Lecture 35: Purposeful Design

- Announcements:
  - HW#11 online and due in 2 weeks on Friday, 12/4
  - Lab#5 due today at 5 p.m. PT
  - Lab#6 online and due Friday, 12/11 (last day of RRR week)
  - Next week, only have lecture on Monday, since Wednesday is a non-instructional day
  - I have computed your Z's and will email you individually to give you the value
    - I will just give the value in the email and we will discuss what it means in lecture

- Lecture Topics:
  - Multi-Transistor Example (Inspection Analysis)
    - Input/Output Resistances
    - Gain
    - High Frequency
  - Purposeful Design
  - Cascade Amplifier
  - MOS Inspection Analysis

- Last Time:
  - Nearly finished with high frequency analysis
  - Now, continue with this ...

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Example: Multi-Transistor Amplifier, Inspection Analysis

(C.E. w/ Degeneration, C.C. Cascade)

Find $R_s, R_o, AV = \frac{V_o}{V_s},$ and $f_H.$

First, find the DC operating point.

Good Design: $I_{B_E1} > 10I_E1$

\[
V_B1 = \frac{R_2}{R_1 + R_2} V_{CC} \quad V_{E1} = V_{B1} - V_{BE1(oN)} \approx 0.7V \\
I_{E1} \approx I_{E1} \approx \frac{V_{E1}}{R_{E1} + R'} \approx \frac{V_{E1} - V_{BE1(oN)}}{R_{E1} + R'} \approx 0.7V \\
V_{E2} = V_{CC} - I_{E1} R_s = V_{B2} \rightarrow V_{E2} = V_{B2} - V_{BE2(oN)}
\]
Incorporating Results from Last Time

\[ \omega_H = \frac{1}{C_1 R_2 + C_2 R_2 + C_3 R_3 + C_M R_{MN} + C_{22} R_{22}} \]

- \( C_1 \) & \( C_2 \): determined
- \( C_{22} \): determined
- \( R_{MN} \): determined

\[ R_{\text{eff}} = \frac{R_{BE} + R_E}{1 + G_{mE} R_E} \]

- \( R_{\text{eff}} \): effective resistance

Using OTC Analysis:

\[ C_1 \text{ at node 2} \]
\[ R_2 \text{ at node 2} \]

\[ T_2 = C_{MN} \left( \frac{1 + G_{mE} R_E}{1 + G_{mE} R_E} \right) R_S \]

\[ T_3 = (C_{CS1} + C_{MN} + C_{22}) R_E \]

\[ T_4 = C_L \left( \frac{R_E + R_E}{R_{22}} \right) \]

\[ \omega_H = \left\{ \begin{array}{c} \omega_H \left( R_{BE} + R_E \right) \left( R_{CS1} + C_{MN} + C_{22} \right) R_E_0 \\ + C_L \left( \frac{R_{22}}{R_2 + R_E} \right) + C_M \left( \frac{R_{BE} + R_E}{1 + G_{mE} R_E} \right) \end{array} \right\} \]

\( \omega_H \approx 1 \]

\( \times \): neglect

\( \checkmark \): include

\( N'N' \approx 0 \text{V} \) no voltage across \( C_{22} \) → neglect its contribution
By merely altering the placements of input/output signals and bypass/coupling capacitors, one can realize many amplifier configurations.

Some of the most useful examples:

1. Common-Collector Amplifier (Emitter Follower)
   - Gain = \( \frac{V_{out}}{V_{in}} = \frac{1}{1 + \frac{R_{e}}{R_{l}} + \frac{1}{g_m R_C}} \)
   - Output resistance: \( R_o \approx \frac{R_{e}}{g_m R_C} \)
   - Input resistance: \( R_i = \infty \)

2. Common-Basis Amplifier
   - Gain = \( \frac{V_{out}}{V_{in}} = \frac{g_m R_C}{R_e} \)
   - Output resistance: \( R_o = \frac{R_{e}}{g_m} \)
   - Input resistance: \( R_i = \infty \)

3. Common-Emitter Amplifier with Degeneration
   - Gain = \( \frac{V_{out}}{V_{in}} = \frac{g_m R_C}{R_{e1} + (g_m R_C) R_{e2}} \)
   - Output resistance: \( R_o = \frac{R_{e1} R_{e2}}{R_{e1} + (g_m R_C) R_{e2}} \)
   - Input resistance: \( R_i = \frac{R_{e1}}{g_m} \)
Multi-Stage Amplifier Design Guidelines
(for voltage amplifiers) (i.e. amps, etc., would have different chart)

<table>
<thead>
<tr>
<th>Ideal Voltage Amp</th>
<th>C.E.</th>
<th>C.E. w/ R_e</th>
<th>C.C.</th>
<th>C.B.</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_i</td>
<td>∞</td>
<td>large</td>
<td>√</td>
<td>small</td>
</tr>
<tr>
<td>R_o</td>
<td>0</td>
<td>large</td>
<td>X</td>
<td>large</td>
</tr>
<tr>
<td>a_v</td>
<td>∞</td>
<td>medium</td>
<td>X</td>
<td>large</td>
</tr>
<tr>
<td>f_H</td>
<td>∞</td>
<td>small</td>
<td>X</td>
<td>large</td>
</tr>
</tbody>
</table>

To Get Better V➔V Performance ➔ Cascade Amplifier

⇒ For a good voltage amplifier:

⇒ add biasing: $V_{cc}$

Biaseing: For stability, $I_{bias} > 10I_B$

$V_B = V_{cc} \left( \frac{R_2}{R_1+R_2} \right) \rightarrow V_{E1} = V_B - V_{BE(on)}$

$I_C = I_E = \frac{V_{E1}}{R_{E1}} \rightarrow V_{E2} = V_{E1} - V_{BE(on)} - V_{B1} - V_{BE(on)}$

$I_C2 = I_E2 = \frac{V_{E2}}{R_{E2}} \rightarrow V_{C2} = V_{CC} - I_{C2}R_{E2}$

$V_{E3} = V_{B3} - V_{BE(on)} \rightarrow I_{E3} = \frac{V_{E3}}{R_{E3}}$
Large Output Swing

$V_{o}$

$V_{max}$ - This can be volts
(e.g., 2V, 10V, ...)

Does this violate our small-signal design criterion? $V_{b-e} << V_t = 25mV$

Gain $\approx 0.99$

$V_{b-e} = 0.01V$

$10mV$

$0.99mV$

$< 25mV / V_t$ (Schottky S.S. criterion)