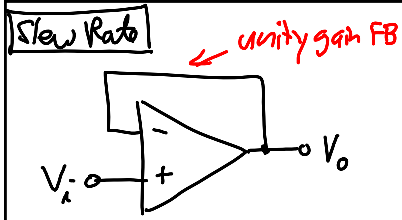
Lecture 17: Slew Rate & Output Stages

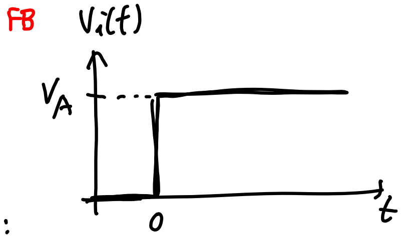
- **Announcements:**
  - HW#7 due Monday, Oct. 26, at ~~8 a.m.~~ 12 noon.
  - 240A students should be working on HW#1A, too, due Friday, Nov. 6
  - I will be traveling again this Friday, returning next Monday – should be back in time for office hours, depending on flight arrival time
  - Midterm will be on the date specified in your syllabus: Thursday, Oct. 29, 6-8 p.m. in 141 McCone
- **Lecture Topics:**
- Slew Rate (a 1st pass)
- Output Stages
- ------------------------------------
- **Last Time:**
- Telescopic op amps

- For the compensation part of your lab, just assume the load is the oscilloscope input, which is probably 1MΩ

↩ over

Slew Rate





Using Laplace Xform Theory:

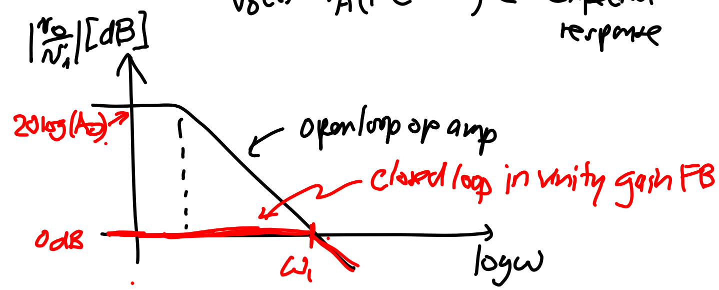
$$\frac{V_o}{V_i}(s) = \frac{1}{1+\frac{s}{\omega_1}} = \frac{1}{1+s\tau_1}$$ ← single (dominant) pole

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

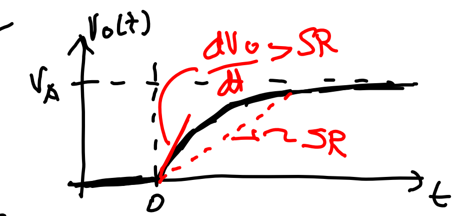
$$V_o(s) = \frac{V_A}{s(1+s\tau_1)} = \frac{V_A}{s} - \frac{V_A}{s+\frac{1}{\tau_1}}$$

⇕ Inverse Laplace Xform

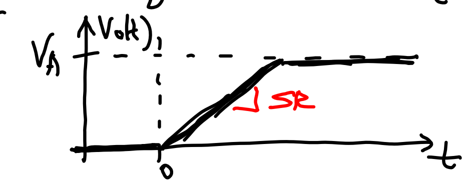
$$V_o(t) = V_A\left(1-e^{-t/\tau_1}\right)$$ ← expected response



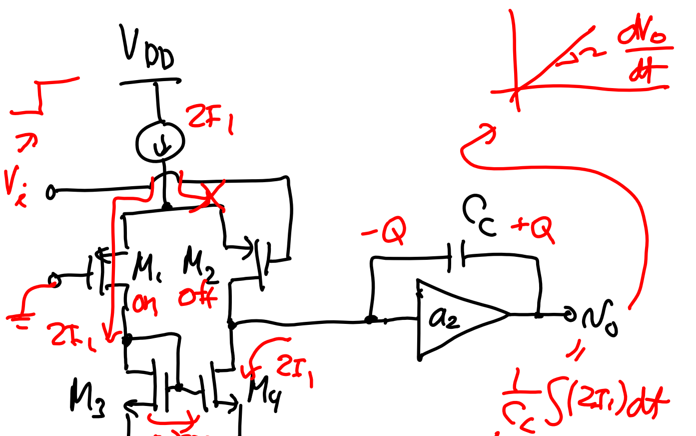
Theoretical Expectation



Reality (Why?)

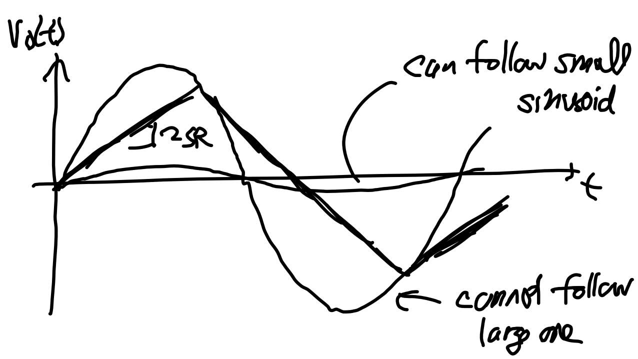


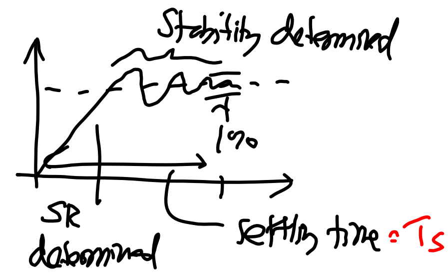
Reason: 1st or 2nd stage of op amp cannot source enough current to mimic the slope (or speed) of a fast rising theoretical output waveform



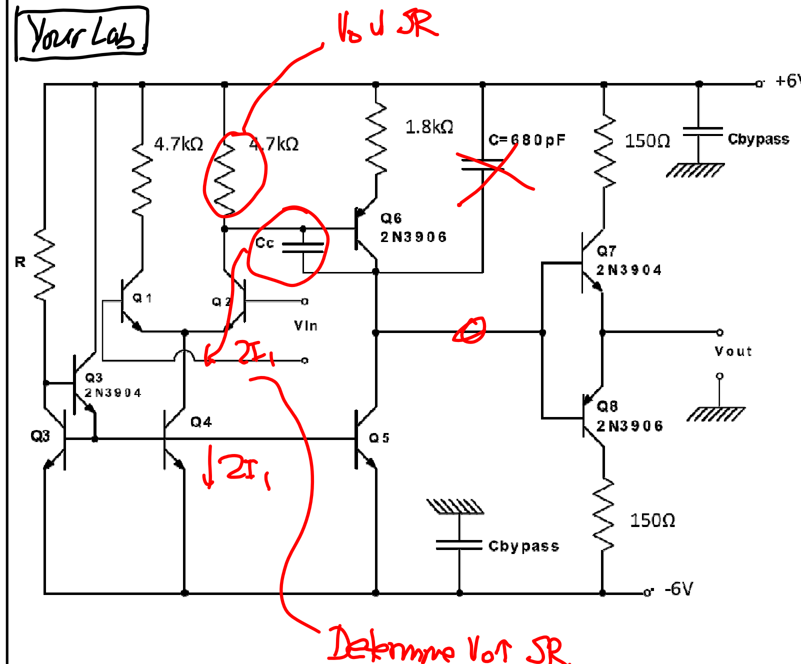
$$SR = \text{Slew Rate} = \frac{dv_o}{dt} = \frac{2I_1}{C_c}$$

Ex. Apply a fast (i.e., high freq., large amplitude) sinusoid





Your Lab



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:

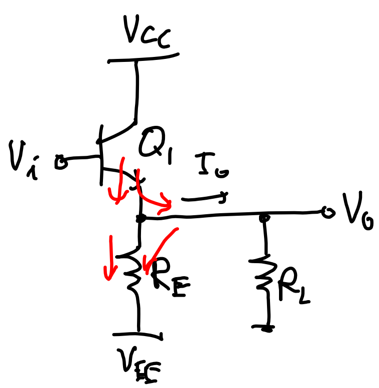
① High R_{in}; Low R_{out}. → assuming voltage application

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 $I_o > 0, V_o > 0$:

I_o comes from Q_1

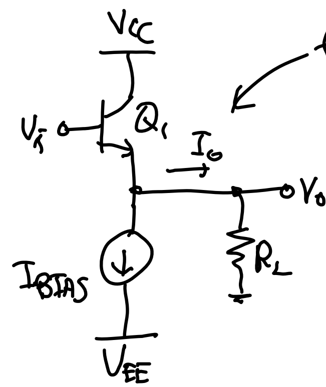
⇒ adequate I_o can be delivered so long as Q stays forward-active

② $I_o < 0$: ($V_o < 0$)

I_o must be sunk through R_E to V_{EE}.

$I_o = \frac{V_o - V_{EE}}{R_E}$ ⇒ Issue: $I_o = f(V_o)$ → $|I_o| \downarrow$ as $V_o \downarrow$ → Problem!

Solution: Replace R_E w/ a current source.



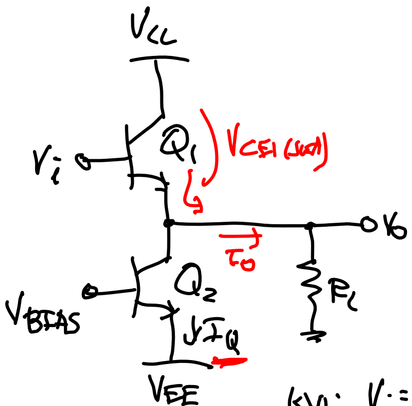
for (+) going V_o can source I_o thru Q_1

& can sink I_o thru $I_{BIAS} = I_o$ (or less) ← when competing w/ Q_1

I_{BIAS} does not get smaller as V_o decreases

∴ can maintain drive power as V_o Δ's!

Actual Implementation:



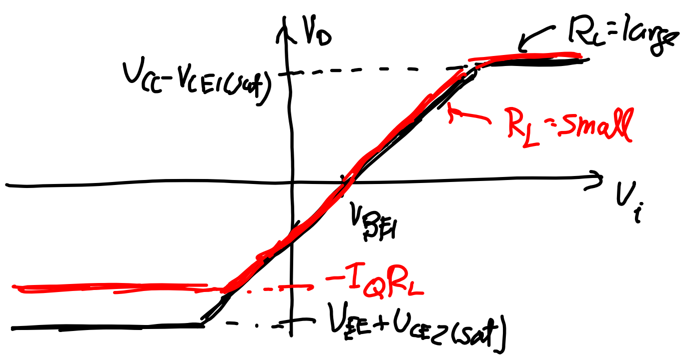
KVL: $V_i = V_o + V_{be1} \approx V_o + V_{BE1}$

More Accurate:

$V_{be1} \neq \text{const.} = V_T \ln\left(\frac{I_{C1}}{I_{S1}}\right)$ (Q_1 in FAR)

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

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



Two Cases: (depending on the size of R_L)

Case ①: R_L = large ($I_o < I_Q$)

⇒ I_o not Δ'ing much → I_{C1} not Δ'ing much

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

$V_o = V_i - V_{BE1}$

at some pt., Q_1 will saturate as V_o ↑

Get $V_{omax} = V_{CC} - V_{CE1(sat)}$

↘ $V_i = V_{CC} - V_{CE1(sat)} + V_{BE1}$ ($\geq V_{CC}$)

For V_i = large and (−): V_o follows V_i until Q_2 saturates

$V_{omin} = V_{EE} + V_{CE2(sat)}$

↘ $V_i = V_o + V_{BE1} = V_{EE} + V_{CE2(sat)} + V_{BE1}$

Case ②: R_L = small → thus, I_o can be large!

For V_i = (+) and large: Q_1 can source as much current as needed until it either saturates or it fries

For V_i = (−) and large: $V_o = I_o R_L$ → min. $V_o = -I_Q R_L$

⇒ Q_1 cut-off ($I_{C1} = 0$)

→ V_o clamps @ $-I_Q R_L$ further decrease in V_i yields no ΔV_o

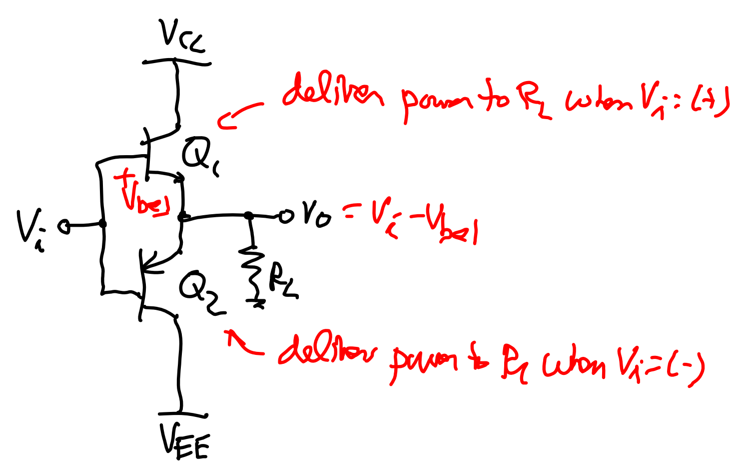
If must drive R_L = small → need large I_Q

Problem: too much power consumption

$P_Q = (V_{CC} - V_{EE}) I_Q$ → DC quiescent power consumption

If want large output swing w/ small R_L → must consume power!

Solution: **Class B Output Stage**



Operation: Q_1 & Q_2 cut-off

$|V_i| < V_{BE(on)}$ → $I_{E1} = I_{E2} = 0$ → $V_o = 0V$

$V_{CC} > |V_i| > V_{BE(on)}$ → $V_o \cong V_i - V_{BE(on)}$

$V_{omax} = V_{CC} - V_{CE1(sat)}$, $V_{omin} = V_{EE} + V_{CE2(sat)}$