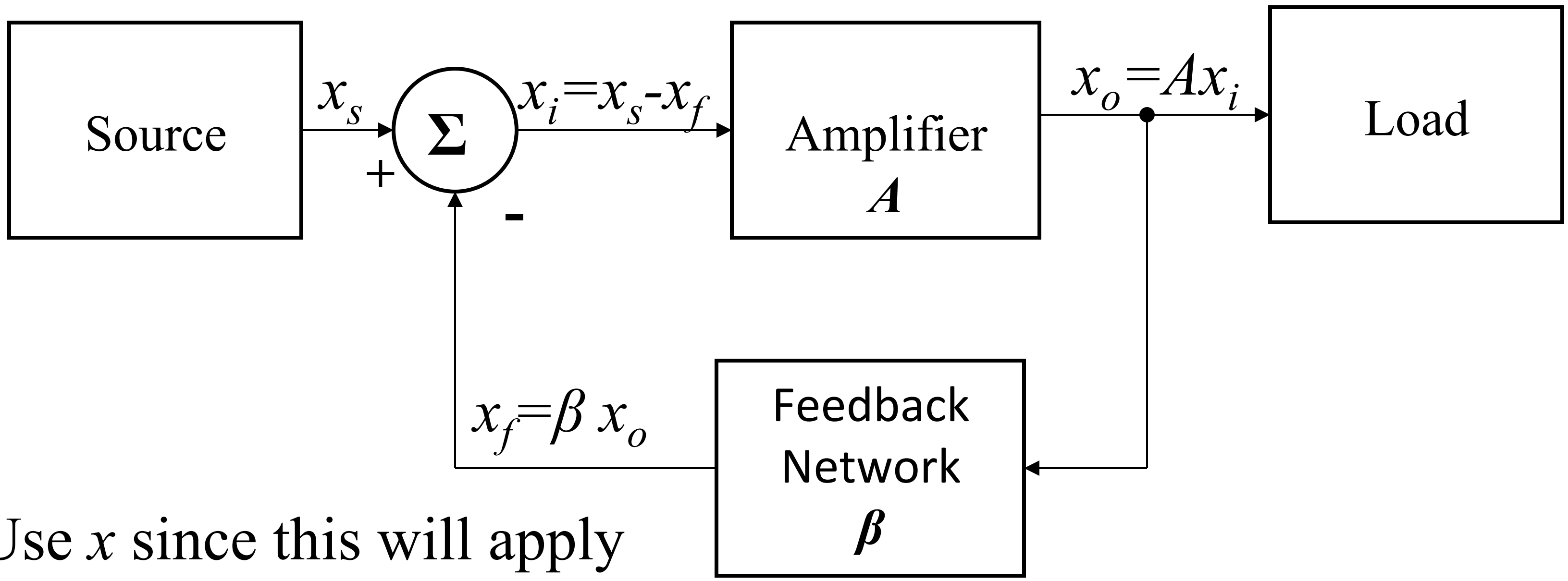
Feedback

Lecture 10

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

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

$$x_o = Ax_i$$

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

=>

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

$$Closed-Loop\ Gain = A_f$$

$$Open-Loop\ Gain = A$$

$$Loop\ Gain = A\beta$$

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:
  - $A = -10$, $\beta = 0.0999$ => $A\beta = -0.999$; $1 + A\beta = 0.001$; $A_f = -10^4$
  - A: -10 ➔ -9.9 => $A\beta = -0.989$; $1 + A\beta = 0.011$; then A_f: -10^4 ➔ -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 $A\beta$ ➔ -1, A_f ➔ ∞ 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 => 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 $A\beta$ ➔ -1 and oscillations result

Gain Stabilization Using Negative Feedback

- For Negative Feedback Amplifiers are designed with $A\beta >> 1$ and $A_f \approx 1/\beta$
- 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 $A \rightarrow 9000$, then $A_f \rightarrow 98.9$
  - 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

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

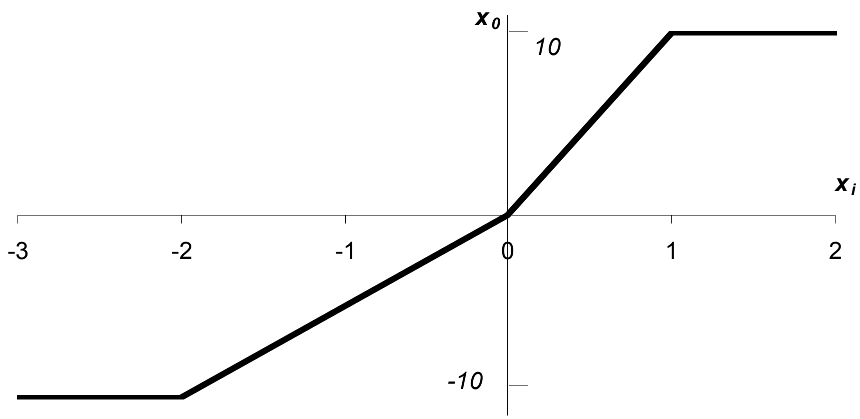
$$dA_f = \frac{dA}{A}\frac{A}{(1 + A\beta)^2} = \frac{dA}{A}\frac{A_f}{1 + A\beta}$$

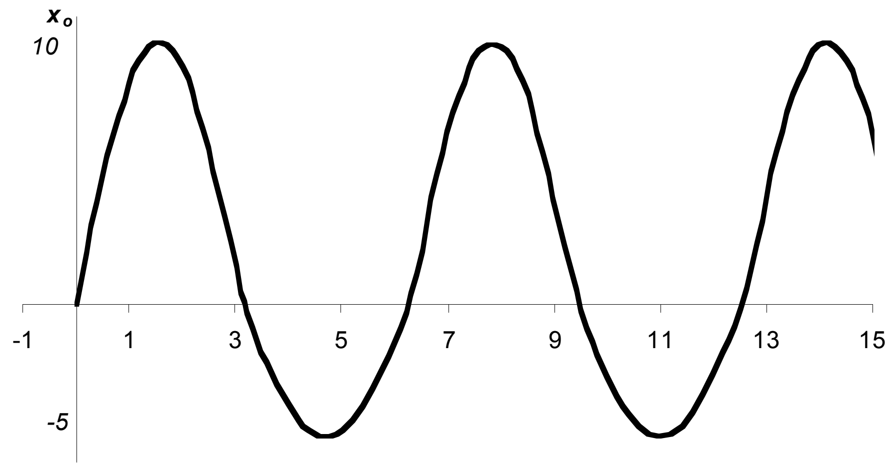
$$\frac{dA_f}{A_f} = \frac{dA}{A}\frac{1}{1 + A\beta}$$

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

Reduction of Non-linear Distortion

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





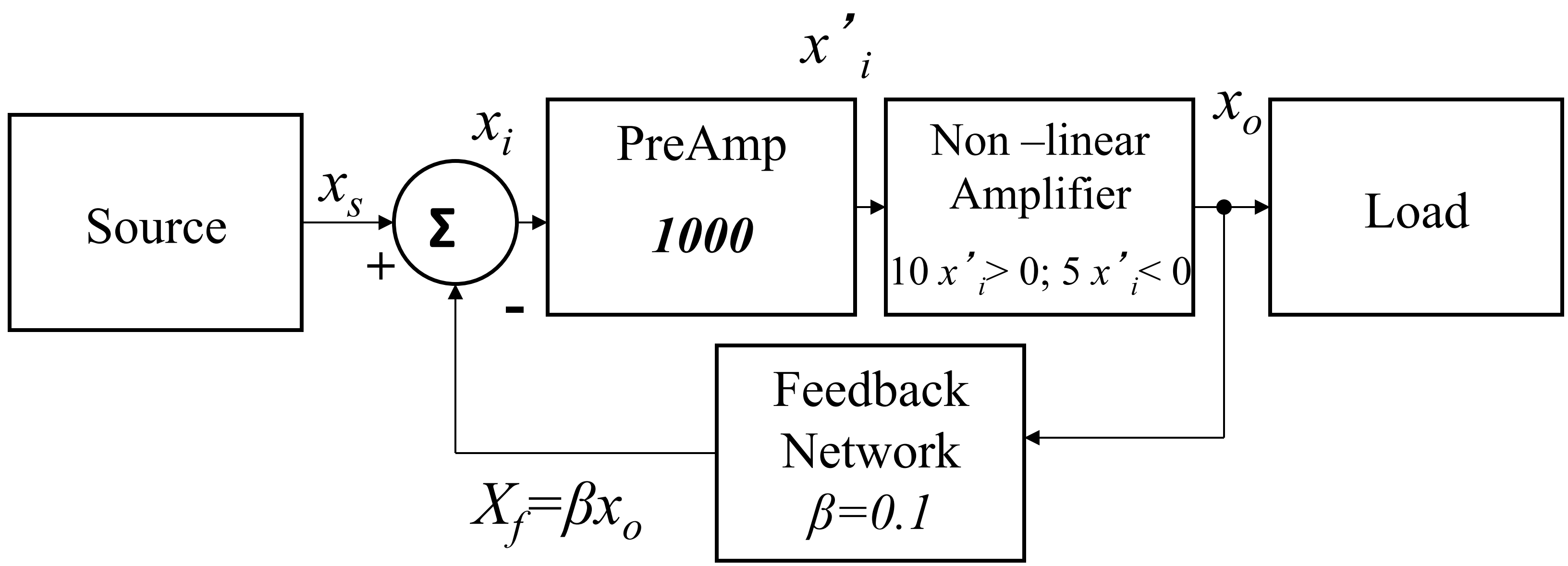
- If we want to reduce this distortion with an amplifier of $A_f \approx 10$ and $\beta = .1$, we would need to have $A\beta >> 1$, but $A = 10$ and 5.

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 $-10<x_o<0$.



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

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

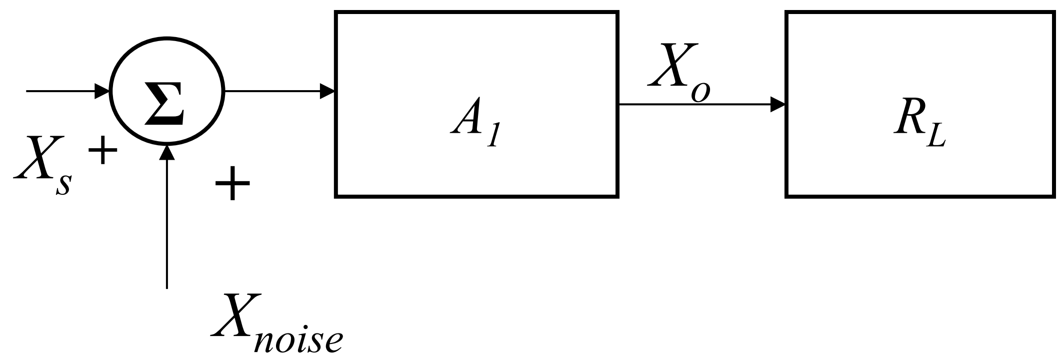
$$P_{noise} = \frac{(A_1 X_{noise})^2}{R_L}$$

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

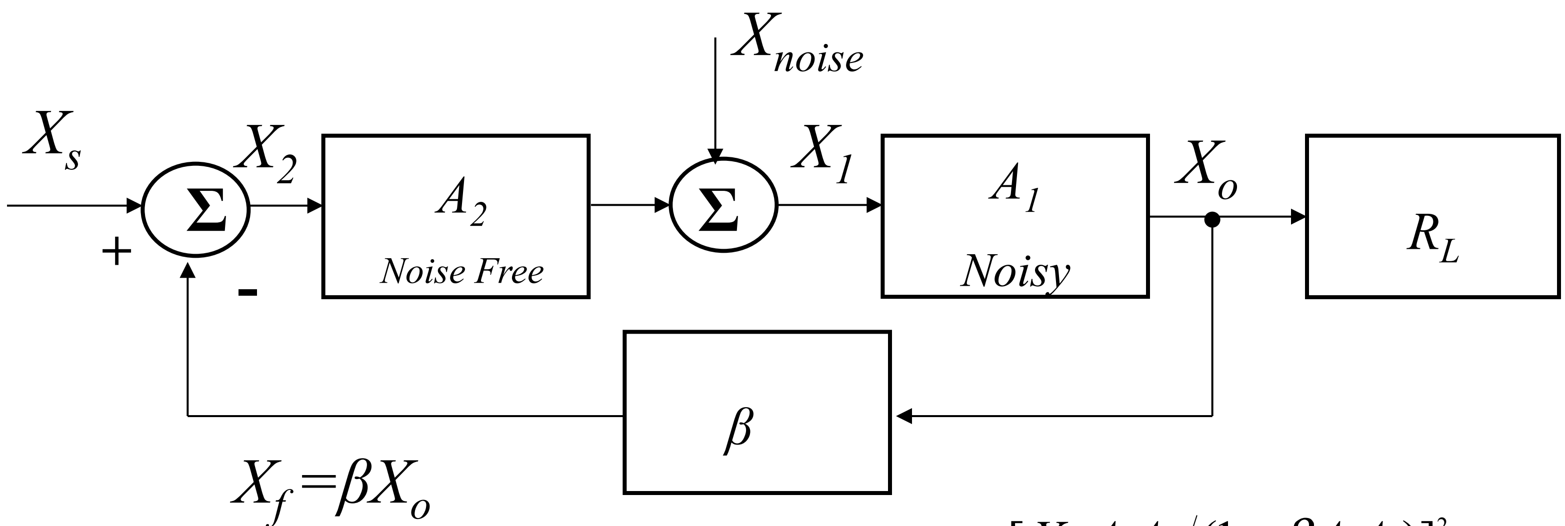
$$SNR_{dB} = 10\log(SNR)$$

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

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



SNR Analysis



$$X_O = A_1 X_1$$

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

$$X_2 = X_S - \beta X_O$$

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

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

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

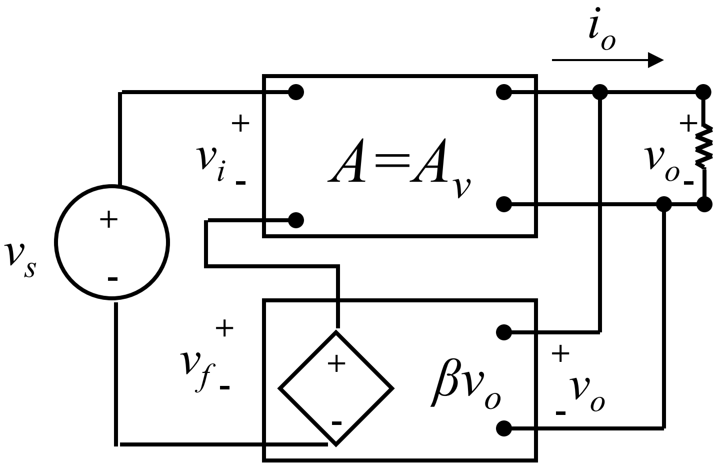
$$SNR = \frac{(X_S)^2}{(X_{noise})^2} \times (A_2)^2$$

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

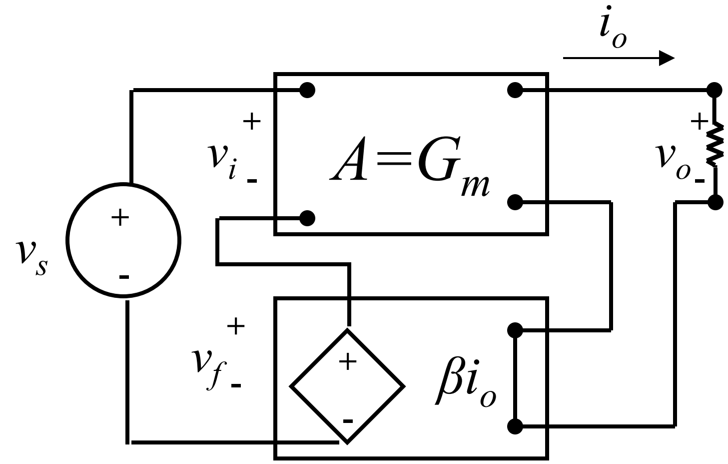
Types of Feedback (Continued)

- Four Combinations
  - Series Voltage: where amplifier input and output are voltages and, therefore, the gain parameter is a voltage gain, A_v and the feedback is a voltage, $\beta\, v_o$,which is proportional to the output voltage
  - Series Current : where amplifier input is a voltage and its output is a current and, therefore, the gain parameter is a transconductance, G_m, and the feedback is a voltage $\beta\, i_o$, which is proportional to the output current
  - Parallel Voltage: where amplifier input is a current and its output is a voltage and, therefore, the gain parameter is a transresistance gain, R_m and the feedback is a current, $\beta\, v_o$,which is proportional to the output voltage
  - Parallel current: where amplifier input and output are currents and, therefore, the gain parameter is a current gain, A_i and the feedback is a current, $\beta\, i_o$,which is proportional to the output current.

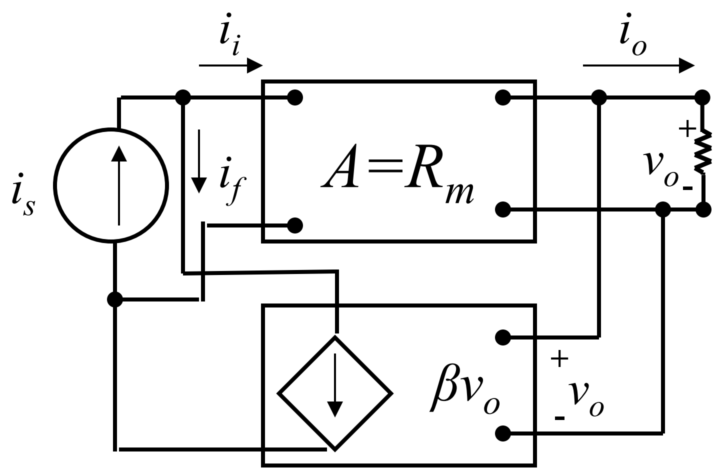
Types of Feedback Circuits



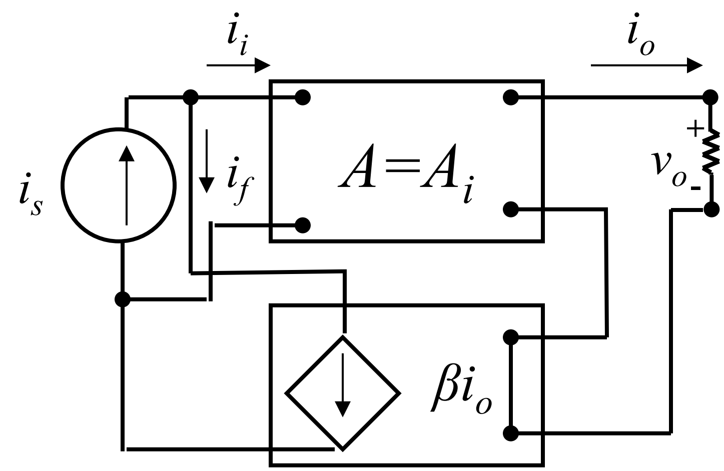
Series Voltage



Series Current



Parallel Voltage



Parallel Current

Effects of Feedback on Frequencies and Gain of Amplifiers

Let's assume that the open-circuit gain of an amplifier is of the form:

$$A(f) = \frac{A_o}{1 + j\frac{\omega}{\omega_b}} = \frac{A_o}{1 + j\frac{2\pi f}{2\pi f_b}} = \frac{A_o}{1 + j\frac{f}{f_b}} = \frac{10^5}{1 + j\frac{f}{10}}$$

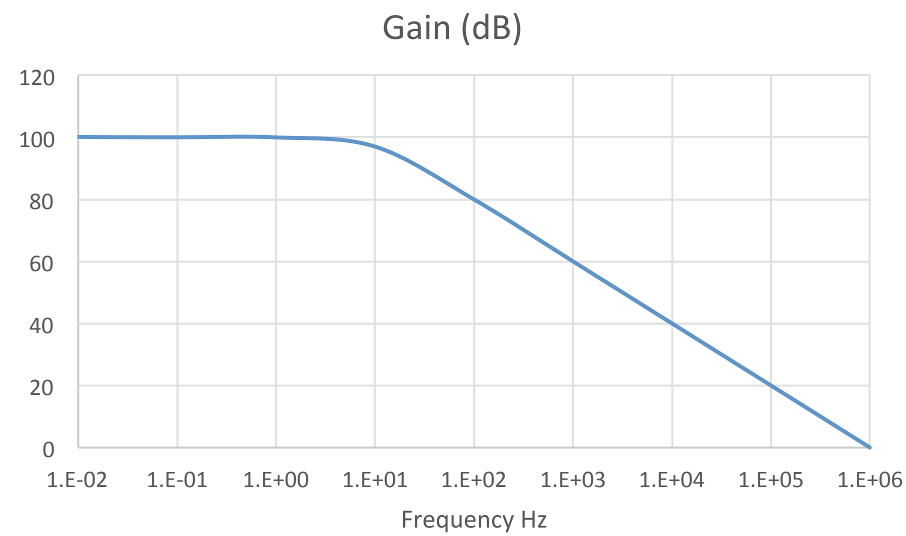
$$A_o = 10^5$$

$$f_b = 10$$

$$|A(f)| = \frac{10^5}{\sqrt{1 + (\frac{f}{10})^2}}$$

$$|A(f)|_{dB} = 20\log(\frac{10^5}{\sqrt{1 + (\frac{f}{10})^2}}) = 20\log(10^5) - 20\log\sqrt{1 + (\frac{f}{10})^2}$$

$$= 100 - 10\log(1 + (\frac{f}{10})^2)$$



Effects of Feedback on Frequencies and Gain of Amplifiers

Let's assume that the open-circuit gain of an amplifier is of the form:

$$A(f) = \frac{A_o}{1 + j\frac{\omega}{\omega_b}} = \frac{A_o}{1 + j\frac{f}{f_b}}$$

Adding feedback to the amplifier:

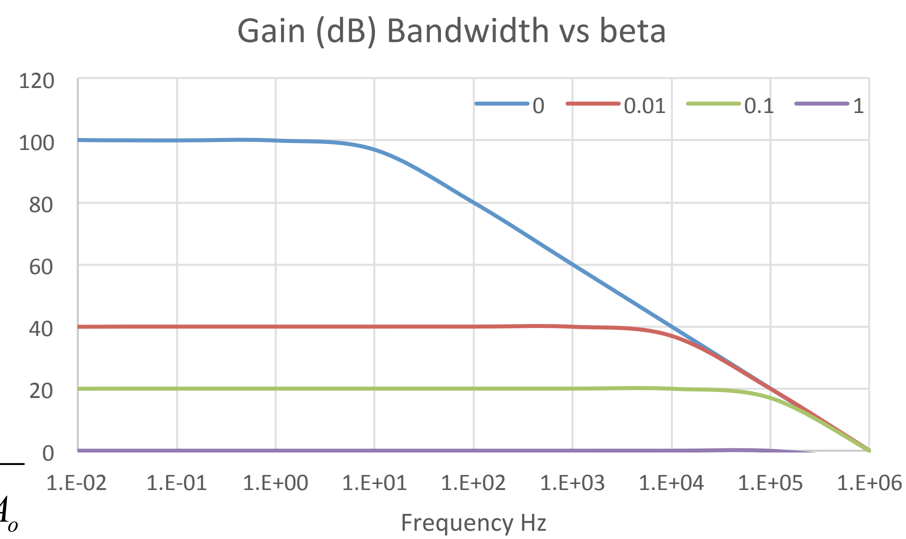
$$A_f(f) = \frac{A(f)}{1 + \beta A(f)} = \frac{\frac{A_o}{1 + j\frac{f}{f_b}}}{1 + \beta \frac{A_o}{1 + j\frac{f}{f_b}}} = \frac{A_o}{1 + j\frac{f}{f_b} + \beta A_o}$$

$$A_f(f) = \frac{A_o}{1 + \beta A_o + j\frac{f}{f_b}} = \frac{A_o/(1+\beta A_o)}{1 + j\ \ f/f_b(1+\beta A_o)} = \frac{A_{of}}{1 + j\ \ f/f_{bf}}$$

$$\left|A_f(f)\right|_{dB} = 20\log\left(\frac{A_{of}}{\sqrt{1 + \ (f/f_{bf})^2}}\right)$$

where:

$$A_{of} = \frac{A_o}{1+\beta A_o}, f_{bf} = f_b(1+\beta A_o)$$



beta	Af (dB)	fb
0	1.00E+02	1.00E+01
0.01	4.00E+01	1.00E+04
0.1	2.00E+01	1.00E+05
1	0.00E+00	1.00E+06

Gain Bandwidth Product

$$A_{of} \times f_{bf} = \frac{A_o}{1+\beta A_o} \times f_b(1+\beta A_o) = A_o f_b$$

Homework

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