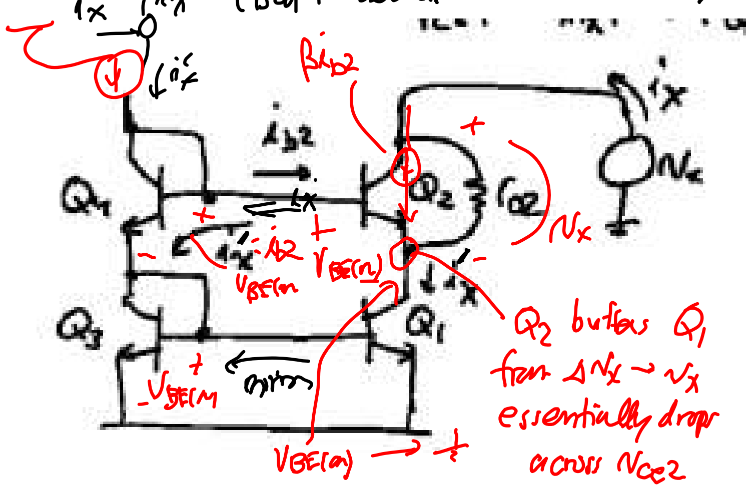
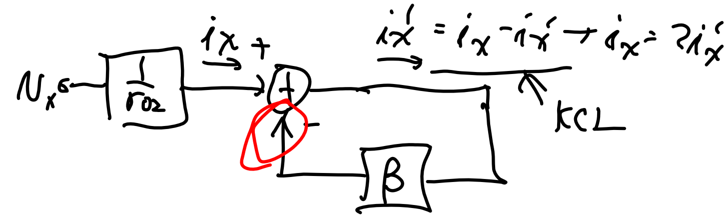
Lecture 18: Stability

- **Announcements**:
  - Midterm: Thursday, Oct. 29, 6-8 p.m. in 141 McCone (this coming Thursday)
  - No lecture this coming Thursday -> Prof. Nguyen will hold office hours, instead
  - Midterm info sheet online (indicates extra office hours this week)
  - Solutions to all HW's through HW#7 online (except 1A)
  - Review Session on Tuesday evening, 6-8 p.m., in 293 Cory
  - 240A students: HW#1A due Friday, Nov. 6
- **Lecture Topics**:
  - Finish output stages
  - Stability
- ------------------------------------
- **Last Time**:
- Nearly finished output stages … finish now (But 1st address a midterm solution) ↑ from Spring 2013





$$\frac{v_x}{i_x'} = (\beta+1) r_{o2} \rightarrow \frac{v_x}{i_x} = \frac{1}{2}(\beta+1) r_{o2} = \frac{1}{2}\beta r_{o2} \checkmark$$

$i_x' = \frac{i_x}{2}$

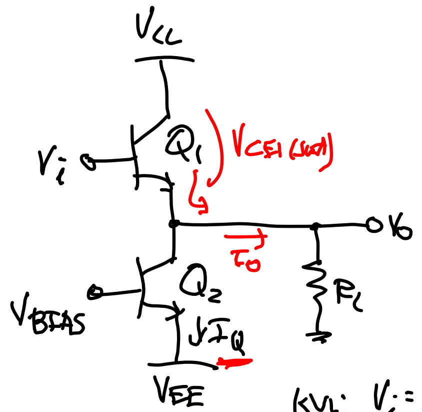
$$i_x' = \frac{v_x}{r_{o2}} - \beta i_x' \rightarrow i_x'(\beta+1) = \frac{v_x}{r_{o2}}$$

$$\frac{v_x}{i_x'} = (\beta+1) r_{o2}$$

⇒ above done by essentially "following the currents" through the feedback ckt.

⇒ Can also do this using full hybrid-π circuit analysis → got the same answer
↘ this is how most did it on the Spring 2013 Midterm

Class A Output Stage (last time)



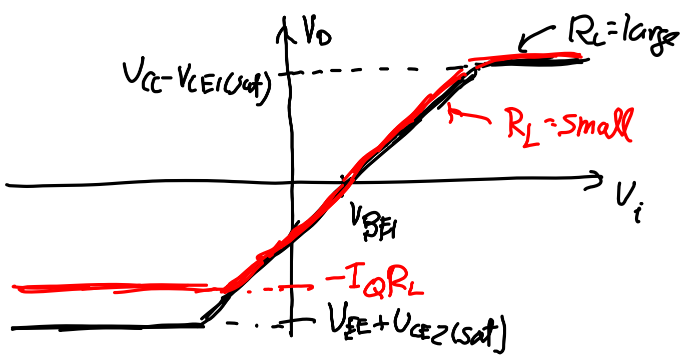
KVL: $V_i = V_o + V_{be1} \approx V_o + V_{BE1}$

More Accurate:

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

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

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



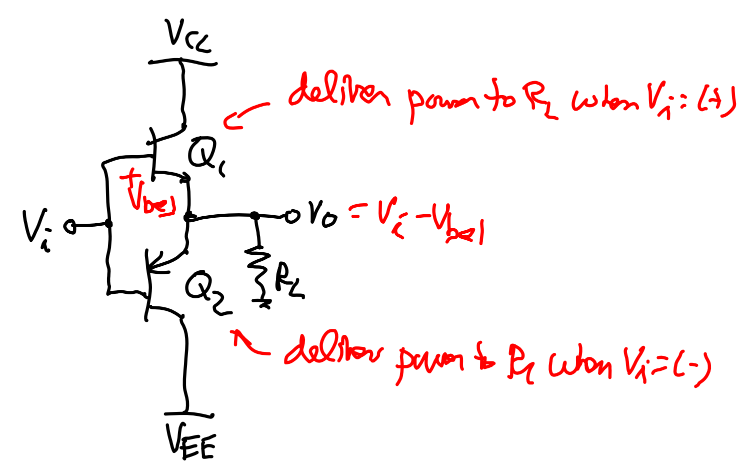
If must drive R_L=small → need large I_Q

Problem: too much power consumption

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

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

Solution: Class B Output Stage

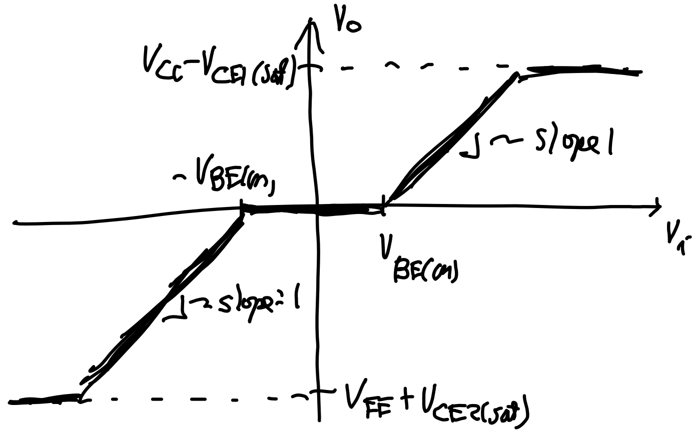


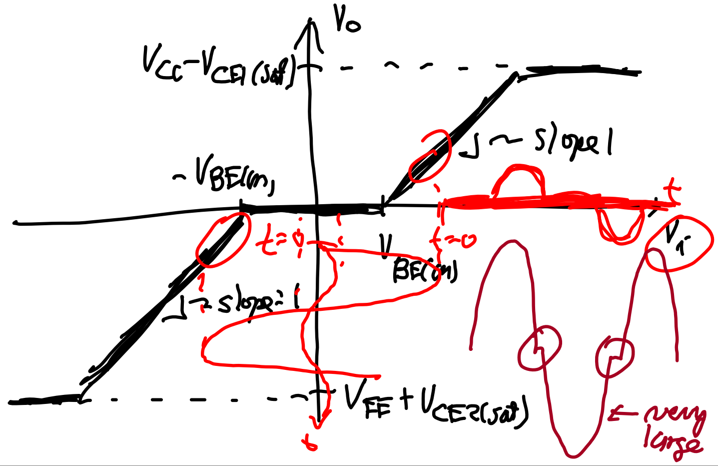
Operation:

$|V_i| < V_{BE(on)} \rightarrow I_{E1} = I_{E2} = 0 \rightarrow V_o = 0V$ (Q_1 & Q_2 cut-off)

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

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

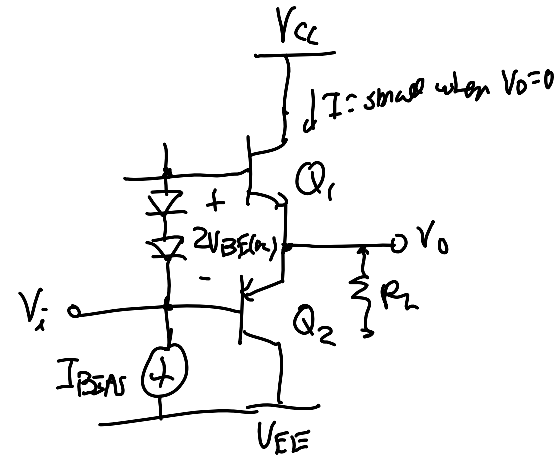




Problem: Distorted output due to the dead zone.

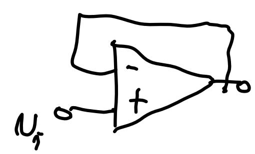
Solution: Class AB Amplifier

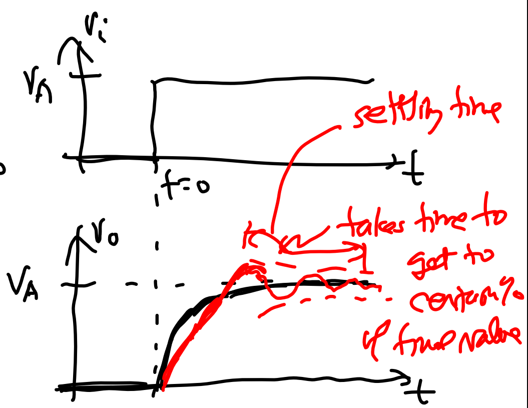
↳ use diodes to supply enough voltage to keep Q_1 & Q_2 on w/ small current



⇒ you will see this on a future HW

Settling Time





Stability & Compensation in Op Amps

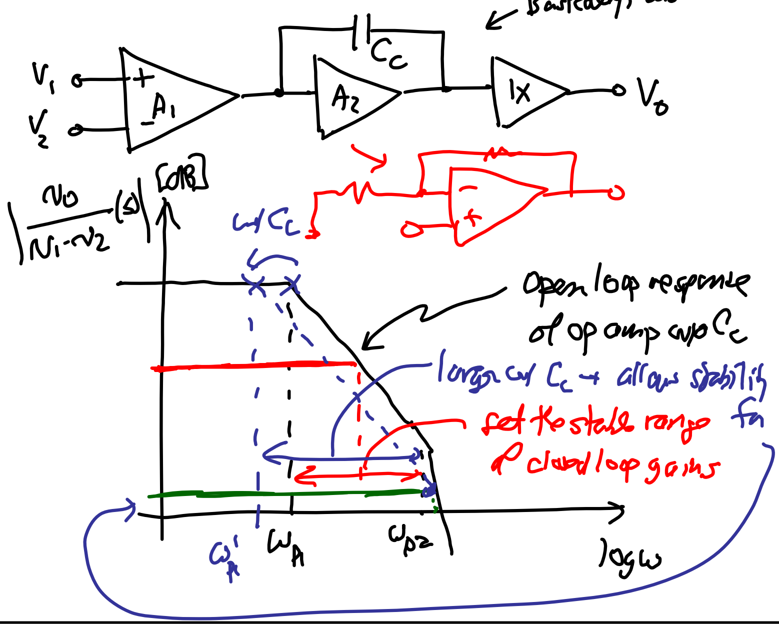
In general, op amps are used in neg FB loops.

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.

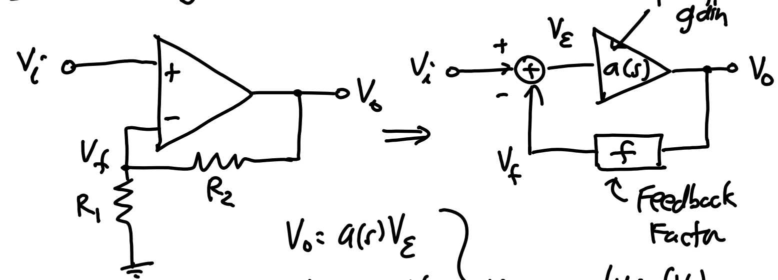
Stability & Compensation

← Basically, Lab#2.



⇒ Problem: any FB loop can become unstable under certain conditions → ∴ must compensate to suppress instability!

Ex. Non-inverting Amplifier



$$V_o = a(s)V_\varepsilon, \quad V_\varepsilon = V_i - V_f, \quad V_f = fV_o \;\Big\}\; V_o = a(s)(V_i - fV_o)$$

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

$A(s)$ ↑ closed loop gain

Loop Transmission $= T(s) = a(s)f$ ↳ fcn of freq.

e.g., loop gain $= a(j\omega{=}0)f = a_o f = T_o$

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

$$\Rightarrow A(s) = \frac{a(s)}{1 + a(s)f} \rightarrow A(s) = \frac{a(s)}{1-1} = \frac{a(s)}{0} \rightarrow \infty$$

↗ $a(s)f = -1$ (loop transmission)

↘ will also go unstable if denominator is (−)

In General:

If $|a(s)f| \geq 1$ when $\measuredangle a(s)f = -180^\circ$ $\Rightarrow$ unstable

This is a simplified form of the Nyquist criterion.

Stability of a FB Ckt. Using a Single-Pole Op Amp

For a single-pole op amp: $a(s) = \dfrac{a_o}{1 - \frac{s}{p_1}}$ = open-loop op amp Xfer Fcn.

Thus: (close the loop)

$$A(s) = \frac{a(s)}{1 + a(s)f} = \frac{a_o}{1 + a_o f} \cdot \frac{1}{1 - \frac{s}{p_1(1 + a_o f)}}$$

$A(s)$ = closed-loop Xfer Fcn

A_o = closed-loop dc gain; if $a_o f >> 1 \rightarrow \approx \frac{1}{f}$

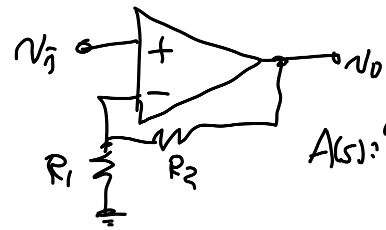
BW increases by $1 + a_o f$

$T_o = a_o f$ = loop gain (defined @ DC)

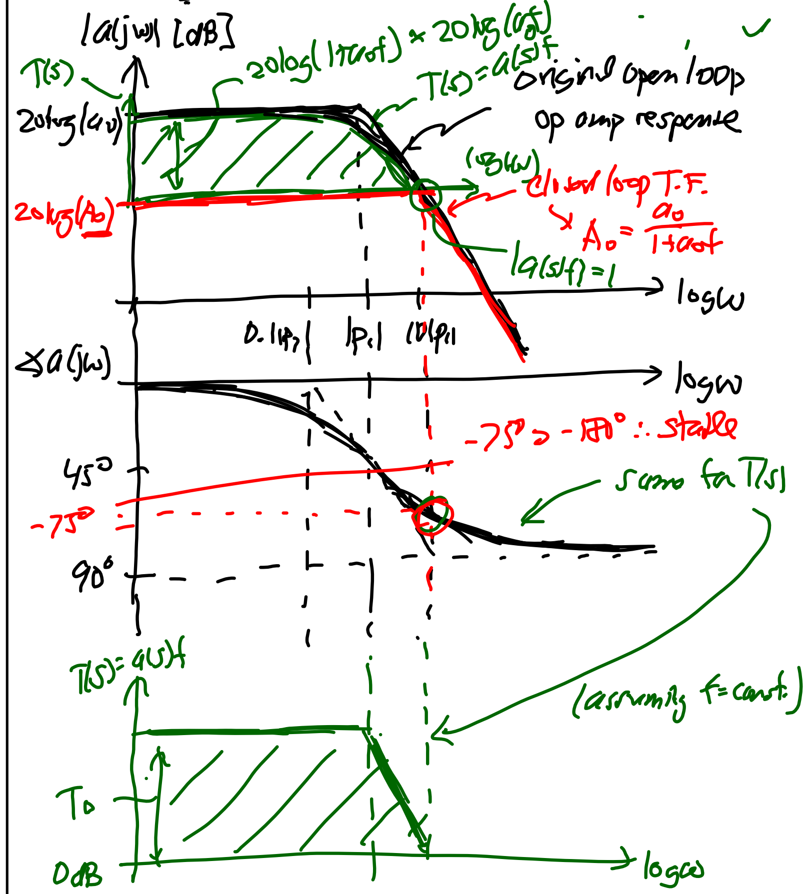
$T(s) = a(s)f$ = loop transmission (defined for general freqs.)

Bode Plot: → use to determine $\measuredangle a(s)f$ when $|a(s)f| = 1 = 0\,dB$

then can determine stability



$$A(s) = \frac{v_o}{v_i}(s) = \frac{a(s)}{1 + a(s)f}$$



Remarks:

① For the case of a single-pole op amp, FB (w/ f = const) can never reach $\angle a(s)f = -180°$. (90° is the limit.)

② Thus, a single-pole op amp in FB w/ f = const., i.e., $f \neq$ function of $s = j\omega$, is always stable!

↓

But in reality, any op amp will have more than one pole → two poles get to $a(s)f = -180°$

↓

instigate instability

↓

Use a Bode plot to investigate