Introduction to Feedback

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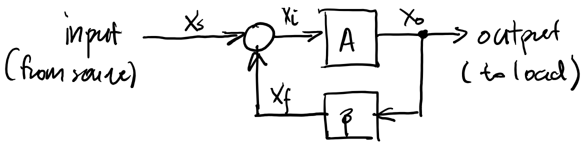
- Desensitize gain
- Reduce Distortion
- Extend BW
- Control I/O impedance
- ↑ Signal to noise ratio.

Recall OPAmps has: BW ~ 10Hz, Gain ~ 1×10^6

By having a gain of 100, BW would be 100kHz.

- Voltage amplifier: High R_i, Low R_o
- Current amplifier: Low R_i, High R_o.
- Transconductance amplifier: Feedback drives up both R_i, R_o.
- Transimpedance —: low R_i, R_o.

Basic Feedback Configuration



Ideally: $x_o = A x_i$

$x_f = \beta x_o$

$x_i = x_s - x_f$

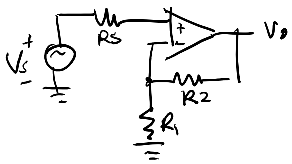
$A_f = \frac{x_o}{x_s}$ $\qquad A_f = \frac{A}{1+A\beta}$

If $A \gg \beta$, then $A_f \approx \frac{1}{\beta}$, so $x_f = \beta x_o = A\beta x_i = A\beta(x_s - x_f)$

$\rightarrow x_f = \frac{A\beta x_s}{1+A\beta} \approx x_s$. for $A\beta \gg 1$.

output follows the input.

Ex. Consider OPAMP with negative feedback (non-inverting)



For open loop gain $A \to \infty$: Find A_f in terms of R_1, R_2

$V_p = V_s$, $V_n = V_o\left(\frac{R_1}{R_1+R_2}\right)$

Ideal negative feedback:

$V_n = V_p$

Gain with feedback:

$$A_f = \frac{V_o}{V_s} = \boxed{\frac{R_1+R_2}{R_1}} = \frac{A}{1+A\beta} = \frac{1}{\beta} \text{ (since } A\to\infty)$$

Thus the feedback $\beta = \frac{R_1}{R_1+R_2}$

For open loop gain $A = 10^4$, and closed loop gain of $A_f = 100$: Find R_2/R_1

$A_f = 100 = \frac{A}{1+A\beta} = \frac{10^4}{1+10^4\cdot\beta}$

Since $\beta = \frac{R_1}{R_1+R_2}$ (from before)

Then $\beta = 99/10000 = \frac{R_1}{R_1+R_2}$

→ The amount of feedback is given as $|1+A\beta|$

$= \left|1 + A\left(\frac{1}{1+\frac{R_2}{R_1}}\right)\right|$, $A = 10^4$, $\frac{R_2}{R_1} = 100.01$

$= 20\log_{10}(100)$

$\boxed{=40dB}$

Since $\beta = \frac{R_1}{R_1+R_2}$ (from above)

Then $\beta = 99/10000 = \frac{R_1}{R_1+R_2}$

$$\frac{1}{1+\frac{R_2}{R_1}} = 99/10000$$

$$\frac{R_2}{R_1} = \frac{10000}{99} - 1$$

$$= \boxed{100.01}$$

$= 20\log_{10}(100)$

$= \boxed{40dB}$

For open loop gain $A = 7500$ (25% decrease), find A_f

$$A_f = \frac{A}{1+A\beta}, \quad \beta = \frac{1}{1+\frac{R_2}{R_1}}, \text{ and } R_2/R_1 = 100.01$$

$$A_f = \frac{7500}{1+7500\left(\frac{1}{1+100.01}\right)} = \boxed{99.67}$$

We see that we changed base gain by 25% but the output gain didn't change that much.

(gain de sensitivity)

Properties of negative feedback:

- Gain Desensitivity: can be found by taking $\frac{dA_f}{dA}$:

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

$$dA_f = \left(\frac{1}{1+A\beta}\right)\underbrace{\left(\frac{A}{1+A\beta}\right)}_{A_f}\left(\frac{1}{A}\right)dA$$

$$\frac{dA_f}{A_f} = \left(\frac{1}{1+A\beta}\right)\frac{dA}{A}$$

$\boxed{1+A\beta}$ is the desensitivity factor

- Bandwidth Extension

Consider: Low pass single pole amplifier

$$A(s) = A_m\left(\frac{\omega_H}{s+\omega_H}\right) = \frac{A_m}{\left(\frac{s}{\omega_H}+1\right)}$$

Applying feedback:

$$A_f(s) = \frac{A_m\left(\frac{\omega_H}{s+\omega_H}\right)}{1+A_m\left(\frac{\omega_H}{s+\omega_H}\right)\beta}$$

$$= \frac{A_m}{1+\frac{s}{\omega_H}+A_m\beta}$$

$$= \frac{\left(\frac{A_m}{1+A_m\beta}\right)}{\left(1+\frac{s}{\omega_H(1+A_m\beta)}\right)}$$

A_m reduced by a factor of $1+A_m\cdot\beta$

ω_H increased by a factor of $1+A_m\beta$

High pass single pole amplifier

$$A(s) = A_m\left(\frac{s}{s+\omega_L}\right)$$

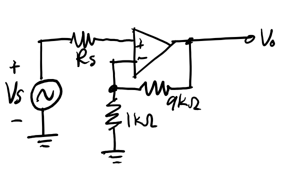
$$A_f(s) = \frac{A_m s}{s(1+A_m\beta)+\omega_L}$$

$$= \frac{\left(\frac{A_m}{1+A_m\beta}s\right)}{\left(s+\left(\frac{\omega_L}{1+A_m\beta}\right)\right)}$$

A_m reduced by a factor of $1+A_m\beta$

ω_L reduced by a factor of $1+A_m\beta$

Ex.



open loop $A = 1\times10^6$

Low pass single pole amplifier: $\omega_L = 2\pi\cdot 10$ rad/s

$$A(s) = A_m\left(\frac{2\pi(10)}{s+2\pi(10)}\right)$$

$$V_n = \left(\frac{1k}{1k+9k}\right)\cdot V_o, \quad V_n = V_p = V_s$$

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$$V_o = \left(\frac{1k+9k}{1k}\right) V_s$$

$$A_f = \frac{V_o}{V_s} = 10$$

But also $A_f = \frac{A(s)}{1+A(s)\beta} \approx \frac{1}{\beta} \Rightarrow \beta \approx 0.10$

$$A_{mf} = \frac{10^6}{1+A_m\beta} = \frac{10^6}{1+10^6 \cdot 0.1} = 9.9999$$

$$f_{Hf} = (10)(1+A_m\beta) = (10)(1+10^6 \cdot 0.1) = 1.00001 \text{ MHz}$$

Nonlinear Distortion Reduction: