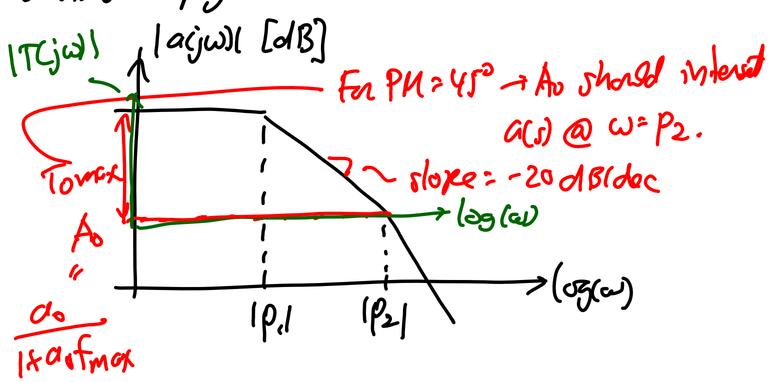
Lecture 21: Choosing Cc

- **Announcements:**
  - Your project cannot use ideal current sources; all you have is Vdd and Vss
  - You need to design your own current sources if you need them
  - You should also try to minimize area, as usual (e.g., a design using an enormous resistor will not be as good as one using a much smaller one, or no resistor at all)
- **Lecture Topics:**
  - Narrowbanding
  - Pole-Splitting
  - Choosing Cc
- ------------------------------------
- **Last Time:**

Compensation of Op Amps

To compensate need the distance between p_1 & p_2 to be large enough to accommodate 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 desired loop gain

→ provided $|p_3| \gg |p_2|$ ← to insure stability!

Need for stability w/ PM = 45° @ all desired closed loop gains

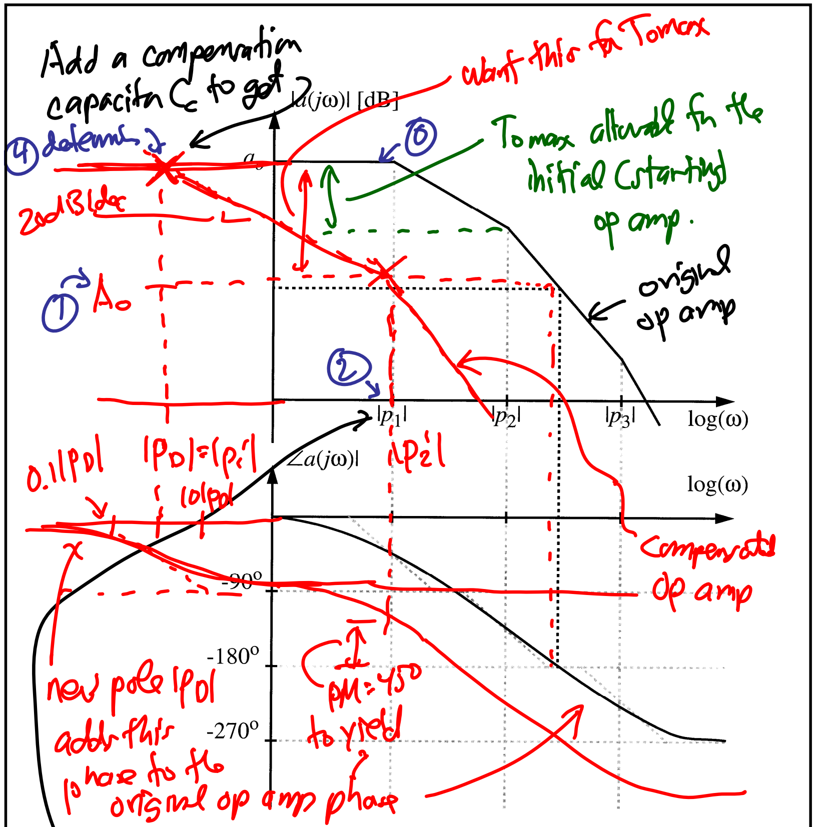
→ Basically, there is a minimum separation needed betw. p_1 & p_2!

Two Ways to Compensate:

1. Narrowbanding
2. Pole-Splitting

Narrowbanding

⇒ introduce a pole p_D (dominant pole) so that there is sufficient separation between p_1 & p_2



Design so that $|p_1| =$ "the new $|p_2|$" coincides w/ the pt. on the "-20dB/dec curve" where $|a(j\omega_2)| = A_o$

Things you need to know in order → blue

Remarks on Narrowbanding

① Assumptions: 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 2nd most dominant pole) → PM = 45° (original (for $|p_2| >> |p_1|$))

③ Why do this? Isn't pole-splitting much better?
↓
Do it when you have no other choice, e.g., when you have a packaged op amp & have access to only a few terminals (not to the optimum compensation node)

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

Problem:

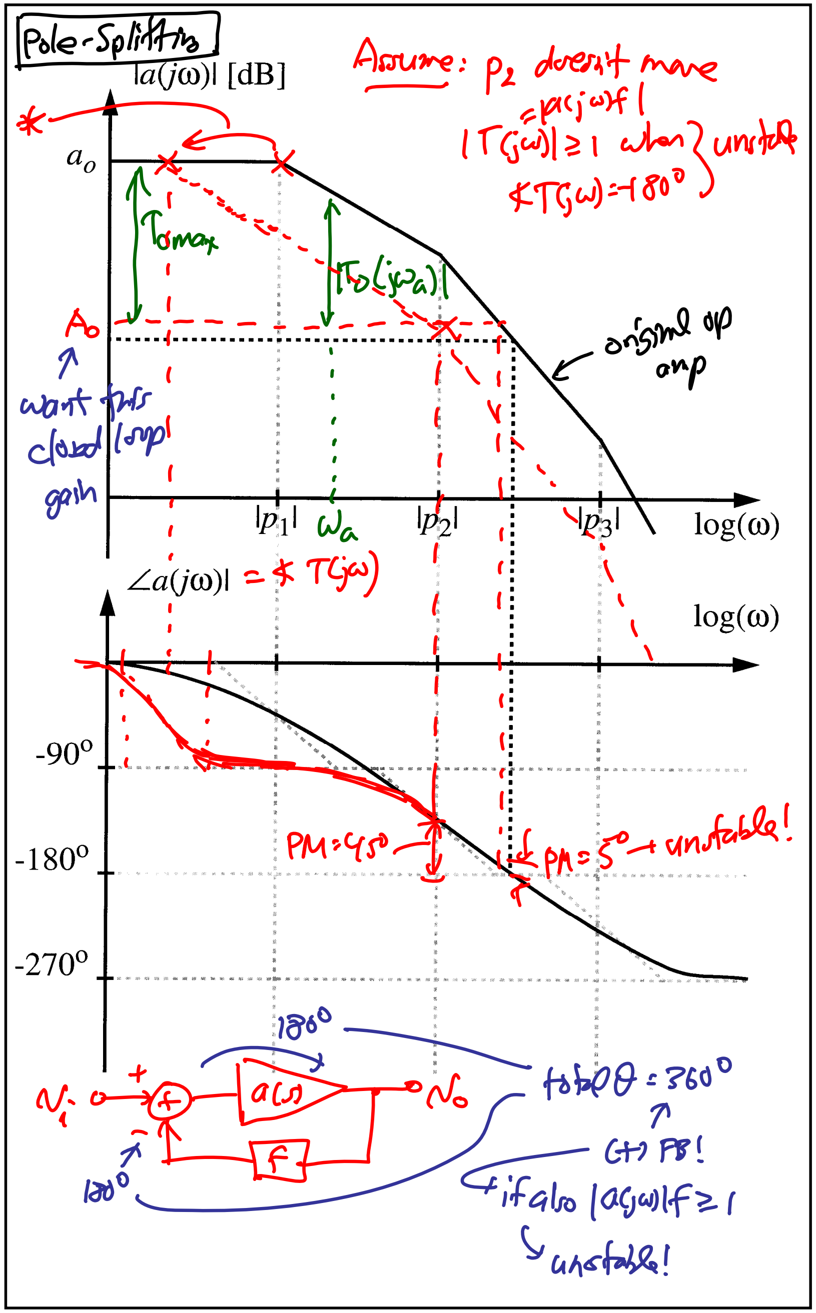
① often, $|p_D| << |p_1|$ ∴ f_{-3dB} BW of the op amp will be very small

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 $\omega_{closed\,loop} = |p_2'|$



* push p_1 down so that the "20 dB/dec" portion of $a(j\omega)$ intersects the "$|T(j\omega)| = 1$ pt." at $|a(j\omega)| = A_o$ → gives 45° phase margin

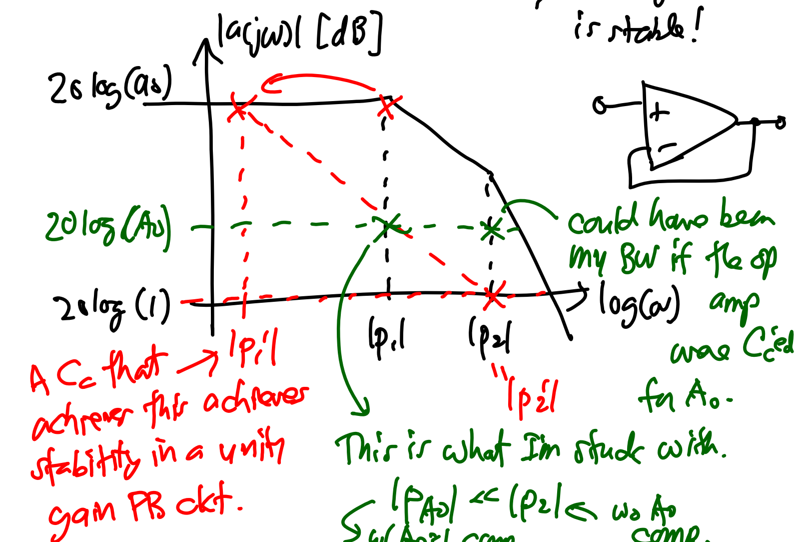
Remark for Pole-Splitting:

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

Unity Gain Stable Op Amps

↳ e.g., 741 op amp

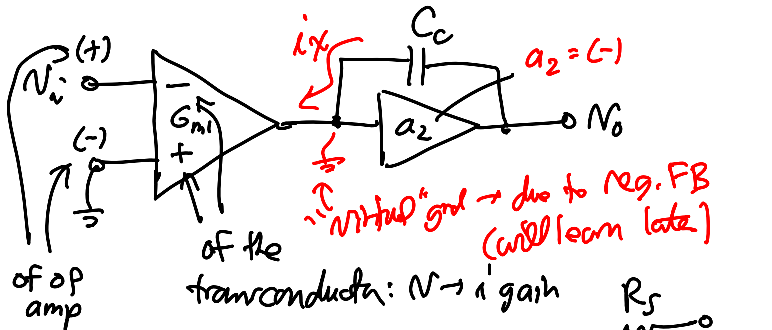
It's compensated monolithically so that even a unity FB ckt. is stable → i.e., a voltage follower is stable!

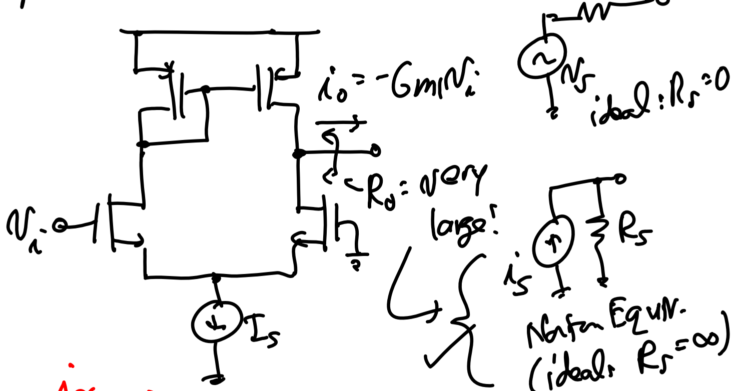


Choosing C_c (assume no RHP zeros & $|p_3| \gg |p_2|$)

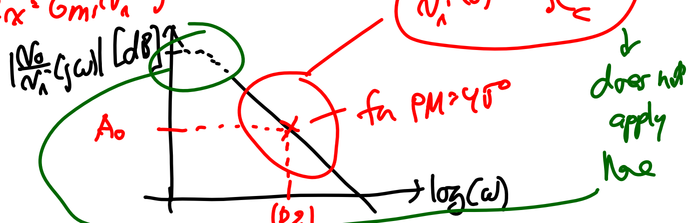
⇒ assume $\frac{1}{sC_c} \ll$ (surrounding impedance) @ high freq.

① Case: Two-Stage Amplifier, Miller Compensation





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



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

For PM = 45°:

$\omega_{ult} = \omega$ @ $|T(j\omega)| = 1$ → "unity loop transmission"

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

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

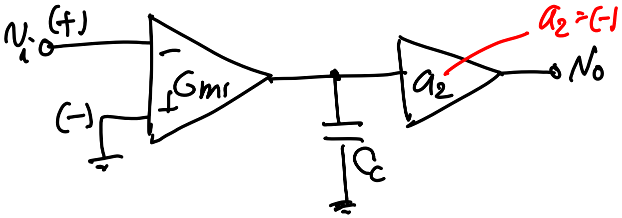
$$\boxed{C_c = \frac{G_{m1}}{\omega_2 A_o}}$$ ← For PM = 45° (provided high-order poles are far away, i.e., $|p_3| \gg |p_2|$)

PM = 60°:

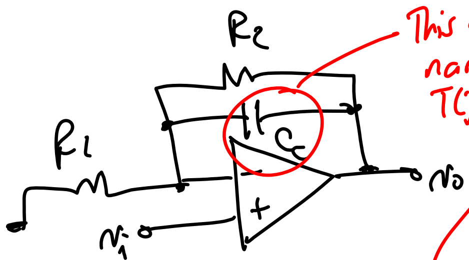
$\omega_{ult} = \frac{\omega_2}{1.73}$ → $\left|\frac{v_o}{v_i}\left(j\frac{\omega_2}{1.73}\right)\right| = A_o = \frac{G_{m1}}{\left(\frac{\omega_2}{1.73}\right) C_c}$

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

② Case: Two-Stage Amplifier, Shunt C_c Compensation



After Lecture Discussion (Narrowbanding)



This external C_c narrowbands the $T(j\omega)$ → introduces a p_D that was not originally in the op amp

Derived from $f(s)$, not $a(s)$!