Lecture 16: High Gain Op Amps II

- **Announcements**:
  - HW#7 due Monday, Oct. 26, at 8 a.m.
  - 240A students should be working on HW#1A, too, due Nov. 2, but let's change this, since Lab#2 is also due that day
  - New HW#1A deadline: Friday, Nov. 6
  - I will be traveling again this Friday, returning next Monday – should be back in time for office hours, depending on flight arrival time
  - Midterm will be on the date specified in your syllabus: Thursday, Oct. 29, 6-8 p.m. in 141 McCone
  - Go through midterm information sheet
- **Lecture Topics**:
  - Telescopic Op Amp in Feedback
  - Lab#2 Hints
  - Compensation (a 1st pass)
  - Slew Rate (a 1st pass)
- -------------------------------------
- **Last Time**:
- Telescopic op amps

over

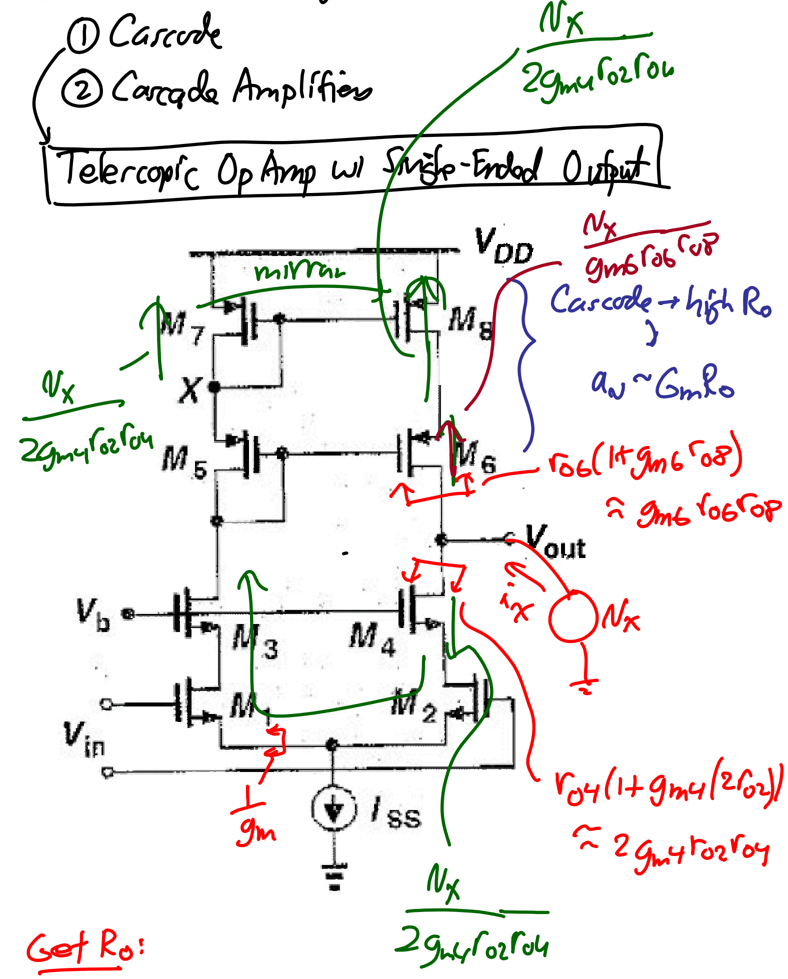
High Gain Op Amps

How can we increase gain?

① Cascode

② Cascade Amplifiers

Telescopic Op Amp w/ Single-Ended Output



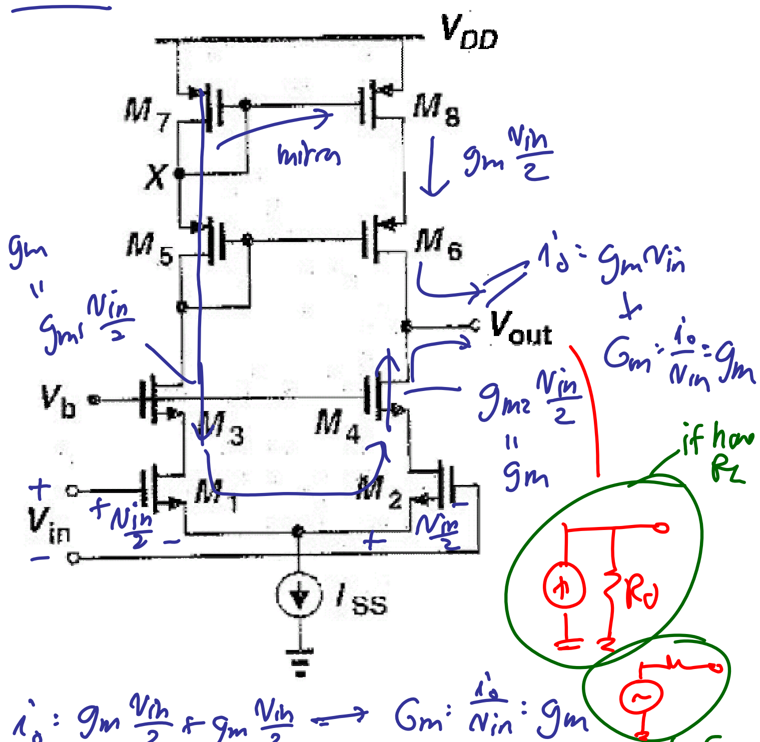
Get R_o:

$$i_x = \frac{v_x}{g_{m6} r_{o6} r_{o8}} + \frac{v_x}{2 g_{m4} r_{o2} r_{o4}} + \frac{v_x}{2 g_{m4} r_{o2} r_{o4}}$$

$R_o = \frac{v_x}{i_x} = (g_{m6} r_{o6} r_{o8}) \| (g_{m4} r_{o2} r_{o4})$

$= (g_{mp} r_{op}^2) \| (g_{mN} r_{oN}^2)$

Get G_m:



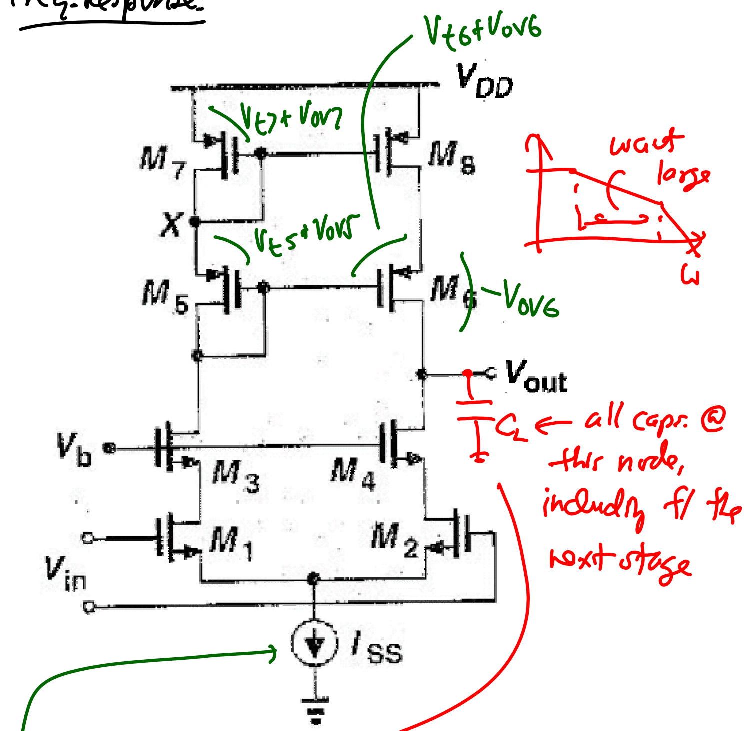
$i_o = g_m \frac{v_{in}}{2} + g_m \frac{v_{in}}{2} \rightarrow G_m = \frac{i_o}{v_{in}} = g_m$

∴ Gain: $A_v = g_{mN}\left[(g_{mN} r_{oN}^2) \| (g_{mp} r_{op}^2)\right]$

huge R! huge R!

Gain will be BIG!

Freq. Response:



This contributes the dominant pole since R_o = huge:

$\omega_H = \frac{1}{R_o C_L}$

Problems/Issues:

① Limited output swing:

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

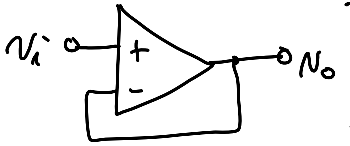
Problem: Not so large!

$V_{omin} = V_{ovSS} + V_{ov2} + V_{ov4}$

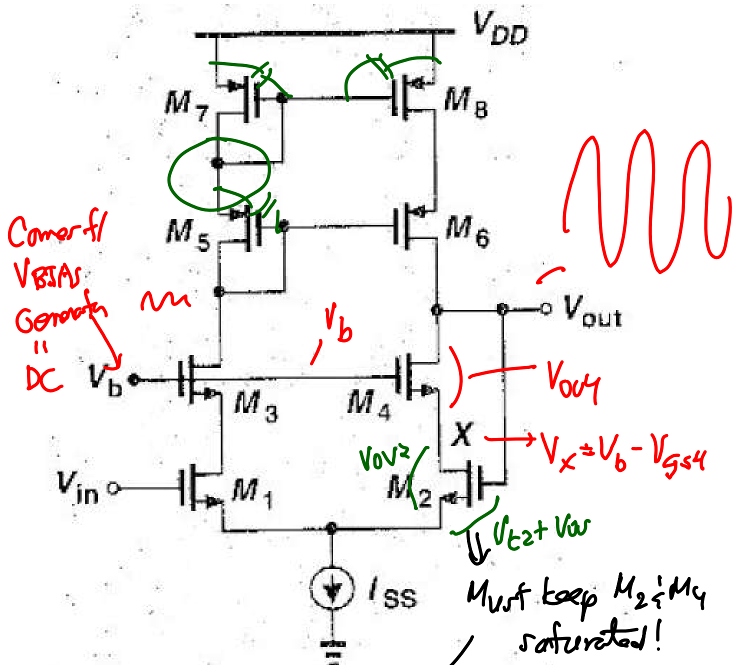
current source V_{ov}

$V_{oswing} = V_{omax} - V_{omin}$

Problem ②: Difficult to tie the input to output!



} unity gain buffer (very useful)



Must keep M_2 & M_4 saturated!

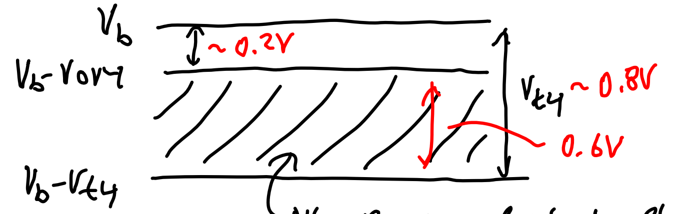
M_4: Need $V_{out} \ge V_b - V_{GS4} + V_{ov4} = V_b - V_{t4} - V_{ov4} + V_{ov4}$

$\therefore V_{out} \ge V_b - V_{t4}$

M_2: Need $V_{out} \le V_X - V_{ov2} + V_{t2} + V_{ov2}$

$V_{out} \le V_b - V_{t4} - V_{ov4} + V_{t2} \approx V_b - V_{ov4}$

$V_{t2} \approx V_{t4}$

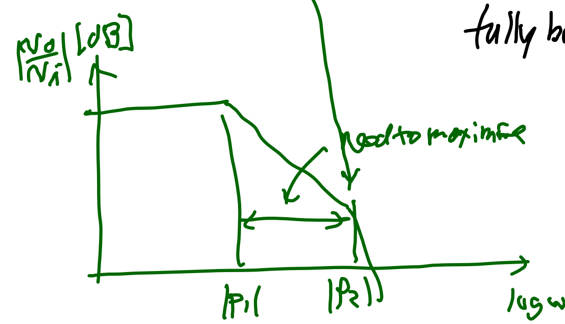


Allowable range of output voltage (not much! → problem!)

Problem ③:

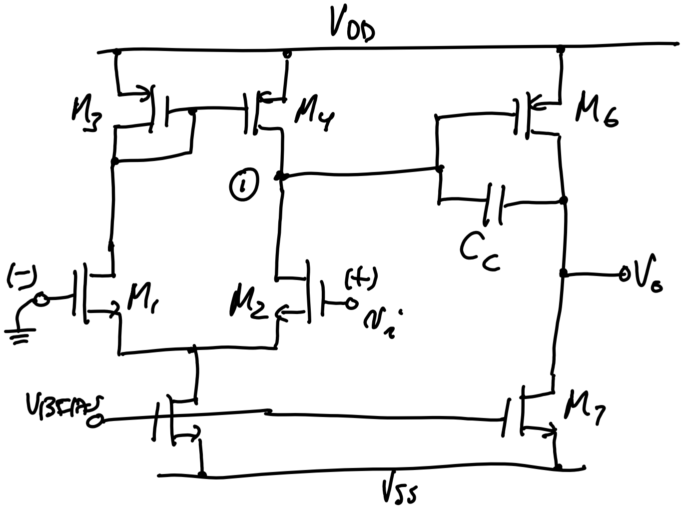
Low freq. non-dominant pole associated w/ the "mirror" node → will hurt stability in FB ckts.! (we'll cover this later)

Soln: fully differential, fully balanced op amp



Another Soln: 2-stage op amp

Classic 2-Stage Op Amp



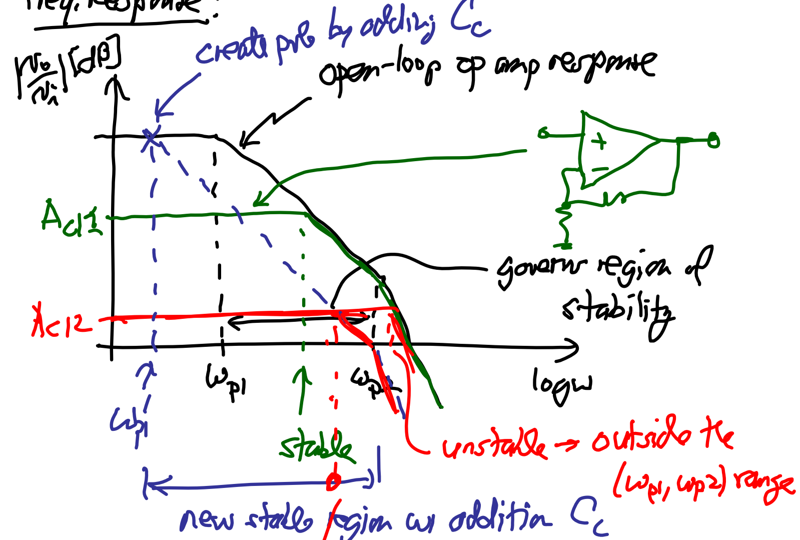
Gain:

1st Stage: $a_{v1} = \frac{v_\Phi}{v_i} = -g_{m2}(r_{o2} \| r_{o4})$ — g_{m1-2}

2nd Stage: $a_{v2} = \frac{v_o}{v_\Phi} = -g_{m6}(r_{o6} \| r_{o7})$

$$a_v = a_{v1}a_{v2} = g_{m2}(r_{o2} \| r_{o4})\, g_{m6}(r_{o6} \| r_{o7})$$

Freq. Response:



now, A_{cl2} is stable → inside the $(\omega_{p1}', \omega_{p2})$ range

Dominant Pole:

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

Miller Effect

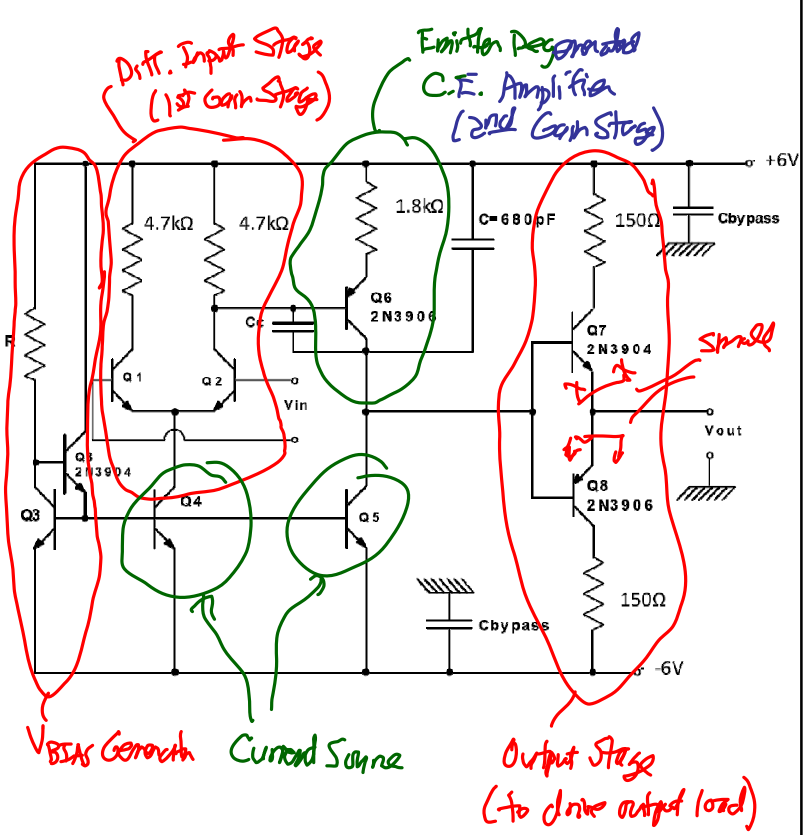
Output Swing:

$$V_{oswing} = V_{DD} - V_{SS} - |V_{ov6}| - V_{o7}$$

↳ much better than single-ended telescopic

↳ but at the cost of 2nd stage — more power!

Lab#2: 2-Stage Bipolar Op Amp



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!