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EE115 Analog Circuits
Feedback 1

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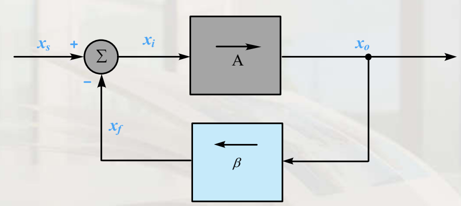
Outline

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

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.

General Feedback Structure



A: open loop gain

$$x_o = Ax_i$$

β: feedback factor

$$x_f = \beta x_o$$

$$x_i = x_s - x_f = x_s - A\beta x_i$$

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

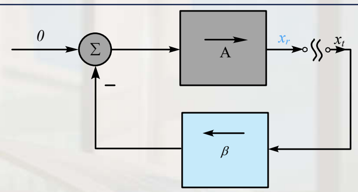
A_f: closed loop gain

$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$$

$A\beta$: loop gain. If $A\beta \gg 1$,

$$A_f \cong \frac{1}{\beta}$$

Loop Gain



$$x_r = -A\beta x_t$$

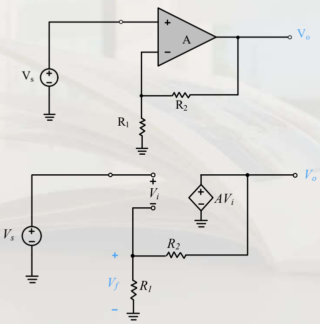
$$A\beta = -\frac{x_r}{x_t}$$

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

- 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.

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:

(a)

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

$$A_f|_{ideal} = \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$

(b)

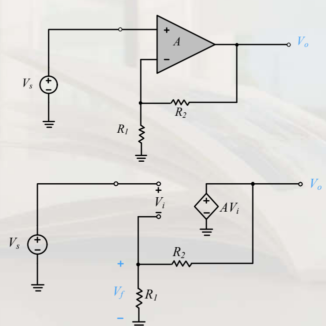
$$For A_f|_{ideal} = 10V/V$$

$$\beta = \frac{1}{A_f|_{ideal}} = 0.1V/V$$

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

Example

- (c) If the open-loop gain A = 10^4 V/V, for the design in (b), β=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)

$$A\beta = 10^4 \times 0.1 = 1000$$

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

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

0.1% below the ideal value of 10V/V

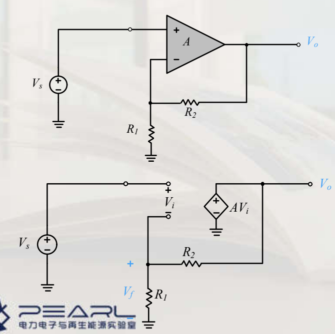
$$(d) A_f = \frac{A}{1 + A\beta}$$

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

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

Example

- (e) For the modified design in (d), β=0.0999, let V_s = 1 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)

$$For\ V_s = 1V$$

$$V_o = A_f V_s = 10 \times 1 = 10V$$

$$V_f = \beta V_o = 0.0999 \times 10 = 0.999V$$

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

(f) If A decreases by 20%

$$A = 0.8 \times 10^4 V/V$$

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

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

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+Aβ,** is also known as the **desensitivity factor.**

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

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

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

Feedback: Bandwidth Extension

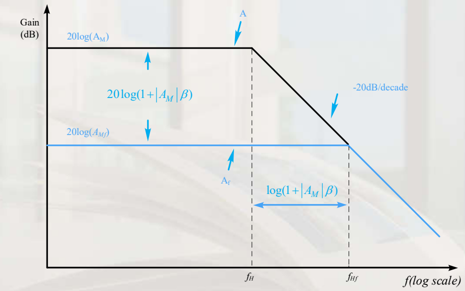


Fig. Negative feedback increases the amplifier bandwidth at the expense of decreasing the midband gain.

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

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

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

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

Gain-bandwidth product unchanged.

Feedback: Reduction in Nonlinear Distortion

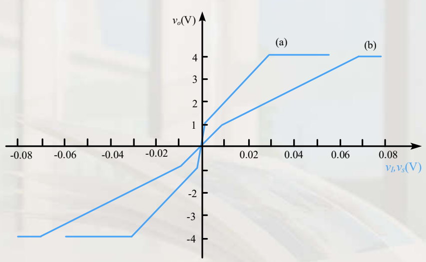


Fig. (a) v_o versus v_i without feedback.
(b) v_o versus v_s with negative feedback (β=0.01).

(a): open loop, piecewise linear, 1000 to 100.

(b): closed loop with negative feedback, β=0.01

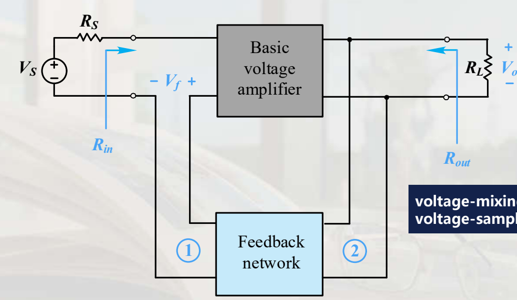
$$A_{f1} = \frac{1000}{1 + 1000 \times 0.01} = 90.9$$

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

Amplifier transfer characteristic can be considerably linearized through negative feedback.

Feedback Voltage Amplifier

- **Series–Shunt Feedback Topology**



voltage-mixing, voltage-sampling

Examples of Series–Shunt Feedback Amp.

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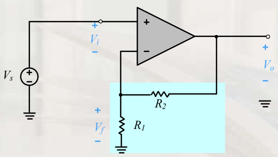

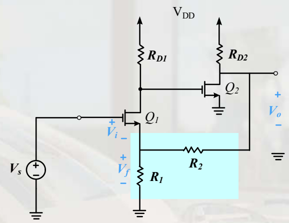

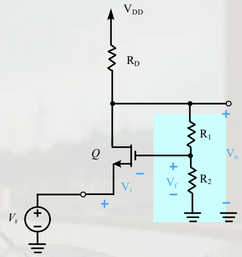

V_s increases, V_o increases and V_f increases: negative feedback

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