Lecture 7: Active Loads I

- Announcements:
  - Lab 1 next week - report to your lab section
  - HW#3 online; due next Wednesday at 8 a.m.
  - Passed out some extra computer account sheets
    - Come to my office if you still don’t have one

- Lecture Topics:
  - Short Ckt Time Constant (SCTC) Analysis
  - Example Low Freq. Response Determination
  - Active Loads
    - Why active loads?
    - Examples of actively loaded amplifiers

- Last Time:
  - OCTC analysis to get dominant high frequency pole
  - Ended with two-stage amplifier example
For a bipolet follower: \[ V_{out} = \frac{V_{in}}{1 + sRC} \]

Low Freq. Amplifier Response Using Short-Circuit Time Constant Analysis (SCTA)

Recall:

- \[ A_{m}(j\omega) \rightarrow \text{midband gain} \]
- \[ A_{m} = \frac{A_{m}(j\omega)}{A_{m}(j\omega)} \]

In general, for the low freq. response:

\[ F_{c}(s) = \frac{s^{n_{1}} + a_{1}s^{n_{1}-1} + \ldots}{s^{n_{2}} + a_{2}s^{n_{2}-1} + \ldots} , \quad n_{1}: \text{poles} \rightarrow \text{zeros} \]

We can express the coefficient \( c_{1} \) by:

\[ c_{1} = \frac{w_{1} + w_{2} + \ldots + w_{n_{1}}}{w_{1}} \]

For the case of a dominant pole:

\[ \text{i.e., the highest freq. pole} \]

\[ F_{c}(s) = \frac{s}{s+w_{l}} = \frac{s}{s+\omega_{l}} \rightarrow c_{1} = \omega_{l} = \omega_{l} \]

\[ \omega_{l} = e_{1} = \sum_{j} w_{j} = \sum_{j} \frac{1}{C_{j}R_{j}} = \sum_{j} \frac{1}{C_{j}R_{j}} \]

Where \( C_{j} \) are various large (>10nF) capacitors in the ckt. (e.g., the bypass caps.)

\( R_{j} \) is driving point resistance seen between the terminals of \( C_{j} \) determined with:

1. all large capacitors short-circuited, except \( C_{j} \), which is replaced by its test voltage source for \( R_{j} \) determination.

For reading:

- Can go to Sedra & Smith.
(2) all independent sources eliminated
(i.e., short voltage sources, open current sources)
(3) open all H.F. capacitors (i.e., small caps in the P.F. range, or < 1 nF)

Again, for the case where there are no dominant poles,
a reasonable approximation is:

$$\omega_L \approx \sqrt{\omega_1^2 + \omega_2^2 - 2\omega_1\omega_2}$$

Ex: Determine the L.F. response of a C.E. Amplifier.

(a) \( Z_{ZCB} = \text{short ckt. } C_C \parallel C_E \)

\( R_{BS} = \frac{V_x}{I_x} = \text{resistance in emitter} \)

\( \frac{R_{BS}}{R_E + R_{BS}} \)

\( T_C = R_C = \frac{1}{C_C} \)

(b) \( T_{due\ to\ C_C} \text{ short ckt. } C_C \parallel C_E \)

\( = \text{again } R_C = \text{resistance in emitter } C_C \)

\( T_C = (R_L + R_4) \frac{1}{C_C} \) \( \text{seen on both sides} \)

\( T_C = \frac{1}{C_C} \left( \frac{1}{R_L} + \frac{1}{R_4} \right) C_C \)

(c) \( T_{due\ to\ C_E} \text{ short } C_E \parallel C_C \)

\( T_C = \frac{1}{C_E} \left( \frac{1}{R_E} + \frac{1}{R_{EC}} \right) C_E \)

And finally:

\( \omega_L = \omega_1 + \omega_2 + \omega_F \)
Active Loads

- Why use them?
  
  $\text{Gain: } \frac{V_O}{V_i} = -g_m R_D$

  $V_{DD} \rightarrow V_{RD}$ \{Resistor\}

  $V_{RD} = \frac{1}{R_D}$ \{Drive Device\}

  $N_i \rightarrow \frac{1}{N_o}$ \{Problem: $V_{RD} = I_o R_D$\}

- Raise $R_D$ again, $V_{RD} \uparrow$
  
  Limited by supply $V_{DD}$

  Another problem: area consumption by $R_D$

  Layout:

  - P polysi
  - $\sim 1k\Omega$

  $V_{DD}$

  Norton Equivalent:

  $I_D \rightarrow R_S$
**Diode-Connected Enhancement Load**

\[
\begin{align*}
V_{DD} & \quad \text{s.s. bias} \rightarrow \quad \text{by inspection} \\
R_L &= \frac{V_{DD}}{I_{DSS}} \approx \frac{1}{10 k}\Omega \\
\text{Diode-Connected} \quad R_L &= \frac{V_{DD}}{J_m + G_m} \approx \frac{1}{G_m}
\end{align*}
\]

How about this?

\[
\begin{align*}
\text{by inspection: } R_L &= \frac{1}{J_m + G_m} + R_D \\
\end{align*}
\]

**Full hybrid-\(T\) Analysis:**

\[
\begin{align*}
\text{(in case you want to see it)} \\
V_X & \quad \text{KCL: } i_X = -g_m V_X - G_{mb} V_{bs} \\
&= -g_m (V_X - i_X R_D) - G_{mb} V_{bs} \\
&= g_m V_X - g_m R_D i_X + G_{mb} V_X \\
i_X (1 + g_m R_D) &= (g_m + G_{mb}) V_X \\
\therefore \quad R_S &= \frac{V_X}{i_X} = \frac{1 + g_m R_D}{g_m + G_{mb}} = \frac{1}{g_m + G_{mb}} + \frac{R_D}{1 + \eta} \\
R_S &\equiv \frac{1}{g_m + G_{mb}} + R_D
\end{align*}
\]
... and from the top:

\[ P_d = \frac{V_x}{I_x} = \frac{1}{g_m} + (1+n)R_S + \frac{1}{g_m + R_S} \]

Apply to a C.S. Ckt:

\[ a_v = \frac{V_o}{V_i} = \frac{g_m}{g_m + g_{m2}} \]

\[ a_v = -\frac{1}{1+n} \frac{g_m}{\sqrt{g_{m1}g_{m2}}} \]

\[ V_o = V_m \left( \frac{W/L}{L} \right) \]

Diode-Connected PMOS Load

\[ a_v = \frac{V_o}{V_i} = g_m \left( \frac{W/L}{L} \right) \]

PMOS Current Source Load

\[ a_v = -\frac{g_m}{g_{ds1} + g_{ds2}} \]

Gain is huge! - but... beware! VSSAS
Ex. Multi-Stage Actively-Loaded MOS Ckt.

Wanted $R_{x1}, R_{x2}, A_n, W_H$.

$A_n = \frac{N_D}{N_S} \cdot \frac{N_G}{N_D} \cdot \frac{N_O}{N_G}$

$A_n = \frac{1}{\left(1 - \frac{g_m (R_o 1 R_o 2)}{1 + g_m (R_o 1 R_o 2)}\right)} \cdot \frac{g_m (R_o 1 R_o 2)}{1 + g_m (R_o 1 R_o 2)}$

$A_{side} = \frac{N_D}{N_S} \cdot \frac{g_m R_e}{1 + g_m R_e}$

Now, tackle freq. response.