Lecture 17: Slew Rate & Output Stages

• **Announcements:**
  - HW#7 due Monday, Oct. 26, at 8 a.m.
  - 240A students should be working on HW#1A, too, due Friday, Nov. 6
  - I will be traveling again this Friday, returning next Monday - should be back in time for office hours, depending on flight arrival time
  - Midterm will be on the date specified in your syllabus: Thursday, Oct. 29, 6-8 p.m. in 141 McCone

• **Lecture Topics:**
  - Slew Rate (a 1st pass)
  - Output Stages

• **Last Time:**
  - Telescopic op amps

• For the compensation part of your lab, just assume the load is the oscilloscope input, which is probably 1MΩ
Reason: 1st or 2nd stage of op amp cannot source enough current to mimic the shape (or speed) of a fast rising theoretical output waveform.

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

\[ V_{no} = \frac{\Delta V}{\Delta t} \]

\[ SR = \text{Slew Rate} = \frac{\Delta V_{no}}{\Delta t} = \frac{2I_t}{C_c} \]

Stability determined

\[ \text{settling time} = T_s \]

Determine \( V_o \) for \( SR \)

Can follow small sinusoid

Cannot follow large one

\[ V_{DD} \]

\[ V_o \]

\[ M_1, M_2 \]

\[ \mu \]

\[ C_c \]

\[ Q \]

\[ \frac{\Delta V_{no}}{\Delta t} \]

\[ V_{in} \]

\[ 2I_t \]

\[ \int 2I_t \, dt \]

\[ T_s \]

\[ V_{no} \]

\[ V_{DD} \]

\[ C_c + Q \]

\[ M_1, M_2 \]

\[ \mu \]

\[ 2I_t \]

\[ \int 2I_t \, dt \]

\[ T_s \]

\[ V_{DD} \]

\[ V_{no} \]

\[ C_c \]

\[ Q \]

\[ V_{in} \]

\[ 2I_t \]

\[ V_{DD} \]

\[ V_{no} \]

\[ C_c + Q \]

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\[ \int 2I_t \, dt \]

\[ T_s \]

\[ V_{DD} \]

\[ V_{no} \]

\[ C_c \]

\[ Q \]

\[ V_{in} \]

\[ 2I_t \]

\[ \int 2I_t \, dt \]

\[ T_s \]
**Output Stages**

- **Class A** (Emmitte a Sava Follina)
- **Class B**
- **Class AB** (we’ll do this one later)

**Purpose:** Drive loads

1. Delins power with small distortion.
2. Minimize output impedance so that the amplifier gain is insensitive to the load.

**Desirable Attributes:**

1. High RH; Low RC: **assuring voltage application**
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 $\approx V_t$, invalidating small-signal approximations)

**Emmitte Follina (Class A)**

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**Two Main Cases:**

1. $I_o > 0, V_o > 0$:
   - $I_o$ can occur from $Q_1$
   - $I_o$ can be achieved for $V_o > V_t$

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: $I_o = f(V_o)$
     - $I_o$ may be $\approx V_t$, invalidating small-signal approximations

**Solution:** Replace $R_E$ with a current source.
Two Cases: (depending on the size of $R_L$)

Case 1: $R_L$ is large ($I_o < I_q$)

- $I_o$ not limiting much
- $I_c$ is not limiting much
- For $V_i$ large and ($+$): $Q_1$ must source $I_o + I_q$
- $V_o = V_i - V_{BE1}$ at some point, $Q_1$ will saturate as $V_o \uparrow$

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

$V_i = V_{CC} - V_{CE1(sat)} + V_{BE1} \leq V_{CC}$

For $V_i$ large and ($-$): $V_o$ follows $V_i$ until $Q_2$ saturates

Get $V_{min} = V_{EE} + V_{CE2(sat)}$

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

Case 2: $R_L$ is small

- $I_o$ can be large
- For $V_i$ large and ($+$): $Q_1$ can source as much current as needed until it either saturates or it fries
- For $V_i$ large and ($-$): $V_o = I_o R_L \Rightarrow \text{min.} V_o = -I_o R_L$

$\Rightarrow Q_1$ cuts off ($I_c \approx 0$)

Further decrease in $V_i$ yields no $V_o$
If must drive $R_L$: small $\rightarrow$ need large $I_Q$

Problem: too much power consumption

$P_Q = (V_C - V_{EE})I_Q \rightarrow$ DC component power consumption

If want large output swing with small $R_L$, must consume power.

Solution: Common Collector Stage

\[ V_o = V_C - V_{BE(m)} \]

\[ V_o = V_C - V_{BE} \]

\[ V_o = V_C - V_{BE(m)} \]

\[ V_{CE(m)} \]

Operation:

1. $|V_x| < V_{BE(m)} \rightarrow I_{E1}, I_{E2} = 0 \rightarrow V_o = 0V$
2. $V_C = (V_x > V_{BE(m)} \rightarrow V_o \approx V_x - V_{BE(m)}$
3. $V_{max} = V_C - V_{CE(1st)}$, $V_{min} = V_{EE} + V_{CE(2nd)}$
4. $V_{CE(m)}$ = slope 1
5. $V_{EE} + V_{CE(2nd)}$
6. $V_{BE(m)}$
7. $V_{max}$

\[ V_{CC} - V_{CE} \]

\[ V_x \]

\[ V_{BE} \]

\[ V_{max} \]

\[ V_{min} \]

\[ V_{EE} + V_{CE} \]