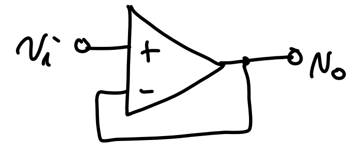
Lecture 16: High Gain Op Amps II

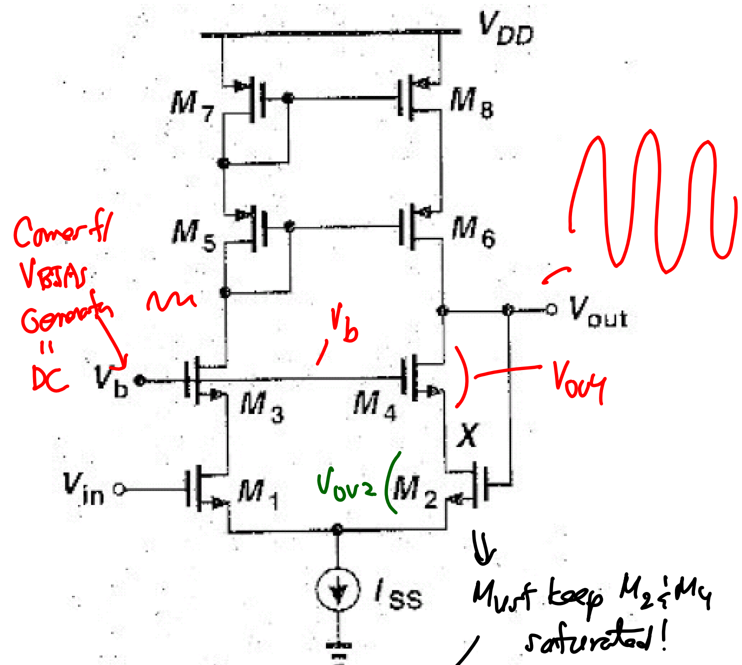
- **Announcements**:
  - Midterm will be on the date specified in your syllabus: Thursday, Oct. 31, 9:00-11 a.m. in this room
  - HW#7 due tomorrow at 8 a.m.
  - HW#8 online
    - due next Tuesday, 5 p.m., so we can get solutions up
  - 240A students should be working on HW#1A, too
- **Lecture Topics**:
  - Telescopic Op Amp in Feedback
  - Lab#2 Hints
  - Compensation (a 1st pass)
  - Slew Rate (a 1st pass)
- ------------------------------------
- **Last Time**:
- Telescopic op amps

over

Problem ②: Difficult to tie the input to output!



unity gain buffer (very useful)



Must keep M_2 & M_4 saturated!

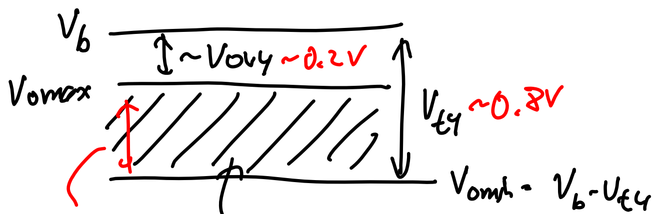
M_4: Need $V_{out} \geq V_b - V_{GS4} + V_{ov4} = V_b - V_{t4} - \cancel{V_{ov4}} + \cancel{V_{ov4}}$

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

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

$V_{out} \leq V_b - V_{t4} - V_{ov4} + V_{t2} \simeq V_b - V_{ov4} \leftarrow V_{omax}$

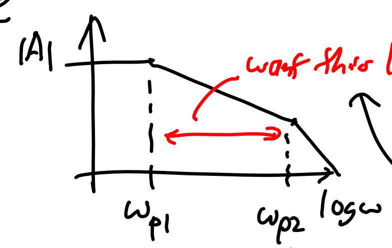
$V_{t2} \simeq V_{t4}$



~0.6V
⇓
very small → major problem!

permissible range of output voltage

Problem ③:



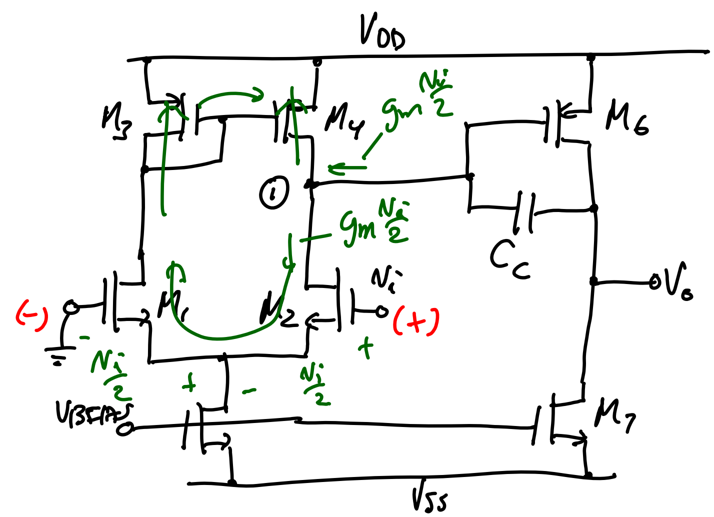
because this can't be so large

Low freq. non-dominant pole associated w/ the "mirror" node → hurt stability in FB ckts.
⇓
Soln: fully differential, fully balanced op amp

Another Soln: 2-stage op amp

⟲ over

Classic 2-Stage Op Amp



Gain:

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

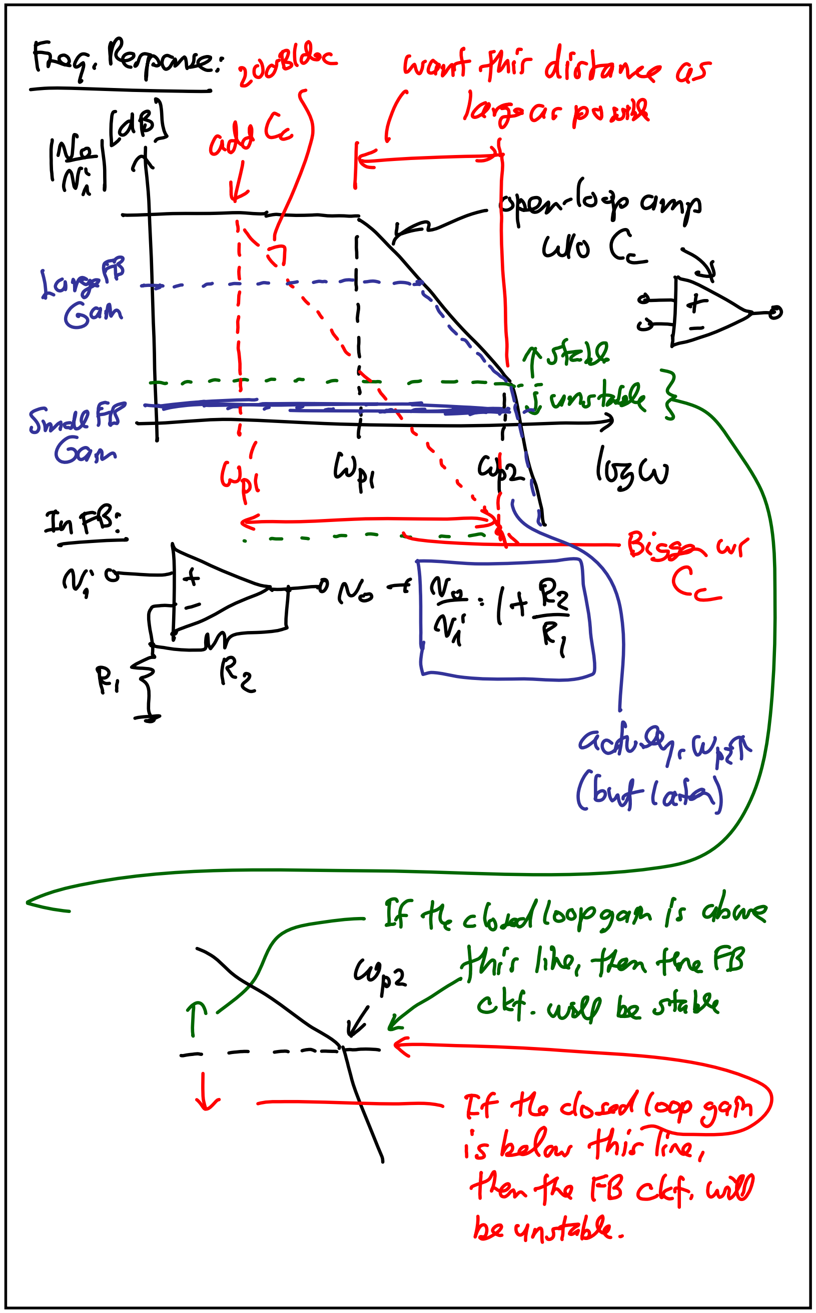
2nd stage: $a_{v2} = \frac{v_o}{v_①} = -g_{m6}(r_{o6} \| r_{o7})$

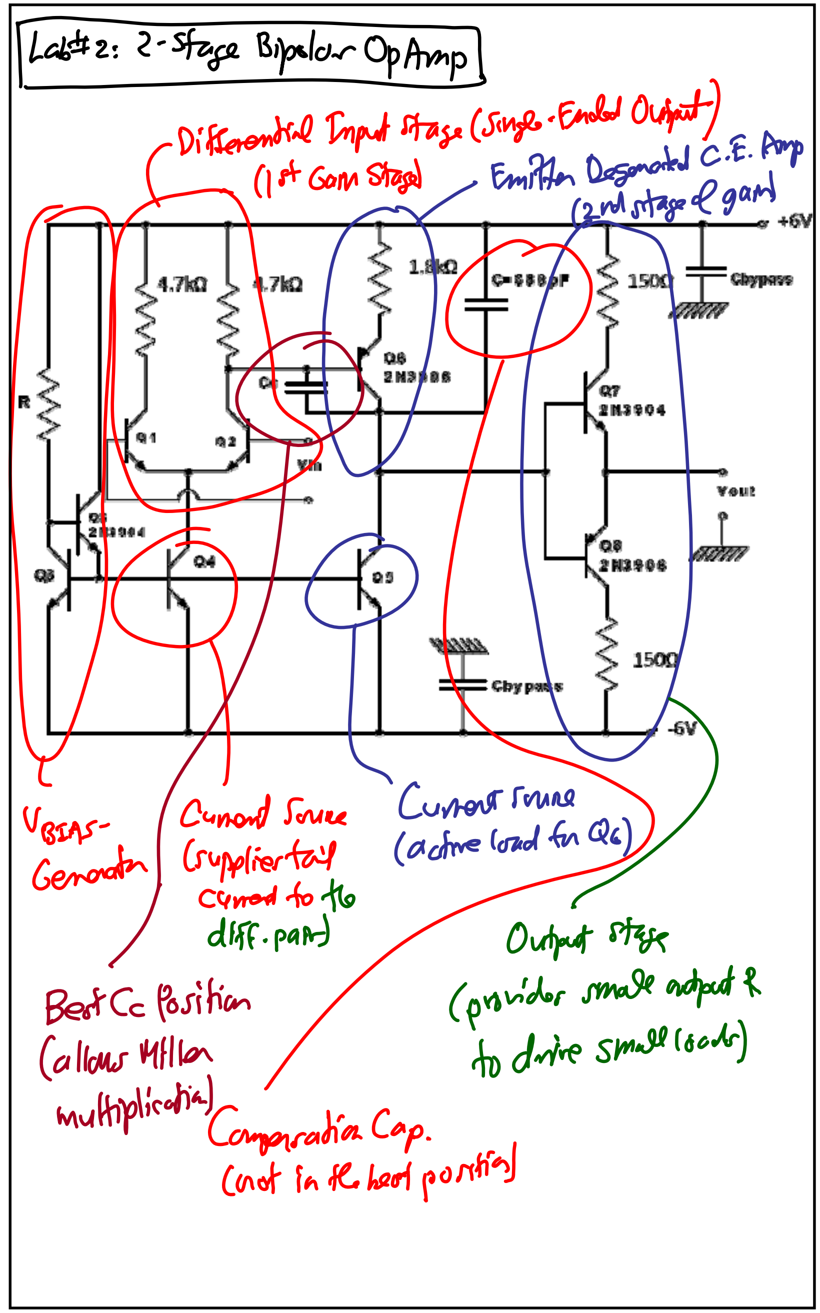
$$\boxed{a_v = a_{v1} a_{v2} = g_{m2}(r_{o2} \| r_{o4})\, g_{m6}(r_{o6} \| r_{o7})}$$

Output Swing: $V_{oswing} = V_{DD} - V_{SS} - |V_{ov6}| - V_{ov7}$

Dominant Pole:

$$\omega_{p1} = \omega_{①} = \frac{1}{(r_{o2} \| r_{o4})\underbrace{(1 + g_{m6}(r_{o6} \| r_{o7}))}_{\text{Miller Effect}} C_c}$$


Freq. Response:
$\left|\frac{v_o}{v_i}\right|$ [dB]
20dB/dec
add C_c
want this distance as large as possible
open-loop amp w/o C_c
Large FB Gain
Small FB Gain
↑ stable
↓ unstable
ω_{p1}'
ω_{p1}
ω_{p2}
$\log\omega$
Bigger w/ C_c
actually, ω_{p2}↑
(but later)
In FB:
v_i
v_o
R_1
R_2
$\frac{v_o}{v_i} = 1 + \frac{R_2}{R_1}$
ω_{p2}
If the closed loop gain is above this line, then the FB ckt. will be stable
If the closed loop gain is below this line, then the FB ckt. will be unstable.


Lab #2: 2-Stage Bipolar Op Amp
Differential Input Stage (Single-Ended Output)
(1st Gain Stage)
Emitter Degenerated C.E. Amp
(2nd stage of gain)
+6V
4.7kΩ
4.7kΩ
1.8kΩ
C=680pF
150Ω
Cbypass
Q6
2N3906
Q7
2N3904
R
Q1
Q2
Vin
Vout
Q5
2N3904
Q3
Q4
Q8
2N3906
150Ω
Cbypass
-6V
V_{BIAS}-Generator
Current Source (supplies tail current to the diff. pair)
Current source (active load for Q6)
Best C_c Position (allows Miller multiplication)
Compensation Cap. (not in the best position)
Output stage (provides small output R to drive small loads)

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.

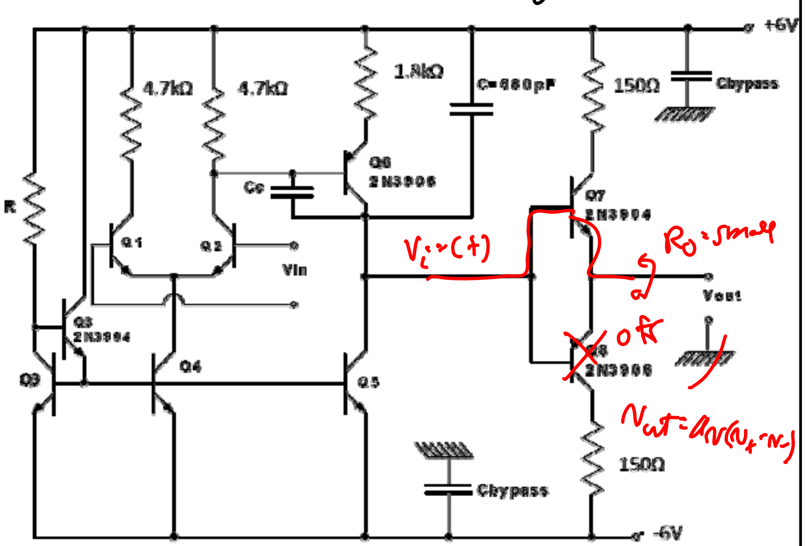
③ R_{E6} raises the input R of Q_6 (of the 2nd gain stage), plus helps w/ biasing.

④ Same comment as ③ for the output stage.

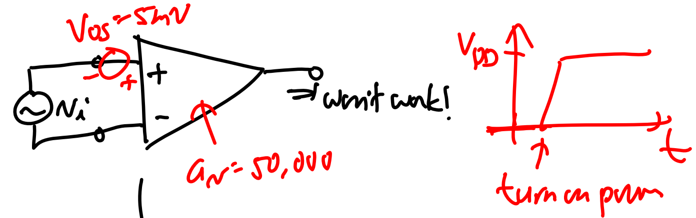
⑤ Output stage needed when driving a resistive load

→ often the case for bipolar

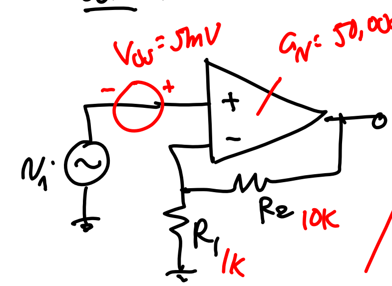
→ not often the case for MOS, where a capacitive load C_L is often more relevant → MOS op amps often don't need output stages!



How Do We Use Op Amps? (to answer a question regarding how we set V_o to a specific DC value)



Soln: Feedback



finite

$v_o = \underbrace{\left(1+\frac{R_2}{R_1}\right)}_{11}(v_i + \underbrace{V_{os}}_{5mV})$

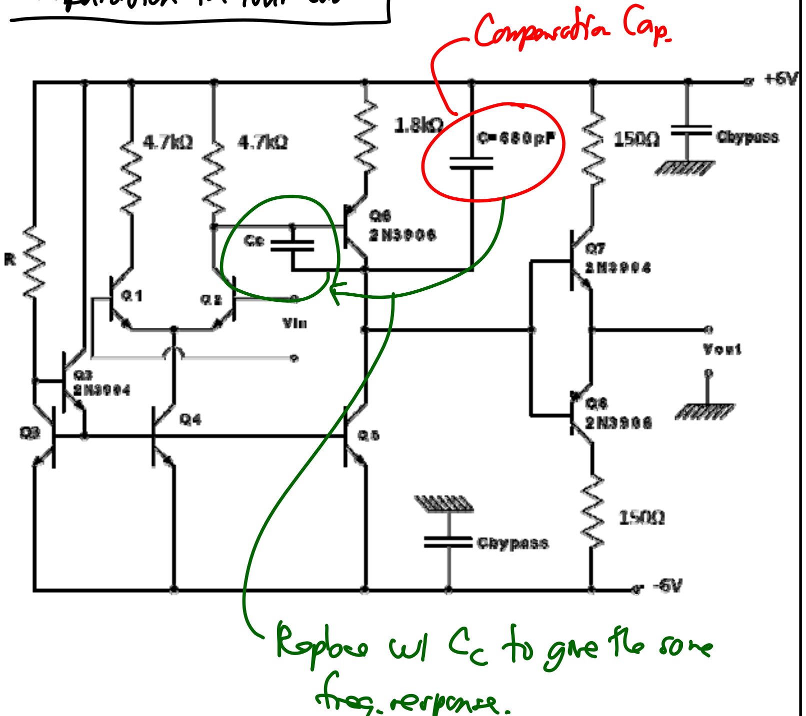
55mV

$= a_v(v_+ - v_-)$

$\infty \quad 0$ ⇒ these must be the case for v_o = finite

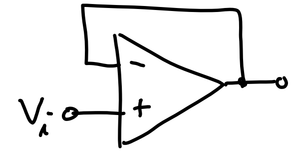
- So basically, one can use feedback to set the output voltage of the op amp to a well-defined value
- When you're given a problem that says "assume Vo=1V", then this is actually often achieved by just hooking the circuit into a feedback loop that sets this voltage

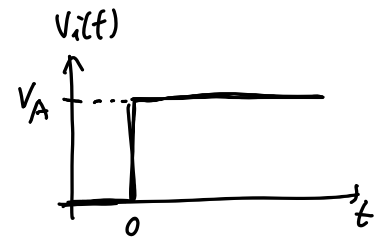
Comparation for Your Lab#2



- In your lab, determine the pole generated when C=680pF is present, then remove C and insert a Cc of value that generates the same pole
- These capacitors are compensating the op amp – moving its first and second poles apart to insure stability over a larger range of closed loop gains
- We will learn more about this in much more detail a few weeks from now

Slew Rate





Using Laplace Xform Theory:

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

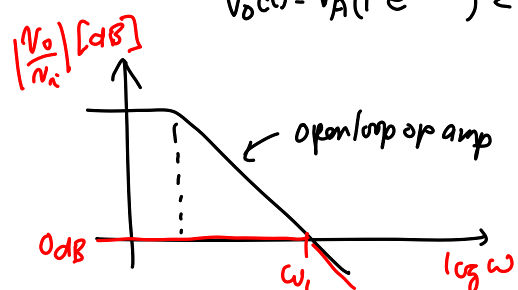
single (dominant) pole

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

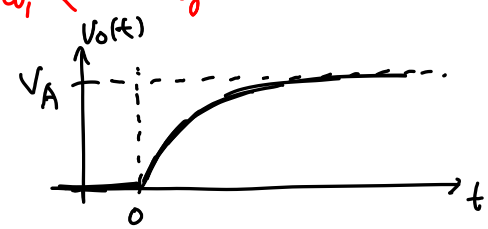
$$V_o(s) = \frac{V_A}{s(1+s\tau_1)} = \frac{V_A}{s} - \frac{V_A}{s+\frac{1}{\tau_1}}$$

$\Updownarrow$ Inverse Laplace Xform

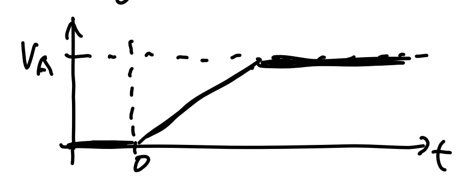
$$V_o(t) = V_A\left(1-e^{-t/\tau_1}\right)$$ ← expected response



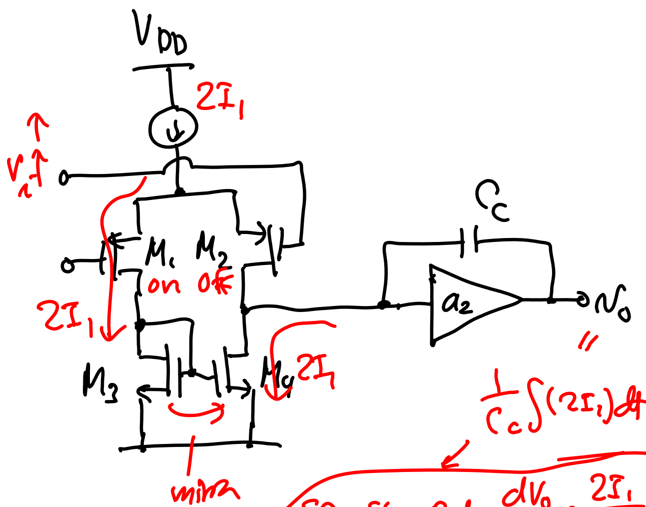
Theoretical Expectation



Reality
Why?



Reason: 1st & 2nd stage of op amp cannot source enough current to mimic the shape (& speed) of a fast rising theoretical output waveform



$$\frac{1}{C_c}\int(2I_1)\,dt$$

$$SR = \text{Slew Rate} = \frac{dV_o}{dt} = \frac{2I_1}{C_c}$$