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EE115 Analog Circuits Feedback 1

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Outline

- Feedback 1
 - General Feedback Structure
 - Some Properties of Negative Feedback
 - Feedback Voltage Amplifier
- Reading: SEDTRA/SMITH book pages 782-797



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Feedback

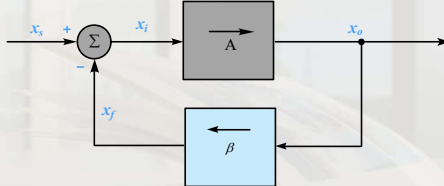
- Feedback is widely used in analog circuits.
- **Negative feedback** allows **high precision** signal processing
 - Desensitize the gain
 - Reduce nonlinear distortion
 - Extend the bandwidth of the amplifier
 - Control the input and output resistances
 - Raise or lower R_{in} and R_o by properly design the feedback topology.



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General Feedback Structure



A : open loop gain
 $x_o = Ax_i$

β : feedback factor
 $x_f = \beta x_o$

$x_i = x_s - x_f = x_s - A\beta x_i$
 $x_s = (1 + A\beta)x_i$

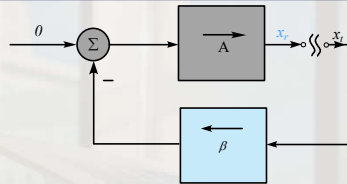
A_f : closed loop gain
 $A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$

$A\beta$: loop gain. If $A\beta \gg 1$,
 $A_f \cong \frac{1}{\beta}$



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Loop Gain



$$x_r = -A\beta x_t$$

$$A\beta = -\frac{x_r}{x_t}$$

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

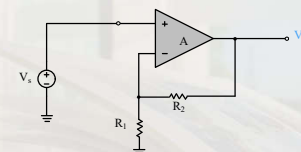
- Loop gain $A\beta \gg 1$,
 - The **sign** of $A\beta$ determines the **polarity** of the feedback.
 - The **magnitude** of $A\beta$ determines how **close** the closed-loop gain A_f is to the ideal value of $1/\beta$.
 - The magnitude of $A\beta$ determines the **amount of feedback** ($1 + A\beta$), the magnitude of the various improvements in amplifier performance.

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Example: noninverting op-amp with feedback



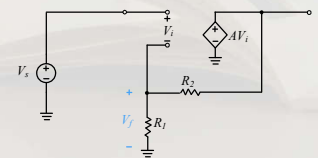
- a) Assume that the op amp has infinite input resistance and zero output resistance. Find an expression for the feedback factor (β).
- b) Find β and R_2/R_1 to obtain an ideal closed-loop gain of 10 V/V.



Solution:

$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}$$

$$A_{f|ideal} = \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$



$$(b) \text{ For } A_{f|ideal} = 10 \text{ V/V}$$

$$\beta = \frac{1}{A_{f|ideal}} = 0.1 \text{ V/V}$$

$$10 = 1 + \frac{R_2}{R_1} \Rightarrow \frac{R_2}{R_1} = 9$$

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Example



- (c) If the open-loop gain $A = 10^4 \text{ V/V}$, for the design in (b), $\beta = 0.1$, find the loop gain, the amount of feedback and the actual value of A_f . By what percentage does A_f deviate from the ideal value?
- (d) To what values must β and R_2/R_1 be changed to obtain a closed-loop gain of exactly 10 V/V?

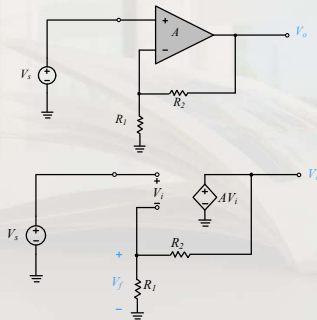
Solution:

$$(c) \quad A\beta = 10^4 \times 0.1 = 1000$$

$$1 + A\beta = 1001 \Rightarrow \approx 60 \text{ dB}$$

$$A_f = \frac{A}{1 + A\beta} = \frac{10^4}{1001} = 9.990 \text{ V/V}$$

$$0.1\% \text{ below the ideal value of } 10 \text{ V/V}$$



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

$$10 = \frac{10^4}{1 + 10^4 \times \beta} \Rightarrow \beta = 0.0999 \text{ V/V}$$

$$\frac{R_1}{R_1 + R_2} = 0.0999 \Rightarrow \frac{R_2}{R_1} = 9.01$$

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Example



- (e) For the modified design in (d), $\beta = 0.0999$, let $V_s = 1 \text{ V}$. Find the values of V_o , V_f and V_i .
- (f) If for the design in (d) the open-loop gain decreases by 20%, what is the corresponding decrease in A_f ?

Solution:

$$(e) \quad \text{For } V_s = 1 \text{ V}$$

$$V_o = A_f V_s = 10 \times 1 = 10 \text{ V}$$

$$V_f = \beta V_o = 0.0999 \times 10 = 0.999 \text{ V}$$

$$V_i = \frac{V_o}{A} = \frac{10}{10^4} = 0.001 \text{ V}$$

(f) If A decreases by 20%

$$A = 0.8 \times 10^4 \text{ V/V}$$

$$A_f = \frac{0.8 \times 10^4}{1 + 0.8 \times 10^4 \times 0.0999} = 9.9975 \text{ V/V}$$

It decreases by 0.025%, **much less** than the % change in A (20%)

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Feedback: Gain Desensitivity



- The percentage change in A_f (due to variations in some circuit parameter) is **smaller** than the percentage change in A by a factor equal to the **amount of feedback**.
- For this reason, the **amount of feedback**, $1 + A\beta$, is also known as the **desensitivity factor**.

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

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

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



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Feedback: Bandwidth Extension

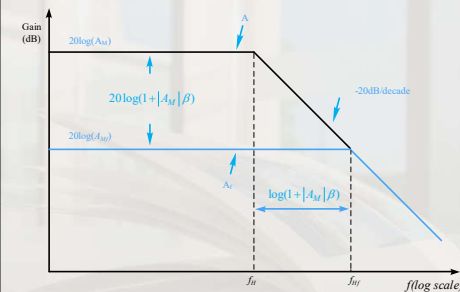


Fig. Negative feedback increases the amplifier bandwidth at the expense of decreasing the midband gain.

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

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

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

$$\omega_{Hf} = \omega_H(1 + A_M\beta)$$

Gain-bandwidth product unchanged.

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Feedback: Reduction in Nonlinear Distortion

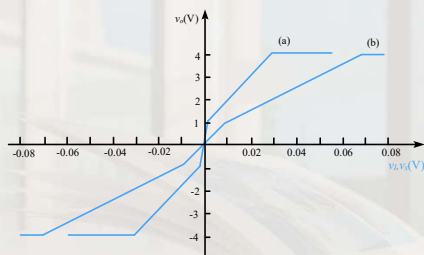


Fig. (a) v_o versus v_i without feedback.
(b) v_o versus v_i with negative feedback ($\beta=0.01$).

- (a): open loop, piecewise linear, 1000 to 100.
- (b): closed loop with negative feedback, $\beta=0.01$

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

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

Amplifier transfer characteristic can be considerably linearized through negative feedback.

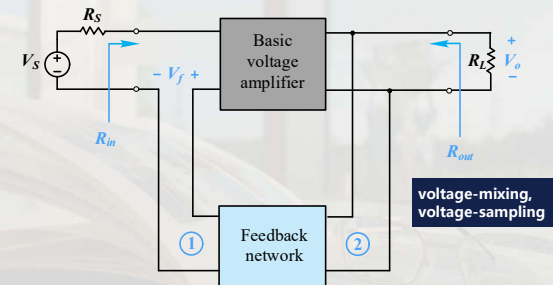


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Feedback Voltage Amplifier

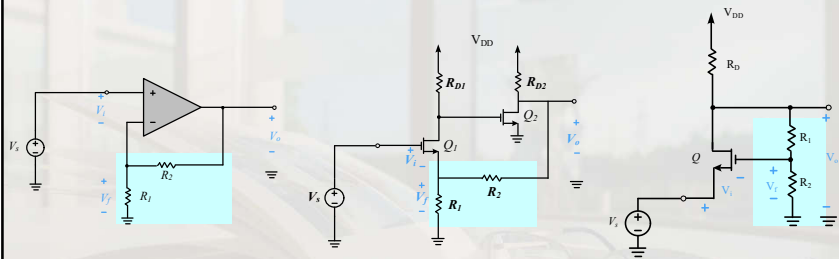


Series-Shunt Feedback Topology



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Examples of Series-Shunt Feedback Amp.



V_i increases, V_o increases and V_f increases: negative feedback



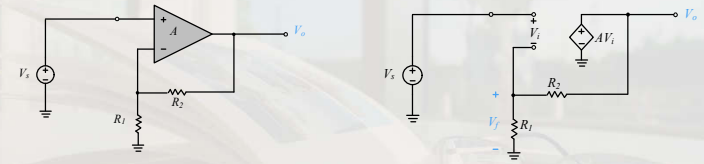
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Quiz



Given a noninverting op-amp with feedback below.

- Assume that the op amp has infinite input resistance and zero output resistance. Find an expression for **input resistance** and **output resistance** of the closed loop system.
- Find β and R_2/R_1 to obtain an ideal closed-loop gain of 50 V/V.



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