EE 140: Analog Integrated Circuits
Lecture 17: Compensation & Slew Rate

- Announcements:
  - Midterm Exam: Thursday, 3/19, 12:30-2 p.m. (during normal class time)
  - Review Session: Tuesday evening, 7-9 p.m., in 145 McCone

- Today:
  - Compensation (1st Pass)
  - Slew Rate (1st Pass)
  - Output Stages

Gain -
1st Stage: \( A_{N1} \frac{N_D}{N_A} = -g_{m2} (r_{ox} |r_{ov}|) \)
2nd Stage: \( A_{N2} = \frac{N_B}{N_D} = -g_{m6} (r_{ox} |r_{ov}|) \)
\( A_N = A_{N1} A_{N2} = g_{m2} (r_{ox} |r_{ov}|) g_{m6} (r_{ox} |r_{ov}|) \)

Freq. Response:
- Dominant Pole
- Gain
- Compensation
- Slew Rate
- Output Stages

\[ W_{in} = \frac{r_{ox} (1 + g_{m6} (r_{ox} |r_{ov}|)) C_C}{C_{min}} \]

\[ V_{swing} = V_{DD} - V_N - |V_{OV}| - V_{OV} \]

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Remarks:

1. You analyze this in Lab 2.
2. Usually, the resistively-loaded diff. pair is replaced with an active current mirror load for more gain.
3. $R_{6}$ raises the input $R$ of $Q_{6}$ (of the 2nd gain stage), plus helps w/ biasing.
4. Same comment as 3 for the output stage.
5. Output stage needed when driving a resistive load
   
   \[ R \approx 0 \]
   
   often the case for bipolar
   
   not often the case for MOS, when a capacitive load $C_{L}$ is often more relevant → MOS op amp often don't need output stage!

over $S$
Compensation: A First Pole

This is a compensation capacitor.

In your lab, you are to replace this with this.

In your lab, simply choose $C_c$ so that it generates the same $w_p$ as the original $C = 680 \text{ pF}$. Again, doing this for stability reasons:

Again, concerned about this $w_p$ issue, the larger this $w_p$, the more stable the op amp ckt.

Slew Rate

Using Laplace Xform Theory:

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

$V_i(s) \Rightarrow V_A \Rightarrow$ single (dominant) pole

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

Inverse Laplace Xform

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

Open-loop op amp transfer function for the unity gain buffer

$|V_o|/|V_i|$

Again, concerned about this $w_p$, the larger this $w_p$, the more stable the op amp ckt.

Why this slow rise?

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Reason: 1st & 2nd stage of op amp cannot source enough current to mimic the slope (or speed) of a fast rising input signal.

If apply a very fast (i.e., high freq., large amplitude) signal:

\[ V_o(t) = \text{slew rate} \] (due to slew)

\[ \text{slew rate} = \frac{\text{d}V_o}{\text{d}t} \]

**Output Stages**

- Class A (Emitter as 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 \( R_h \), low \( R_o \)
2. Low quiescent power
3. Minimal effect on amplifier freq. response
4. Should be able to handle large input/output swings (i.e., \( V_i \) may be > \( V_h \), invalidating small-signal approximations)