connection with the input, the input impedance is decreased.

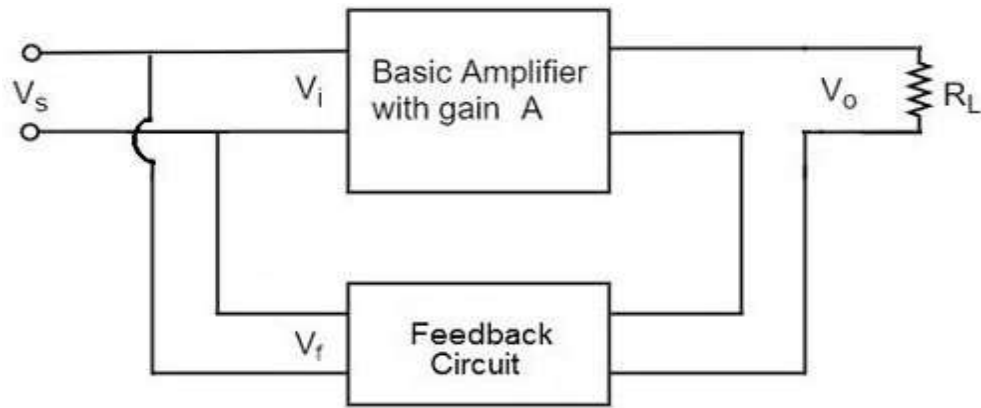


Fig1.4.5. current shunt feedback circuit

(Source: “ Microelectronics ” by J. Millman and A. Grabel, , 2nd ed., Page-221)

- Let us now tabulate the amplifier characteristics that get affected by different types of negative feedbacks.

Characteristics	Types of Feedback			
	Voltage-Series	Voltage-Shunt	Current-Series	Current-Shunt
Voltage Gain	Decreases	Decreases	Decreases	Decreases
Bandwidth	Increases	Increases	Increases	Increases
Input resistance	Increases	Decreases	Increases	Decreases
Output resistance	Decreases	Decreases	Increases	Increases
Harmonic distortion	Decreases	Decreases	Decreases	Decreases
Noise	Decreases	Decreases	Decreases	Decreases