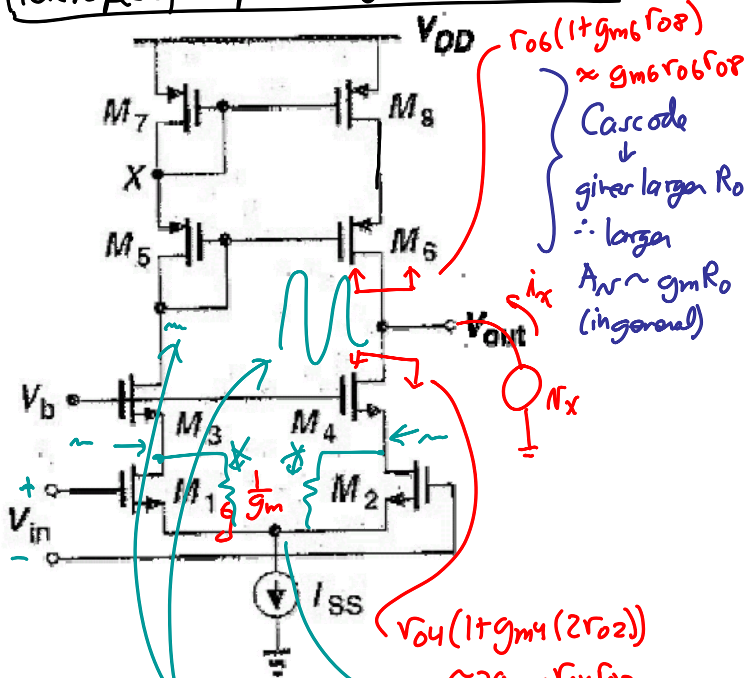
- **Today**: Higher Gain Op Amps

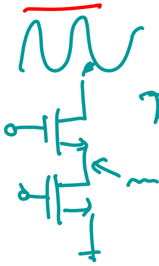
How can we increase gain?

1. Cascode
2. Cascade of amplifiers

Telescopic Op Amp w/ Single-Ended Output



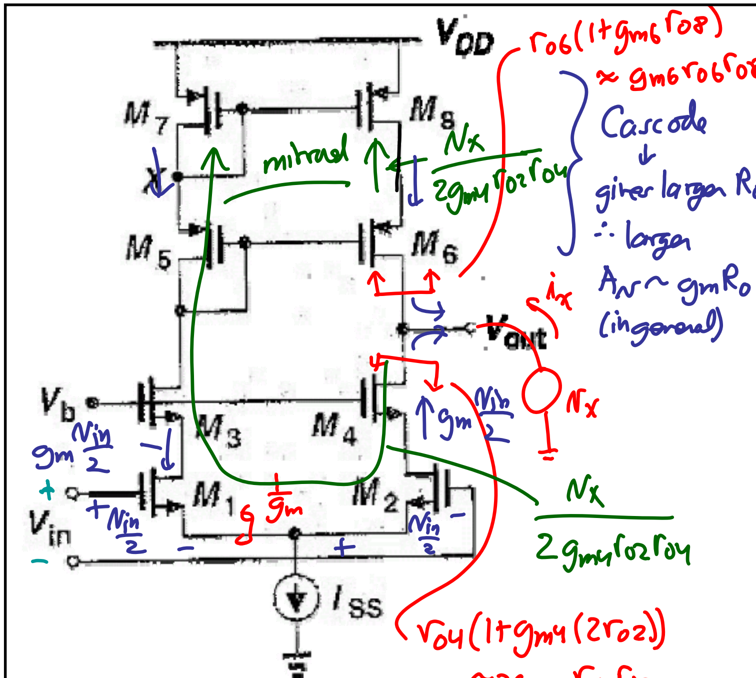
Get R_o:



Due to huge difference in node resistance.

These cascodes effectively shield the drains of M_1 & M_2 from large voltage excursions.

This node stays still → virtual ground! → Do it this way later for the folded cascode.



Get R_o:

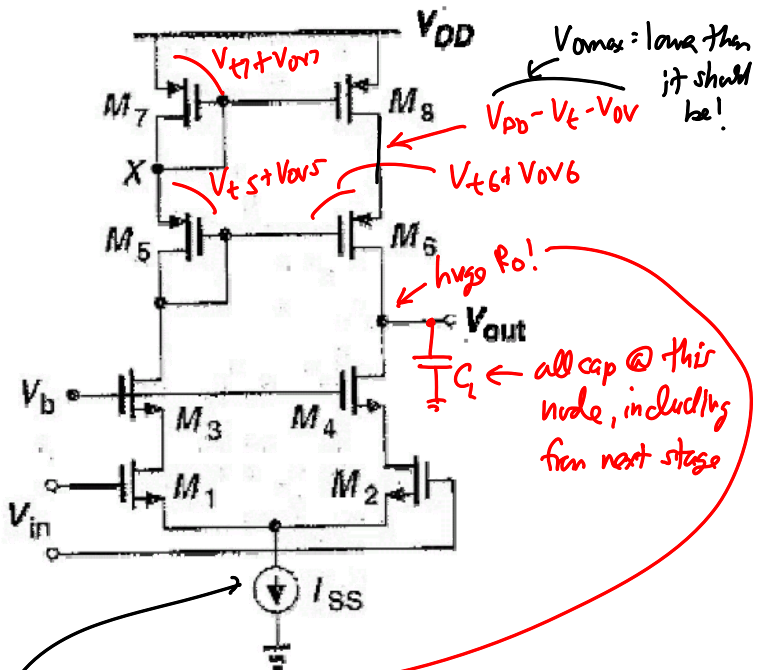
$R_o = (g_{mN}r_{oN}^2) \| (g_{mP}r_{oP}^2)$

$G_m = \frac{i_o}{v_{in}} = g_m$

∴ 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!



Vomax: lower than it should be!

This contributes the dominant pole:

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

Problems/Issues:

① Limited output swing.

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

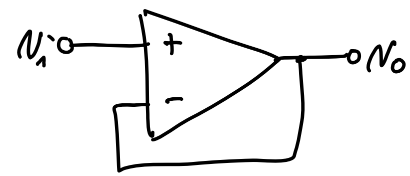
$V_{omin} = V_{ovss} + V_{ov1} + V_{ov2}$

↑ from tail current source

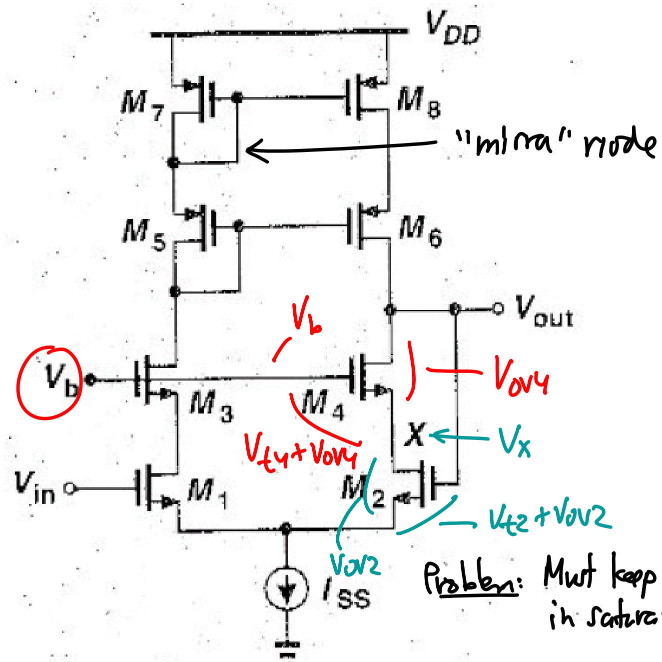
Swing Not Enough! → problem!

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

Problem ②: Difficult to tie input to output!



unity gain buffer → very useful!



Problem: Must keep M_2 & M_4 in saturation!

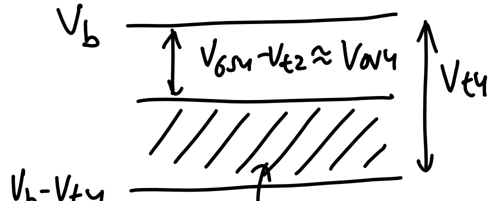
M_4: Need $V_{out} \geq V_b - V_{GS4} + V_{ov4} = V_b - V_{t4} - \cancel{V_{ov4}} + \cancel{V_{ov4}}$

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

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

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

↑ $V_{t2} \approx V_{t4}$



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

Problem ③:

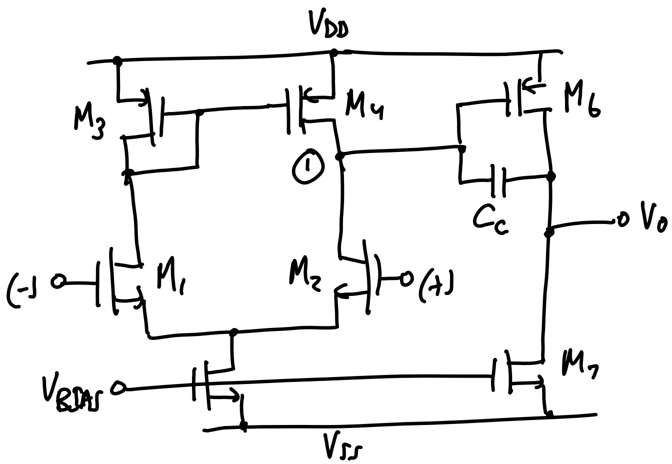
Low freq. non-dominant pole associated w/ the "mirror" node. → will hurt stability in Feedback ckts! (we'll cover this later)

Soln: use fully differential, fully balanced op amp

One solution to the above: use folded-cascode → we'll do this later

Another solution: 2-stage op amp

Classic 2-Stage Op Amp



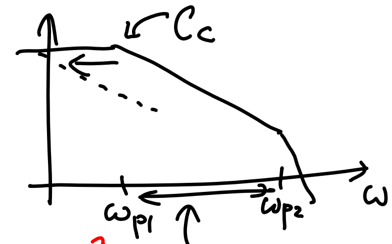
Gain –

1st Stage: $A_{v1} = \frac{v_①}{v_i} = -g_{m2}(r_{o2} \| r_{o4})$

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

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

Freq. Response:



distance decides whether or not a FB ckt using this op amp is stable or not!

Dominant Pole:

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

Output Swing:

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