Lecture 18: Stability

- **Announcements**:
  - Lab#2 due week of 3/19 (next week) which is one week after the original due date
  - Suggestion: Get it done this week
  - Midterm Exam next Thursday, 3/22
  - Review Session: Monday, 3/19, 7-9 p.m., Hogan Room (521 Cory)
- **Lecture Topics**:
  - Midterm information
  - Output Stages (continued)
  - Stability
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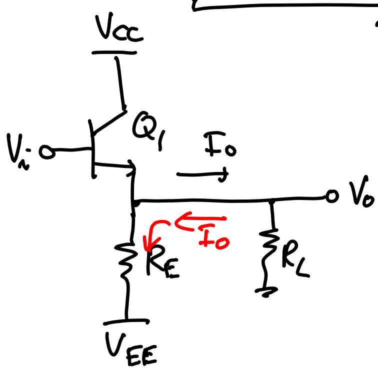
- **Last Time**: Emitter Follower (Class A)

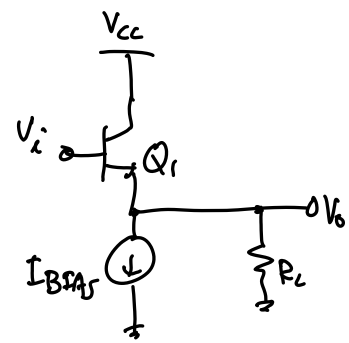


Two main cases:

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
↓
$I_o = \frac{V_o - V_{EE}}{R_E}$ → $|I_o|$ gets smaller as $V_o \downarrow$
↓
Problem!

Solution: Replace R_E w/ a current source.

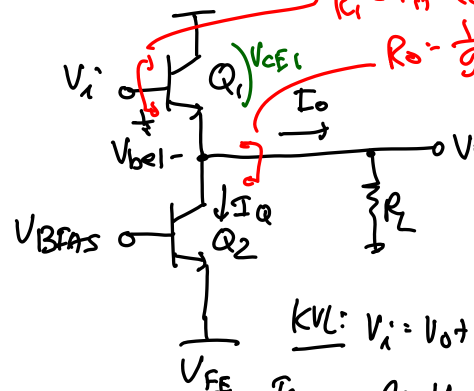


Now can source I_o through Q_1 for $V_o = (+)$.
↓
And can sink $I_o = I_{BIAS}$, where I_o stays $= I_{BIAS}$ as V_o changes.

Actual Implementation:

$R_i = r_\pi + (\beta+1)(r_{o1} \| r_{o2} \| R_L)$

$R_o = \frac{1}{g_m}$

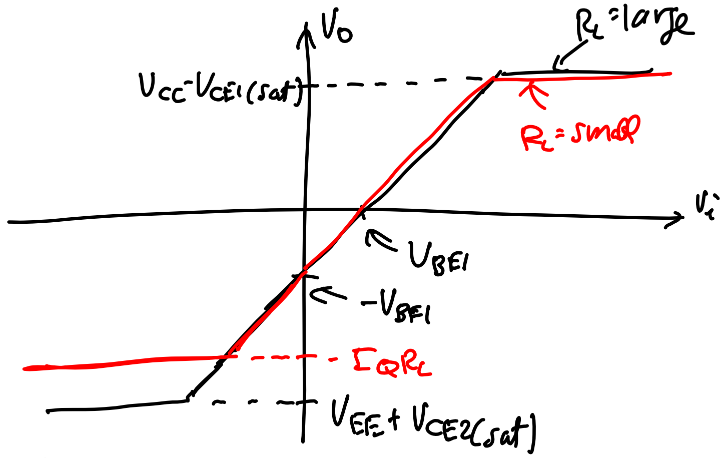


KVL: $V_i = V_o + V_{be1}$

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}

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

↳ and $V_i = V_{CC} - V_{CE1(sat)} + V_{be1}$

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

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

↳ $V_i = V_o + V_{BE1} = V_{EE} + V_{CE2(sat)} + V_{BE1}$ (0.2V)

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 saturates (or it fries)

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

⇒ Q_1 cuts off ($I_{C1} = 0$)

⇒ V_o clamps @ $-I_Q R_L$

& further decreases in V_i → no Δ in V_o

Fix by making I_Q = large

↳ Problem: too much power consumption

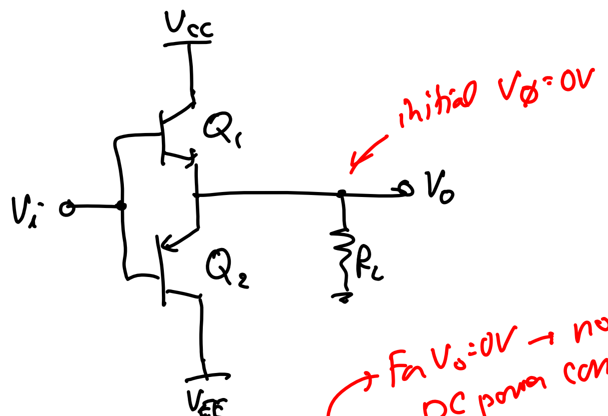
$P_Q = (V_{CC} - V_{EE}) I_Q$ ← DC power consumption!

V_{EE} = (−)

w/ Class A, if you want a large output swing w/ R_L = small, you must consume power!

Solution: Class B Output Stage

↳ Can attain zero DC (a quiescent) power



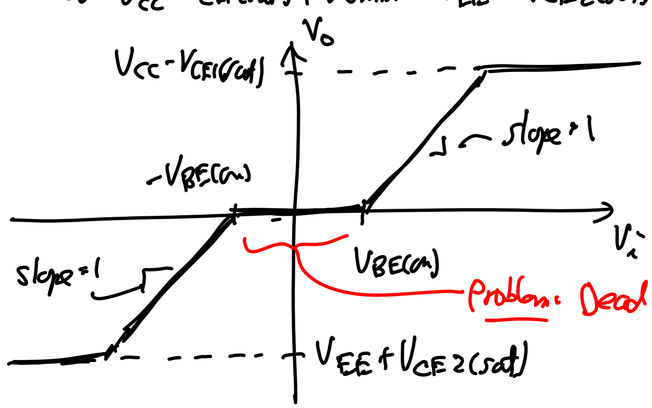
For $V_o = 0V$ → no DC power consumption!

Operation:

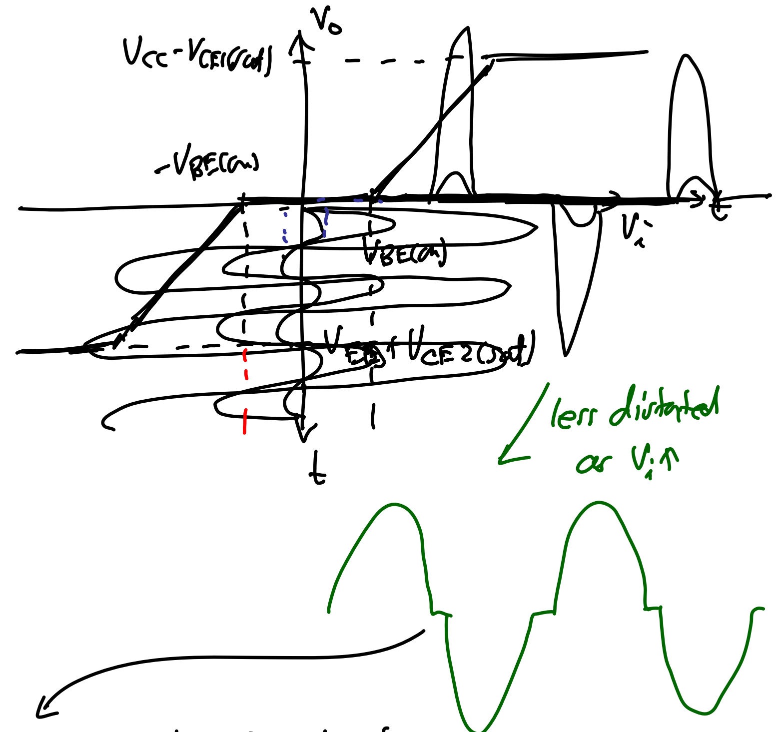
$|V_i| < V_{BE(on)} \rightarrow I_{E1} = I_{E2} = 0 \rightarrow V_o = 0V$

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

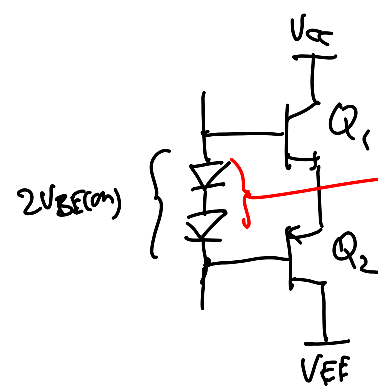
$V_{omax} = V_{CC} - V_{CE1(sat)}$, $V_{omin} = V_{EE} + V_{CE2(sat)}$



Problem: Dead Zone.



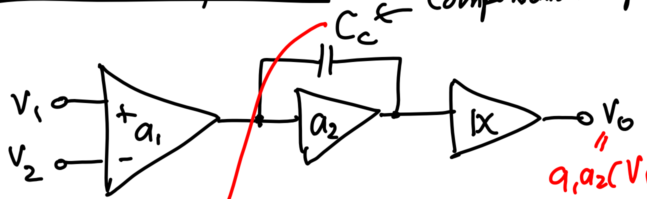
To remove distortion due to the dead zone → compromise: Class AB



These keep Q_1 & Q_2 on, but w/ much less DC power consumption than Class A

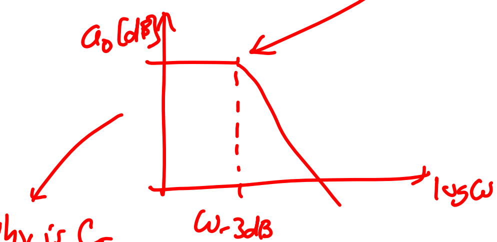
Stability & Compensation

compensation capacitor



$V_o = a_1 a_2 (V_1 - V_2)$, with $a_1 a_2 = a_o$

Used to set BW.



Why is C_c needed?

Stability & Compensation in Op Amps

causes instability!

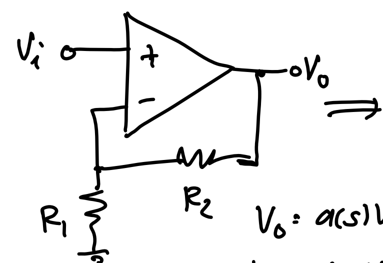
In general, op amps are used in neg. FB loops.

Reasons:

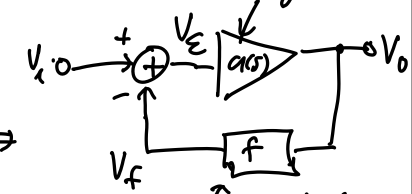
1. Feedback sets the biasing → no large coupling or bypass caps needed.
2. FB increases BW.
3. FB increases linearity or input range. (e.g., emitter degeneration is a type of FB)
4. Gain determined by external FB components → more accurate than op amp gain.
5. FB sets R_i and R_o.
6. FB can improve temperature stability.

→ Problem: any FB loop can become unstable under certain conditions
→ need to compensate the instabilities

Ex. Non-Inverting Amplifier



⟹



$V_o = a(s) V_\varepsilon$
$V_\varepsilon = V_i - V_f$
$V_f = f V_o$

$$V_o = a(s)(V_i - fV_o)$$

$$A(s) = \frac{V_o(s)}{V_i(s)} = \frac{a(s)}{1 + a(s)f} = \frac{a(s)}{1 + T(s)}$$

$A(s)$: Closed Loop Voltage Gain

$a(s)f$, $T(s)$: Loop Transmission

$T(s) = a(s)f$, $T_o = T(0)$

Instability occurs when $A(s) \to \infty$.

$$\Rightarrow A(s) = \frac{a(s)}{1 + a(s)f} \longrightarrow A(s) = \frac{a(s)}{1 - 1} \to \infty$$

$a(s)f = -1$

will also go unstable when denominator = (−)

In General:

$\boxed{\text{If } |a(s)f| \geq 1 \text{ when } \measuredangle a(s)f = -180^\circ \Rightarrow \text{Unstable!}}$

This is just a simplified form of the Nyquist Criterion.