Lecture 21: Choosing Cc

Lab#3 models

- **Announcements**:
  - Lab#3: Note that models have been online
- **Lecture Topics**:
  - Review of Pole/Zero Plots
  - Compensation: Narrowbanding & Pole-Splitting
  - Choosing Cc
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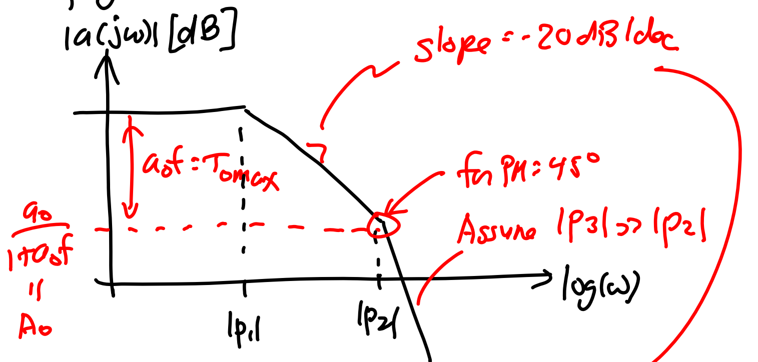
- **Last Time**: Compensation of Op Amps

To compensate, need the distance between p_1 & p_2 to be large enough to encompass the largest desired loop gain!



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

$\frac{|p_2|}{|p_1|} = T_{omax} \rightarrow |p_2| = |p_1| T_{omax}$

↑ Largest expected loop gain

↳ For stability w/ PM = 45°

Two Ways to Compensate:

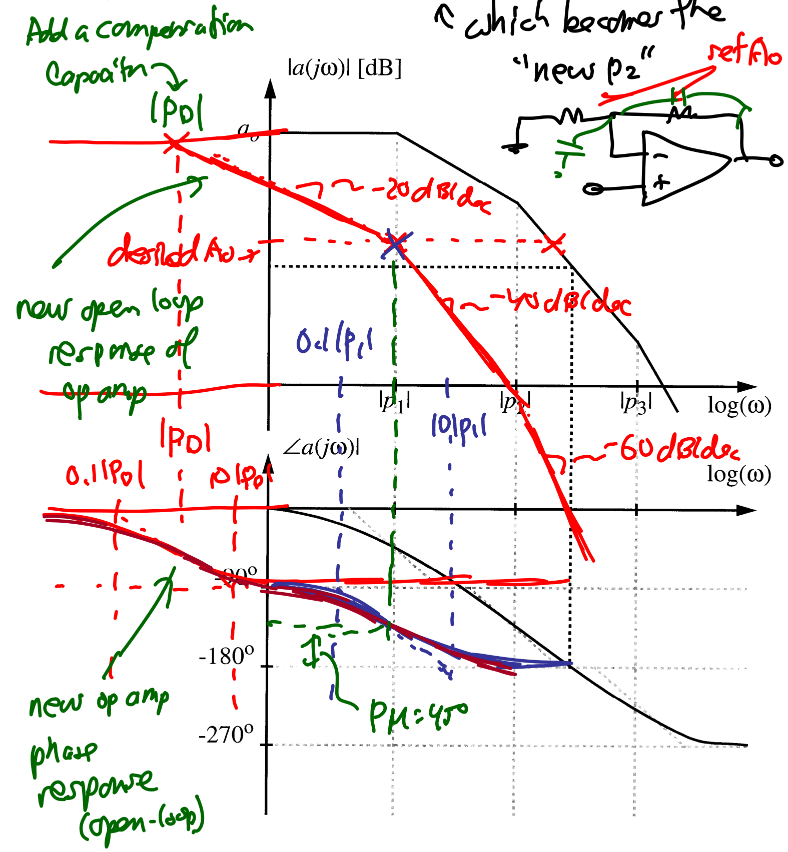
1. Narrowbanding
2. Pole-Splitting

Narrowbanding

→ introduce a pole p_D so that is sufficient separation between p_D & p_1

dominant: "D"

↑ which becomes the "new p_2"



Remarks on Narrowbanding

① Assumption: p_1, p_2, p_3 don't move when p_D is introduced (often not true, but that movement isn't that big)

② Summarize: choose p_D such that $|T(j\omega)| = 0\text{dB} = 1$ @ p_1 (which becomes the "new 2^{nd} most dominant pole")
↳ this gives PM=45° (for $|p_2| >> |p_1|$ & $|p_3| >> |p_2|$)

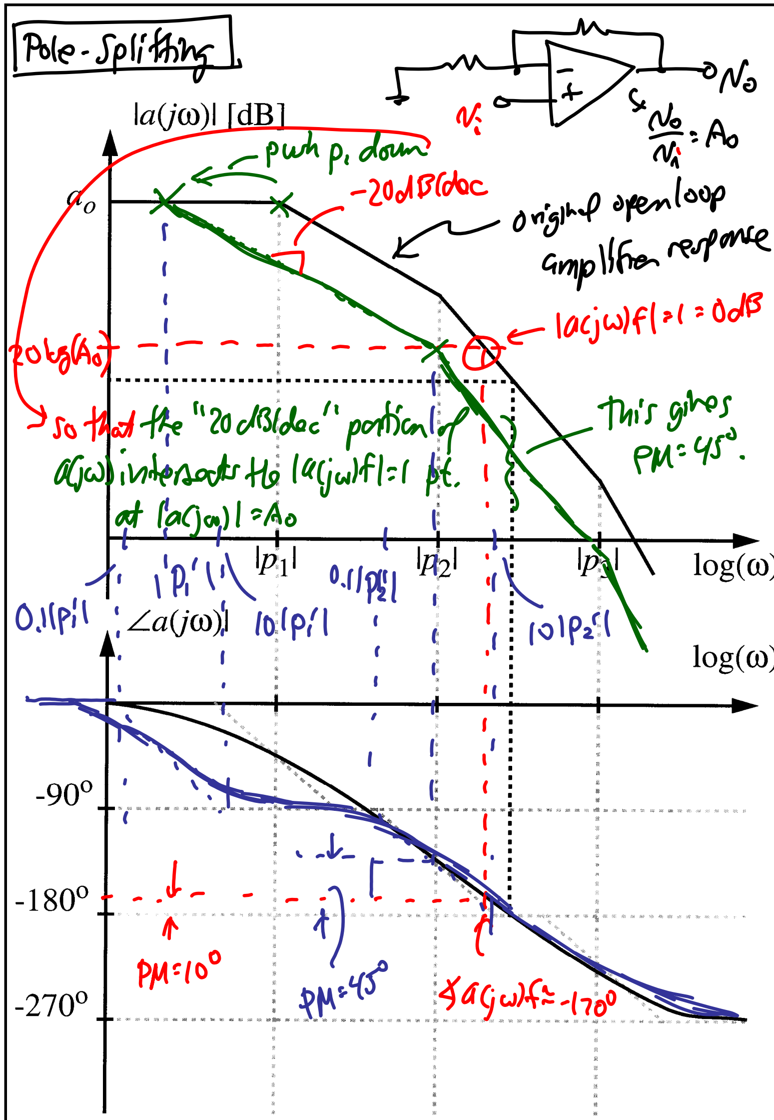
③ Why do this? Wouldn't it be much better to just move the original $|p_1|$ (i.e., pole-split)
↳ Do it when you have no other choice, e.g., when you have a packaged op amp & have access only to a few terminals, not the optimum compensation node.

④ $\boxed{|p_D| = \frac{|p_1|}{T_{0max}}}$ ← maximum expected/needed loop gain

Problem:
① often, $|p_D| << |p_1|$ ∴ 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

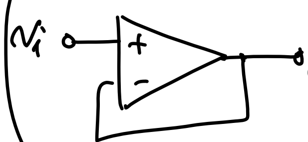


Assumption (for above): p_2 doesn't move

Remarks for Pole-Splitting

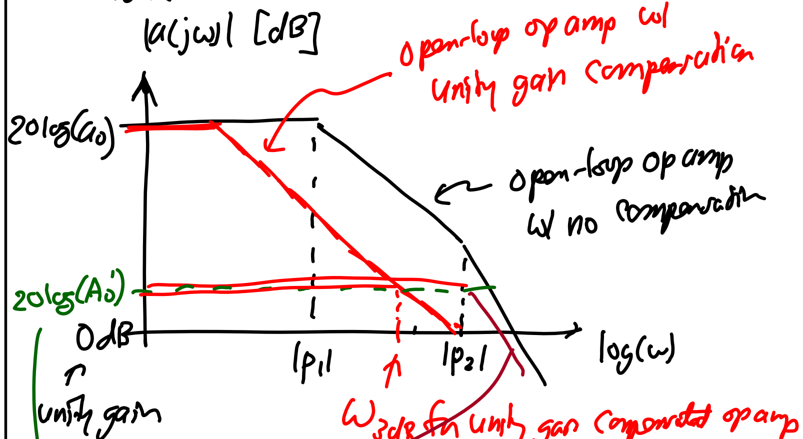
① For pole-splitting, $\boxed{|p_1| = \frac{|p_2|}{T_{omax}}}$

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



→ $\frac{v_o}{v_i}(s) = 1 = A_o$

monolithically compensated w/ an internal C_c to be stable when $A_o = 1$



What if this was the lowest gain you needed > 1?

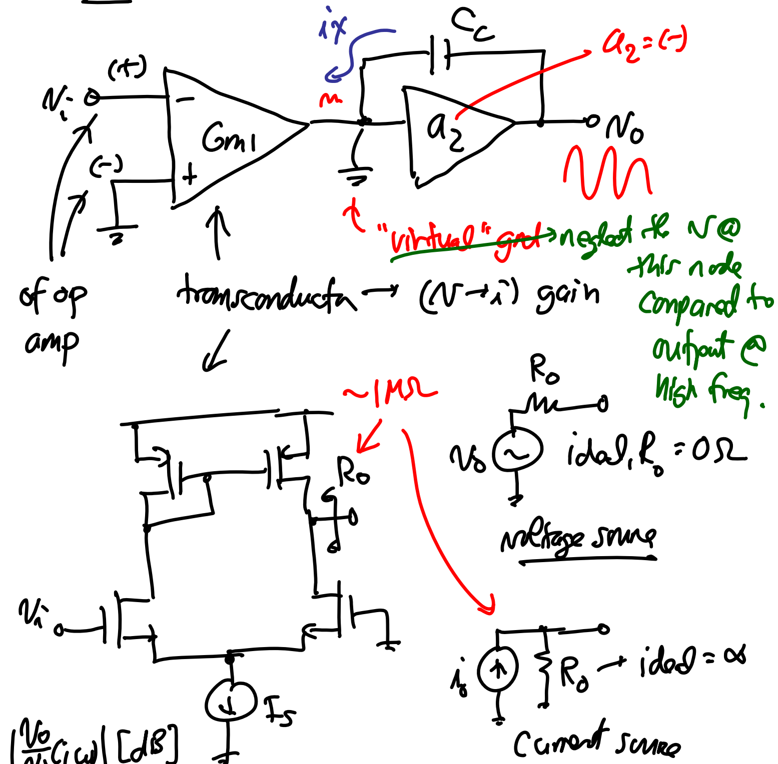
Could have done this! → compensate for the A_o you need → get higher BW! (vs. unity gain comp.)

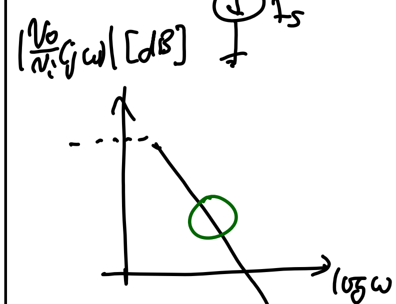
Choosing C_c

(assume no RHP zeros & $|p_3| >> |p_2|$)

⇒ assume $\frac{1}{sC_c}$ << surrounding impedance @ high freq.

① Case: Two-Stage Amplifier, Miller compensation

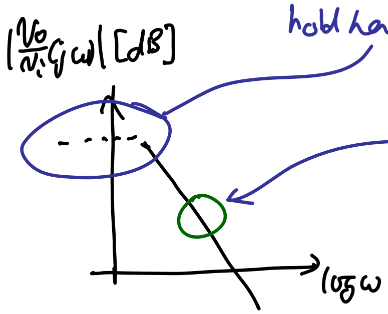




$$\left.\begin{array}{l} v_o = \dfrac{i_x}{sC_c} \\ i_x = G_{m1} v_i \end{array}\right\} \; v_o = \frac{G_{m1}}{sC_c} v_i \rightarrow \boxed{\frac{v_o}{v_i}(s) = \frac{G_{m1}}{sC_c}}$$

does not hold here

but does hold here



This is all that matters for Phase Margin determination!

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

For PM = 45°:

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

"ult" = "unity $\underbrace{\text{loop transmission}}_{|a(j\omega)f| = 1}$"

For PM = 45° → $\omega_{ult} = \omega_2$ ← freq. of the 2nd pole in the $a(j\omega)$ transfer fcn.

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

For PM = 45° (provided $|p_3| >> |p_2|$)

For PM = 60°:

$$\omega_{ult} = \frac{\omega_2}{1.73} \rightarrow \left|\frac{v_o}{v_i}\left(j\frac{\omega_2}{1.73}\right)\right| = A_o = \frac{G_{m1}}{\left(\frac{\omega_2}{1.73}\right) C_c}$$

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

② Case: Two Stage Amplifier, Shunt C_c Compensation