Feedback

tough to get stable gain w/ e.g. CS

easy w/ feedback & ratio of passives

<u>but</u> stability!

pole locations and step response

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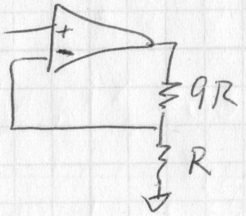
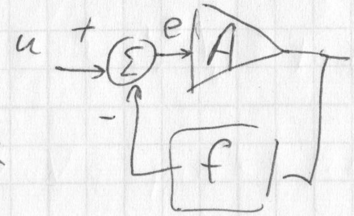
but really r_o varies all over the map

compare to





$f = \frac{R}{10R} \approx \frac{1}{10}$

$y = Ae = A(u - fy)$

$(1 + Af)y = Au$

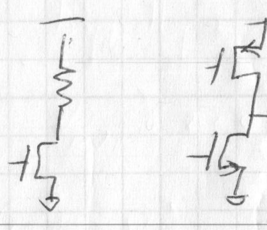
$H(s) = \frac{y}{u} = \frac{A}{1+Af} \approx \frac{1}{f}$

Feedback

consider gain accuracy of amps we've looked at.

goal: gain of 10 (or −10)

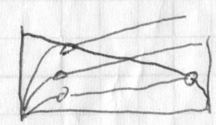
$A_v = -g_m r_o$



really bad — g_m varies a lot

still bad

best case



I_D varies, V_{OV} varies

A_v varies

λ is not really const.

PVT have big effect

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2 sources of error

- mismatch in R, 9R

  with careful layout $\approx 0.1\%$

- $\frac{A}{1+Af} \neq \frac{1}{f}$

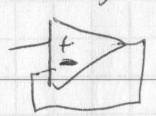
$\frac{A}{1+Af} = \frac{A}{Af} \frac{1}{1+\frac{1}{Af}} = \frac{1}{f} \left(\frac{1}{1+\frac{1}{Af}} \right)$

make A big enough so that $\frac{1}{Af}$ is as small as you need, over all input, PVT variation < 1

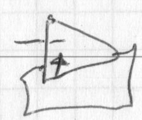
feedback is good for a lot of things
- stable gain (and better linearity) & gain accuracy
- improved input/output resistance
- wider bandwidth

but there's a risk of instability

unity gain buffer



latch



$f=1 \quad \frac{A}{1+Af} \approx 1$

instability occurs when feedback becomes positive at some frequency w/ magnitude ≥ 1

in that case ⇒ oscillations

for this picture, that freq = 0

Once you have oscillations, other nonlinearities can make weird things happen

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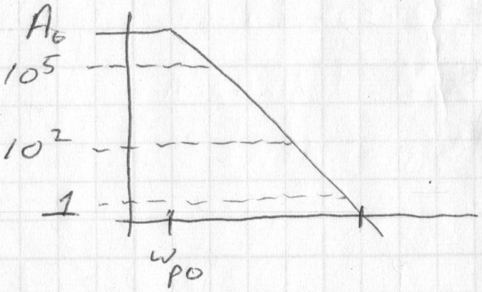
poles move in feedback

say A is a single pole amp, $A = \frac{A_0}{1+s/\omega_{p0}}$

$$\frac{A}{1+Af} = \frac{A_0}{1+s/\omega_{p0}} \frac{1}{\left(1+\frac{A_0 f}{1+s/\omega_{p0}}\right)} = \frac{A_0}{1+A_0 f + s/\omega_{p0}}$$

$$= \frac{A_0}{(1+A_0 f)\left(1+\frac{s}{\omega_{pCL}}\right)}$$

where $\omega_{pCL} = (1+A_0 f)\omega_{p0}$



$A_0 = 10^6$

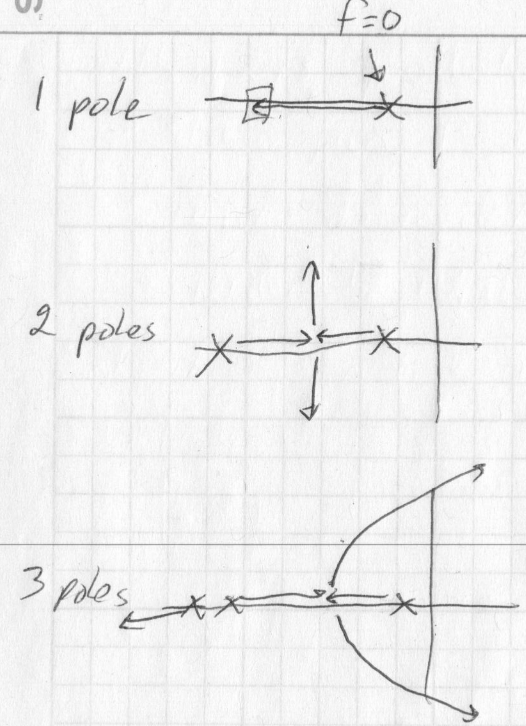
$\omega_{p0} = 10$ rad/s

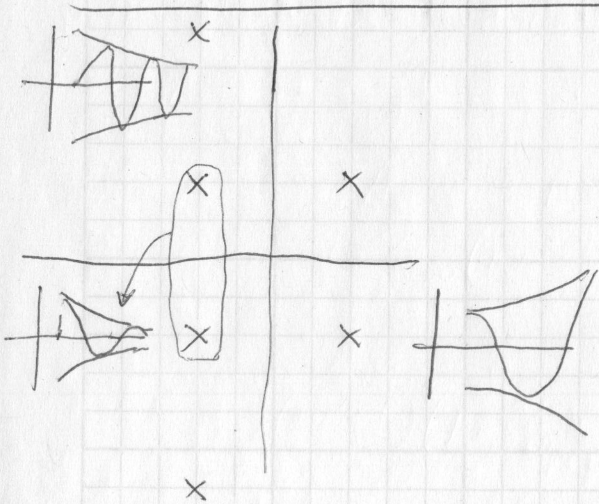
$f = 0.00001 = 10^{-5}$ $\quad 1/f \approx 10^5 \quad \omega_{pCL} \approx 10\omega_{p0}$

$f = 0.01 = 10^{-2}$ $\quad 1/f = 10^2 \quad \omega_{pCL} = 10^4 \omega_{p0}$

$f = 1$ $\quad 1/f = 1 \quad \omega_{pCL} = 10^6 \omega_{p0}$

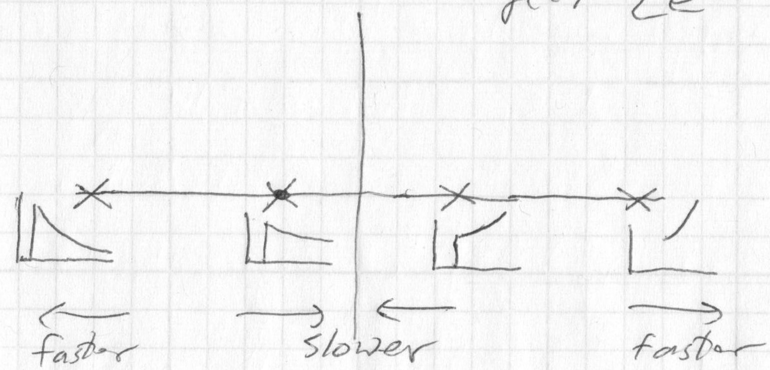
$f: 0 \to 1 \quad A_{CL} \downarrow \quad \omega_{pCL} \rightarrow$





~~frequency~~ time ($y(t)$) response & pole location p_i

$y(t) \sim \sum e^{p_i t}$



$p_i = \sigma \pm j\omega \Rightarrow e^{\sigma t} \, e^{\pm j\omega t}$

$e^{\sigma t}(\cos\omega t + \phi)$