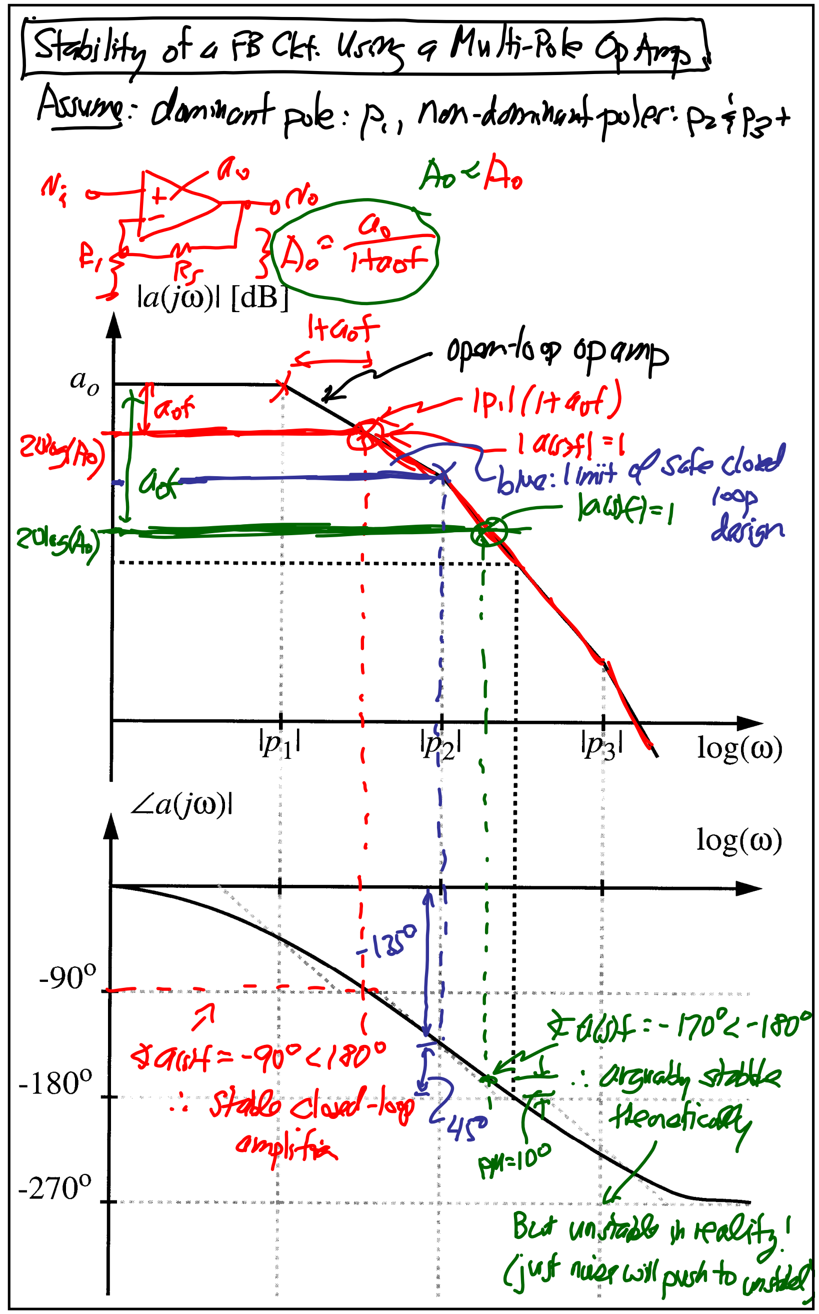
Lecture 20: Choosing Cc

- Announcements:
  - HW#8 online; due Wednesday next week
  - Lab#2 due this coming Monday in lab
  - 240A students: HW#1A due tomorrow
- Lab#3 (Design Project) in progress
- Design Project Checkpoint:
  - Due Tuesday, Nov. 17, 11:59 p.m.
  - Send to your TA a spice file for your op amp design that simulates correctly, i.e., that reaches a stable bias point where all transistors are saturated (or linear if an MOS resistor)
  - It doesn't need to meet the project specs, but it should simulate correctly
- Lecture Topics:
  - Compensation
  - Choosing Cc
- ------------------------------------
- Last Time: Stability

over



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

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

⇒ i.e., @ freqs. > $|p_1|(1+a_o f)$, the A(s) curve just follow the a(s) curve (provided the new p_1' is not too close to the original p_2)

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

when $|p_1|(1+a_o f) < |p_2|$

↳ after p_2, get peaking

Definitions:

Phase Margin = 180° + (∠a(jω) @ freq. where |a(jω)f| = 1)

if = 90° → stable

if = 10° → probably unstable (but theoretically stable)

if = 45° → "design" stable (practically)

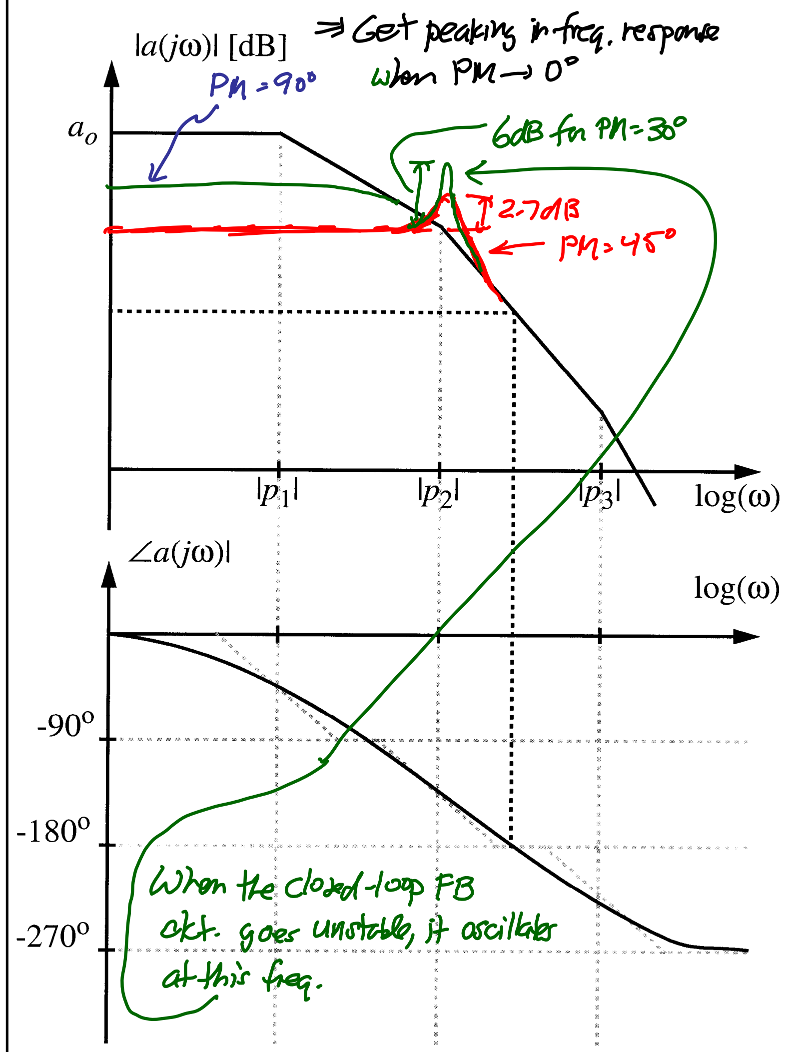
⇒ phase margin must be > 0° for theoretical stability

For Theoretical Stability: PM > 0°

⇒ for design safety, design for **Phase Margin ≥ 45°**

⇒ even safer (for settling time):

PM ≥ 60°

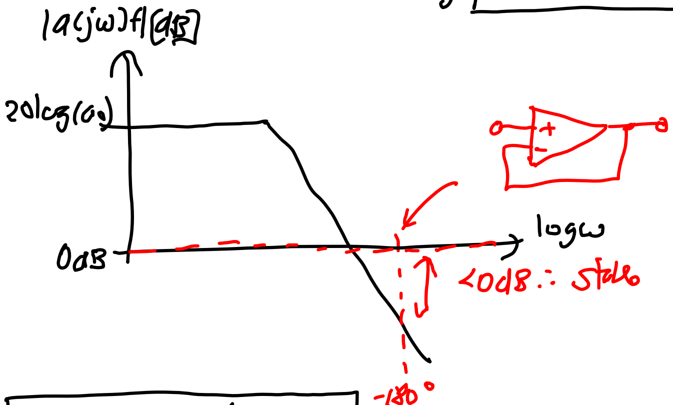


If you see peaking on a network analyzer > 30dB, check the signal on an oscilloscope → it may very well be oscillating!

Definition.

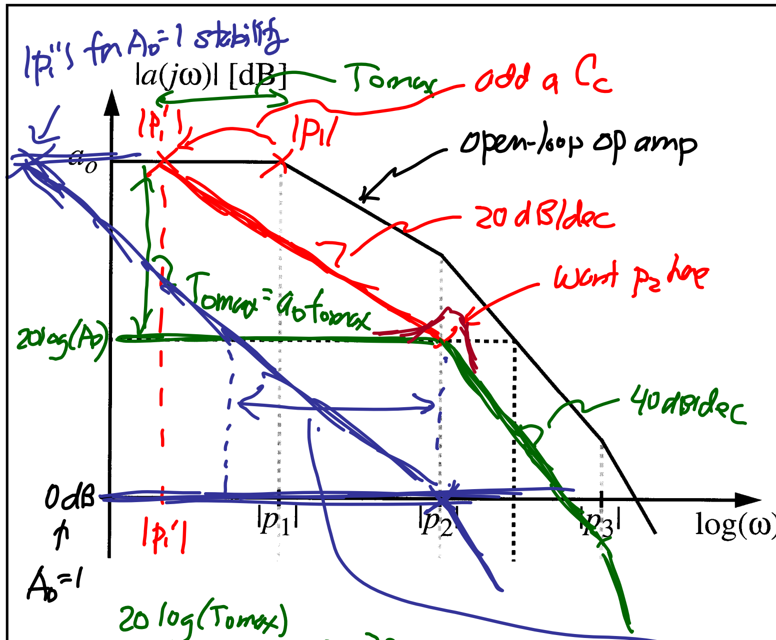
Gain Margin = $|a(j\omega f)|$ in dB @ freq. where $\angle a(j\omega f) = -180°$

↳ for stability: **Gain Margin < 0dB**



Compensation of Op Amps

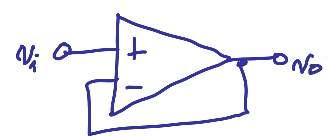
To compensate, make distance between p_1 & p_2 large enough to encompass the largest desired loop gain = $a_o f_{max}$ = T_{omax}



$$\frac{20\log(T_{omax})}{\log|p_1'| - \log|p_2|} = -20 \rightarrow \frac{|p_2|}{|p_1'|} = T_{omax}$$

$$|p_2| = |p_1'|\, T_{omax}$$

Unity Gain Stable Op Amp e.g., 741 (this stuff in blue)



$\rightarrow \left|\frac{v_o}{v_i}(s)\right| = 1 = A_o$

⇒ for this to be stable, $|p_1| \rightarrow |p_1''|$ so the $A_o = 1 = 0dB$ line intercepts to original $|a(s)|$ curve at $\omega = |p_2|$

⇒ for green A_o, sacrifice substantial bandwidth when compensating the op amp for unity gain

Two Ways to Compensate:

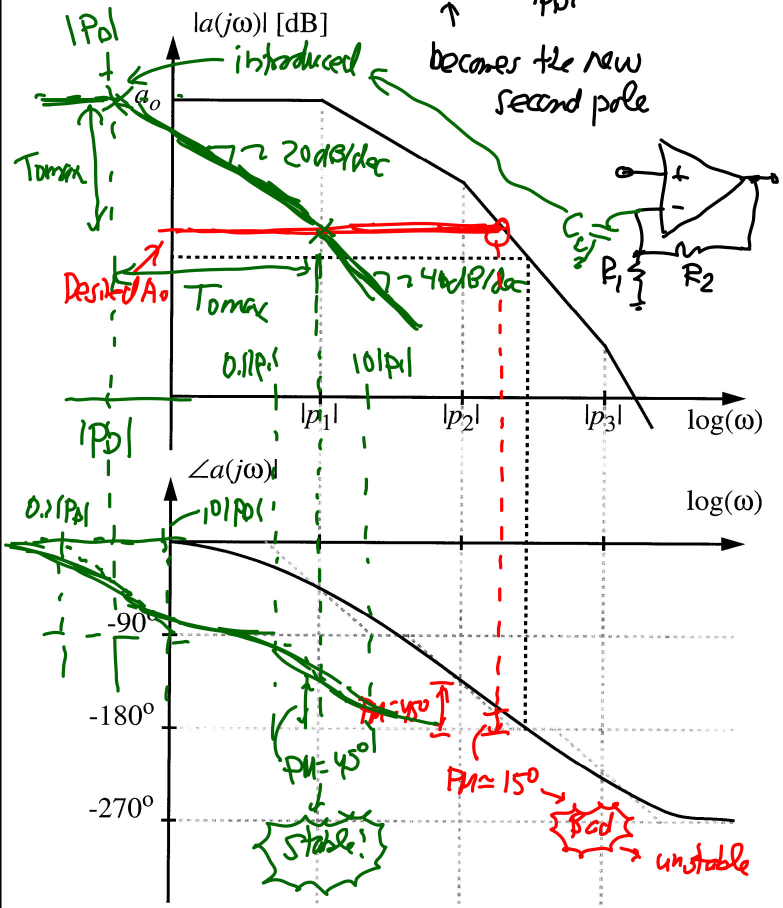
1. Narrowbanding
2. Pole Splitting

Narrowbanding

"D" = dominant

⇒ introduce a pole p_D so that there is sufficient separation between p_D & p_1 → $\frac{|p_1|}{|p_D|} \geq T_{omax}$

↑ becomes the new second pole



Remarks on Narrowbanding

1. Assumption: p_1, p_2, p_3 don't move when p_D is introduced (often not true, but the movement isn't that big)
2. Summarize: choose p_D such that $|T(j\omega)| = 0\,dB = 1$ @ p_1 (which becomes the "new 2nd most dominant pole") ↳ this gives PM=45° (for $|p_2| \gg |p_1|$ & $|p_3| \gg |p_2|$)
3. Why do this? Wouldn't it be much better to just move the original $|p_1|$ (i.e., pole-split) ↳ Do it when you have no other choice, e.g., when you have a packaged op amp & have access only to a few terminals, not the optimum compensation node.
4. $$|p_D| = \frac{|p_1|}{T_{omax}}$$ ← maximum expected/needed loop gain

Problem:

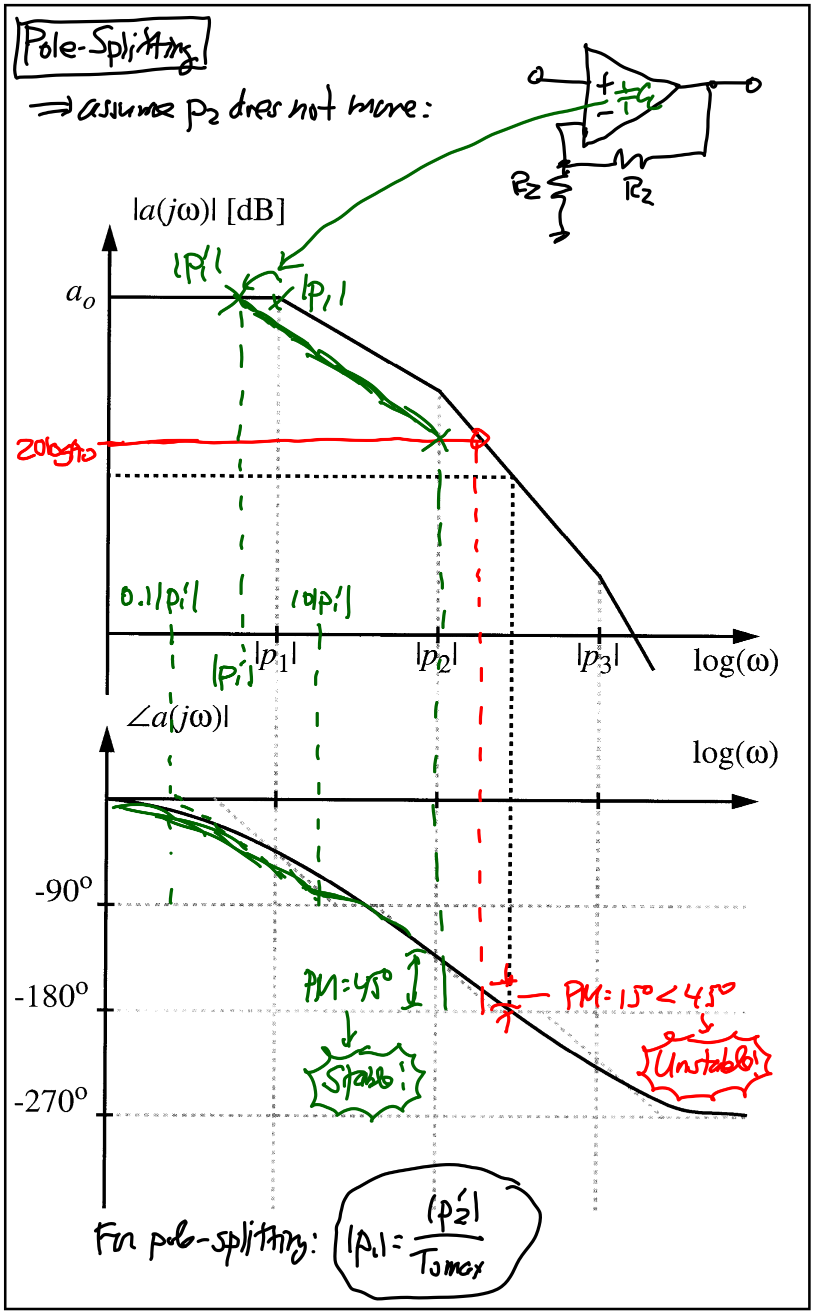
1. often, $|p_D| \ll |p_1|$ ∴ f_{-3dB} BW of the op amp will be very small
2. $\omega_{closed\,loop} = |p_1|$ which isn't that large

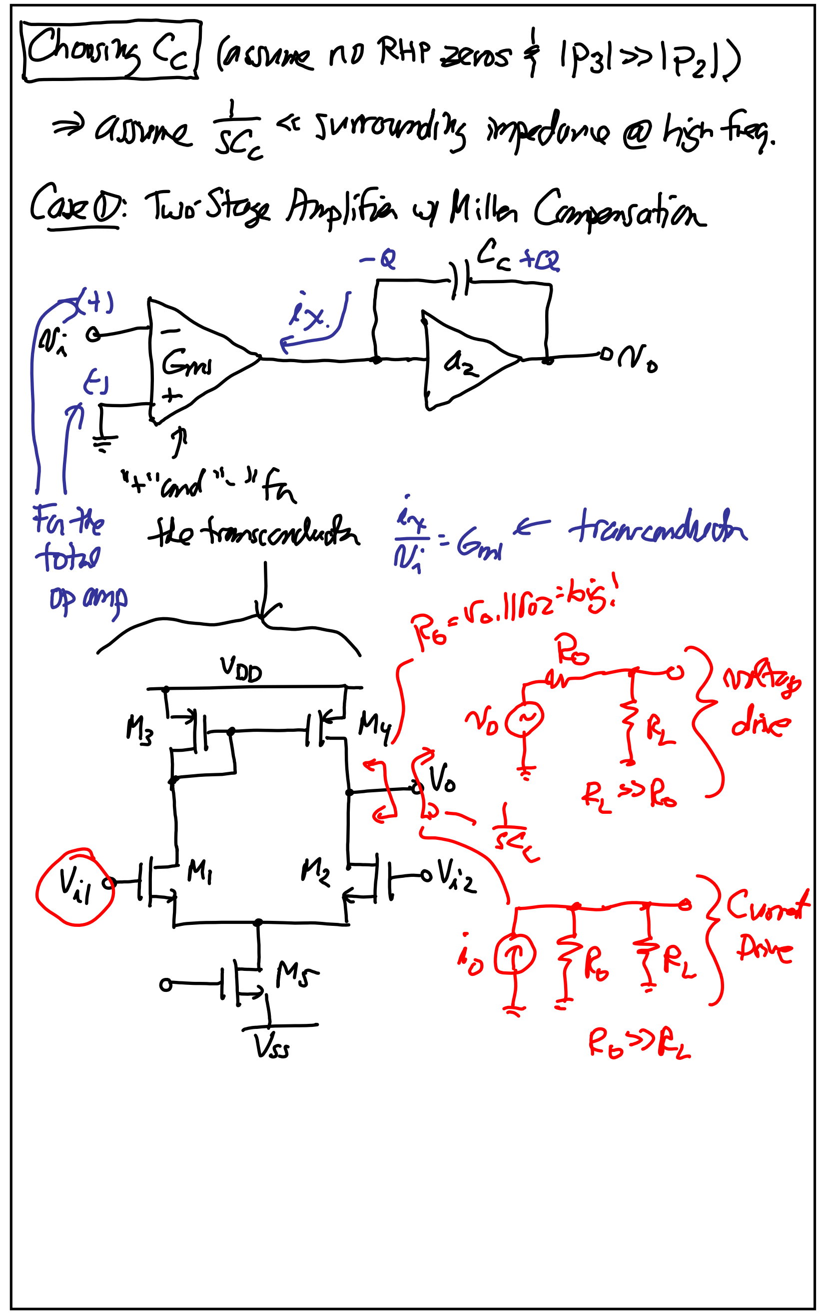
Solution: Pole-Splitting

↳ move $|p_1|$ down & either keep $|p_2|$ still ↳ or move $|p_2|$ up simultaneously

↳ after doing this:

1. $\omega_{-3dB} = |p_1'|$
2. $\omega_{closed\,loop} = |p_2'|$


Pole-Splitting
⇒ assume p2 does not move:
|a(jω)| [dB]
a_o
|p1'|
|p1|
20log f_o
0.1|p1'|
10|p1'|
|p1'|
|p1|
|p2|
|p3|
log(ω)
∠a(jω)|
log(ω)
-90°
-180°
-270°
PM=45°
Stable!
PM=15°<45°
Unstable!
For pole-splitting: |p1| = |p2'| / T_o max


Choosing Cc (assume no RHP zeros & |p3|>>|p2|)
⇒ assume 1/sCc << surrounding impedance @ high freq.
Case ①: Two-Stage Amplifier w/ Miller Compensation
-Q
Cc
+Q
(+)
vi
(-)
Gm1
ix
a2
vo
"+" and "-" for the total op amp
"+" and "-" for the transconductor
ix/vi = Gm1 ← transconductor
Ro = ro4||ro2 = big!
VDD
M3
M4
M1
M2
M5
Vi1
Vi2
Vo
VSS
1/sCc
Ro
vo
RL
RL>>Ro
voltage drive
io
Ro
RL
Ro>>RL
Current Drive

Lecture 20w: Choosing Cc

$$\left.\begin{aligned} i_x &= G_{m1} v_i \\ v_o &= \frac{i_x}{sC_c} \end{aligned}\right\} v_o = \frac{G_{m1}}{sC_c} v_i \rightarrow \boxed{\frac{v_o}{v_i}(s) = \frac{G_{m1}}{sC_c}}$$