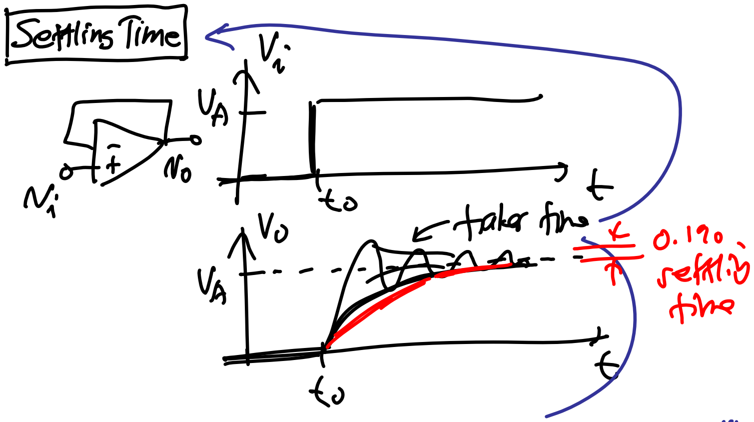
Lecture 18: Stability

- **Announcements:**
  - Midterm Thursday, Oct. 31, 9:00-11 a.m. in this room
  - Midterm info sheet online (indicates extra office hours this week)
  - Solutions to past EE140/240A exams passed out in class last time
  - Solutions to all HW's through HW#7 online (except 1A)
  - Solution to HW#8 will be emailed on Tuesday, shortly after it's due at 6 p.m. (it will also be online within a day)
  - Review Session on Tuesday evening, probably 5-7 p.m., in a 241 Cory (right here)
- **Lecture Topics:**
  - Stability
- ------------------------------------
- **Last Time:**
- Finished output stages

Settling Time



Function of amplifier stability!

Stability & Compensation in Op Amps

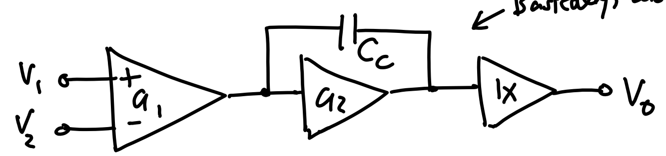
In general, op amps are used in neg FB loops.

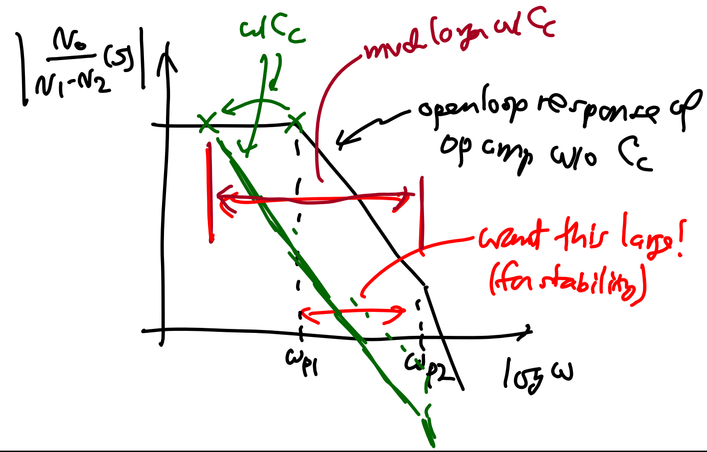
Reasons:

1. Feedback sets the biasing → no large coupling or bypass caps needed.
2. FB increases BW.
3. FB increases linearity or input range. (e.g., emitter degeneration is a type of FB)
4. Gain determined by external FB components → more accurate than op amp gain.
5. FB sets R_i and R_o. → determines type of gain: e.g. $v \to v$, $i \to v$
6. FB can improve temperature stability.

Stability & Compensation

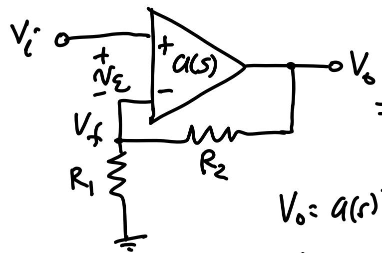
← Basically, Lab#2.



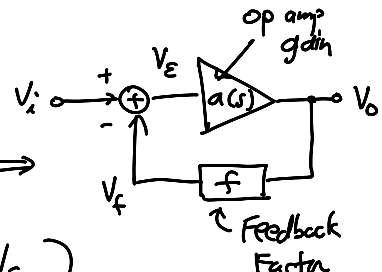


⇒ Problem: any FB loop can become unstable under certain conditions → ∴ must compensate to suppress instability!

Ex. Non-inverting Amplifier



⟹



$V_o = a(s)V_\varepsilon$

$V_\varepsilon = V_i - V_f$

$V_f = fV_o$

$\Big\} \; V_o = a(s)(V_i - fV_o)$

$$A(s) = \frac{V_o}{V_i}(s) = \frac{a(s)}{1+a(s)f} = \frac{a(s)}{1+T(s)}$$

Closed loop gain

Loop Transmission: $T(s) = a(s)f$ ↳ fcn of freq.

@ dc: loop gain $= a_o f = T_o$

Instability occurs when $A(s) \to \infty$!

$$\Rightarrow A(s) = \frac{a(s)}{1+a(s)f} \to A(s) = \frac{a(s)}{1-1} = \frac{a(s)}{0} \to \infty$$

$a(s)f = -1$

loop transmission

will also go unstable if denominator is (−)

In General:

$$\boxed{\text{If } |a(s)f| \geq 1 \text{ when } \measuredangle a(s)f = -180^\circ \Big\} \Rightarrow \text{Unstable}}$$

0 dB

This is a simplified form of the Nyquist Criterion.

Stability of a FB Ckt. Using a Single-Pole Op Amp

For a single pole op amp: $a(s) = \dfrac{a_o}{1-\dfrac{s}{p_1}} \equiv$ op amp transfer fcn

Thus: (close the loop)

$$A(s) = \frac{a(s)}{1+a(s)f} = \frac{a_o}{1+a_o f} \cdot \frac{1}{1-\dfrac{s}{p_1(1+a_o f)}}$$

closed loop T.F.

A_o = closed loop dc gain

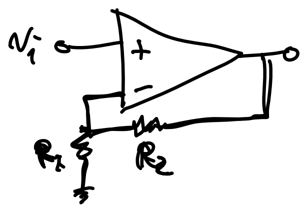
if $a_o f > 1 \to \approx \frac{1}{f}$

BW increases by $1+a_o f$

$T_o = a_o f$ = loop gain (defined @ DC)

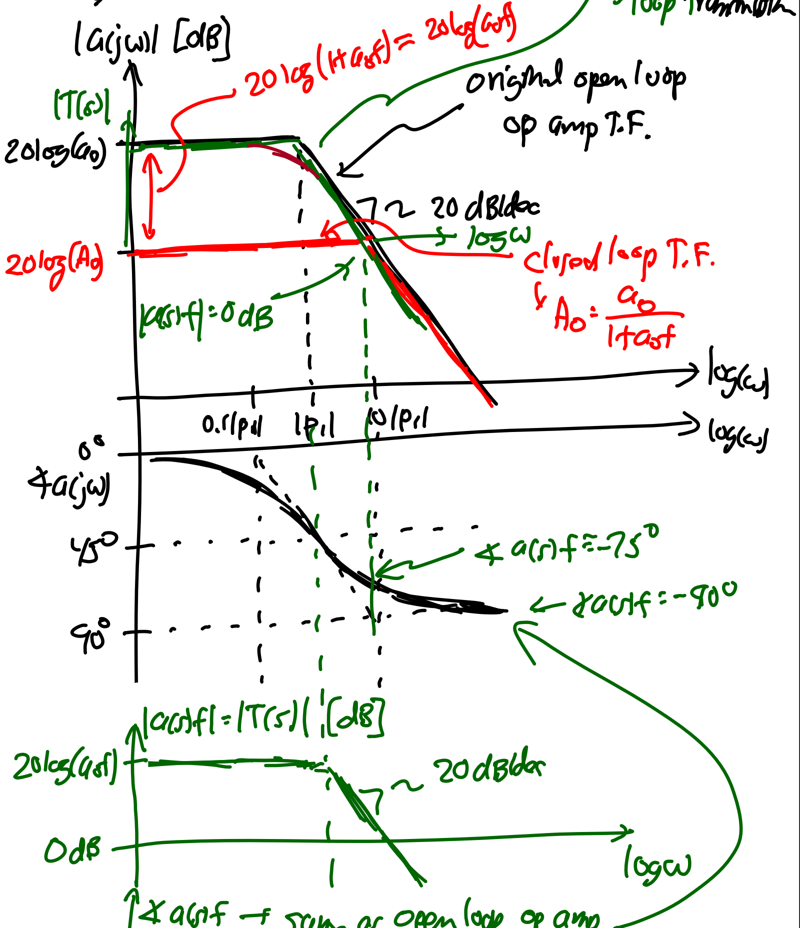
$T(s) = a(s)f$ = loop transmission (defined for general freqs.)

Bode Plot: → use to determine $\measuredangle a(s)f$ when $|a(s)f| = 1$
then can determine stability



$$A(s) = \frac{V_o}{V_i}(s) = \frac{a(s)}{1 + a(s)f}$$

$a(s)f$ → loop transmission



Remarks:

① For the case of a single-pole op amp, FB (w/ f = const.) can never reach $\measuredangle a(s)f = -180°$. ($90°$ is the limit.)

② Thus, a single-pole op amp in FB w/ f = const., i.e., f ≠ function of $s = j\omega$, is always stable!

↓

But in reality, any op amp will have more than one pole → just two poles suf. to $a(s)f = -180°$

↓

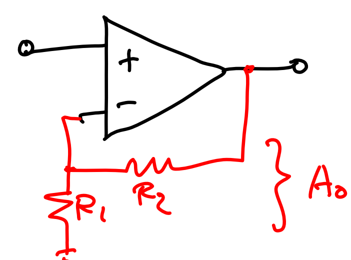
three poles pass $a(s)f = -180°$

↓

Can instigate instability

↓

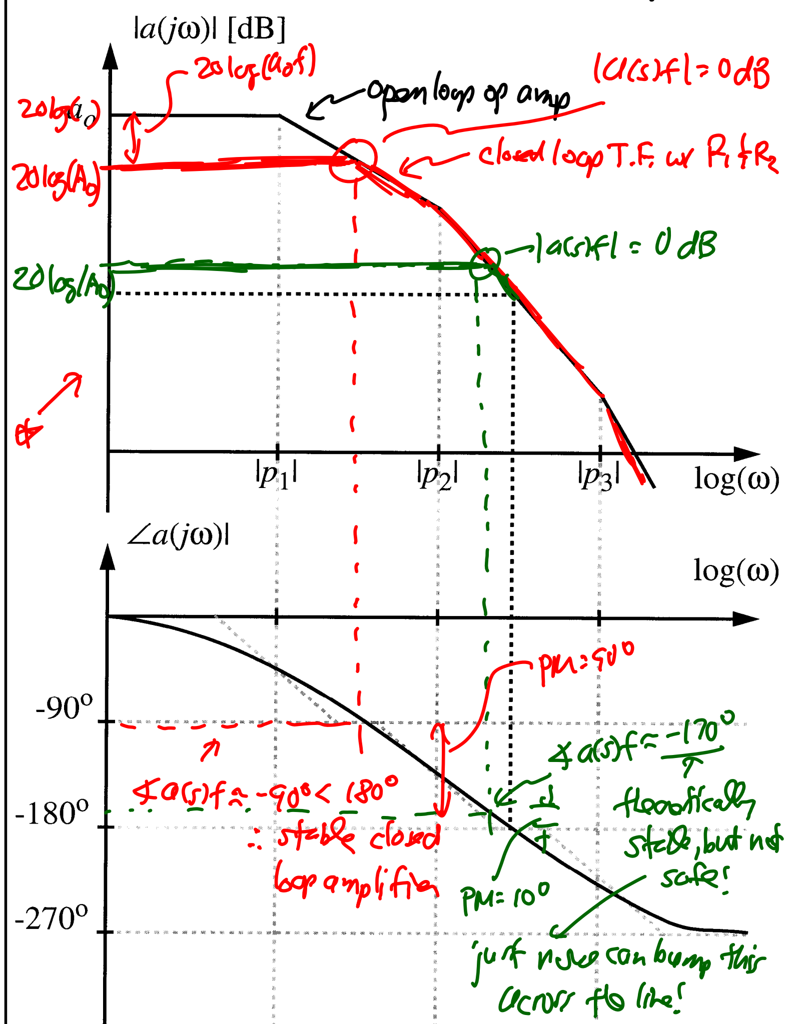
Use a Bode plot to investigate



$\boxed{\text{Stability of a FB Ckt. Using a MultiPole Op Amp}}$

Assume: dominant pole: p_1, non-dominant pole: p_2 & p_3 +

$|p_3|, |p_4| \gg |p_2|$



For the general case where a(s) has multiple poles:

⇒ A(s) has the same additional poles (f = const.)

⇒ i.e., @ freq. > $|p_1|(1+a_of)$, the A(s) curve just follows the a(s) curve:

$$A(s) \cong \frac{A_o}{\left(1 - \frac{s}{|p_1|(1+a_of)}\right)\left(1 - \frac{s}{|p_2|}\right)\left(1 - \frac{s}{|p_3|}\right)}$$

when $|p_1|(1+a_of) < |p_2|$ (red curve) → *

↳ after this, get peaking

Definitions:

Phase Margin = $180^\circ + (\measuredangle a(j\omega)f$ @ freq. where $|a(j\omega)f| = 1)$

= 90° (stable)

= 10° (stable, but very dangerous) → unstable

⇒ phase margin must be $> 0^\circ$ for theoretical stability

$\boxed{\text{For Theoretical Stability, PM} > 0^\circ}$

⇒ for design safety, design for

$\boxed{\text{Phase Margin} \geq 45^\circ}$

⇒ even safer (for settling time): $\boxed{\text{PM} \geq 60^\circ}$