LECTURE 250 – INTRODUCTION TO FEEDBACK CONCEPTS
(READING: GHLM – 553-563)

Objective

The objective of this presentation is:

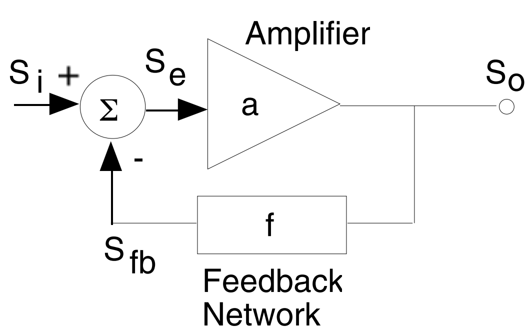
1.) Introduce the background and basic concepts of negative feedback

Outline

- Influence of negative feedback
- Feedback configurations with ideal source/load
- Examples
- Summary

Ideal Feedback Equation

Ideal Negative Feedback Configuration:



$$S_e = S_i - S_{fb} = S_i - fS_o \qquad S_o = aS_e = aS_i - afS_o$$

$$A = \frac{S_o}{S_i} = \frac{a}{1+af} \quad \Rightarrow \text{Closed Loop Gain} \qquad T = af \Rightarrow \text{Loop Gain}^{\dagger}$$

$$A = \frac{S_o}{S_i} = \frac{a}{1+\mathrm{T}} \qquad \text{for } T >> 1, \quad A \rightarrow \frac{1}{f}$$

$$\text{Feedback signal/Input signal} = \frac{S_{fb}}{S_i} = \frac{T}{1+T}$$

$$\text{Error signal/Input signal} = \frac{S_e}{S_i} = \frac{1}{1+T}$$

† Some authors (Allen and Holberg) define the loop gain as $-af$.

Gain Sensitivity

Sensitivity of the closed loop gain with respect to the open loop gain:

$$\frac{dA}{da} = \frac{1 + af - af}{(1 + af)^2} = \frac{1}{(1 + T)^2} = \frac{1}{a}\frac{a}{(1 + T)^2} = \frac{A}{a}\frac{1}{1+T}$$

$$\frac{dA}{A} = \frac{1}{(1 + T)}\frac{da}{a}$$

Example:

An amplifier with a gain of 10 has a gain variation of 3.3%. Use these amplifiers to design an amplifier with a gain of 10 and a gain variation ≤ 0.1%.

Solution:

We must cascade several amplifiers together and feedback around the cascade. With feedback, dA/A = 0.001. For three cascaded stages,

$$a = 1000 \quad \text{and} \quad \frac{da}{a} = \frac{[10(1+0.033)]^3 - 1000}{1000} = 0.1023$$

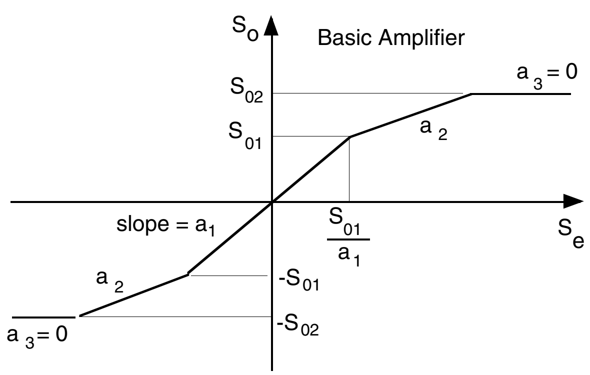
$$\frac{dA}{A} = \frac{1}{(1 + T)}\frac{da}{a} = \frac{0.1023}{1+T} = 0.001 \Rightarrow T = 101.$$

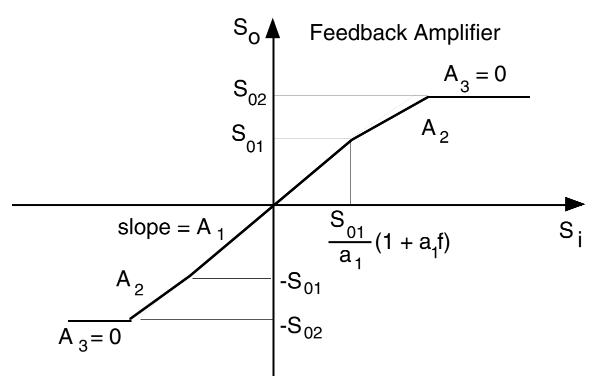
$$A = \frac{1000}{1+101} = 9.80 \qquad a = 1000 \qquad f = \frac{101}{1000} = 0.101$$

Gain is close to 10 but not exactly. However, the tolerance will be 0.1%

Effect of Negative Feedback on Nonlinear Distortion

The major cause of nonlinear distortion in amplifiers is due to changes of gain with signal level.





$$A_1 = \frac{a_1}{1 + a_1 f} \cong \frac{1}{f} \qquad A_2 = \frac{a_2}{1 + a_2 f} \cong \frac{1}{f}$$

Key points:

1. Three gain regions exist for each case
2. Horizontal scale compression for feedback amplifier
3. No distortion improvement for hard saturation cases
4. Distortion improvement with feedback ≈ $(1 + T)$

Demonstration 1 – Reduction of Nonlinearity by Negative Feedback

Consider the following circuit for this demonstration.

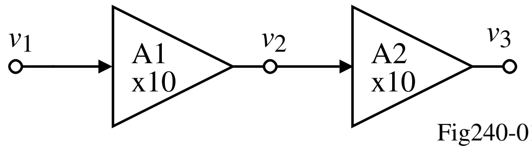


Fig240-01

Assume that the amplifiers have the following voltage transfer functions.

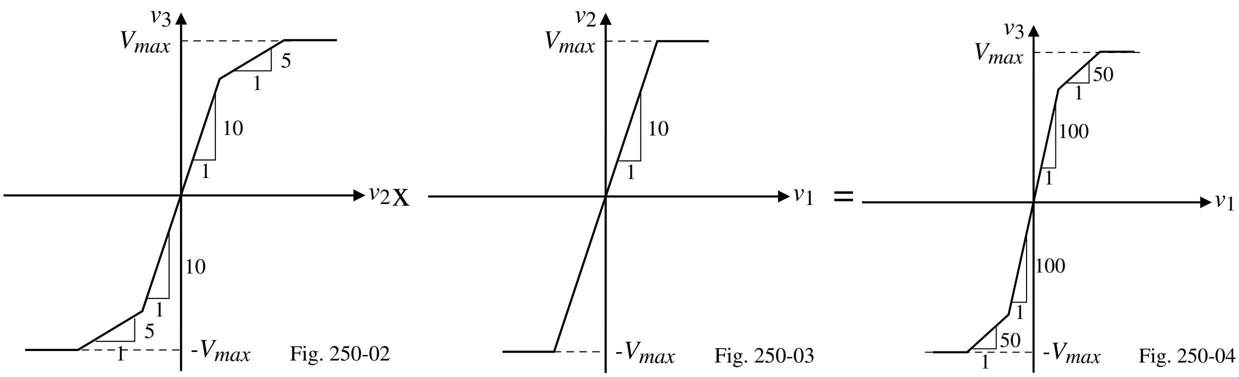


Fig. 250-02 Fig. 250-03 Fig. 250-04

Demonstration 1 - Continued

Now let us apply feedback around the second stage resulting in a gain of x2 and increase the gain of the first stage from x10 to x50.

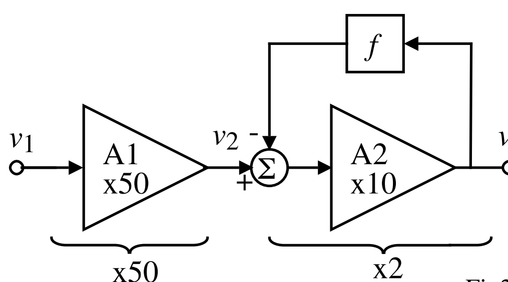


Fig240-05

To find the value of f, we can solve the following,

$$\frac{v_3}{v_2} = \frac{A_2}{1+A_2 f} = 2 \quad \Rightarrow \quad f = 0.4$$

The resulting transfer function is,

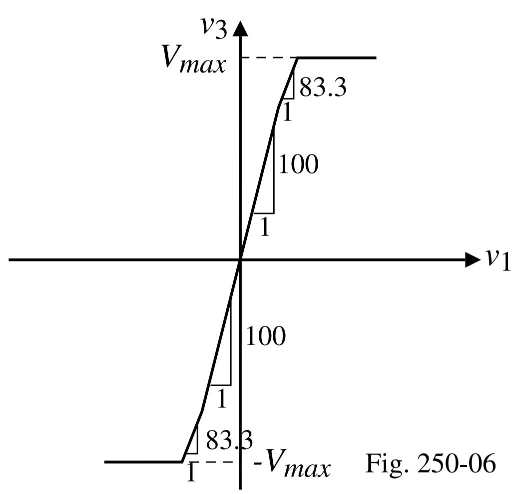


Fig. 250-06

Demonstration 1 – Continued

The demo circuit:

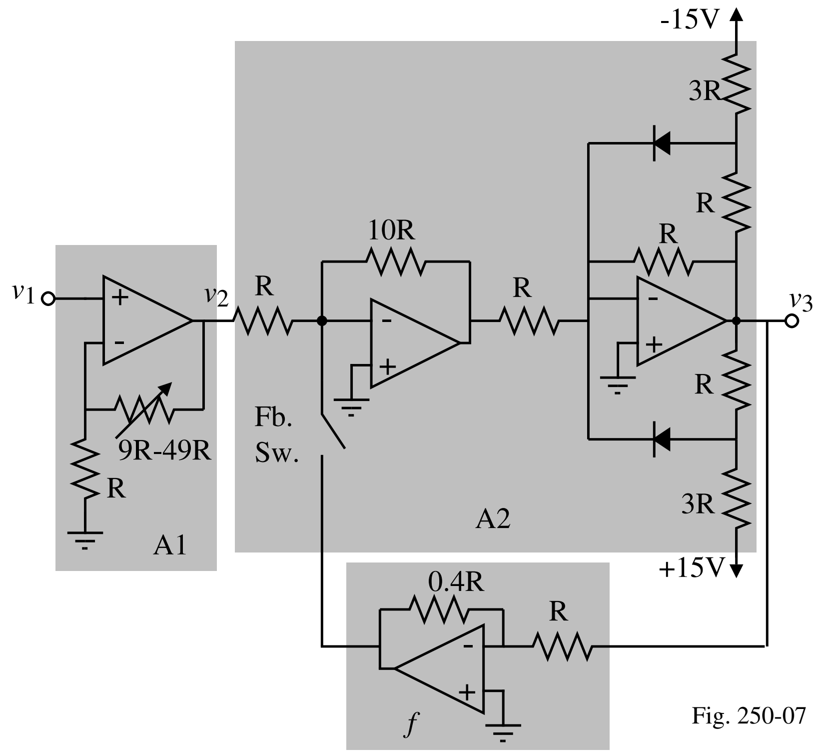
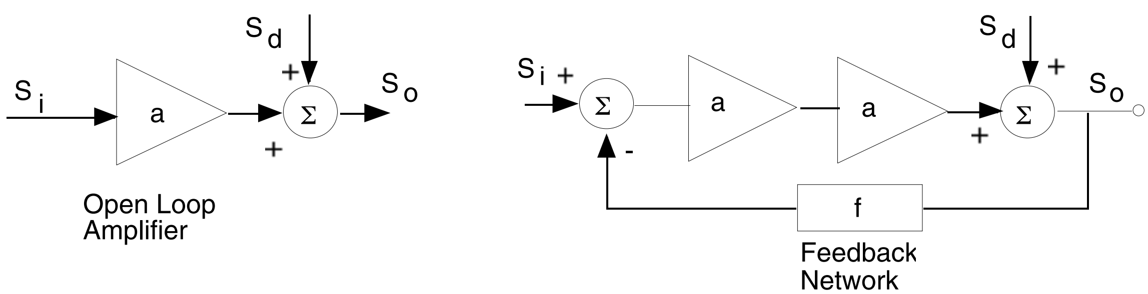


Fig. 250-07

Effects of Negative Feedback on Signal Distortion

Consider the output stage of an amplifier where distortion occurs because this stage is being driven very hard and a distortion signal S_d is introduced. Examine the two cases of with and without feedback.



$$S_o = aS_i + S_d$$

$$S_o = \frac{a^2 S_i}{1 + a^2 f} + \frac{S_d}{1 + a^2 f}$$

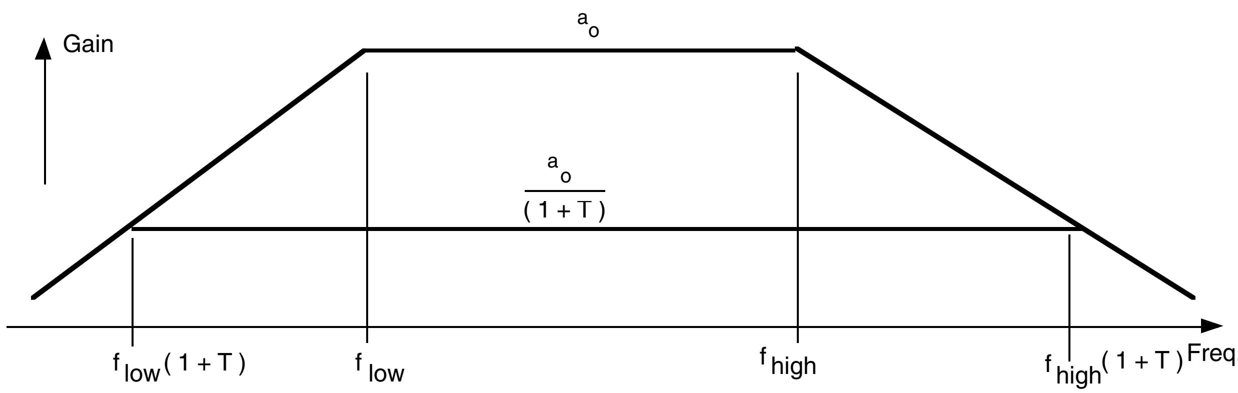
Now choose $f = \dfrac{a - 1}{a^2} \rightarrow S_o = aS_i + \dfrac{S_d}{a}$

Key points:

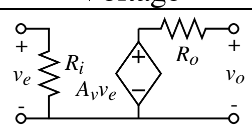
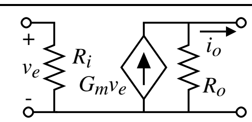
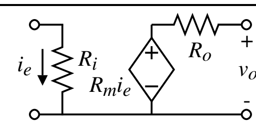
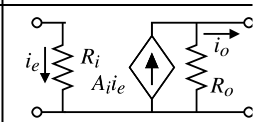
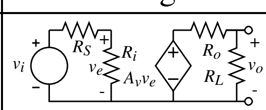
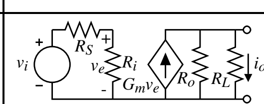
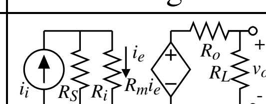
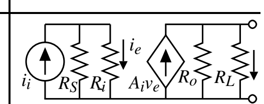
1. Desired output signal is the same in both cases
2. With feedback, distortion is reduced by gain "*a*"
3. $T = a^2 f = a - 1$
4. Improved performance with inferior amplifier (if used in large quantities – sometimes more can be better)

Influence of Negative Feedback on Frequency Response

When negative feedback is used with an amplifier having a single dominant low and a single dominant high frequency pole, gain and bandwidth can be traded evenly as shown.

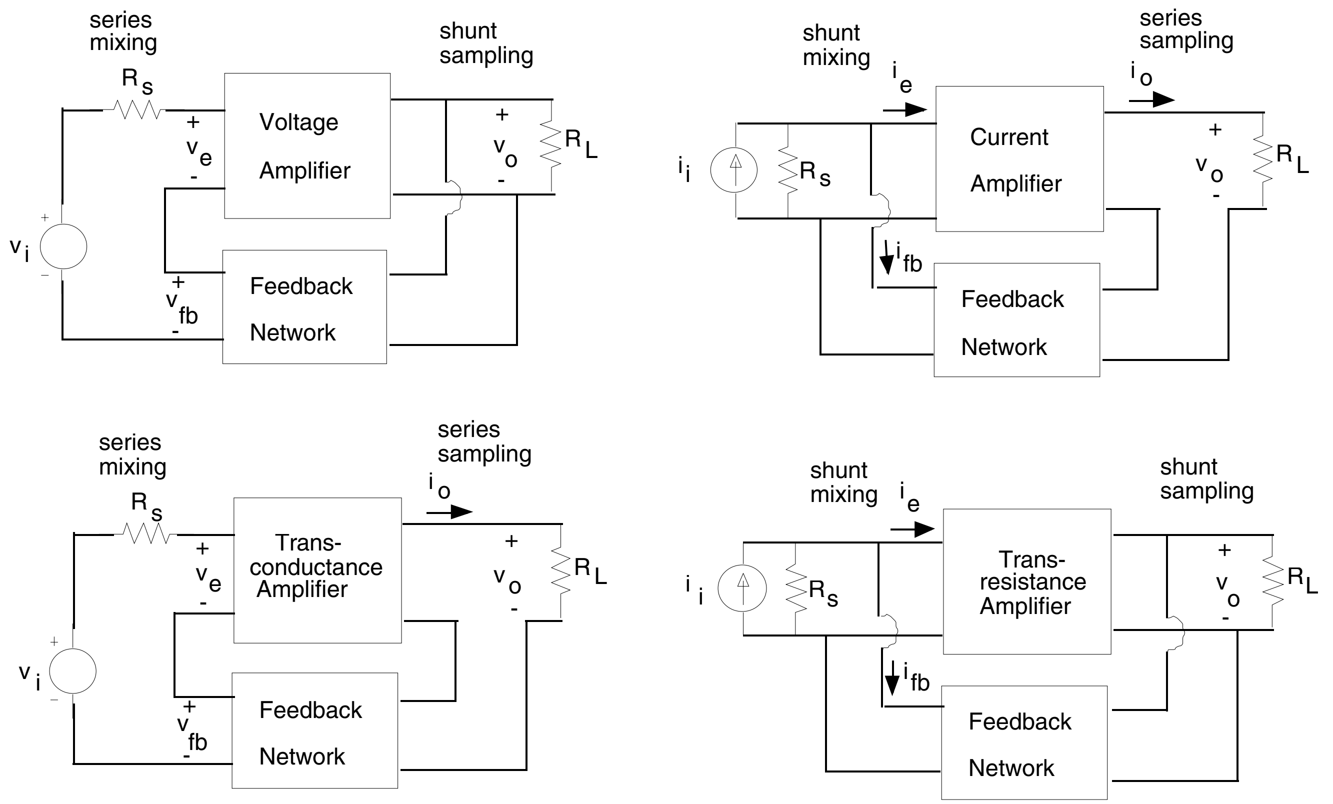


Four Basic Amplifiers

Parameter	Amplifier Type			
	Voltage	Transconductance	Transresistance	Current
Small-Signal Model				
Ideal Forward Gain	$v_o = A_v v_e$	$i_o = G_m v_e$	$v_o = R_m i_e$	$i_o = A_i i_e$
Ideal R_i	→ ∞ Ω	→ ∞ Ω	→ 0 Ω	→ 0 Ω
Ideal R_o	→ 0 Ω	→ ∞ Ω	→ 0 Ω	→ ∞ Ω
S_i, S_{fb} and S_e	Voltage	Voltage	Current	Current
S_o Variable	Voltage	Current	Voltage	Current
SS Model with Source and Load				
Ideal source, R_S	R_S=0 or R_S<<R_i	R_S=0 or R_S<<R_i	R_S=∞ or R_S>>R_i	R_S=∞ or R_S>>R_i
Ideal load, R_L	R_L=∞ or R_L>>R_o	R_L=0 or R_L<<R_o	R_L=∞ or R_L>>R_o	R_L=0 or R_L<<R_o
Overall Forward Gain	$\frac{R_i R_L A_v}{(R_S+R_i)(R_L+R_o)}$	$\frac{R_i R_o G_m}{(R_S+R_i)(R_L+R_o)}$	$\frac{R_S R_L R_m}{(R_S+R_i)(R_L+R_o)}$	$\frac{R_S R_L A_i}{(R_S+R_i)(R_L+R_o)}$

FEEDBACK WITH IDEAL SOURCE AND LOAD

Four Basic Feedback Topologies



Series-Shunt Feedback Amplifier

Series-shunt configuration:

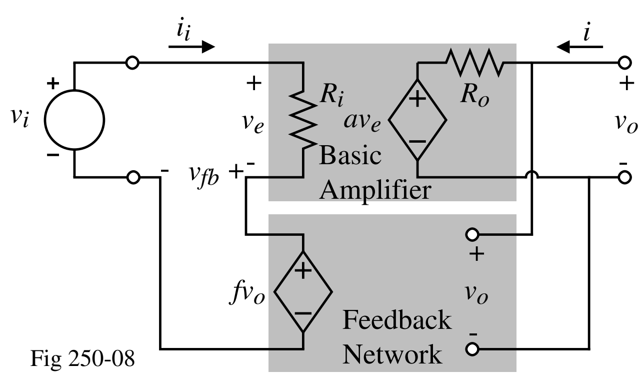


Fig 250-08

Find the equivalent voltage gain, input resistance (R_{if}), and output resistance (R_{of}).

$$v_o = av_e = a(v_i\text{-}v_{fb}) = av_i - av_{fb} = av_i - afv_o \quad \rightarrow \quad v_o(1+af) = av_i \quad \rightarrow \quad \frac{v_o}{v_i} = \frac{a}{1+af}$$

$$R_{if} = \frac{v_i}{i_i} = \frac{v_i}{v_e}R_i = R_i\frac{v_e+v_{fb}}{v_e} = R_i\frac{v_e+fv_o}{v_e} = R_i\frac{v_e+afv_e}{v_e} = R_i(1+af) = R_i(1+T)$$

$$R_{of} = \frac{v_o}{i}\Big|_{v_i=0} \qquad i = \frac{v_o\text{-}av_e}{R_o} = \frac{v_o\text{-}a(\text{-}v_{fb})}{R_o} = \frac{v_o+afv_o}{R_o} \quad \Rightarrow \quad R_{of} = \frac{R_o}{1+af} = \frac{R_o}{1+T}$$

Shunt-Shunt Feedback Amplifier

Shunt-shunt feedback configuration:

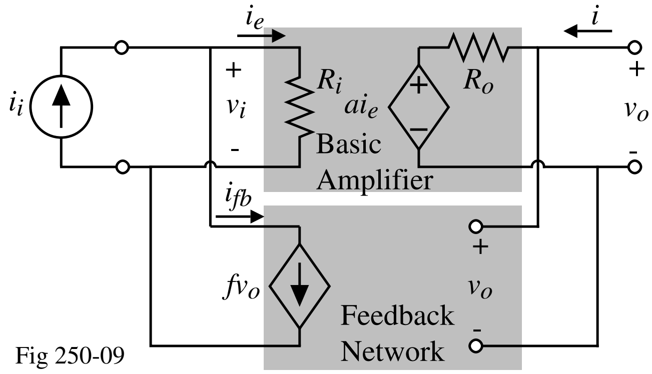


Fig 250-09

$$v_o = ai_e = a(i_i\text{-}i_{fb}) = ai_i - ai_{fb} = av_i - afv_o \quad \rightarrow \quad v_o(1+af) = ai_i \quad \rightarrow \quad \frac{i_o}{i_i} = \frac{a}{1+af}$$

$$R_{if} = \frac{v_i}{i_i} = \frac{i_eR_i}{i_e+i_{fb}} = \frac{i_eR_i}{i_e+fi_o} = \frac{i_eR_i}{i_e+afi_e} = \frac{R_i}{1+af} = \frac{R_i}{1+T}$$

$$R_{of} = \frac{v_o}{i}\Big|_{i_i=0} \qquad v_o = R_oi+ai_e = R_oi+a(\text{-}i_{fb}) = R_oi\text{-}afv_o \quad \rightarrow \quad v_o(1+af) = R_oi$$

$$\therefore \quad R_{of} = \frac{v_o}{i} = \frac{R_o}{1+af} = \frac{R_o}{1+T}$$

Shunt-Series Feedback Amplifier

Shunt-series feedback configuration:

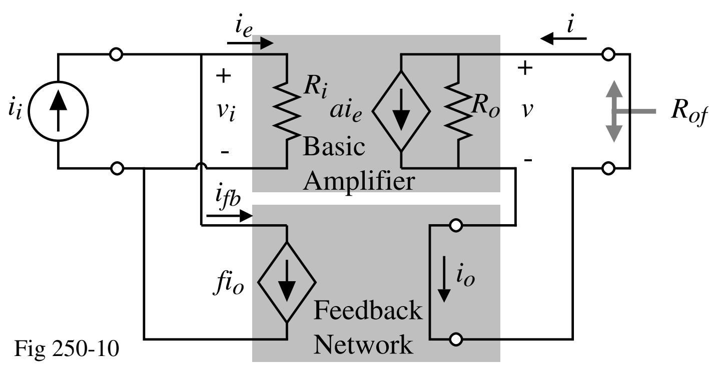


Fig 250-10

$$i_o = ai_e = a(i_i\text{-}i_{fb}) = ai_i - ai_{fb} = ai_i - afi_o \rightarrow i_o(1+af) = ai_i \quad \rightarrow \quad \frac{i_o}{i_i} = \frac{a}{1+af}$$

$$R_{if} = \frac{v_i}{i_i} = \frac{i_eR_i}{i_e+i_{fb}} = \frac{i_eR_i}{i_e+fv_o} = \frac{i_eR_i}{i_e+afi_e} = \frac{R_i}{1+af} = \frac{R_i}{1+T}$$

$$R_{of} = \frac{v}{i_o}\Big|_{i_i=0} \qquad R_{of} = \frac{v}{i_o} = \frac{R_o(i_o\text{-}ai_e)}{i_o} = \frac{R_o(i_o+afi_o)}{i_o} = R_o(1+af)$$

Series-Series Feedback Amplifier

Series-series feedback configuration:

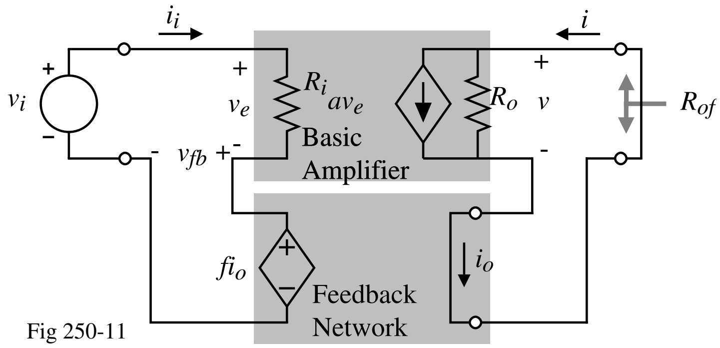


Fig 250-11

$$i_o = av_e = a(v_i\text{-}v_{fb}) = av_i - av_{fb} = av_i - afi_o \quad \rightarrow \quad i_o(1+af) = av_i \quad \rightarrow \quad \frac{i_o}{v_i} = \frac{a}{1+af}$$

$$R_{if} = \frac{v_i}{i_i} = \frac{v_i}{v_e}R_i = R_i\frac{v_e+v_{fb}}{v_e} = R_i\frac{v_e+fi_o}{v_e} = R_i\frac{v_e+afv_e}{v_e} = R_i(1+af) = R_i(1+T)$$

$$R_{of} = \frac{v}{i_o}\Big|_{i_i=0} \qquad R_{of} = \frac{v}{i_o} = \frac{R_o(i_o\text{-}av_e)}{i_o} = \frac{R_o(i_o+afi_o)}{i_o} = R_o(1+af)$$

SUMMARY

Four Basic Feedback Topologies (Ideal Source/Load)

Parameter	Amplifier Type			
	Voltage	Transconductance	Transresistance	Current
Feedback Topology	Series-shunt	Series-series	Shunt-shunt	Shunt-series
S_i, S_{fb} and S_e	Voltage	Voltage	Current	Current
S_o Variable	Voltage	Current	Voltage	Current
Closed Loop Gain	$A_{vf} = \frac{A_v}{1+fA_v}$	$G_{mf} = \frac{G_m}{1+fG_m}$	$R_{mf} = \frac{R_m}{1+fR_m}$	$A_{if} = \frac{A_i}{1+fA_i}$
Closed Loop Input Resistance	$R_{if} = R_i(1+fA_v)$	$R_{if} = R_i(1+fG_m)$	$R_{if} = \frac{R_i}{1+fR_m}$	$R_{if} = \frac{R_i}{1+fA_i}$
Closed Loop Output Resistance	$R_{of} = \frac{R_i}{1+fA_v}$	$R_{of} = R_o(1+fG_m)$	$R_{of} = \frac{R_i}{1+fR_m}$	$R_{of} = R_o(1+fA_i)$