Feedback and Oscillators

Lesson #13

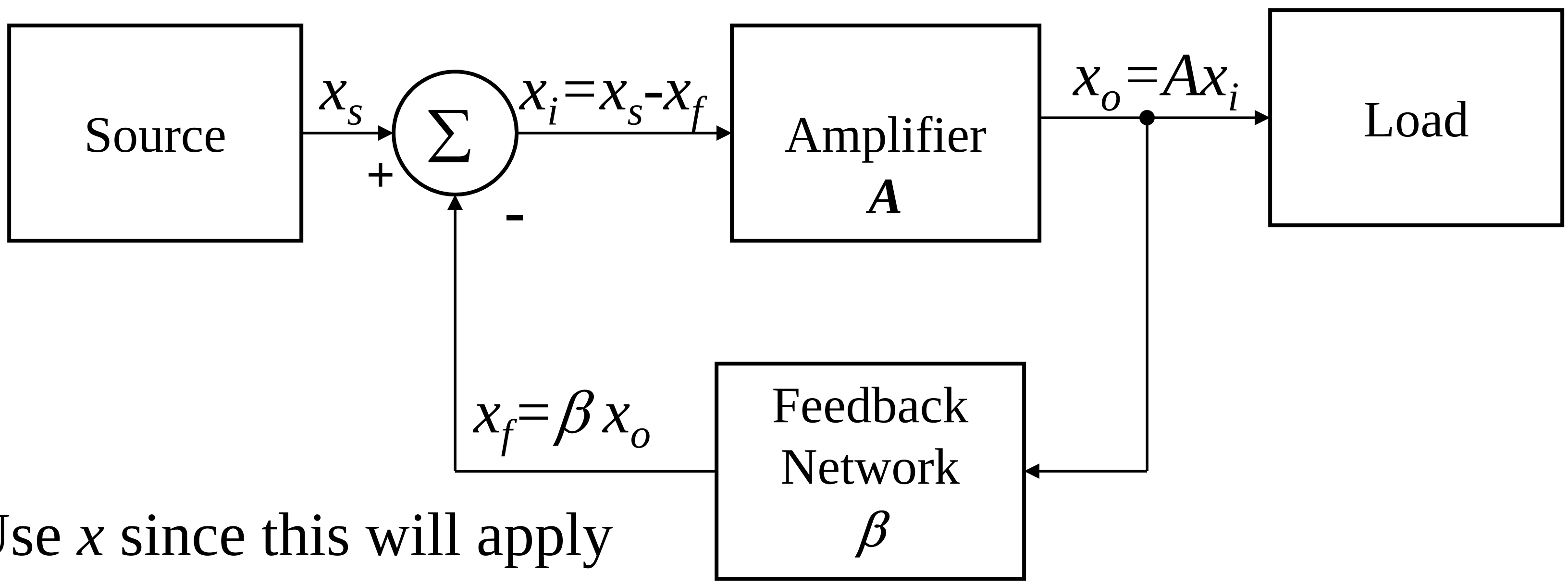
Feedback

Section 9.1-2

Feedback

- Types of Feedback
  - Positive: aids the input signal
  - Negative: reduces the input signal
- Positive Feedback Benefits
  - Oscillators
- Negative Feedback Benefits
  - Stabilization of Gain
  - Reduction of Nonlinear Distortion
  - Reduction of noise
  - Control of input and output impedances
  - Extension of Bandwidth
- Design of feedback amplifier to avoid unwanted oscillations

Closed-Loop Gain



Use *x* since this will apply equally to voltages and currents

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

$x_o = Ax_i$

$x_o = A(x_s - \beta x_o)$

$\Rightarrow$

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

$$Closed-Loop\ Gain = A_f$$

$$Open-Loop\ Gain = A$$

$$Loop\ Gain = A\beta$$

Problems With Positive Feedback

- If $|A\beta| \leq 1$ and $A\beta$ is negative:
  - then $1+A\beta \leq 1$; and A_f (closed-loop gain) > A (open-loop gain)
  - if $A\beta = -1$, then oscillations occur
  - POSITIVE FEEDBACK
- Example:
  - $A = -10$, $\beta = 0.0999 \Rightarrow A\beta = -0.999$; $1 + A\beta = 0.001$; $A_f = -10^4$
  - A: $-10 \rightarrow -9.9 \Rightarrow A\beta = -0.989$; $1 + A\beta = 0.011$; then A_f : $-10^4 \rightarrow -901$
  - For a 1% reduction in A there was a 91% reduction of A_f
  - POOR GAIN STABILITY: worse than the original amplifier

Problems (Continued)

- Another Example:
  - As $A\beta \rightarrow$ -1, $A_f \rightarrow \infty$ and this implies for a zero input signal an output signal can be generated and a signal will flow around the loop w/o an input $\Rightarrow$ oscillations. This is ok if an oscillator design is desired.
  - Clearly, a high gain amplifier can be designed with positive feedback; however, care must be taken because any change in the design (temperature shifts increase the power supply voltages) may cause $A\beta \rightarrow$ -1 and oscillations result

Gain Stabilization Using Negative Feedback

- For Negative Feedback Amplifiers are designed with $A\beta >> 1$ and $A_f \cong 1/\beta$
  - This is desirable since the value of β can be designed using solely stable passive components (e.g., resistors and capacitors)
  - On the other hand A is a function of active components (e.g., BJT, FET, etc.) whose operating point is highly dependent on temperature V_T and operating point *(e.g., for a BJT* $r_\pi = V_T/I_{BQ}$ and $g_m = \sqrt{2KP}\sqrt{W/L}\sqrt{I_{DQ}}$)
  - This occurs for op amps

Gain Stabilization Using Negative Feedback Continued

- *Example:* $A = 10^4$ and $\beta = 0.01 \Rightarrow A_f = 99$
  - If $A \to 9000$, then $A_f \to 98.9$
  - For a 10% reduction in A there was only a 0.1% reduction of A_f
- Therefore, we can design precision amplifiers using Negative Feedback

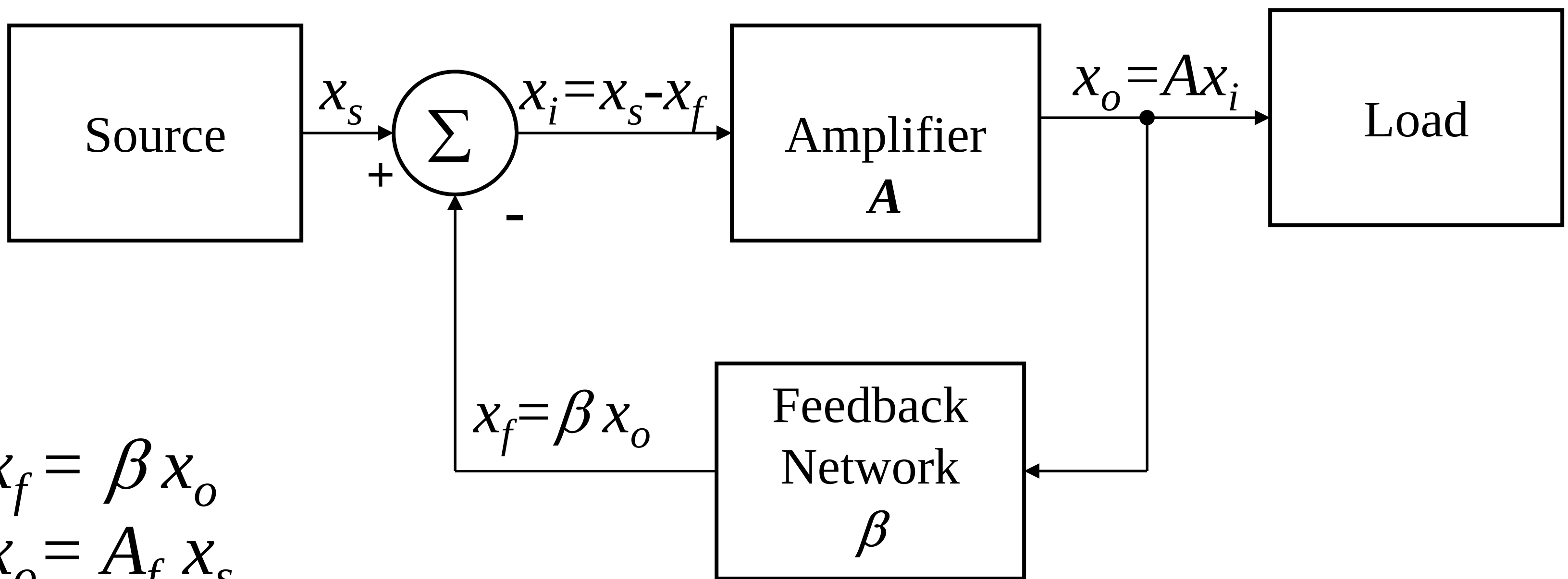
$$\frac{dA_f}{dA} = \frac{1 + A\beta - A\beta}{(1 + A\beta)^2} = \frac{1}{(1 + A\beta)^2}$$

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

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

- This states that for small fractional changes of A_f is the fractional change in A divided by $1+A\beta$
- Clearly, if the loop gain $A\beta >> 1$ changes of A_f are less than A

Summing-Point Constraint Revised



$$x_f = \beta x_o$$

$$x_o = A_f x_s$$

$$x_f = A_f \beta x_s$$

$$x_f = x_s \frac{A\beta}{1 + A\beta}$$

- If $A\beta >> 1$ then $x_f \cong x_s$ and $x_i = x_s - x_f \cong 0$
- This is the summing point constraint
  - Here is how we can design operational amplifiers from negative feedback amplifiers with $A\beta >> 1$

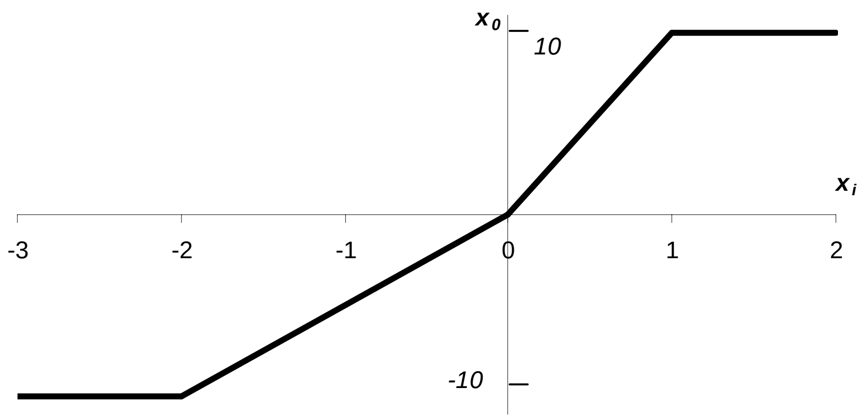
Examples

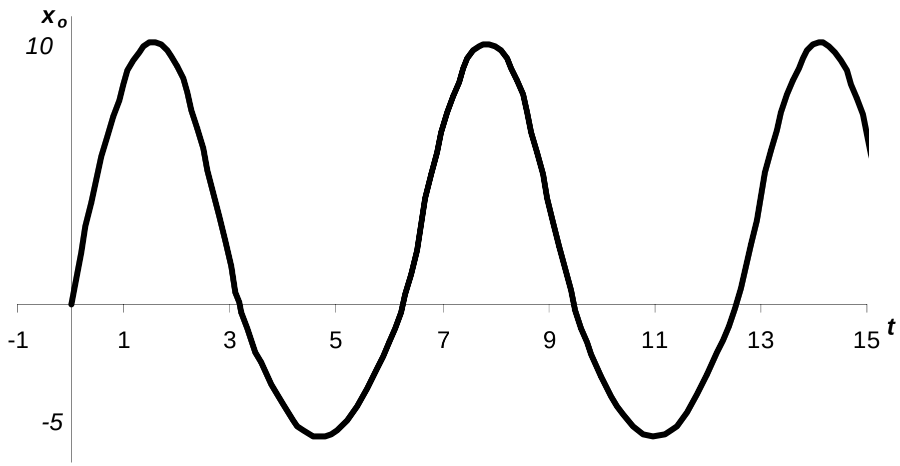
- Find A_f, x_o, x_f, and x_i for a negative feedback amplifier with $A=10^5$, $\beta = 0.01$ and $x_s = 5\ sin(2000\pi t)$
  - $A_f = A / (1+A\beta) = 10^5 / (1+ 10^5 * 0.01) = 99.9$
  - $x_o = A_f\ x_s = 499.5\ sin(2000\pi t)$
  - $x_f = \beta x_o = 4.995\ sin(2000\pi t)$
  - $x_i = x_s - x_f = .004995\ sin(2000\pi t)$

- What is the maximum value of A_f if we want it not to vary greater than $\pm$ 1% (and $\pm$ 0.1%) for an amplifier with A = $10^5 \pm 10\%$
  - $\Delta A/A = .10$; $\Delta A_f/A_f < .01$
    - $\Delta A_f/A_f = \Delta A/A * [1/(1+A\beta)]$
    - $A_f = A/(1+A\beta) \Rightarrow A_f = A* \Delta A_f / A_f *(A/\Delta A) = 10^5*.01/.1=10^4$
  - $A_f = A* \Delta A_f / A_f *(A/\Delta A) = 10^5*.001/.1=10^3$

Reduction of Non-linear Distortion

- Assume we have an amplifier which has the following non-linear gain characteristics.





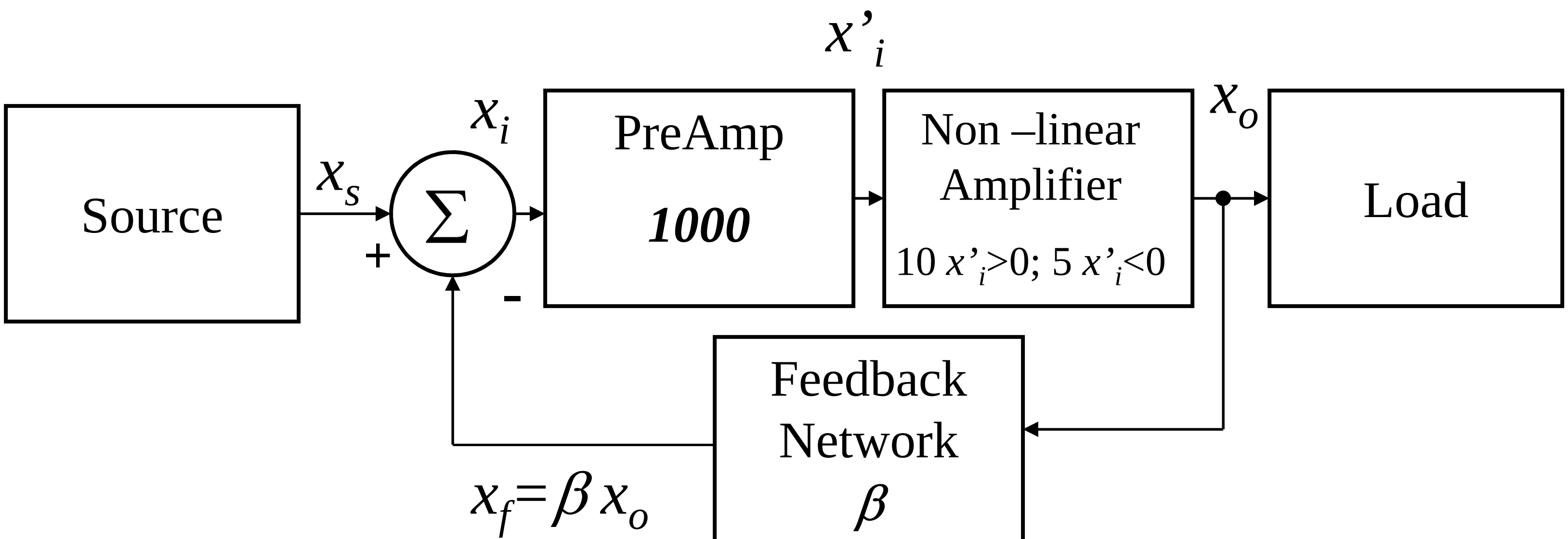
- If we want to reduce this distortion with an amplifier of $A_f \cong 10$ and $\beta = .1$, we would need to have $A\beta >> 1$, but $A = 10$ and 5.

Reduction of Non-linear Distortion (Continued)

- To solve this we can add a linear preamplifier of gain of 1000.
- The cascade has an open-loop gain of:

  10^4 ($=10^3$x10) for $0< x_o<10$ and 5000 ($=10^3$x5) for $-10< x_o<0$.
- And a closed loop gain of

  9.99 for $0<x_o<10$ and 9.98 for $-10<x_o<0$.



Compensation of Non-linear Distortion

- Let's look at the input signal at the amplifier:

$$x_i = x_s - x_f$$

$$x_i = x_s - x_s \frac{A\beta}{1 + A\beta} = x_s \frac{1}{1 + A\beta}$$

$$x_i = x_s \big/ (1 + 10^4 \times .1) = x_s \big/ 1001 \text{ for } 0 < x_s < 10$$

$$x_i = x_s \big/ (1 + 5000 \times .1) = x_s \big/ 501 \text{ for -10} < x_s < 0$$

- We see that the negative feedback compensate for the non-linear distortion by altering (pre-distorting) the input signal to the amplifier.

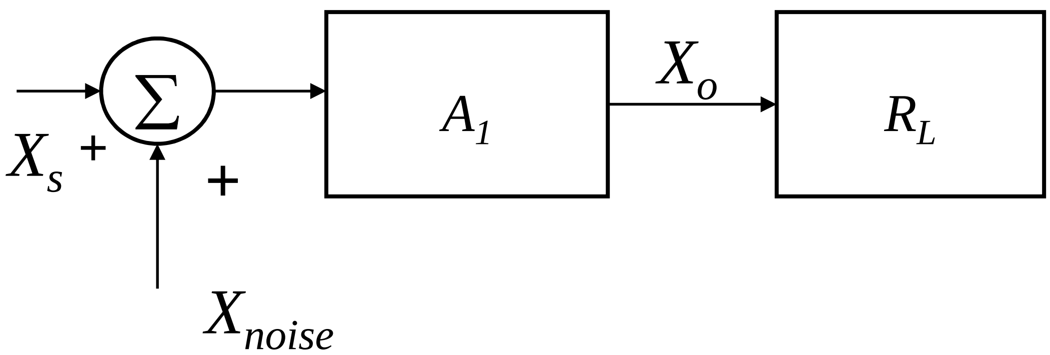
Noise Reduction

- Sources of Noise
  - Power-supply (60 cycle) hum
  - Coupling of non-wanted signals
  - Thermal noise in resistors (heat dissipation)
  - Shot noise (current flow may not be continuous)
- Signal-to-Noise Ratio
  - A way of quantifying the noise performance of a circuit
  - Desired power divided by the noise power
  - Given in terms of rms values of the signals and dBs

Signal-to-Noise Ratio

$$P_{signal} = \frac{(A_1 X_S)^2}{R_L}$$

$$P_{noise} = \frac{(A_1 X_{noise})^2}{R_L}$$



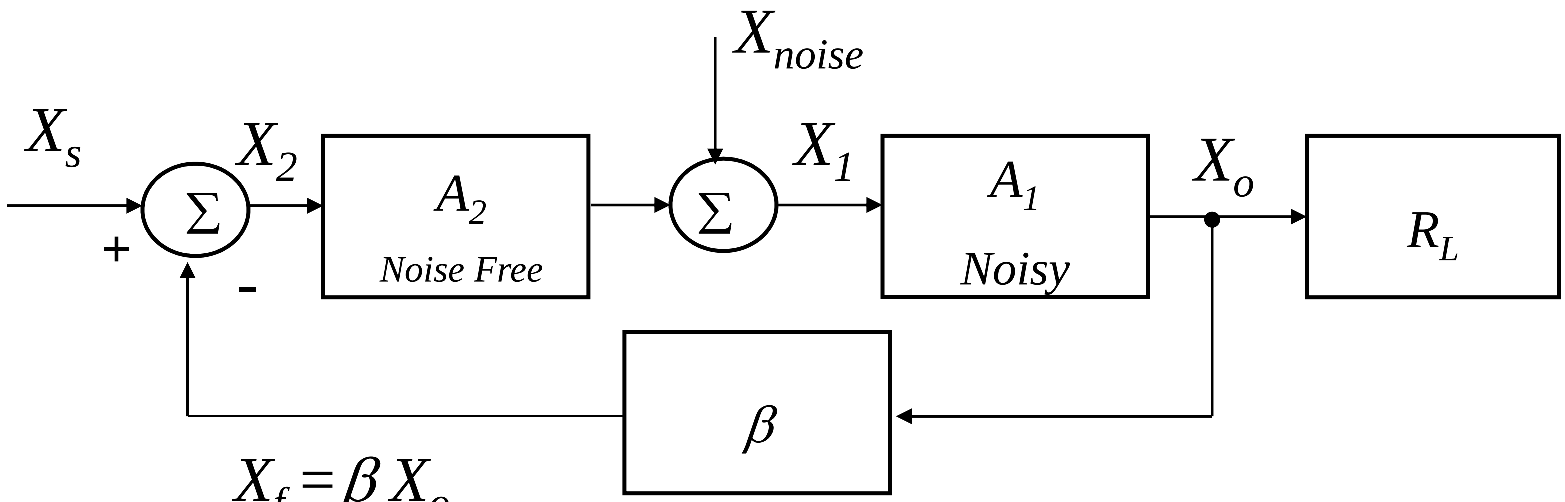
$$SNR = \frac{P_{signal}}{P_{noise}} = \frac{(X_s)^2}{(X_{noise})^2}$$

$$SNR_{dB} = 10\log(SNR)$$

$$SNR_{dB} = 10\log\frac{P_{signal}}{P_{noise}}$$

$$SNR_{dB} = 20\log\frac{X_s}{X_{noise}}$$

SNR Analysis



$$X_f = \beta X_o$$

$$X_O = A_1 X_1$$

$$X_1 = X_{noise} + A_2 X_2$$

$$X_2 = X_S - \beta X_O$$

$$X_O = A_1[X_{noise} + A_2(X_S - \beta X_O)]$$

$$X_O = \frac{A_1 A_2}{1 + A_1 A_2 \beta} X_S + \frac{A_1}{1 + A_1 A_2 \beta} X_{noise}$$

$$SNR = \frac{[X_S A_1 A_2 / (1 + \beta A_1 A_2)]^2}{[X_{noise} A_1 / (1 + \beta A_1 A_2)]^2}$$

$$SNR = \frac{(X_S)^2}{(X_{noise})^2} \times (A_2)^2$$

This says that by using negative feedback, SNR can be improved by $(A_2)^2$.

Examples

- Power Supply output is 10 V rms and receives hum at .1 V rms. Compute the SNR in dB.
  - SNR = 20 log(10/.1) = 40 dB
- Using a low noise amp we want to improve the SNR by 20 dB, what is the gain of the amp?
  - $SNR_{pre\text{-}amp} = SNR_{original} A^2$
  - $SNR_{pre\text{-}amp\ db} = SNR_{original\ db} + 20 \log A$
  - $SNR_{pre\text{-}amp\ db} = SNR_{original\ db} + 20\ dB$
  - $20 \log A = 20$
  - $\log A = 1$
  - $A = 10$

Homework

- Effects of Feedback
  - Problems: 9.1-3,5-9
- Reduction of Nonlinear Distortion and Noise
  - Problems: 9.10,16,18-20