Lecture 17: Slew Rate & Output Stages

- **Announcements:**
  - HW#7 due today; HW#8 online
  - Lab#2 due week of 3/19 (next week)
  - Midterm Exam next Thursday, 3/22
- **Lecture Topics:**
  - Slew Rate; Output Stages
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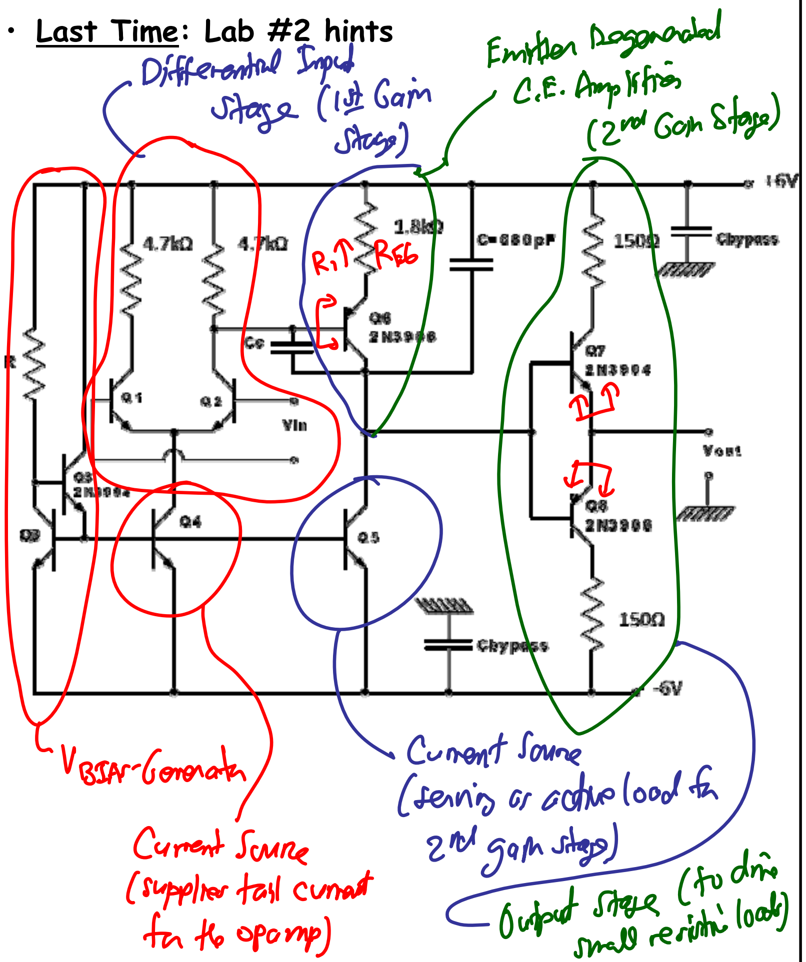
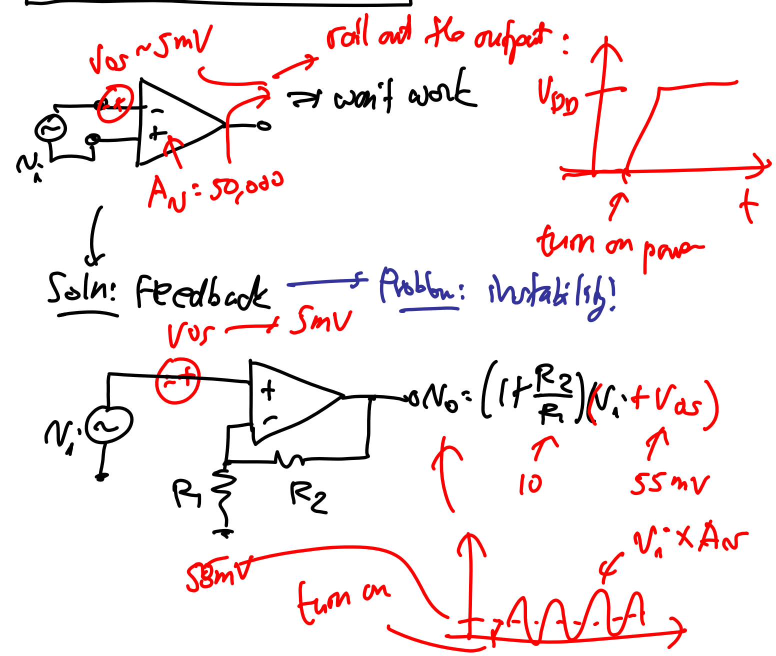
- **Last Time:** Lab #2 hints



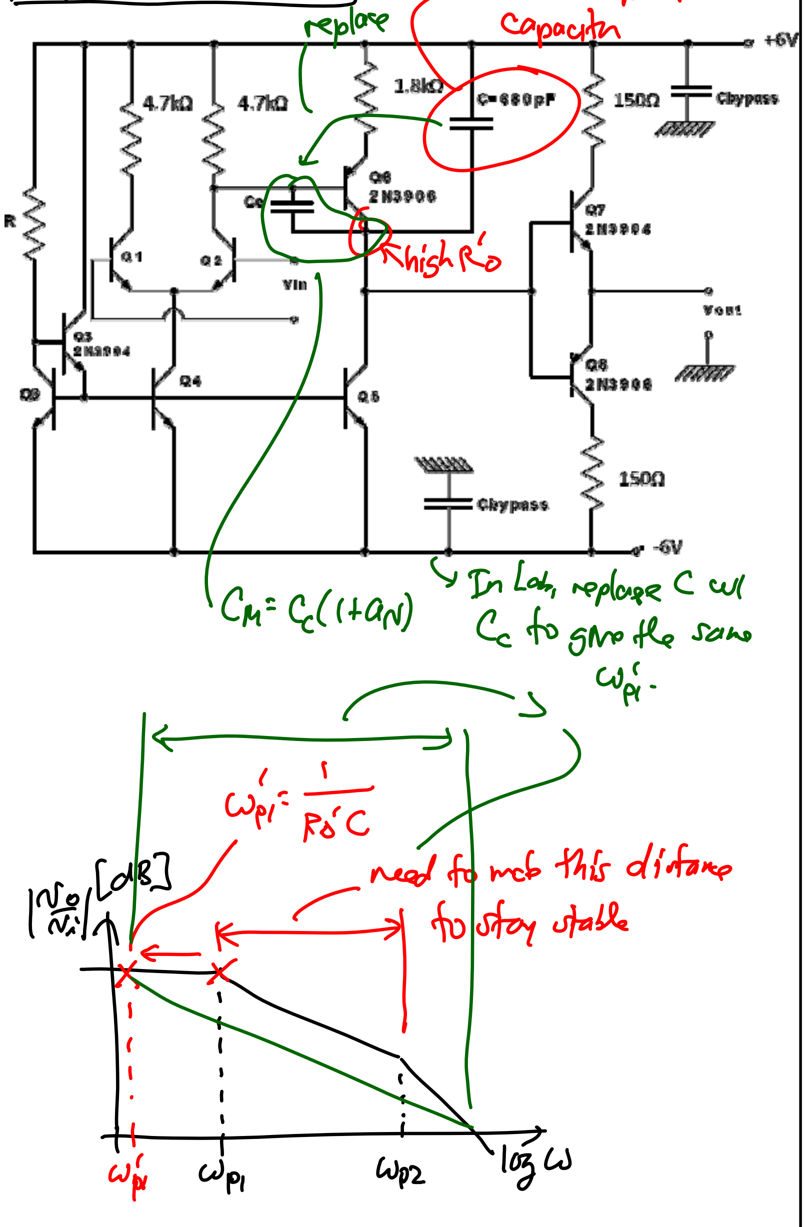
Remarks.

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!

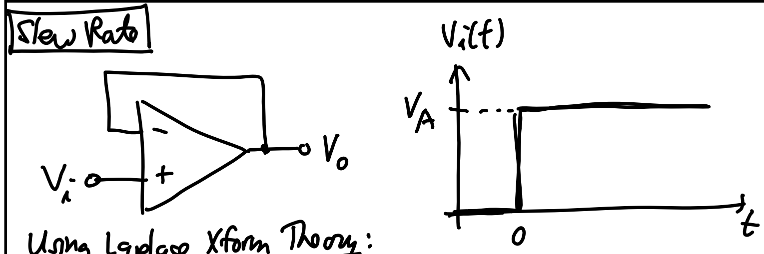
How Do we use OpAmps?



Compensation: A 1st Pass



Slew Rate



Using Laplace Xform Theory:

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

← single (dominant) pole

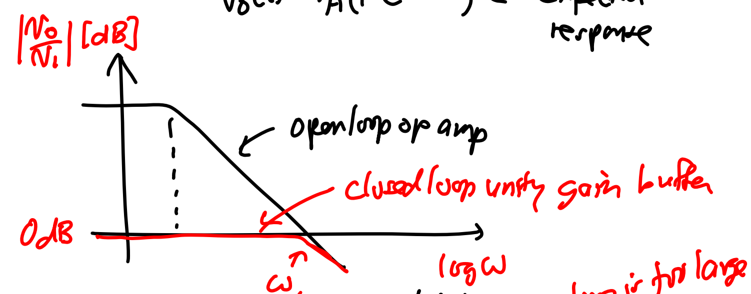
$$V_i(s) = \frac{V_A}{s}$$

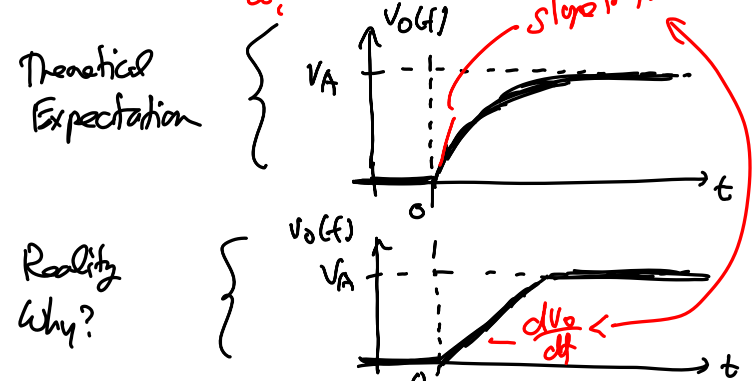
$$V_o(s) = \frac{V_A}{s(1+s\tau_1)} = \frac{V_A}{s} - \frac{V_A}{s+\frac{1}{\tau_1}}$$

⇕ Inverse Laplace Xform

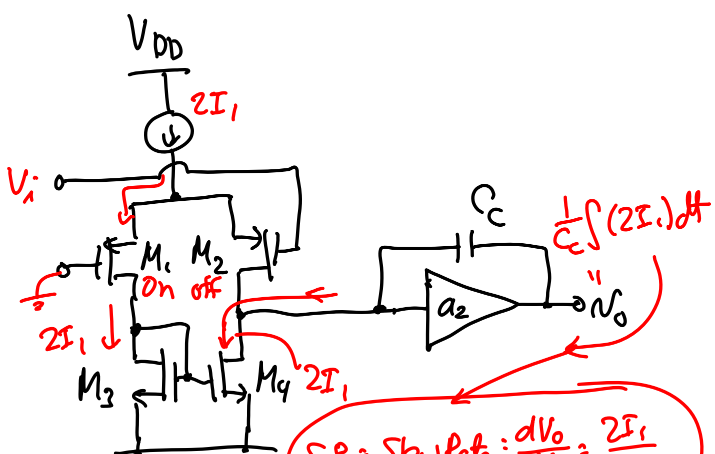
$$V_o(t) = V_A(1-e^{-t/\tau_1})$$

← expected response; ← the constant



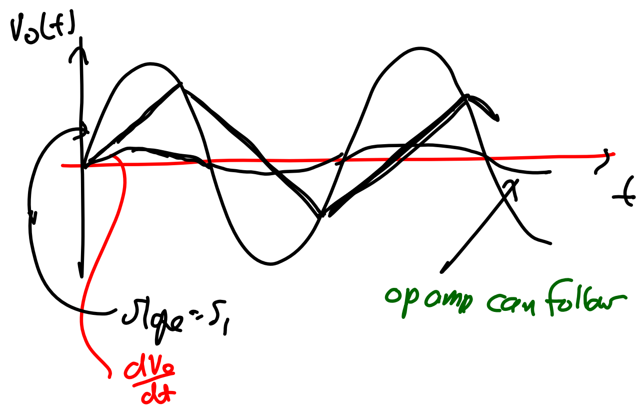


Reason: 1st & 2nd stage of op amp cannot source enough current to mimic the shape (or speed) of a fast rising input signal

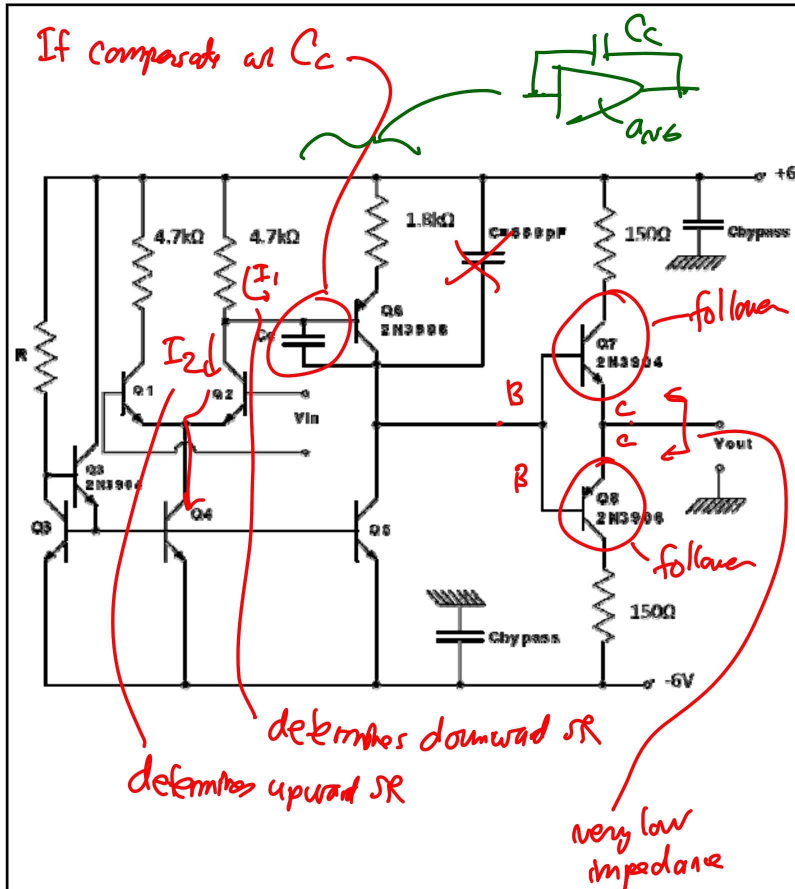


$$S.R. = \text{Slew Rate} = \frac{dV_o}{dt} = \frac{2I_1}{C_c}$$

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



If compensate w/ C_c



Output Stages

- Class A (Emitter or Source Follower)
- Class B
- Class AB (we'll do this one later)

Purpose: Drive loads

① Deliver power w/ small distortion.

② Minimize output impedance → so that the amplifier gain is insensitive to the load.

Desirable Attributes:

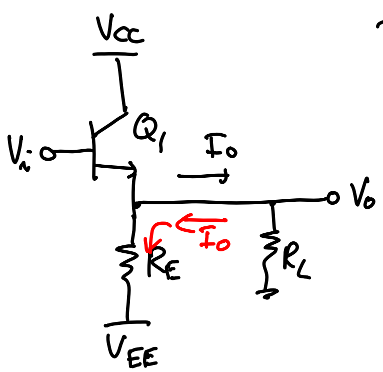
① High R_{in}; Low R_{out}.

② Low quiescent power.

③ Minimal effect on the amplifier freq. response.

④ Should be able to handle large input/output swings. (i.e., V_i may be $> V_T$, invalidating small-signal approximations)

Emitter Follower (Class A)



Two main cases:

① $I_o > 0$: I_o comes f/ Q_1 ⇒ adequate I_o can be supplied so long as Q_1 stays in forward active

② $I_o < 0$: (i.e., $V_o = (-)$)

I_o must be sunk to V_{EE} through R_E

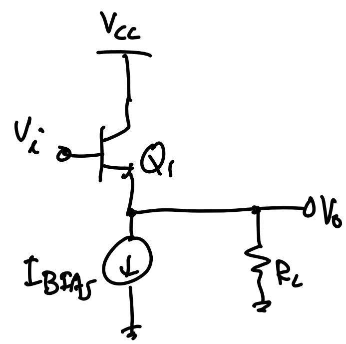
↓

$I_o = \dfrac{V_o - V_{EE}}{R_E}$ → $|I_o|$ gets smaller as $V_o \downarrow$

↓

Problem!

Solution: Replace R_E w/ a current source.

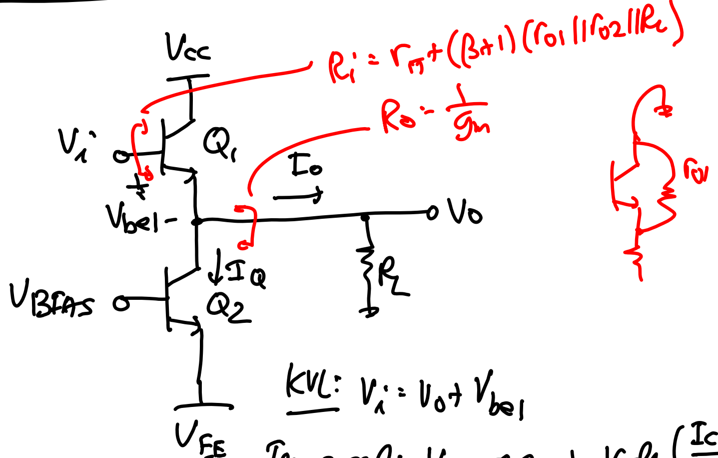


Now can source I_o through Q_1 for $V_o = (+)$.

↓

And can sink $I_o = I_{BIAS}$, where I_o stays $= I_{BIAS}$ as V_o changes.

Actual Implementation:

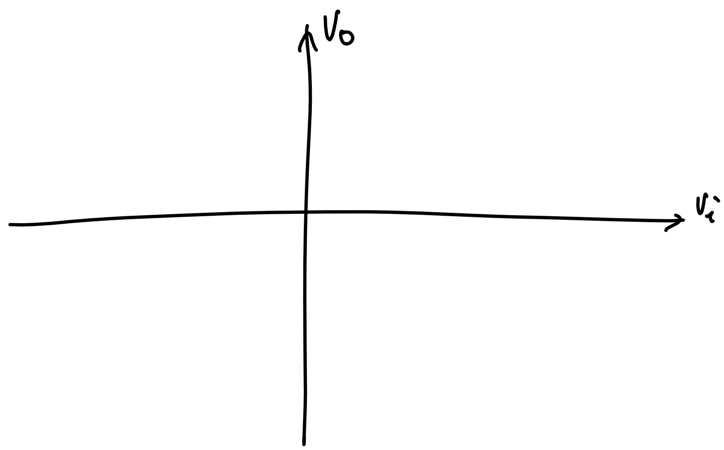


KVL: $V_i = V_o + V_{be1}$

In general: $V_{be1} \neq const = V_T \ln\left(\frac{I_{C1}}{I_{S1}}\right)$ (for Q in FAR)

$I_{C1} = I_o + I_Q = I_Q + \frac{V_o}{R_L}$

$\therefore\ V_i = V_o + V_T \ln\left(\frac{I_Q + \frac{V_o}{R_L}}{I_{S1}}\right)$



Two Cases:

Case ①: R_L = large

→ I_o not Δ'ing much to deliver large excursion in V_o

↳ I_{C1} not Δ'ing much

For V_i = large and (+): Q_1 must source $I_o + I_Q$

$V_o = V_i - V_{be1}$

@ some pt., Q_1 will saturate as V_o↑

↳ defines V_{omax}

$V_{omax} = V_{CC} - V_{CE(sat)}$

↳ and $V_i = V_{CC} - V_{CE(sat)} + V_{be1}$