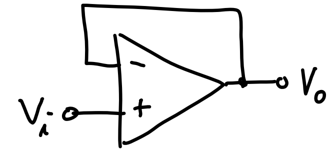
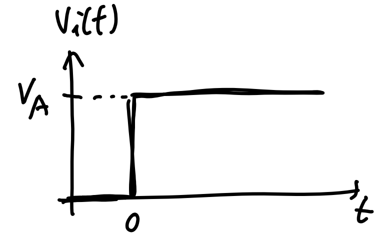
Lecture 17: Slew Rate & Output Stages

- **Announcements**:
  - Midterm Thursday, Oct. 31, 9:00-11 a.m. in this room
  - Midterm info sheet online
  - Solutions to past EE140/240A exams also passed out in class
  - Solutions to all HW's through HW#7 online (except 1A)
  - Solution to HW#8 will be emailed on Tuesday, shortly after it's due at 6 p.m. (it will also be online within a day)
  - Discussion sections turn into office hours next week
  - Review Session on Tuesday evening, probably 5-7 p.m., in a room TBD
- **Lecture Topics**:
  - Midterm Info Sheet
  - Finish 1st Pass Slew Rate
  - Output Stages
- ------------------------------------
- **Last Time**:
- Started slew rate

over

Slew Rate





Using Laplace Xform Theory:

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

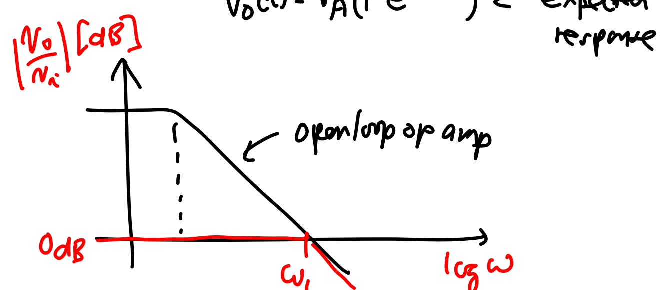
← single (dominant) pole

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

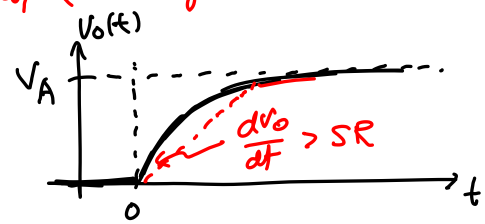
$$V_o(s) = \frac{V_A}{s(1+s\tau_1)} = \frac{V_A}{s} - \frac{V_A}{s+\frac{1}{\tau_1}}$$

⇕ Inverse Laplace Xform

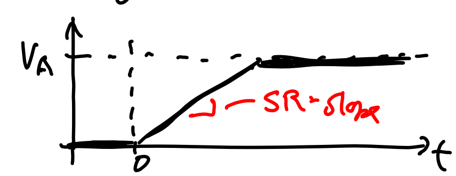
$$V_o(t) = V_A(1-e^{-t/\tau_1})$$ ← expected response



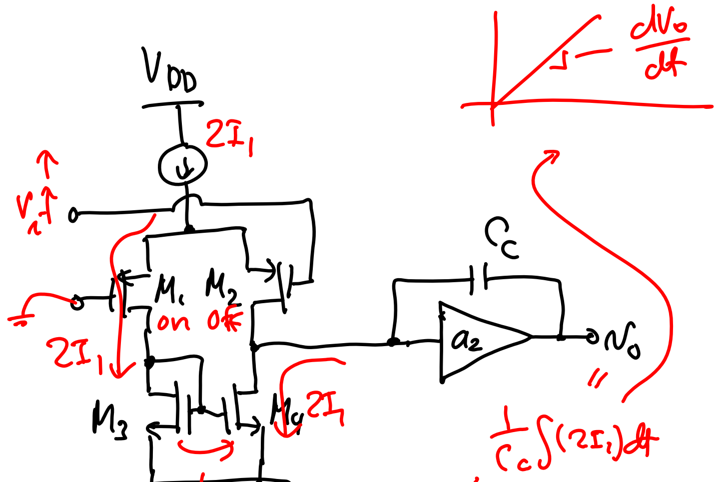
Theoretical Expectation



Reality Why?

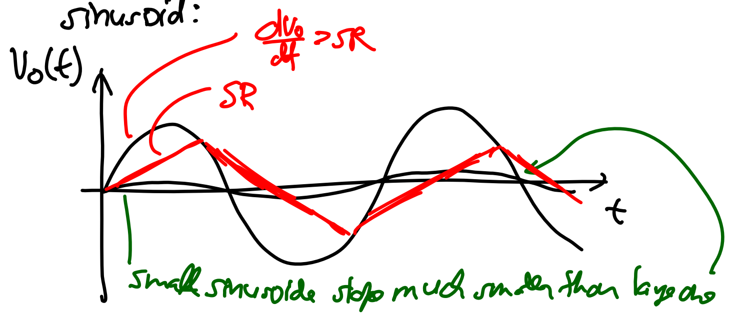


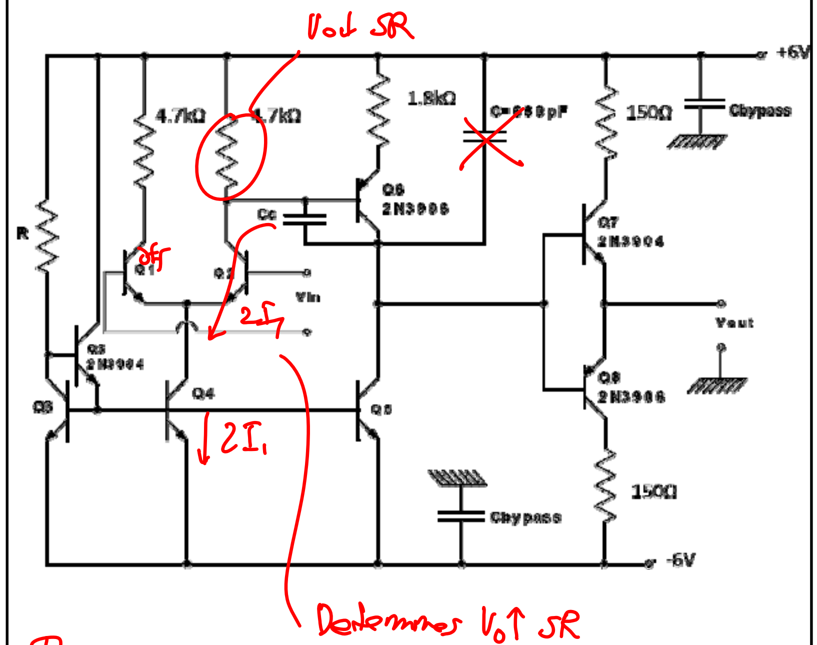
Reason: 1st & 2nd stage of op amp cannot source enough current to mimic the shape (& speed) of a fast rising theoretical output waveform



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

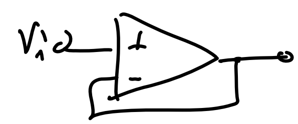
Ex. Apply a very fast (i.e., high freq., large amplitude) sinusoid:



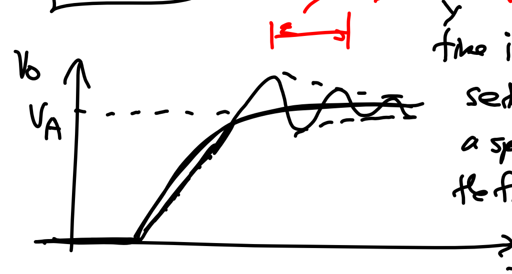


There are (+)-going & (-)-going SR's.

Settling Time → determined by stability & slewing



$T_s \triangleq$ Settling Time: time it takes to settle to within a specific % of the final value



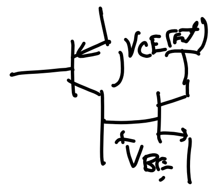
Output Stages

- 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:

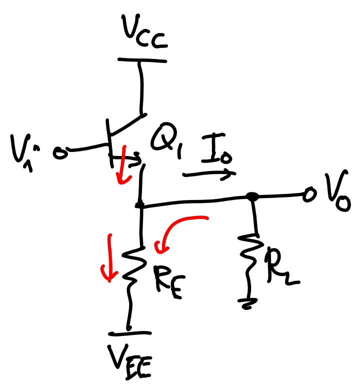
① High R_{in}; Low R_{out}.

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: $V_o > 0$

① $I_o > 0$: I_o comes f/ Q_1

⇒ adequate I_o can be delivered so long as Q_1 stays forward-active

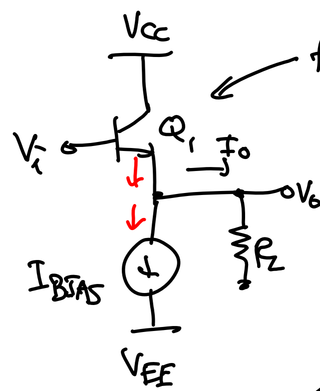
② $I_o < 0$: ($V_o < 0$)

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:



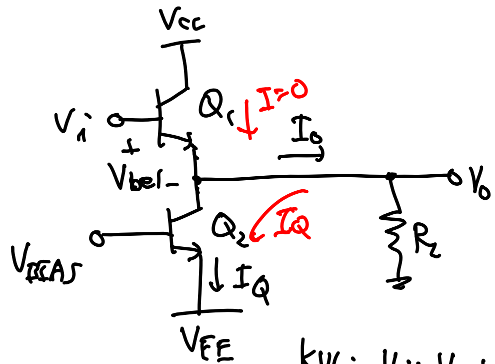
for (+) going V_o, can source I_o thru Q_1

{ can sink I_o through $I_{BIAS} = I_o$ (or less)

↙ I_{BIAS} does not get smaller as V_o decreases

∴ can maintain drive power as V_o ↓'s!

Actual Implementation:



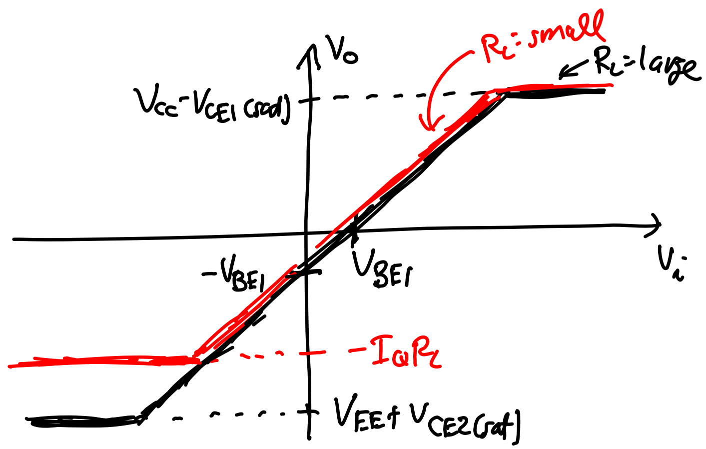
KVL: $V_i = V_o + V_{be1} \approx V_o + V_{BE1}$

More Accurate:

$V_{be1} \neq const. = V_T \ln\left(\frac{I_{C1}}{I_{S1}}\right)$ (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 small → $I_o < I_Q$

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

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

$V_o = V_i - V_{BE1}$

@ some pt., Q_1 saturates as V_o↑

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

→ $V_i = V_{CC} - V_{CE1(sat)} + V_{BE1} > V_{CC}$ ($V_{CE1(sat)}$ = 0.2V, V_{BE1} = 0.7V)

For V_i = large and (−): V_o follow 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 → then I_o can be large!

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

For V_i = (−) and large: $V_o = I_Q R_L$ → 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

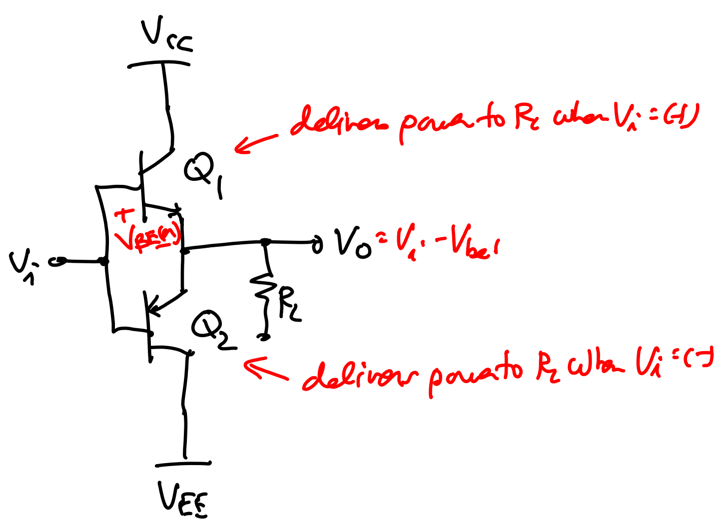
If must drive R_L = small → need large I_Q

Problem: too much power consumption

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

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

Solution: **Class B Output Stage**

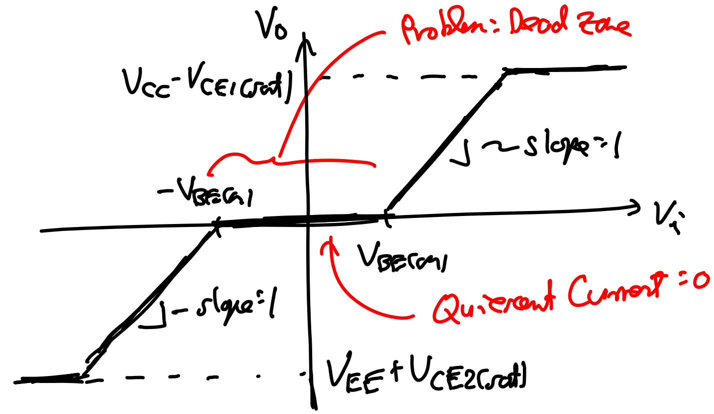


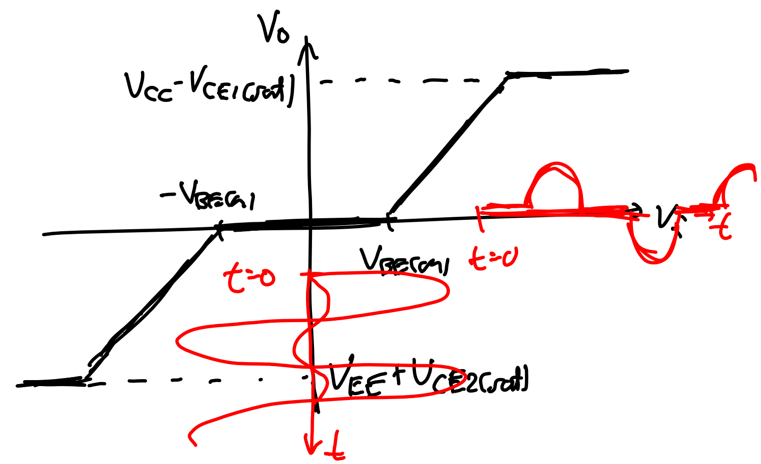
Operation: Q_1 & Q_2 are cut-off

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

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

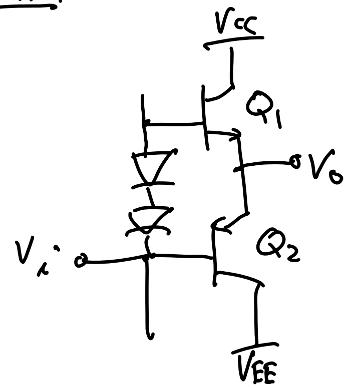
$V_{omax} = V_{CC} - V_{CE1(sat)}$, $V_{omin} = V_{EE} + V_{CE2(sat)}$





Problem: Distorted output due to the dead zone.

Solution: Class AB ckt. → use diodes to supply enough voltage to keep Q_1 & Q_2 on



⇒ You will see this on a future HW