Lecture 34: Multi-Transistor High Freq. Analysis

- Announcements:
  - No homework this week
  - Lab#5 due Friday at 5 p.m. PT
    - Ideally, you should be focused on writing your report on Wednesday, with no further measurements needed
    - Remember, it is your report that ultimately gets graded
  - Lab#6 online
    - Let’s go through this now

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

- Last Time:
  - Got $R_i$, $R_o$, and Gain of a multi-transistor circuit via inspection
  - Now, get the high frequency cutoff ...

---

**Example: Multi-Transistor Amplifier Inspection Analysis**

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

- Find $R_i$, $R_o$, $f_T$, and $f_H$.
  - First, find the DC operating point.

  Good design: $I_{B_{E2}} > 10I_{E1}$

  \[
  V_B = \frac{R_2}{R_1 + R_2} V_{CC} \rightarrow V_{E1} = V_{B1} - V_{BE(on)} \ \text{neglecting} \ I_{B1}
  \]

  \[
  I_{E1} \approx I_{E1} = \frac{V_{E1}}{R_E1 + R'_E1} = \frac{V_{B1} - V_{BE(on)}}{R_E1 + R'_E1} \ \text{neglecting} \ I_{B1}
  \]

  \[
  V_{E2} = V_{CC} - I_{E2} R_o = V_{B2} \rightarrow V_{E2} = V_{B2} - V_{BE(on)}
  \]
Procedure for High Frequency Inspection Analysis:

- Identify and label all signal path nodes
- Draw in the small transistor capacitors
- Use the Miller transform to turn the base-to-collector or gate-to-drain capacitor into shunt capacitors to ground
- For the base-to-emitter or gate-to-source capacitor you will need to know the equation for driving point resistance, i.e., resistance in parallel
- Get the time constant for each node by
  \[ \text{Determining the total capacitance } C_{\text{node}} \text{ from that node to ground} \]
  \[ \text{Determining the total resistance } R_{\text{node}} \text{ from that node to ground} \]
  \[ \text{Time constant } = R_{\text{node}} * C_{\text{node}} \]
- Handle each feedback capacitor separately using knowledge of its driving point R equation (or derive the equation from scratch using the hybrid-\pi model)
- Add up all the time constants and take the reciprocal to get the \( \omega_H \)

\[ \omega_H = \frac{1}{C_{\text{node}} R_{\text{node}}} \]

\( C_{\text{node}} \) at node 2
\( R_{\text{node}} \) at node 2
\( C \) at node 3
\( R \) at node 3

Have not seen these yet — need to determine the \( R_{10} \)’s.
Do it for the general case:

\[ N_X = N_{\text{be}} \]

\[ N_X = N_{\text{be}} + N_{\text{em}} + \frac{N_{\text{em}}}{N_{\text{er}}} + \frac{N_{\text{em}}}{R_B} \]

\[ N_{\text{er}} = \frac{R_E}{N_{\text{er}}} \left( \frac{N_{\text{em}}}{R_{\text{er}}} - N_{\text{em}} \right) \]

\[ i_X = \frac{N_{\text{em}}}{R_{\text{er}}} + \frac{R_E}{N_{\text{er}}} \left( \frac{N_{\text{em}}}{R_{\text{er}}} - i_X + \frac{N_{\text{em}}}{R_{\text{er}}} \right) \]

\[ i_X = \frac{N_{\text{em}}}{R_{\text{er}}} + \frac{R_E}{N_{\text{er}}} \left( \frac{N_{\text{em}}}{R_{\text{er}}} - i_X + \frac{N_{\text{em}}}{R_{\text{er}}} \right) \]

\[ \frac{N_{\text{em}}}{R_{\text{er}}} \]

\[ R_{\text{to}} = \frac{N_{\text{em}}}{i_X} = \frac{R_E}{R_{\text{er}} + R_B} + \frac{N_{\text{em}}}{i_X + \frac{R_E}{R_{\text{er}}}} \]

\[ R = \frac{R_{\text{to}}}{1 + g_{mR_E}} = \frac{R_{\text{to}}}{1 + g_{mR_E}} \]

\[ \text{For large } R_E \]

\[ \frac{R_{\text{to}}}{1 + g_{mR_E}} \]

\[ \text{For } g_{mR_E} \approx 1 \]

\[ \text{large} \]

\[ \text{small} \]

\[ \text{often can neglect} \]

\[ I_d = \frac{1}{g_{m}} \approx 2.5 \]

Now get the T's for \( \omega_1 \):

\[ C_2 = C_{\text{mu}} \left( \frac{1 + g_{mR_E}}{1 + g_{mR_E}} \right) \]

\[ C_2 = C_{\text{mu}} \left( \frac{1 + g_{mR_E}}{1 + g_{mR_E}} \right) \]

\[ \text{large} \]

\[ \text{large} \]

\[ \text{large} \]

\[ R_0 = R_s || R_{\text{BB}} \left( \frac{r_{\text{in}}(1 + g_{mR_E})}{R_E} \right) = R_s || R_{\text{BB}} \geq R_s \]
\[ Q_3 = C_{C1} + C_{M1} + C_{M2} \]
\[ R_3 = R_{d1} \parallel r_o (1 + \frac{g_m R_i}{1 + R_f R_{gs}}) \parallel \frac{r_o + (R + R_f R_{gs})}{r_{in}} \]

\[ L_0 = (C_{C1} + C_{M1} + C_{M2}) R_{d1} \]

\[ C_0 = C_L \]
\[ R_0 = R_{E2} \parallel \frac{r_o (1 + \frac{g_m R_i}{1 + R_f R_{gs}})}{r_{in}} \]

\[ L_0 = R_{E2} \parallel \frac{(r_o + R_f R_{gs})}{\beta_2 + 1} \]

\[ C_0 = C_L \left( \frac{R_{E2} \parallel R_{d1}}{\beta_2 + 1} \right) \]