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

  \[ i_x = i_{x'} \]

  \[ \frac{v_x}{i_x} = \frac{R_{o2}}{R_{o2}} \]

  \[ \frac{v_x}{i_x'} = \frac{1}{2} (B+1) \]

  \[ \frac{v_x}{i_x} = \frac{1}{2} \frac{1}{R_{o2}} \]

  \[ \frac{i_x'}{i_x} = (B+1) \]

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**Class A Output Stage** (last time)

\[ V_{CC} \]
\[ V_i \]
\[ V_{BE} \]
\[ V_{EE} \]
\[ V_C \]
\[ V_{CE} (sat) \]
\[ V_o \]
\[ (V_C = V_o + V_{BE}) \approx V_o + V_{BE} \]

More accurate:

\[ V_{BE} \neq \text{const.} = V_T \ln \left( \frac{I_{C1}}{I_{S1}} \right) \quad (Q_1 \text{ in FAB}) \]

\[ I_C = I_Q + I_0 = I_Q + \frac{V_o}{R_L} \]

\[ V_C = V_o + I_Q R_L \left( \frac{I_Q + V_o}{I_{S1}} \right) \rightarrow \text{for large power} \]

If must drive \( R_L \) small \( \rightarrow \) need large \( I_Q \)

*Problem:* too much power consumption

\[ P_Q = (V_{CC} - V_{EE}) I_Q \rightarrow \text{Dc quiescent power consumption} \]

If want large output swing we need small \( R_L \) \( \rightarrow \) must consume power!

**Solution:** **Class B Output Stage**

\[ V_{CC} \]
\[ V_i \]
\[ V_{BE} \]
\[ V_o = V_C - V_{BE} \]
\[ V_{EE} \]
\[ V_{CE} (sat) \]

\( \text{deliver power to } R_L \text{ when } V_i \geq 3 \)

\( \text{deliver power to } R_L \text{ when } V_i \leq 6 \)
Operation: $C_1 + C_2$ cut-off

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

$V_C > V_i > V_{BE(on)} \rightarrow V_o = V_i - V_{BE(on)}$

$V_{omax} = V_c - V_{CE(sat)}$, $V_{omin} = V_{EE} + V_{CE(sat)}$

Problem: Distorted output due to the dead zone.

Solution: Class AB Amplifier

The divider reduces supply emmy voltage to keep $Q_1, Q_2$ on a very small current.

For $V_o = 0$:

$I_f = \text{small}$

$V_0 = 0$

Setting Time:

$V_A$ takes time to get to constant if time needed.
Stability & Compensation

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

Reason:
1. Feedback sets the biasing and no large coupling or bypass caps needed.
2. FB increases BW.
3. FB increases linearity at inpt range.
   (e.g., emitter degeneration is a type of FB)
4. Gain determined by external FB comp. more accurate than op amp gain.
5. FB sets R1 and R2.
6. FB can improve temp. stability.

Stability & Compensation

= Problem: any FB loop can become unstable under certain conditions. Must compensate to suppress instability.

Ex. Non-inverting Amplifier

\[ V_o = \frac{A(s)}{1+A(s)f} \]

Loop Transmission: \( T(c) = A(s)f \) for op freq.

Instability occurs when \( A(s) \rightarrow \infty \!

\[ \Rightarrow A(s) = \frac{a(s)}{1+a(s)f} \Rightarrow A(s) = \frac{\frac{a(s)}{1+a(s)f}}{1} \rightarrow \infty \]

\[ f \] will also go

\( a(s)f = -1 \) unstable if

loop transmission denominator is \((-1)\)
In General:

If $|a(s)| \geq 1$ when $\phi(s) = -180^\circ$, then the circuit is 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: $a(s) = \frac{a_0}{1 - \frac{s}{p_1}}$  

Thus: (closed loop)  

$$A(s) = \frac{a(s)}{1 + a(s)} = \frac{a_0}{1 + \frac{s}{p_1}}$$

$T(s) = a(s) = \text{open-loop gain}$  

$T(c) = a(s)T(s) = \text{loop transmission (defined for general freqs.)}$

**Bode Plot**

- Use to determine $a(s)$ when $|a(s)| = 1$ dB
- Then can determine stability

![Bode Plot Diagram]

- $T(s)$: open-loop TF
- $T(c)$: closed-loop TF
- $a_0 = 1 + a(s)$
- $a(s) = 1 + a(s)$
- $T(s) = 1 + a(s)$
Remarks:

1. For the case of a single-pole op amp, $\angle A(s) = -180^\circ$. (90° is the limit.)

2. Thus, a single-pole op amp in FB with $f = \text{const.}$, i.e., $f$ is a function of $s = j\omega$, is always stable.

But in reality, any op amp will have more than one pole, and the poles get to

\[ \angle A(s) = -180^\circ \]

instigate instability.

Use a Bode plot to investigate.