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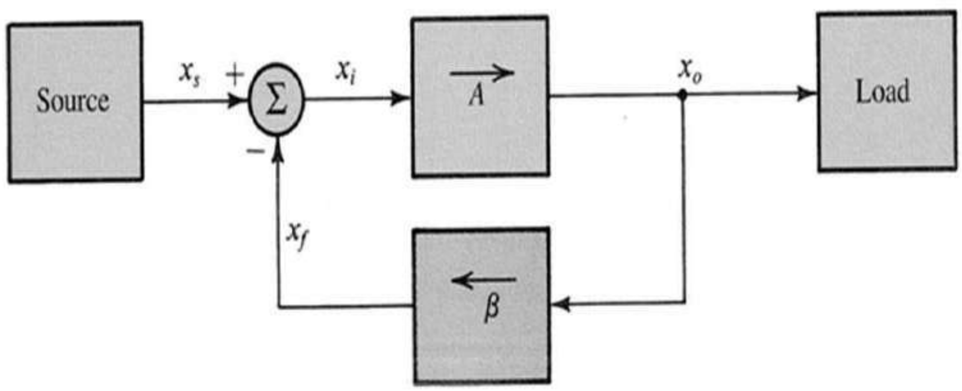
UNIT –III

Feedback Amplifiers : Feedback principle and concept, types of feedback, classification of amplifiers, feedback topologies, Characteristics of negative feedback amplifiers, Generalized analysis of feedback amplifiers, Performance comparison of feedback amplifiers, Method of analysis of feedback amplifiers.

FEEDBACK AMPLIFIER:



- Signal-flow diagram of a feedback amplifier
- Open-loop gain: A
- Feedback factor:
- Loop gain: A
- Amount of feedback: 1 + A
- Gain of the feedback amplifier (closed-loop gain):

Negative feedback:

- The feedback signal xf is subtracted from the source signal xs
- Negative feedback reduces the signal that appears at the input of the basic amplifier
- The gain of the feedback amplifier Af is smaller than open-loop gain A by a factor of (1+A)
- The loop gain A is typically large (A >>1):
- The gain of the feedback amplifier (closed-loop gain)
- The closed-loop gain is almost entirely determined by the feedback network □ better accuracy of Af.
- xf = xs(A)/(1+A) xs□ error signal xi = xs – xf

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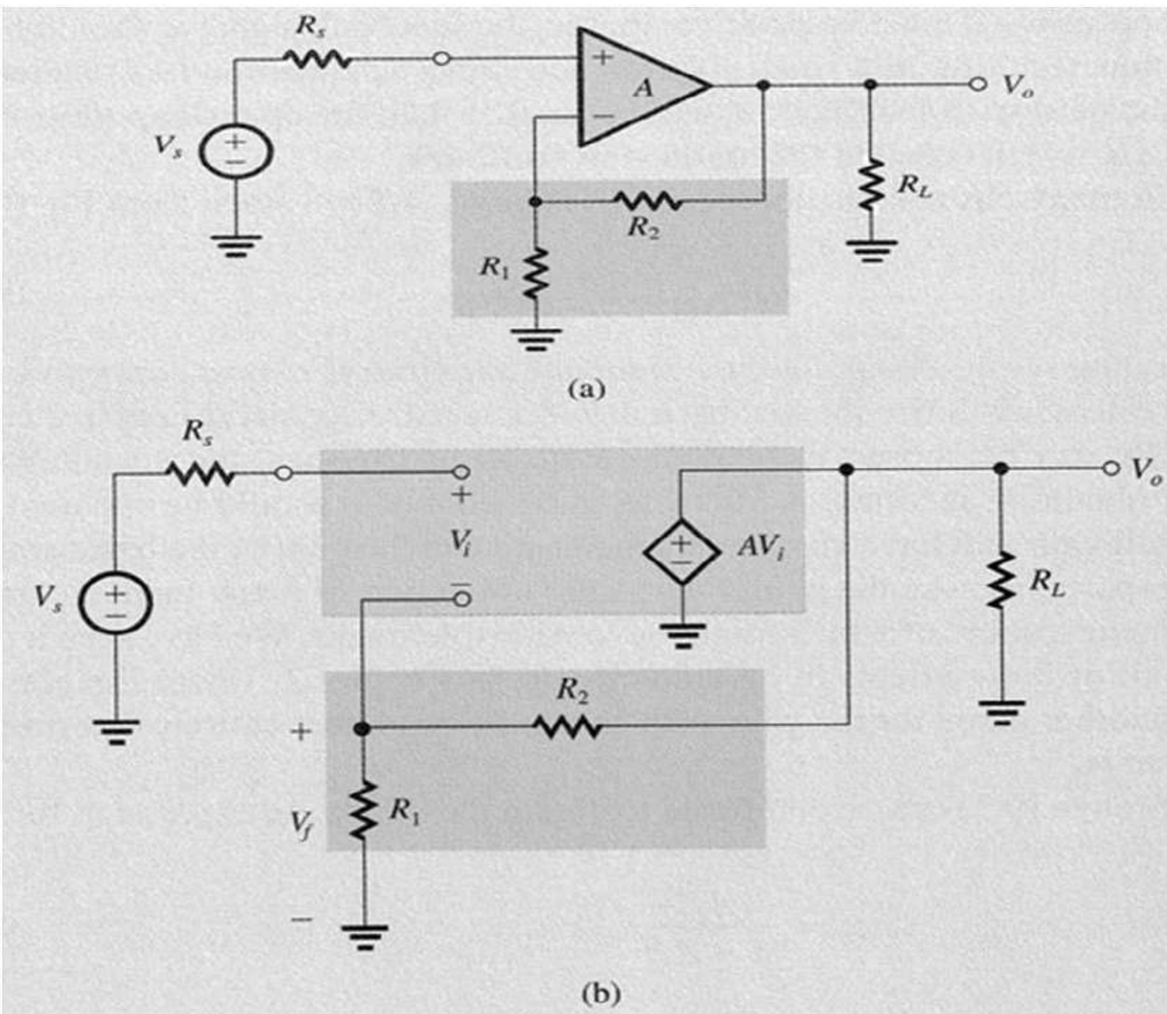
For Example, The feedback amplifier is based on an op amp with infinite input resistance and zero output resistance.

- Find an expression for the feedback factor.
- Find the condition under which the closed-loop gain Af is almost entirely determined by the feedback network.
- If the open-loop gain A = 10000 V/V, find R2/R1 to obtain a closed-loop gain Af of 10 V/V.
- What is the amount of feedback in decibel?
- If Vs = 1 V, find Vo, Vf and Vi.
- If A decreases by 20%, what is the corresponding decrease in Af ?



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Some Properties of Negative Feedback

Gain de sensitivity:

- The negative reduces the change in the closed-loop gain due to open-loop gain variation

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

- Desensitivity factor: $1+A\beta$

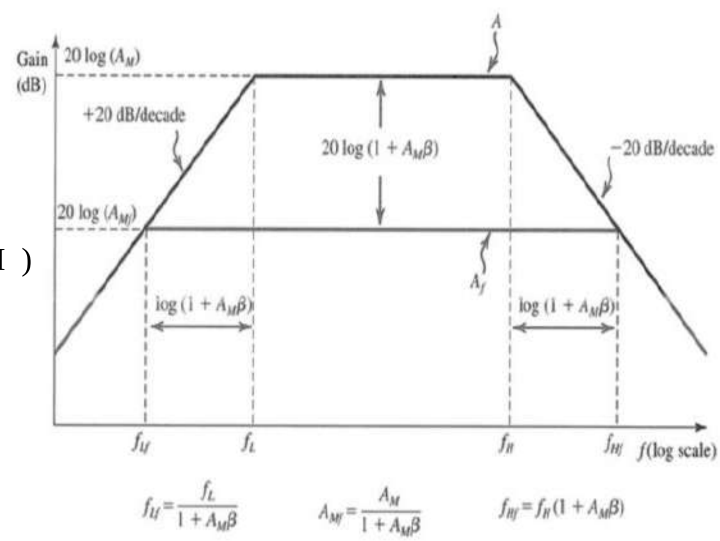
Bandwidth extension

High-frequency response of a single-pole amplifier:

$$A(s) = \frac{A_M}{1+s/\omega_H} \rightarrow A_f(s) = \frac{A_M/(1+A_M\beta)}{1+s/\omega_H(1+A_M\beta)}$$

Low-frequency response of an amplifier with a dominant low-frequency pole:

$$A(s) = \frac{sA_M}{s+\omega_L} \rightarrow A_f(s) = \frac{sA_M/(1+A_M\beta)}{s+\omega_L/(1+A_M\beta)}$$



Negative feedback:

Reduces the gain by a factor of (1+AM)

Extends the bandwidth by a factor of (1+AM)

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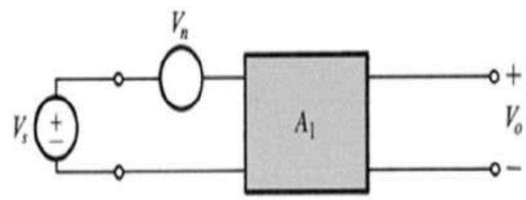
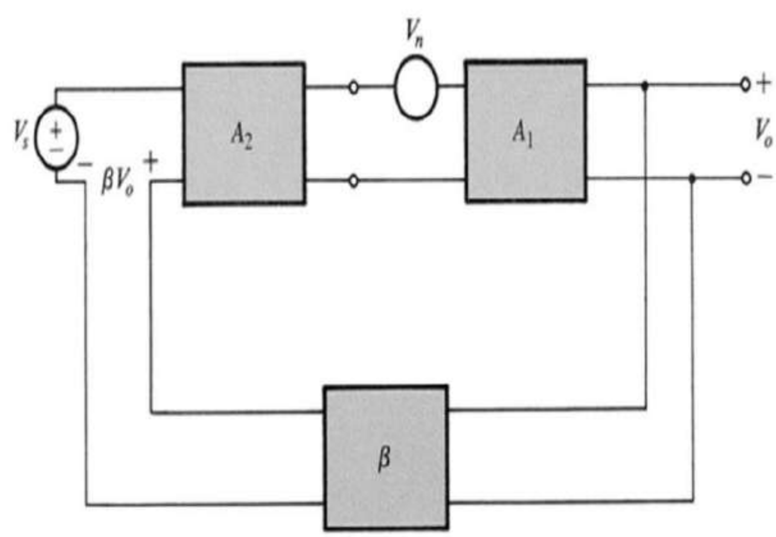
Interference reduction

- The signal-to-noise ratio:
    - The amplifier suffers from interference introduced at the input of the amplifier
    - Signal-to-noise ratio: S/I = Vs/Vn

- Enhancement of the signal-to-noise ratio:
    - Precede the original amplifier A1 by a clean amplifier A2
    - Use negative feedback to keep the overall gain constant.

$$V_0 = V_s \frac{A_1 A_2}{1 + A_1 A_2 \beta} + V_n \frac{A_1}{1 + A_1 A_2 \beta} \rightarrow \frac{S}{I} = \frac{V_s}{V_n} A_2$$





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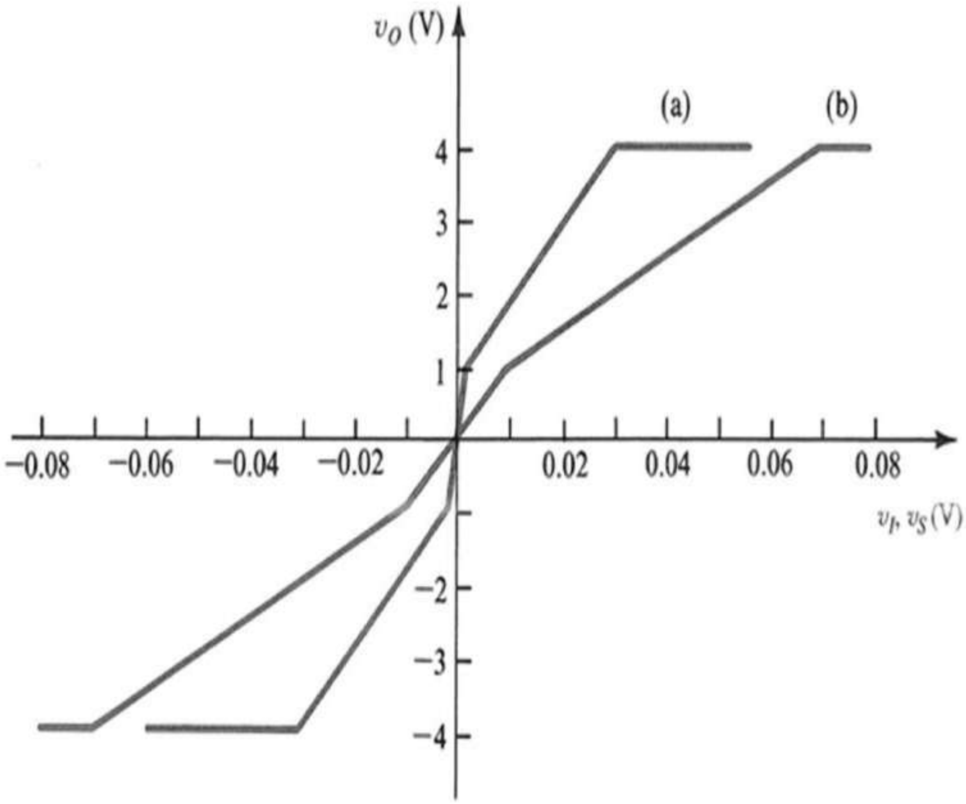
Reduction in nonlinear distortion:

The amplifier transfer characteristic is linearised through the application of negative feedback.



□□= 0.01

□*A*□changes from 1000 to 100

$$A_{f1} = \frac{1000}{1+1000\times 0.01} = 90.9$$

$$A_{f2} = \frac{100}{1+100\times 0.01} = 50$$

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The Four Basic Feedback Topologies:

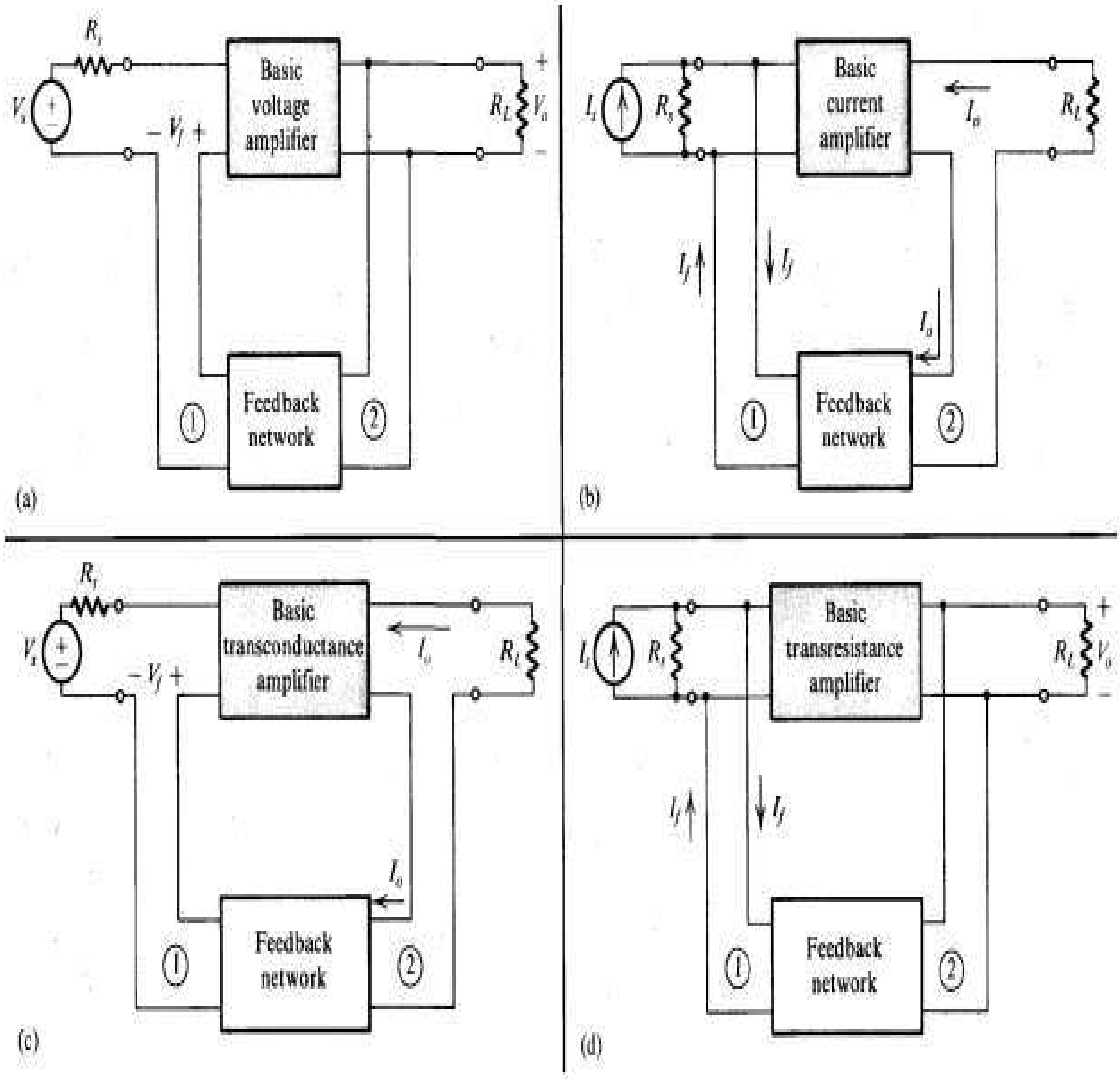

Fig. The four basic feedback topologies: (a) voltage-sampling series-mixing (series-shunt) topology; (b) current-sampling shunt-mixing (shunt-series) topology; (c) current-sampling series-mixing (series-series) topology; (d) voltage-sampling shunt-mixing (shunt-shunt) topology.

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Method of analysis of Feedback Amplifiers:

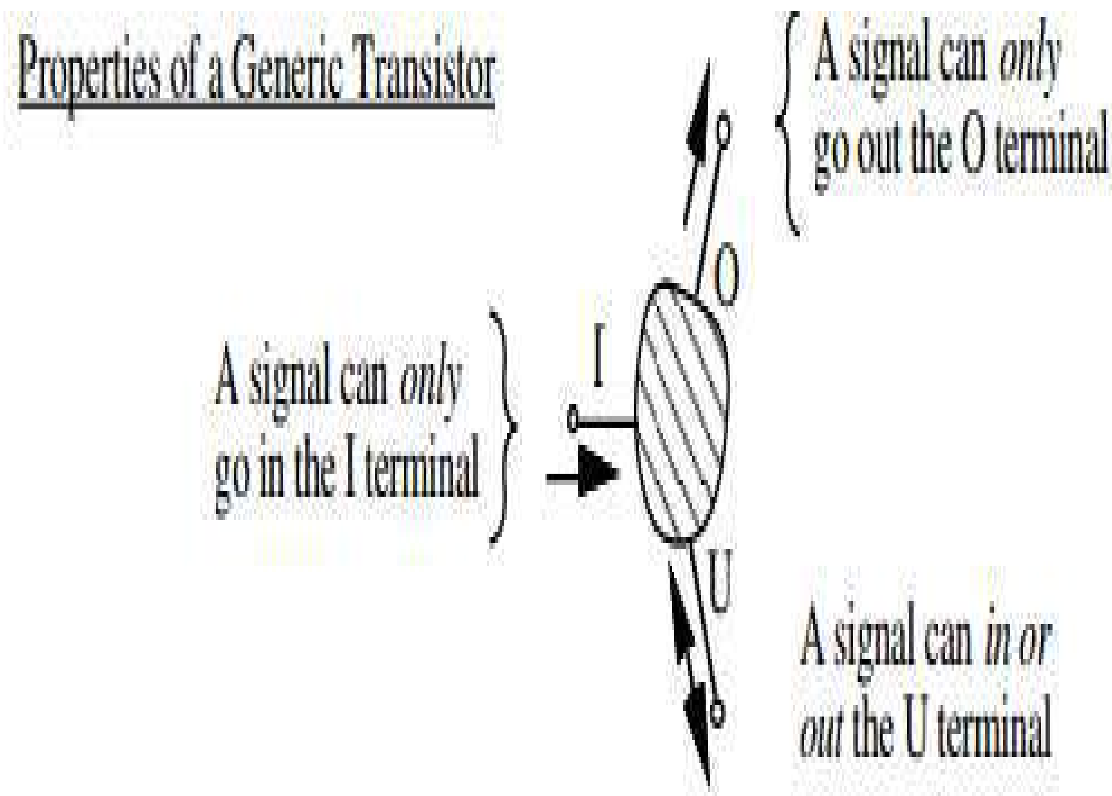
1. Identify the topology.

2. Determine whether the feedback is positive or negative.

3. Open the loop and calculate A, ß, Ri, and Ro.

4. Use the Table to find Af, Rif and Rof or AF, RiF, and RoF.

5. Use the information in 4 to find whatever is required (v_{out}/v_{in}, R_{in}, R_{out}, etc.)



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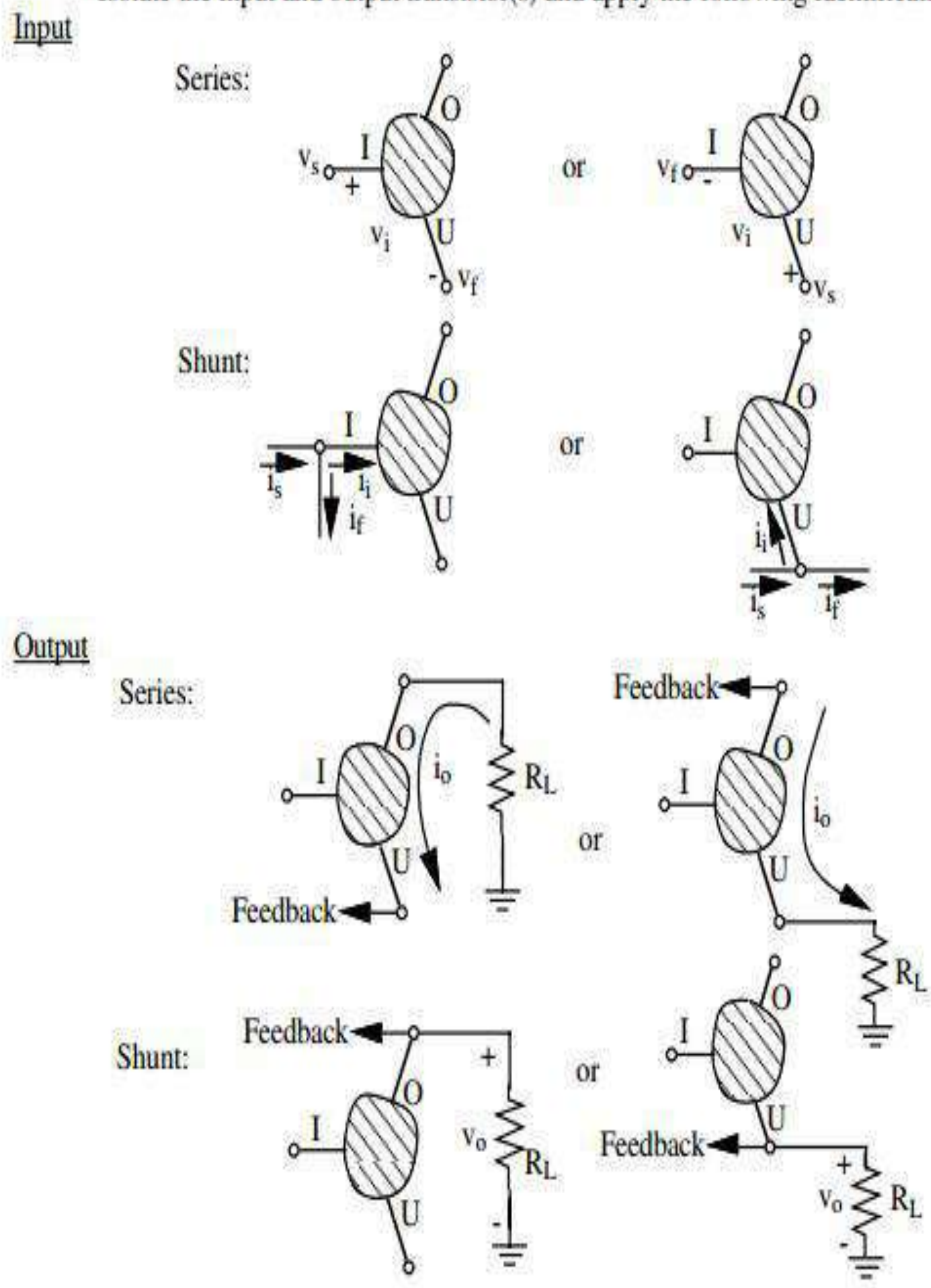
Identification of the Feedback Topology

Isolate the input and output transistor(s) and apply the following identification.



Performance comparison of feedback amplifiers:

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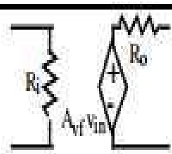
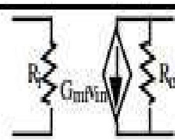
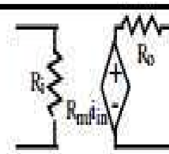
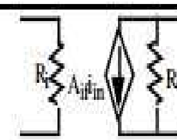
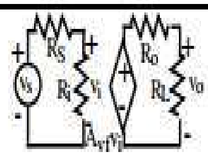
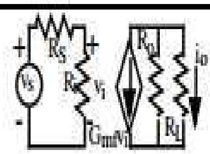
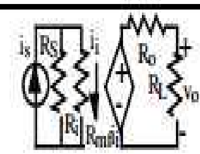
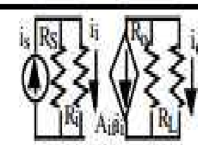
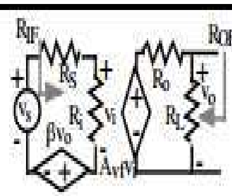
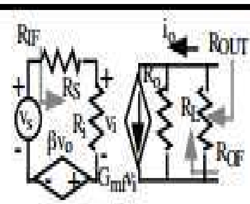
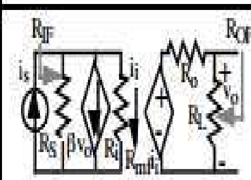
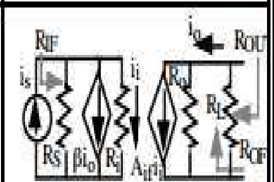
Summary of the Important Relationships of Open-loop and Closed-loop Feedback Amplifiers.

Quantity	Voltage Amplifier	Transconductance Amplifier	Transresistance Amplifier	Current Amplifier
Input-output variable	Voltage-voltage	Voltage-current	Current-voltage	Current-current
Small Signal Model				
Small Signal Amplifier with Source & Load				
Ideal R_S	$R_S = 0$ or $R_S << R_i$	$R_S = 0$ or $R_S << R_i$	$R_S = \infty$ or $R_S >> R_i$	$R_S = \infty$ or $R_S >> R_i$
Ideal R_L	$R_L = \infty$ or $R_L >> R_o$	$R_L = 0$ or $R_L << R_o$	$R_L = \infty$ or $R_L >> R_o$	$R_L = 0$ or $R_L << R_o$
Overall Forward Gain	$A_V = \frac{R_i R_L A_{vf}}{(R_S+R_i)(R_L+R_o)}$	$G_M = \frac{R_i R_o G_{mf}}{(R_S+Ri)(R_L+R_o)}$	$R_M = \frac{R_S R_L R_{mf}}{(R_S+Ri)(R_L+R_o)}$	$A_I = \frac{R_S R_o A_{if}}{(R_S+Ri)(R_L+R_o)}$
Feedback Topology	Series-shunt	Series-series	Shunt-shunt	Shunt-series
Ideal ß, finite R_S and R_L Feedback Small Signal Models				
Closed-Loop Gain (Ideal R_S and R_L)	$A_{VF} = \frac{A_{vf}}{(1+A_{vf}\beta_v)}$	$G_{mF} = \frac{G_{mf}}{(1+G_{mf}\beta_g)}$	$R_{mF} = \frac{R_{mf}}{(1+R_{mf}\beta_r)}$	$A_{iF} = \frac{A_{if}}{(1+A_{if}\beta_i)}$

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Closed-Loop Input Resistance (Ideal R_S and R_L)	$R_{iF} = R_i(1 + A_{vf}\beta_v)$	$R_{iF} = R_i(1 + G_{mf}\beta_g)$	$R_{iF} = \frac{R_i}{1 + R_{mf}\beta_r}$	$R_{iF} = \frac{R_i}{1 + A_{if}\beta_i}$
Closed-Loop Output Resistance (Ideal R_S and R_L)	$R_{oF} = \frac{R_o}{1 + A_{vf}\beta_v}$	$R_{oF} = R_o(1 + R_{mf}\beta_g)$	$R_{oF} = \frac{R_o}{1 + R_{mf}\beta_r}$	$R_{oF} = R_o(1 + A_{if}\beta_i)$
Closed-Loop Gain	$A_{VF} = \frac{A_V}{(1+A_V\beta_v)}$	$G_{MF} = \frac{G_M}{(1+G_M\beta_g)}$	$R_{MF} = \frac{R_M}{(1+R_M\beta_r)}$	$A_{IF} = \frac{A_I}{(1+A_I\beta_i)}$
Closed-Loop Input Resistance	$R_{IF} = (R_i+R_S)(1+A_V\beta_v)$	$R_{IF} = (R_i+R_S)(1 + G_M\beta_g)$	$R_{IF} = \frac{\frac{R_iR_S}{R_i+R_S}}{1 + R_M\beta_r}$	$R_{IF} = \frac{\frac{R_iR_S}{R_i+R_S}}{1 + A_I\beta_i}$
Closed-Loop Output Resistance	$R_{OF} = \frac{\frac{R_oR_L}{R_o+R_L}}{1 + A_V\beta_v}$	$R_{OF} = (R_o+R_L)(1+G_M\beta_g)$	$R_{OF} = \frac{\frac{R_oR_L}{R_o+R_L}}{1 + R_M\beta_r}$	$R_{OF} = (R_o+R_L)(1+A_I\beta_i)$
Output Resistance of Series Output Fb. Ckt	$R_{OUT} = R_{OF}$	$R_{OUT} = \frac{R_L}{R_{OF}}(R_{OF}-R_L)$	$R_{OUT} = R_{OF}$	$R_{OUT} = \frac{R_L}{R_{OF}}(R_{OF}-R_L)$

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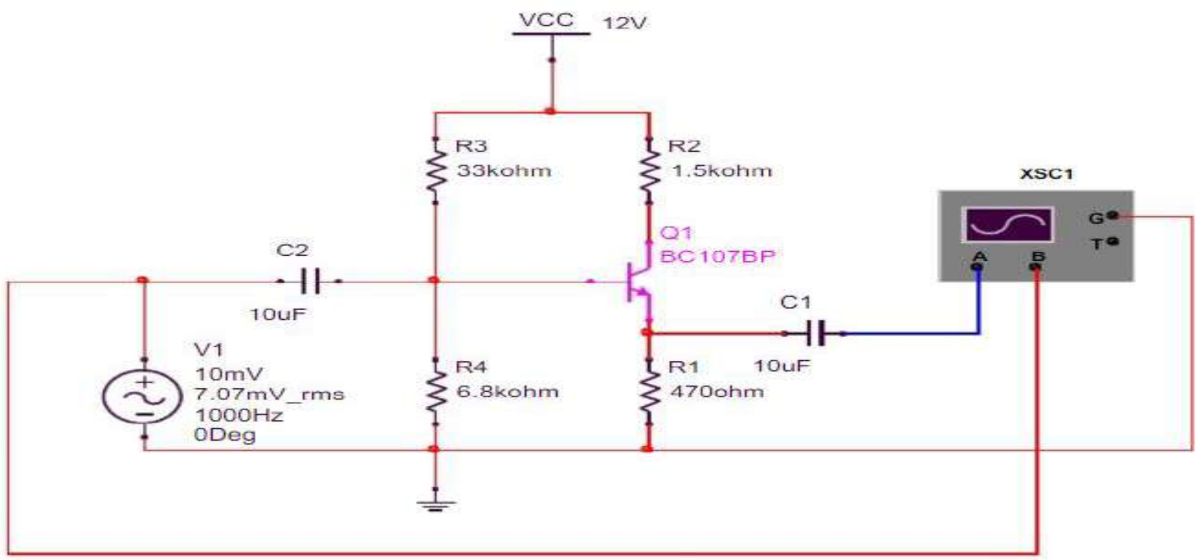
In voltage series feedback amplifier, sampling is voltage and series mixing indicates voltage mixing. As both input and output are voltage signals and is said to be voltage amplifier with gain A_{vf}.



Band width is defined as the range frequencies over which gain is greater than or equal to 0.707 times the maximum gain or up to 3 dB down from the maximum gain

Bandwidth (BW) = f_h- f_l

Where f_h= Upper cutoff frequency

And f_l= Lower cutoff frequency.

Cutoff frequency is the frequency at which the gain is 0.707 times the maximum gain or 3dB down from the maximum gain. In all feedback amplifiers we use negative feedback, so gain is reduced and bandwidth is increased

$$\mathbf{A_{vf}= Av/[1+A_v\beta]}$$

$$\mathbf{And\ BW_{f.}= BW\ [1+ A_v\beta]}$$

Where A_{vf} = Gain with feedback

Av= Gain without feedback

β=feedback gain

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BW_f = Bandwidth with feedback and

BW = Bandwidth without feedback Output resistance will decrease due to shunt connection at output and input resistance will increase due to series connection at input.

$$\text{So } \mathbf{R_{0f} = R_0/[1+A_v\beta]} \text{ and}$$

$$\mathbf{R_{if} = R_i[1+A_v\beta].}$$

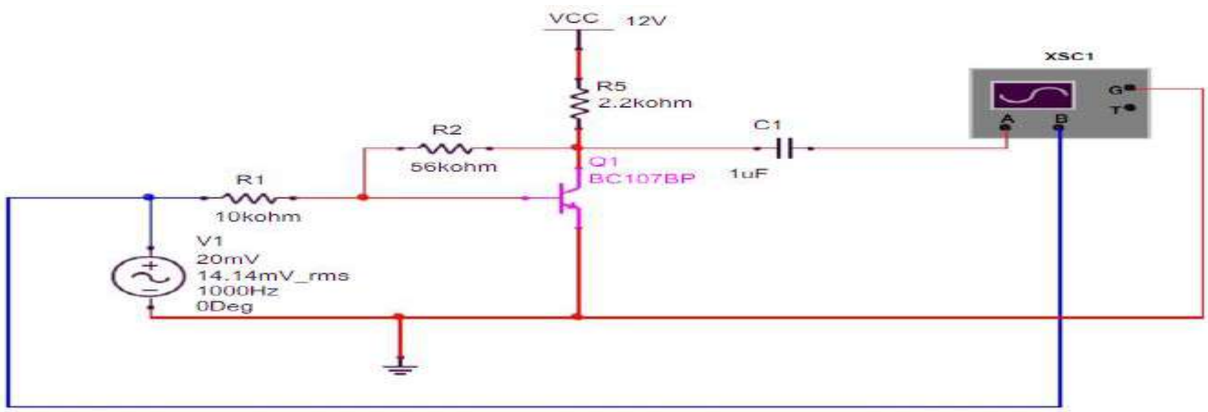
Where R 0f = Output resistance with feedback

R_0= Output resistance without feedback.

R_{if}= Input resistance with feedback

R_i= Input resistance without feedback

In voltage shunt feedback amplifier, sampling is voltage and shunt mixing indicates current mixing. As input is current signal and output is voltage signal, so it is said to be trans-resistance amplifier with gain R_{mf}.



Band width is defined as the range frequencies over which gain is greater than or equal to 0.707 times the maximum gain or up to 3 dB down from the maximum gain.

$$\text{Bandwidth (BW)} = f_h - f_l$$

Where f_h= Upper cutoff frequency

And f_l= Lower cutoff frequency.

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Cutoff frequency is the frequency at which the gain is 0.707 times the maximum gain or 3dB down from the maximum gain. In all feedback amplifiers we use negative feedback, so gain is reduced and bandwidth is increased.

$$R_{mf}= Rm/[1+R_m\beta]$$

$$\text{And } BW_f= BW\ [1+ R_m\beta]$$

Where

R_{mf} = Gain with feedback

R_m= Gain without feedback

β=feedback gain

BW = Bandwidth without feedback

Output resistance and input resistance both will decrease due to shunt connections at input and output. So

$$R_{0f} =R_0/[1+ R_m\ \beta] \text{ and}$$

$$R_{if}=R_i/[1+ R_m\ \beta].$$

Where R 0f = Output resistance with feedback

R_0= Output resistance without feedback.

R_{if}= Input resistance with feedback

R_i= Input resistance without feedback

Current series feedback

- Feedback technique is to sample the output current (Io) and return a proportional voltage in series.
- It stabilizes the amplifier gain, the current series feedback connection increases the input resistance.
- In this circuit, emitter of this stage has an un bypassed emitter, it effectively has current-series feedback.
- The current through RE results in feedback voltage that opposes the source signal applied so that the output voltage Vo is reduced.

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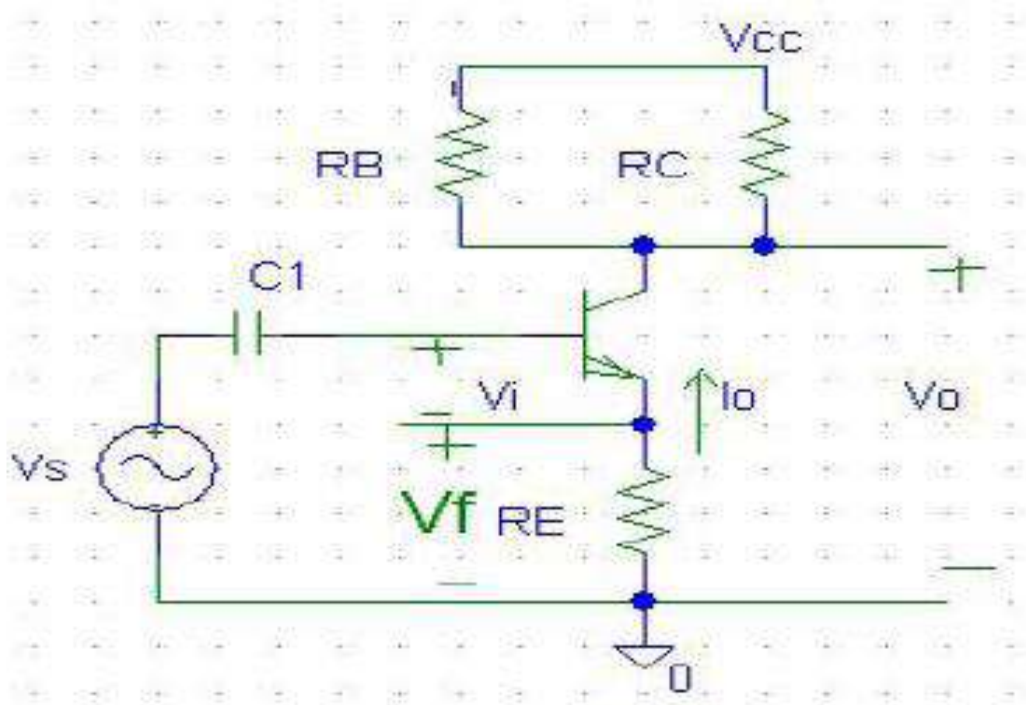
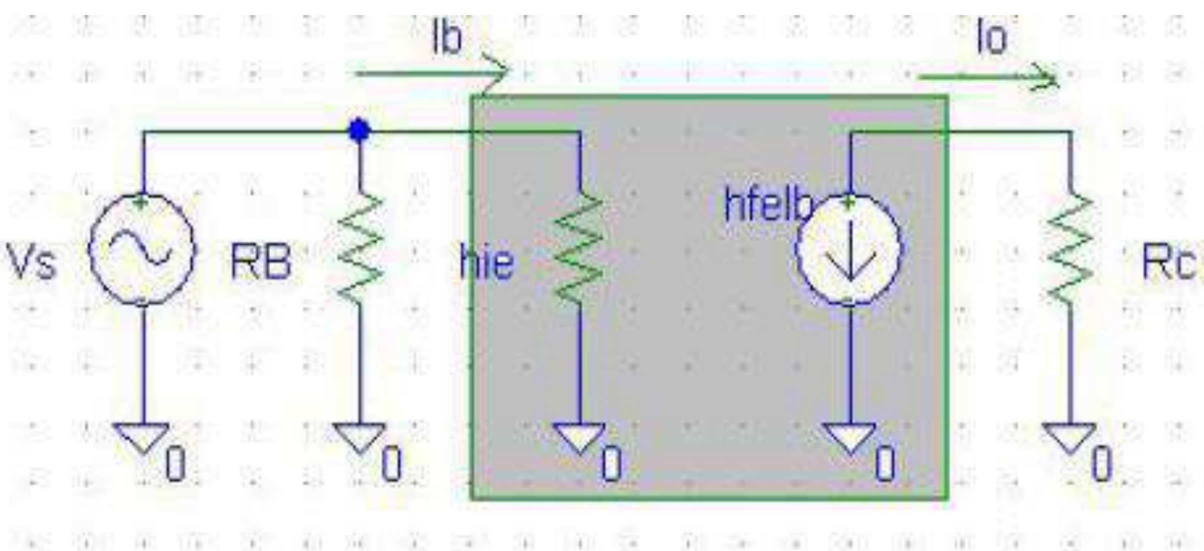


• To remove the current-series feedback, the emitter resistor must be either removed or bypassed by a capacitor (as is done in most of the amplifiers)

The fig below shows the equivalent circuit for current series feedback



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Gain, input and output impedance for this condition is,

$$A_f = \frac{I_o}{V_s} = \frac{A}{1+A\beta} = \frac{-h_{fe}/h_{ie}}{1+(-R_E)\left(\frac{-h_{fe}}{h_{ie}+R_E}\right)}$$

$$Z_{if} = Z_i(1+A\beta) \cong h_{ie}\left(1+\frac{h_{fe}R_E}{h_{ie}}\right)$$

$$Z_{of} = Z_o(1+A\beta) \cong R_c\left(1+\frac{h_{fe}R_E}{h_{ie}}\right)$$

$$with - feedback..A;$$

$$A_{vf} = \frac{V_o}{V_s} = \frac{I_o R_c}{V_s} = \left(\frac{I_o}{V_s}\right)R_c = A_f R_C \cong \frac{-h_{fe}R_C}{h_{ie}+h_{fe}R_E}$$

We now know that by plotting the gain and phase shift of a negative feedback amplifier's loop gain—denoted by $A\beta$, where A is always a function of frequency and β can be considered a function of frequency if necessary—we can determine two things: 1) whether the amplifier is stable, and 2) whether the amplifier is *sufficiently* stable (rather than *marginally* stable). The first determination is based on the stability criterion, which states that the magnitude of the loop gain must be less than unity at the frequency where the phase shift of the loop gain is 180°. The second is based on the amount of gain margin or phase margin; a rule of thumb is that the phase margin should be at least 45°.

It turns out that we can effectively analyze stability using an alternative and somewhat simplified approach in which open-loop gain A and feedback factor β are depicted as separate curves on the same axes. Consider the following plot for the discrete BJT amplifier with a frequency-independent (i.e., resistor-only) feedback network configured for β = 0.5:

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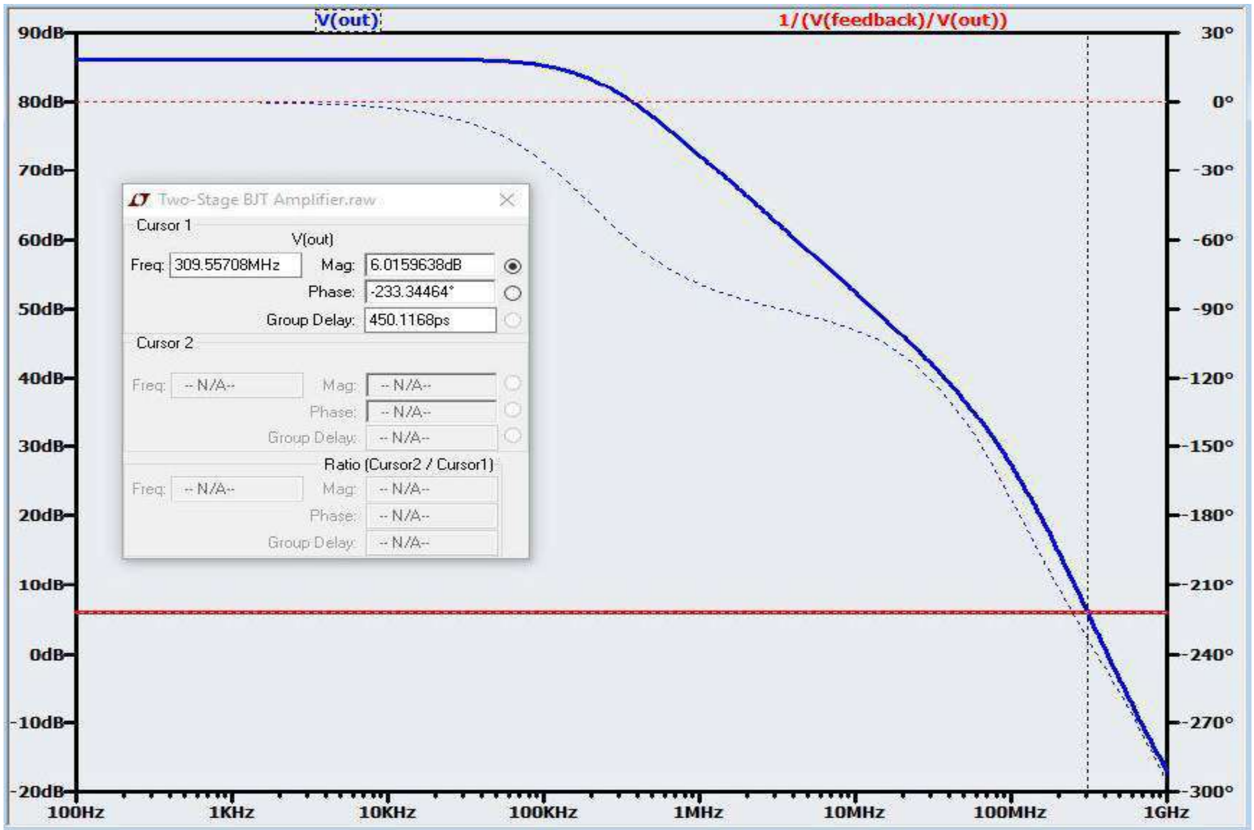

Here you see V(out), which corresponds to the open-loop gain, and 1/(V(feedback)/V(out)). If you recall that β is the percentage (expressed as a decimal) of the output fed back and subtracted from the input, you will surely recognize that this second trace is simply $1/\beta$. So why did we plot $1/\beta$? Well, we know that loop gain is A multiplied by β, but in this plot the y-axis is in decibels and is thus logarithmic. Our high school math teachers taught us that multiplication of ordinary numbers corresponds to addition with logarithmic values, and likewise numerical division corresponds to logarithmic subtraction. Thus, a logarithmic plot of A multiplied by β can be represented as the logarithmic plot of A **plus** the logarithmic plot of β. Remember, though, that the above plot includes not β but rather $1/\beta$, which is the equivalent of **negative** β on a logarithmic scale. Let's use some numbers to clarify this:

$$\beta=0.5 \Rightarrow 20\log(\beta)\approx-6\ \text{dB}\beta=0.5 \Rightarrow 20\log(\beta)\approx-6\ \text{dB}$$

$$1\beta=2 \Rightarrow 20\log(1\beta)\approx6\ \text{dB}1\beta=2 \Rightarrow 20\log(1\beta)\approx6\ \text{dB}$$

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Thus, in this logarithmic plot, we have 20log(A) and -20log(β), which means that to reconstruct 20log($A\beta$) we need to **subtract the 1/β curve from the A curve**:

20log(Aβ)=20log(A)+20log(β) ⇒ 20log(Aβ)=20log(A)−(−20log(β))20log(Aβ)=20log(A)+20 log(β) ⇒ 20log(Aβ)=20log(A)−(−20log(β))

⇒ 20log(Aβ)=20log(A)−20log(1β).

Gain and phase margin

- The stability of a feedback amplifier is determined by examining its loop gain as a function of frequency.
- One of the simplest means is through the use of Bode plot for $A\beta$.
- Stability is ensured if the magnitude of the loop gain is less than unity at a frequency shift of 180 .
- Gain margin:
  - The difference between the value $|A\beta|$ of at 180 and unity.
  - Gain margin represents the amount by which the loop gain can be increased while maintaining stability.
- Phase margin:
  - A feedback amplifier is stable if the phase is less than 180 at a frequency for which $|A\beta|$ =1.
  - A feedback amplifier is unstable if the phase is in excess of 180 at a frequency for which $|A\beta|$ =1.
  - The difference between the a frequency for which $|A\beta|$ =1 and 180 .

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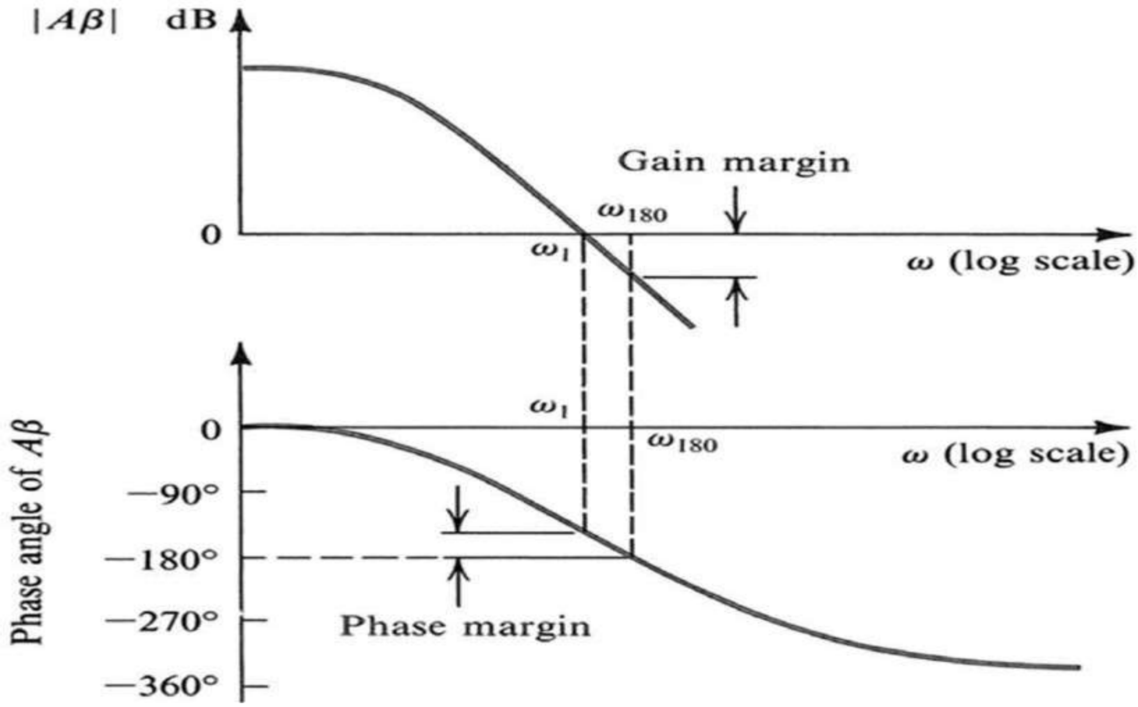

Effect of phase margin on closed-loop response:

- Consider a feedback amplifier with a large low-frequency loop gain (A_0 >> 1).

- The closed-loop gain at low frequencies is approximately $1/\beta$.

- Denoting the frequency at which | $A\beta$ | =1 by ω_1: $A(j\omega_1)\beta = 1 \times e^{-j\theta}$ and $\theta = 180^\circ -$ phase margin

- The closed-loop gain at $_1$ peaks by a factor of 1.3 above the low-frequency gain for a phase margin of 45 .

$$A_f(j\omega_1) = \frac{A(j\omega_1)}{1 + A(j\omega_1)\beta} = \frac{1}{\beta}\frac{e^{-j\theta}}{1 + e^{-j\theta}}$$

$$|A_f(j\omega_1)| = \frac{1/\beta}{|1 + e^{-j\theta}|}$$

- This peaking increase as the phase margin is reduced, eventually reaching infinite when the phase margin is zero (sustained oscillations).

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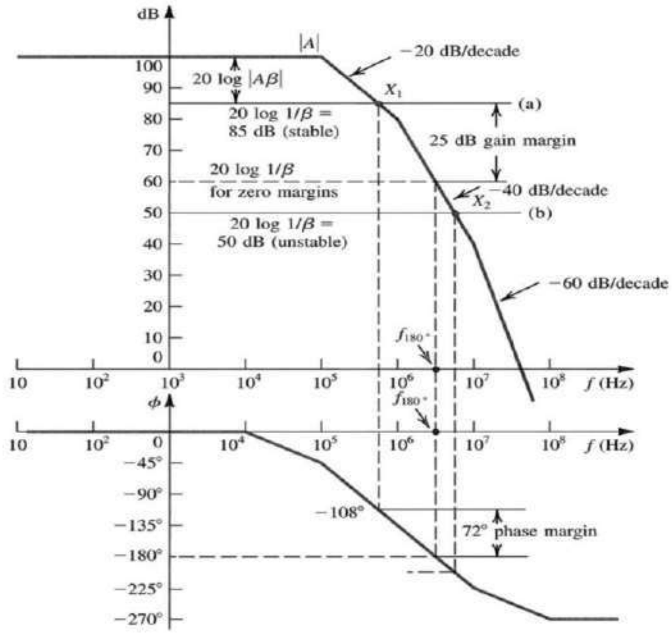
An alternative approach for investigating stability

➢ In a Bode plot, the difference between 20 log|$A(j\omega)$| and 20 log($1/\beta$) is 20 log| $A\beta$ |.



$$A = \frac{10^5}{(1 + jf/10^5)(1 + jf/10^6)(1 + jf/10^7)}$$

$$\phi = -\left[\tan^{-1}(f/10^5) + \tan^{-1}(f/10^6) + \tan^{-1}(f/10^7)\right]$$