Lecture 17: Compensation & Slew Rate

- **Announcements**:
  - Video and sound of the make-up lecture are available online; the pdf of the notes were emailed last Friday
  - 1st 5 min. of video is corrupt → just advance through this to get to good stuff
  - Lab#2 will be due the week AFTER Spring Break; this should give ample time to write up a good lab report
  - Midterm Exam, Thursday, March 17, in 213 Wheeler (our regular room), during the regular class period
- ------------------------------------
- **Lecture Topics**:
  - High Gain Op Amps (cont.)
  - Lab#2 Compensation (a 1st pass)
  - Slew Rate
- ------------------------------------
- **Last Time**:
- Covered the telescopic op amp

Problems/Issues:

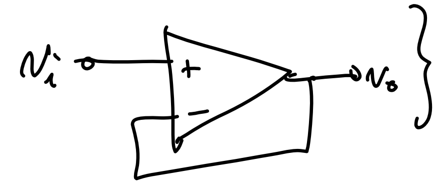
① Limited output swing:

$V_{omax} = V_{DD} - |V_{t7}| - |V_{ov7}| - |V_{t5}| - |V_{ov5}| + |V_{t6}| + |V_{ov6}| - |V_{ov6}|$

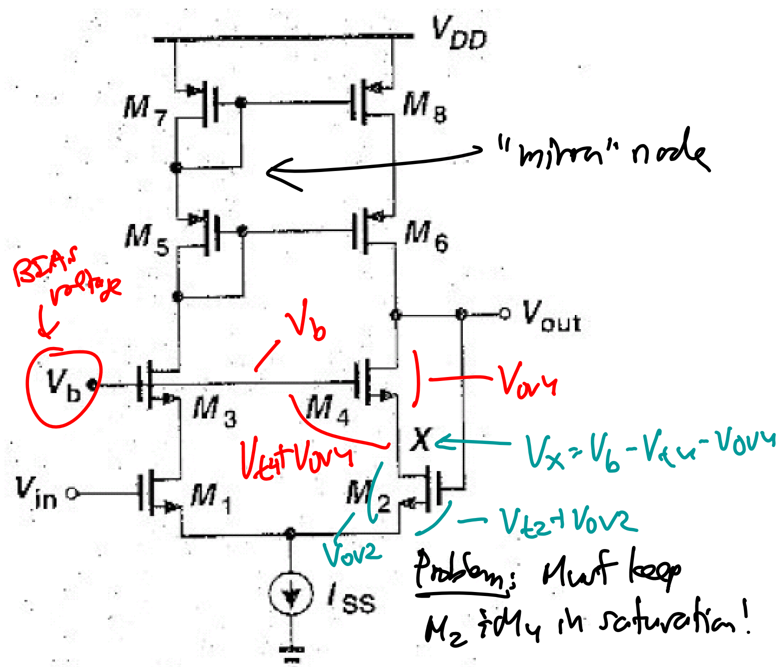
$V_{omin} = V_{ovss} + V_{ov2} + V_{o4}$ ← from tail current source

$V_{swing} = V_{omax} - V_{omin}$ → Swing not enough! → Problem!

Problem ②: Difficult to tie the input to the output?



unity gain buffer ← extremely useful!

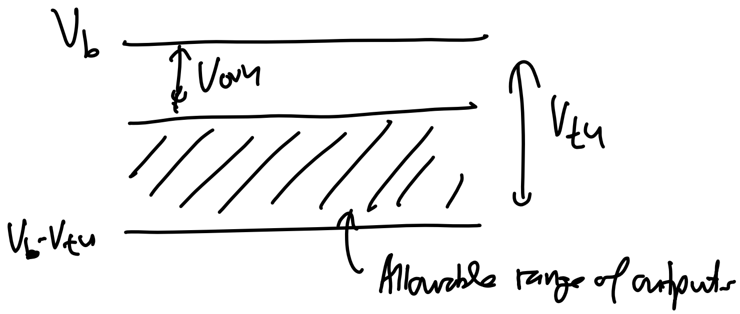


Problem: Must keep M_2 & M_4 in saturation!

M_4: Need $V_{out} \geq V_b - V_{t4} - V_{ov4} + V_{ov4}$ ∴ $V_{out} \geq V_b - V_{t4}$

M_2: Need $V_{out} \leq V_x - V_{ov2} + V_{t2} + V_{ov2}$

$V_{out} \leq V_b - V_{t4} - V_{ov4} + V_{t2} \approx V_b - V_{ov4}$ ($V_{t2} \approx V_{t4}$)

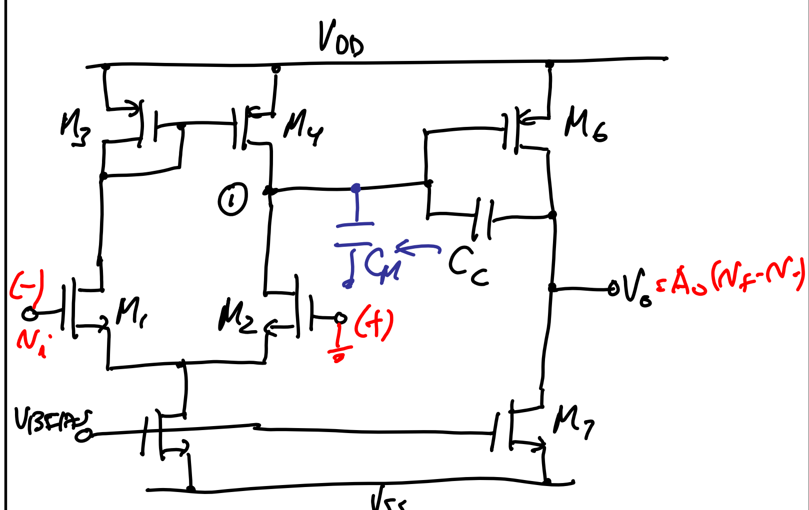


Problem ②:

Low freq. non-dominant pole associated w/ the "mirror" node → will hurt stability in feedback ckts!

→ **Soln:** use a fully differential, fully-balanced op amp

Classic 2-Stage Op Amp



Gain:

1st stage: $A_{v1} = \frac{v_①}{v_i} = g_{m1}(r_{o2} \| r_{o4})$

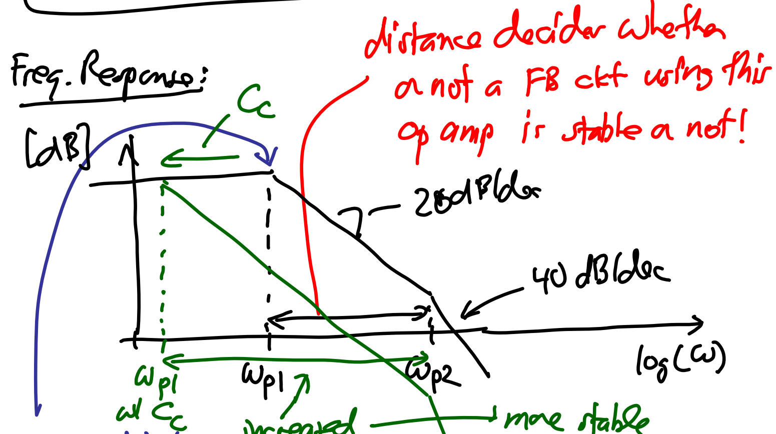
2nd stage: $A_{v2} = \frac{v_o}{v_①} = -g_{m6}(r_{o6} \| r_{o7})$

$$A_v = A_{v1} A_{v2} = -g_{m2}(r_{o2} \| r_{o4}) g_{m6} (r_{o6} \| r_{o7})$$

Output Swing:

$$V_{o,swing} = V_{DD} - V_{SS} - |V_{ov6}| - V_{ov7}$$

Freq. Response:



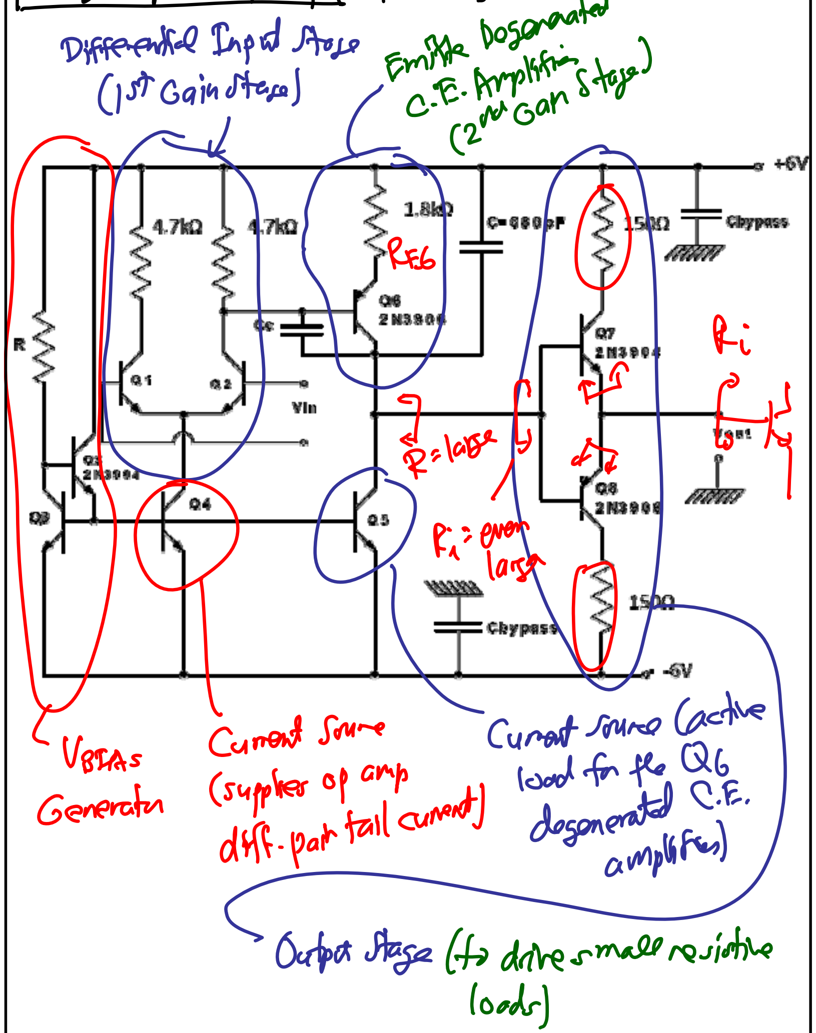
Dominant Pole:

$$\omega_H = \frac{1}{(r_{o2} \| r_{o4})(1 + g_{m6}(r_{o6} \| r_{o7}))C_c} = \omega_{p1}$$

C_M

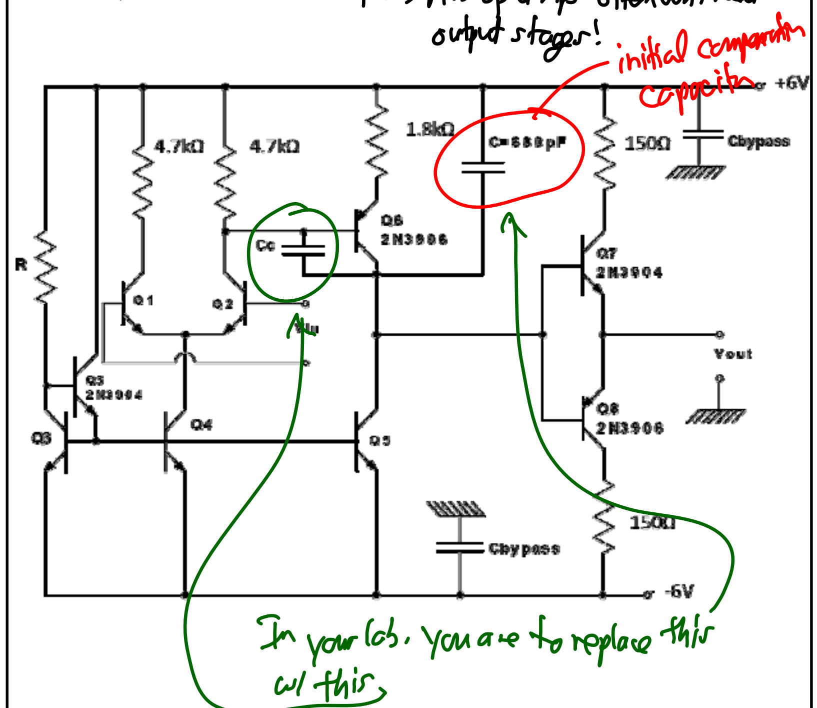
Assume C_c >> device C's

2-Stage Bipolar Op Amp (your lab)



Remarks.

1. You analyze this in Lab#2.
2. Usually, the resistively-loaded diff. pair is replaced w/ an active current mirror load for more gain.
3. R_{E6} raises the input R of Q_6 (of the 2nd gain stage), plus helps w/ biasing.
4. Same comment as 3 for the output stage.
5. Output stage needed when driving a resistive load
   - often the case for bipolar
   - not often the case for MOS, where a capacitive load C_L is often more relevant → MOS op amps often don't need output stages!

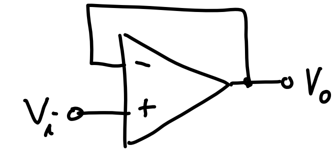


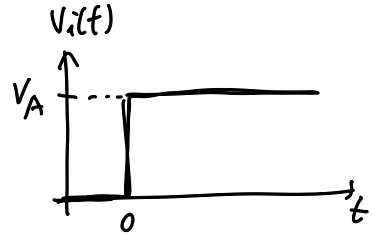
In your lab, simply choose C_c so that it generates the same ω_{p1} as the original $C = 680$ pF.

(again, all for stability reasons)

& all related to keeping ω_{p1} & ω_{p2} as far apart as needed for stability.

Slew Rate





Using Laplace Xform Theory:

$$\frac{V_o}{V_i}(s) = \frac{1}{1+\frac{s}{\omega_1}} = \frac{1}{1+s\tau_1}$$

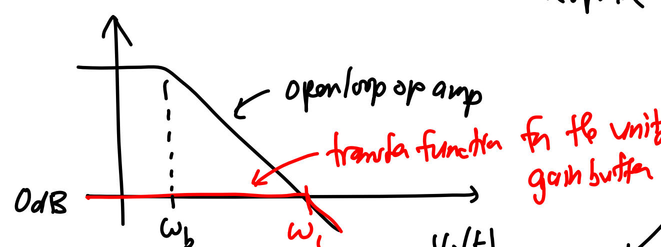
↖ single (dominant) pole

$$V_i(s) = \frac{V_A}{s}$$

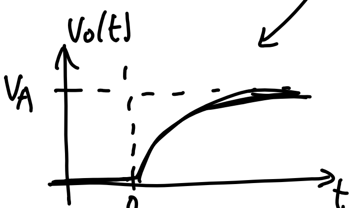
$$V_o(s) = \frac{V_A}{s(1+s\tau_1)} = \frac{V_A}{s} - \frac{V_A}{s+\frac{1}{\tau_1}}$$

⇕ Inverse Laplace Xform

$$V_o(t) = V_A\left(1-e^{-t/\tau_1}\right) \leftarrow \text{expected response}$$

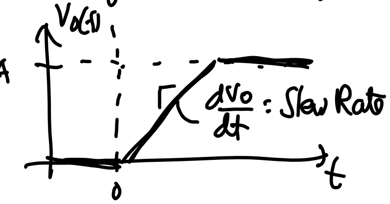


Expectation

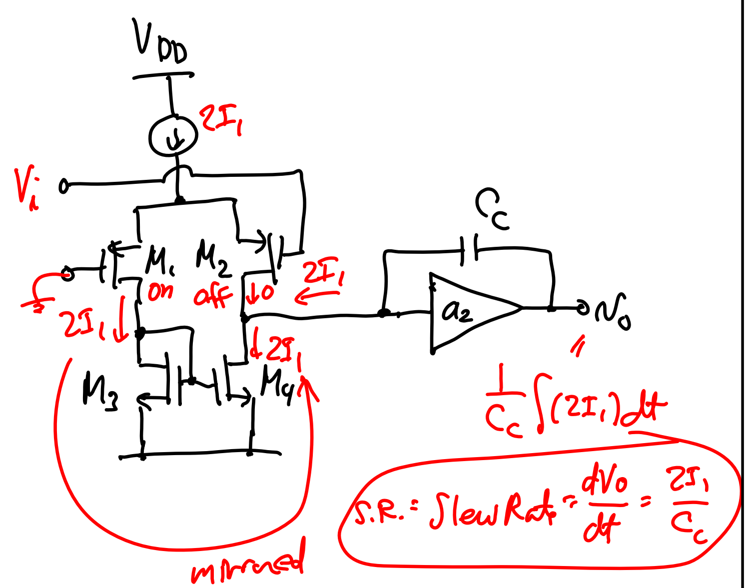


Actually:

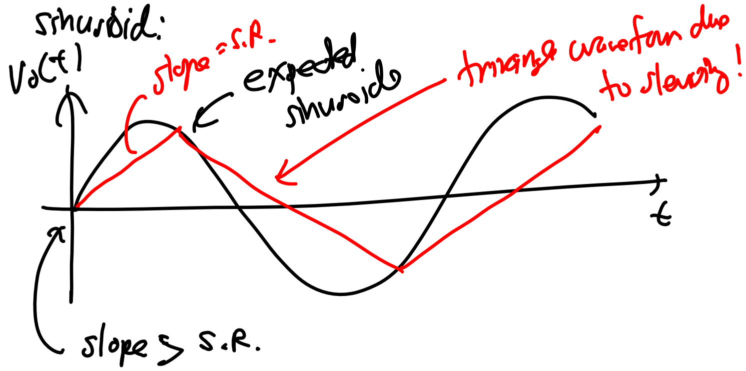
Why this slow rise?



Recall: 1st or 2nd stage of an op amp cannot source enough current to mimic the slope (or speed) of a fast rising signal



If apply a very fast (i.e., high freq., large amplitude) sinusoid:



If compensate w C_c: