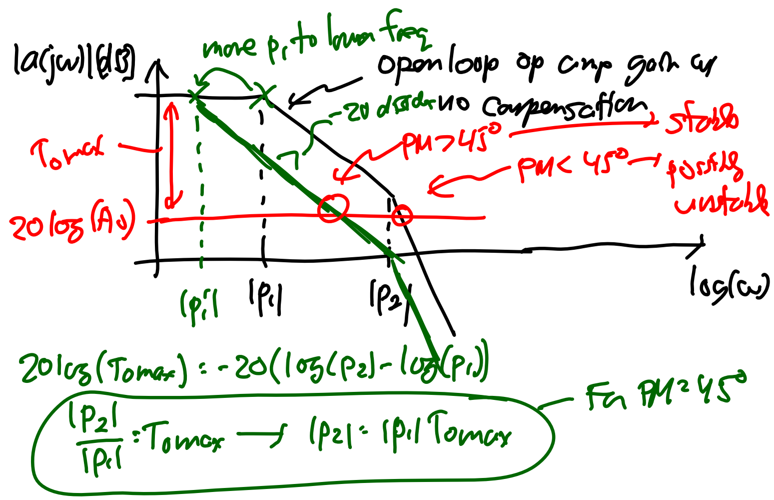
Lecture 20: Choosing Cc

- Announcements:
- Lab#2 due this week
- HW#9 online
- Lab#3 (Design Project) in progress
- Design Project Checkpoint:
  - Due Tuesday, Nov. 19, 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: Compensation



Two Ways to Compensate:

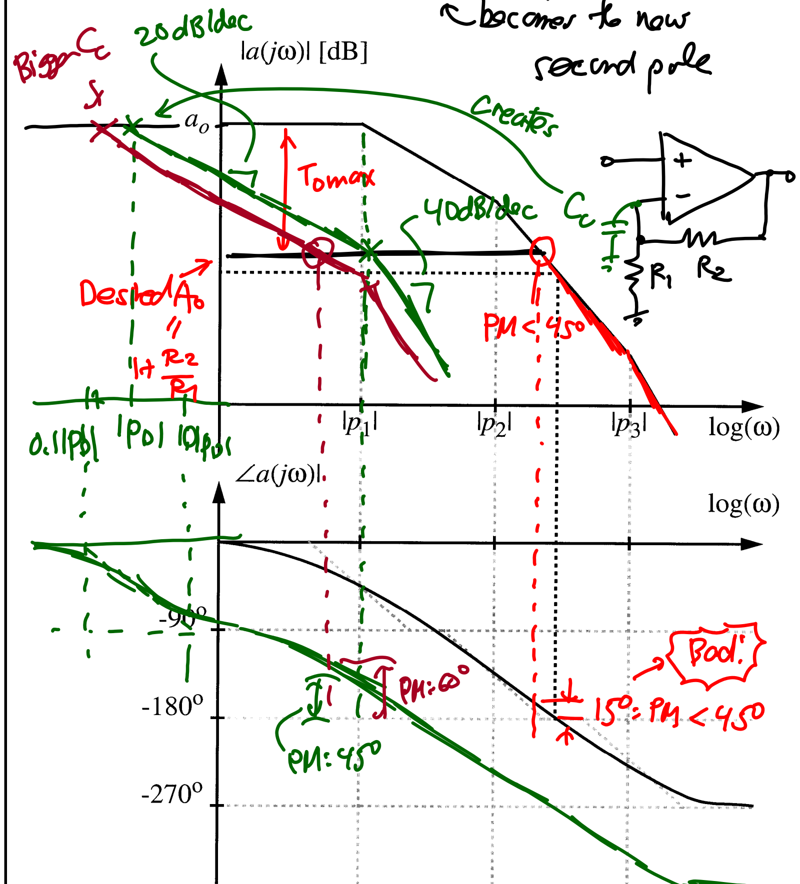
1. Narrowbanding
2. Pole Splitting

Narrowbanding

"D": dominant

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

↖ becomes the new second pole



Remarks on Narrowbanding

① Assumptions: p_1, p_2, p_3 don't move when p_D is introduced (often not true, but their 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 $|p_D| = \dfrac{|p_1|}{T_{0max}}$ ← maximum expected/needed loop gain

Problem:

① often, $|p_D| \ll |p_1|$ ∴ f_{-3dB} BW of the op amp will be very small

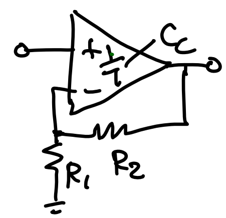
② $\omega_{closed\,loop} = |p_1|$ which isn't that large

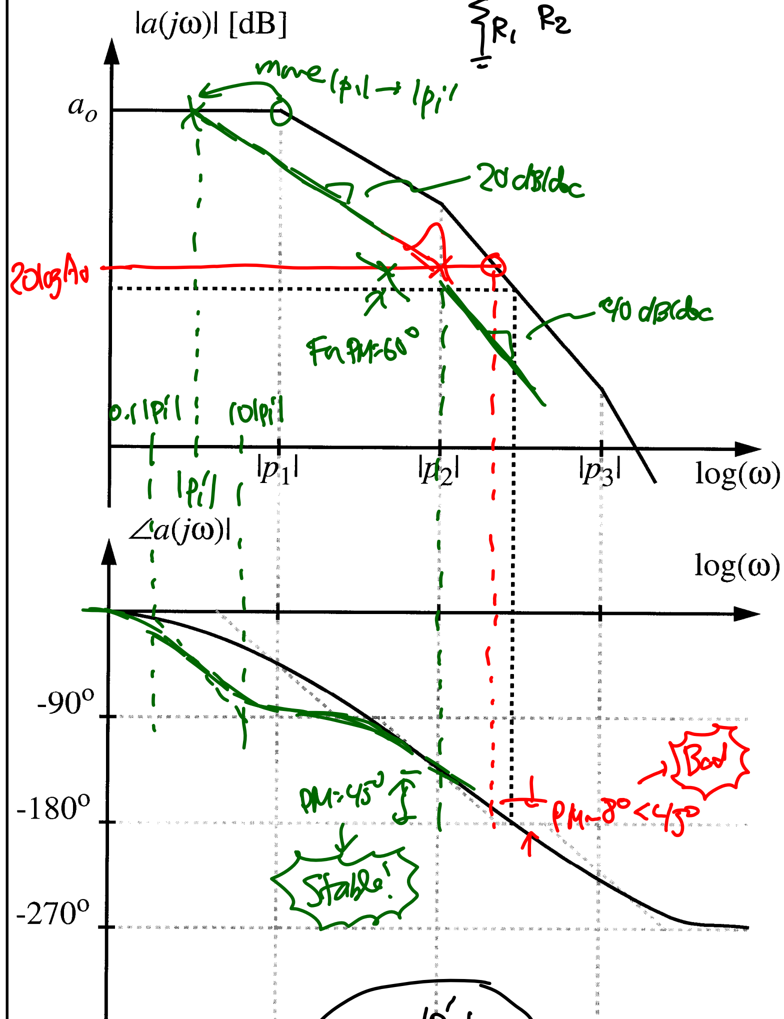
Solution: **Pole-Splitting**

↳ 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

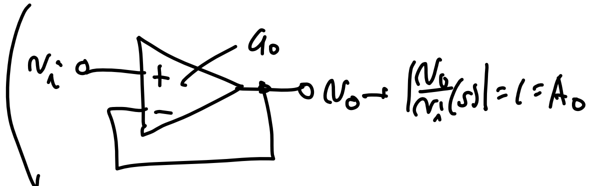
⇒ assume p_2 does not move



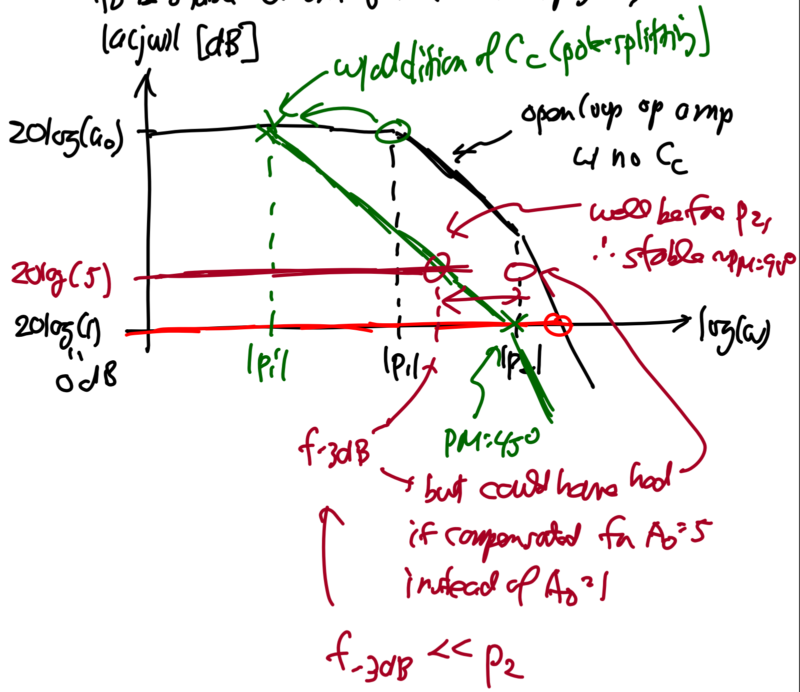


For Pole-Splitting: $|p_1'| = \dfrac{|p_2'|}{T_{0max}}$

Unity Gain Stable Op Amps → e.g., 741 op amp



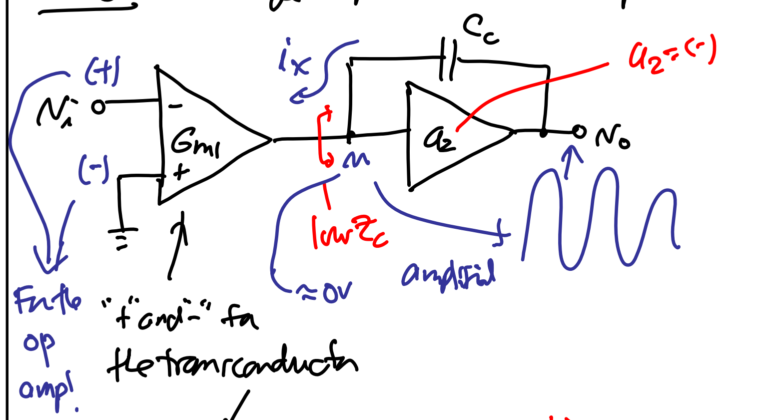
monolithically compensated w/ an internal C_c to be stable when $A_o = 1$ (closed loop gain)

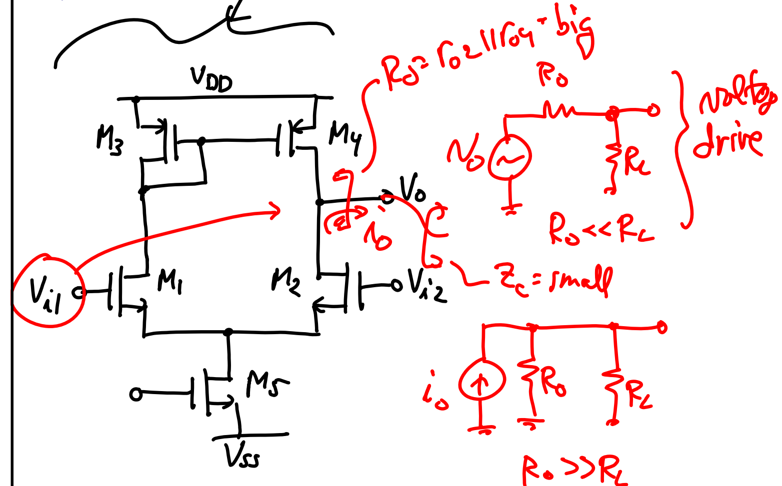


Choosing C_c (assume no RHP zeros & $|p_3| \gg |p_2|$)

→ assume $\frac{1}{sC_c} \ll$ surrounding impedance @ high freq.

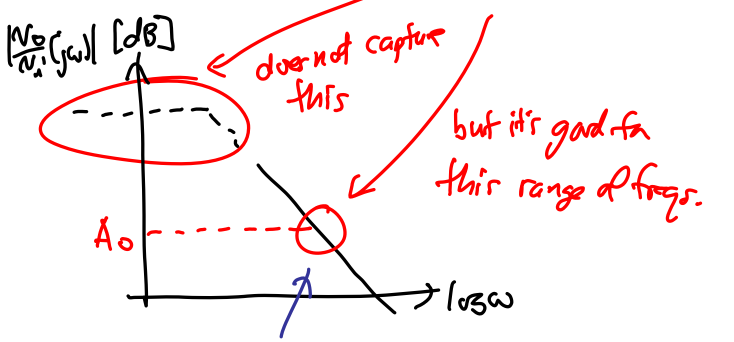
Case ①: Two Stage Amplifier w/ Miller Compensation





Lecture 20w: Choosing Cc

$i_x = G_{m1} v_i$, $v_o = \frac{i_x}{sC_c}$ } $v_o = \frac{G_{m1}}{sC_c} v_i \rightarrow \boxed{\frac{v_o}{v_i}(s) = \frac{G_{m1}}{sC_c}}$



Really care most about this freq. range, since PM determined out here

$|\frac{v_o}{v_i}(j\omega)| = \frac{G_{m1}}{\omega C_c}$ ⇒ this should equal A_o @ the freq. corresponding to the target phase margin (PM)

For PM=45°:

$\omega_{ulf} = \omega$ @ $|a(j\omega)f| = 1$

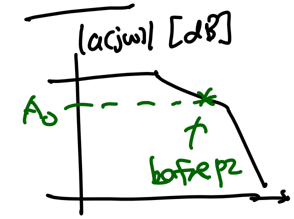
↳ "ulf" = "unity loop transmission"

↳ For PM=45° → $\omega_{ulf} = \omega_2$ ← freq. of the 2nd pole of the open loop $a(j\omega)f$ transfer function

$|\frac{v_o}{v_i}(j\omega_2)| = A_o = \frac{G_{m1}}{\omega_2 C_c} \rightarrow \boxed{C_c = \frac{G_{m1}}{\omega_2 A_o}}$

↑ PM=45° (provided $|p_3| >> |p_2|$)

For PM=60°:



$\omega_{ulf} = \frac{\omega_2}{1.73}$

↓

$|\frac{v_o}{v_i}(j\frac{\omega_2}{1.73})| = A_o = \frac{G_{m1}}{(\frac{\omega_2}{1.73})C_c}$

↙

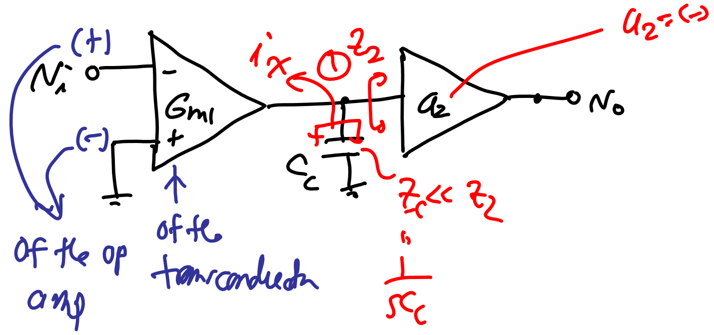
$\boxed{C_c = \frac{1.73 G_{m1}}{\omega_2 A_o}}$ ← For PM=60°

Remarks:

① Smaller A_o requires larger C_c.

② Dependence on G_{m1}

② Case: Two-Stage Amplifier w/ Shunt C_c



$$v_① = -\frac{G_{m1} v_i}{sC_c}, \quad v_o = a_2 v_①$$
$$\Rightarrow v_o = -\frac{G_{m1} a_2}{sC_c} v_i$$

$$\therefore \frac{v_o}{v_i}(s) = -\frac{G_{m1} a_2}{sC}$$

(−) ... (+)

Closed-loop gain A_o must again intersect this curve @ the right $\omega_{u\ell f}$ for the desired PM

For PM = 45°:

$$\left|\frac{v_o}{v_i}(j\omega_{u\ell f})\right| = A_o = \frac{G_{m1} a_2}{\omega_2 C_c} \rightarrow C_c = \frac{G_{m1} a_2}{\omega_2 A_o}$$

[For PM = 45°, $\omega_{u\ell f} = \omega_2$]

↑ For PM = 45°

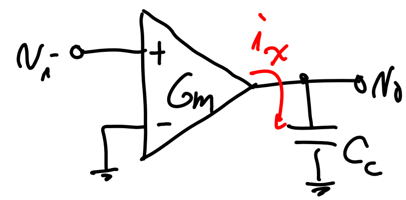
For PM = 60°:

$$C_c = \frac{1.73\, G_{m1} a_2}{\omega_2 A_o}$$

⇐ For PM = 60°

Case ③: Single-Stage Amplifier w/ Shunt C_c

e.g., telescopic cascode op amp



$$v_o = \frac{i_x}{sC_c}, \quad i_x = G_m v_i$$
$$\frac{v_o}{v_i}(s) = \frac{G_{m1}}{sC_c} \rightarrow \text{same as Case ①!}$$

(Miller Cap)

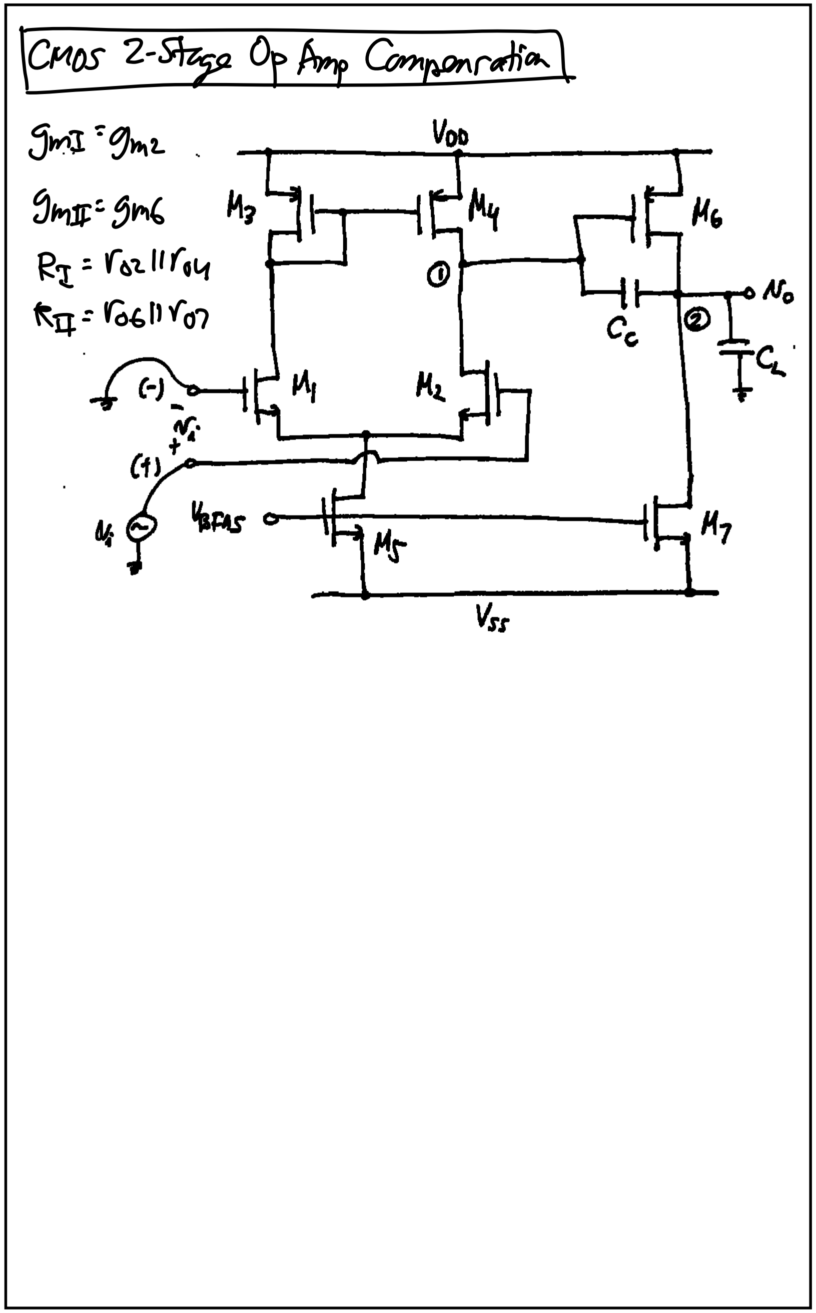
Thus:

$$C_c = \frac{G_{m1}}{\omega_2 A_o}$$

↑ For PM = 45°

$$C_c = \frac{1.73\, G_{m1}}{\omega_2 A_o}$$

↑ For PM = 60°


CMOS 2-Stage Op Amp Compensation
gmI = gm2
gmII = gm6
RI = ro2 || ro4
RII = ro6 || ro7
VDD
M3
M4
M6
M1
M2
M5
M7
Cc
CL
VBIAS
VSS
(-)
(+)