Lecture 19: Compensation

- Announcements:
  - Lab#2 due this week (and Monday next week for those in the Monday section: use the 140 box in the Cory Hall lounge)
  - Midterm Exam Thursday, 3/22
  - Lab#3 will be online very soon
- Lecture Topics:
  - Stability (continued)
  - Compensation
    - —Narrowbanding
    - —Pole-Splitting
- ------------------------------------
- Went through Lab#3
- Last Time:

Stability & Compensation in Op Amps

In general, op amps are used in neg FB loops. ← causes instability!

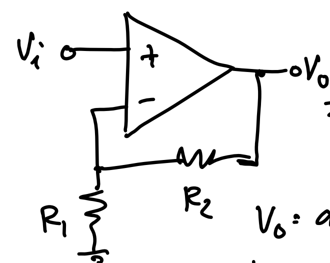
Reasons:

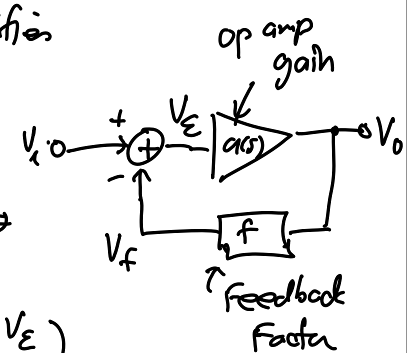
1. Feedback sets the biasing → no large coupling or bypass caps needed.
2. FB increases BW.
3. FB increases linearity or input range. (e.g., emitter degeneration is a type of FB)
4. Gain determined by external FB components → more accurate than op amp gain.
5. FB sets R_i and R_o.
6. FB can improve temperature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

→ Problem: any FB loop can become unstable under certain conditions

↳ need to compensate the instabilities

Ex. Non-Inverting Amplifier





$$\left.\begin{aligned} V_o &= a(s)V_\varepsilon \\ V_\varepsilon &= V_i - V_f \\ V_f &= fV_o \end{aligned}\right\} \quad V_o = a(s)(V_i - fV_o)$$

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

$A(s)$: Closed Loop Voltage Gain

$T(s) = a(s)f$: Loop Transmission

$T_o = T(0)$

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

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

$a(s)f = -1$

will also go unstable when denominator $= (-)$

In General:

If $|a(s)f| \geq 1$ when $\measuredangle a(s)f = -180^\circ$ } ⇒ Unstable!

This is just a simplified form of the Nyquist Criterion.

Stability of FB Ckt. Using a Single Pole Op Amp

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

Thus: closed loop Xfer fcn

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

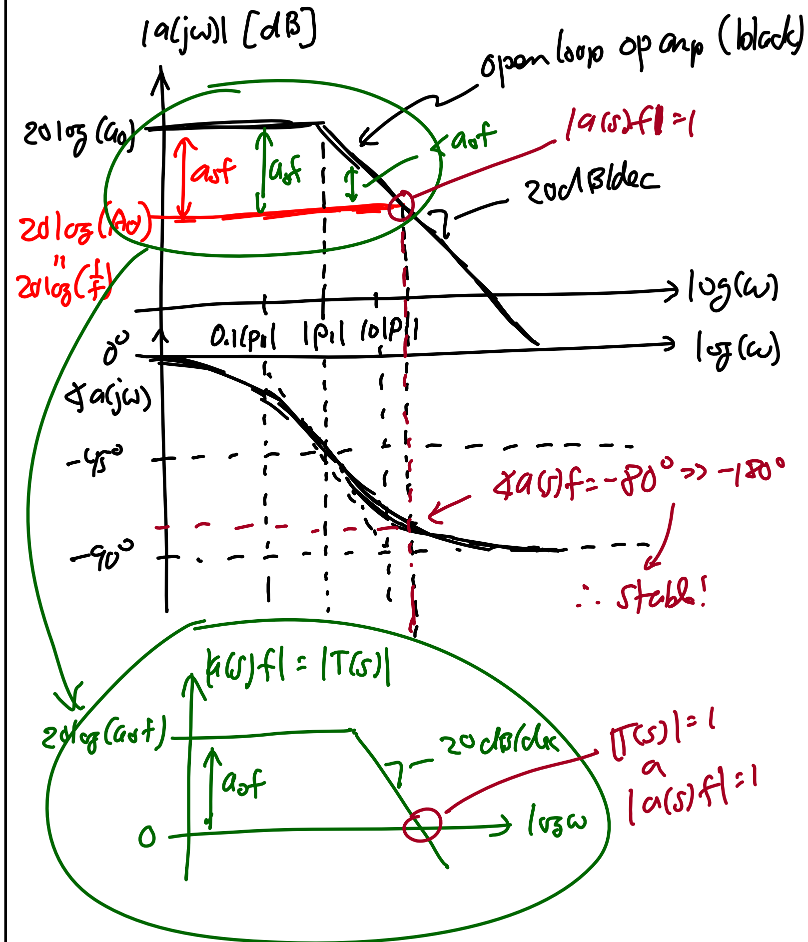
A_o = closed loop dc gain → $(1 + a_o f) \approx a_o f$ × smaller than a_o

$$\frac{a_o}{1 + a_o f} \simeq \frac{1}{f}$$

$T_o = a_o f$ = loop gain (defined at 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 determine stability



Remarks:

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

② Thus, an op amp FB ckt. w/ f = const. and using a single-pole op amp is always stable!

↓

But add a few non-dominant poles → then instability is possible!

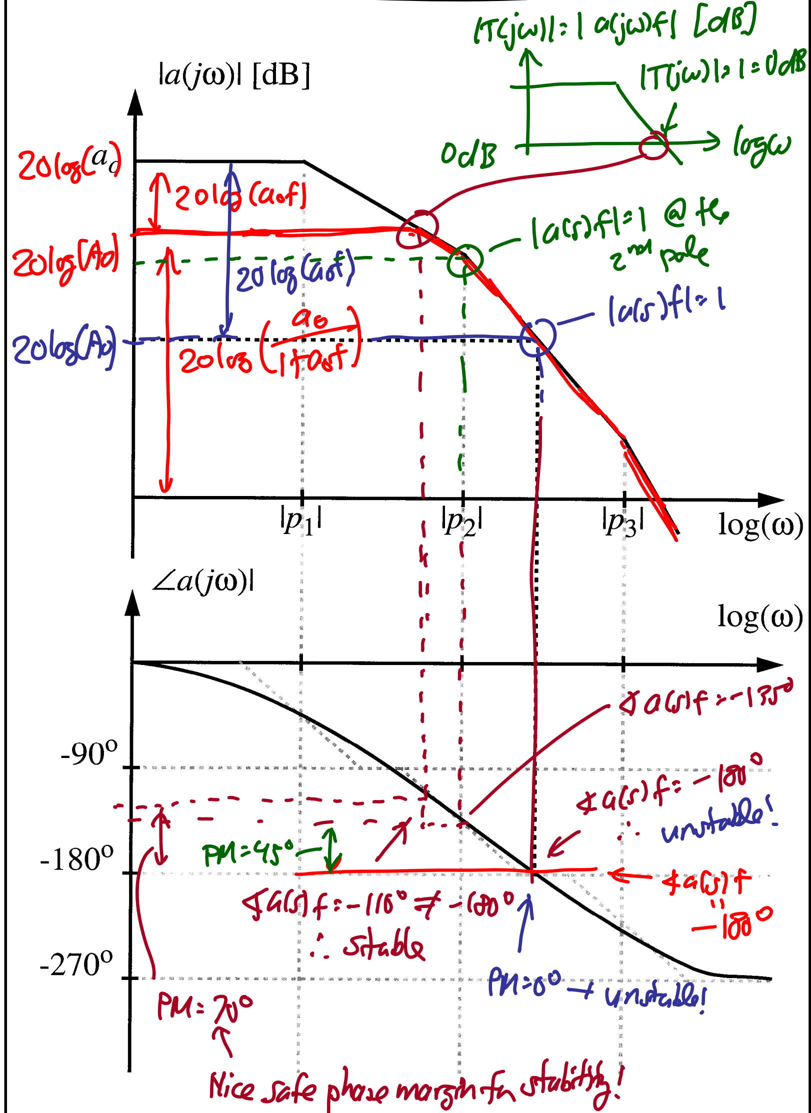
&

since now, $\measuredangle a(s)f$ can reach −180°!

↓

Can best visualize this via a Bode plot.

Stability of a FB Ckt. Using a Multi-Pole Amp



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

$\Rightarrow$ $A(s)$ has the same additional poles

$\Rightarrow$ i.e., @ freqs. $> |p_1|(1+a_o f)$, the $A(s)$ curve just follows the $a(s)$ curve

$$A(s) \cong \frac{A_0}{\left(1 - \frac{s}{|p_1|(1+a_o f)}\right)\left(1 - \frac{s}{p_2}\right)\left(1 - \frac{s}{p_3}\right)}$$

makes sense, because @ freqs $> |p_1|(1+a_o f)$, the loop transmission $|a(s)f| < 1$ $\rightarrow$ $\therefore$ there really isn't much FB anymore

Definition:

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