Lecture 31: Multi-Transistor High Frequency

Announcements:
- HW#10 online, but not due till Friday next week
- Lab#6 coming soon
- Midterm 2 this Friday, Nov. 15, @ 7 p.m., in 160 Kroeber Hall

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

Last Time:
- Got the gain of the amplifier
- Now, get the high frequency cut-off

Example: Multi-Transistor Amplifier Inspection Analysis

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

Find $R_x, R_o, q_w, N_3$, and $f_n$.

First, find the DC operating pt:

Good Design: (Stable bias pt.) = $I_{BIAS1} > 10 I_B$

- $V_{BI} = \frac{R_2}{R_1 + R_2} V_{cc} \rightarrow V_{E1} = V_{BI} - V_{BE(on)} \approx 0.7V$
- $I_{E1} = \frac{V_{E1}}{R_E1 + R_E1} = \frac{V_{BI} - V_{BE(on)}}{R_E1 + R_E1}$
- $V_{E2} = V_{CC} - I_{E1} R_E1 = V_{B2} \rightarrow V_{E2} = V_{B2} - V_{BE(on)}$
Remarks:
1. Look for the \( V_{BE(on)} \) to well-defined voltages
2. Current is usually determined by \( \frac{V_{CE}}{R_{E}} \).

For bias stability:
\( I_{B1A1} > 10I_{B1} \), also \( I_{Q1} = I_{B1A2} > 10I_{B1} \)

Midband Small-Signal Analysis for Gain, \( R_{o} \), and \( N_{o} \):

\[
R_{o} = R_{E2} \left( \frac{R_{E2} + R_{E1}}{R_{E2}} \right) \]

Get gain \( \frac{N_{o}}{N_{s}} \): (gain from \( 0 \) to \( \theta \))

\[
\frac{N_{o}}{N_{s}} = \frac{R_{E1}}{R_{E1} + R_{E2} + R_{B2}(1 + (\beta_{1} + 1)R_{E1})} \]

\[
\frac{V_{o}}{V_{s}} = \frac{R_{E1}}{R_{E1} + R_{E2} + R_{B2}(1 + (\beta_{1} + 1)R_{E1})} \]

\[
\frac{V_{o}}{V_{s}} = \frac{-g_{m1}R_{E1}}{1 + g_{m1}R_{E1}} \]

\[
\frac{V_{o}}{V_{s}} = \frac{-g_{m1}R_{E1}}{1 + g_{m1}R_{E1}} \]

\[
\frac{V_{o}}{V_{s}} = \frac{R_{E2}R_{E1}}{R_{E2}R_{E1} + R_{o}} \approx 1 \]

\[
\frac{V_{o}}{V_{s}} = \frac{R_{o}}{R_{o} + R_{E2} + R_{E1}} \approx 1 \]

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Procedure for Midband Gain Inspection Analysis:
- Identify and label all signal path nodes
- Get stage gain from node to node
  - For each stage, be sure to account for loading by the next stage, specifically load resistance to ground
  - For transistor terminal-to-terminal gains, will likely need to determine output node resistance to ground
    - including loading by the next stage, and
    - even the influence of loading by the previous stage, e.g., when determining $R_c$
- Take the product of all node-to-node gains to get the total gain
- Can do all of this by inspection if
  - There is no feedback
  - You know all the terminal-to-terminal gain equations or can “see” or “derive” them quickly
  - You know all the equations for resistances looking into the transistor terminals (to ground) or can “see” or “derive” them quickly
  - “see” or “derive” quickly can often be done by following the currents

\[ \frac{N_0}{N_f} = \frac{N_0}{N_f} \cdot \frac{N_0}{N_f} \cdot \frac{N_0}{N_f} \]

\[ = \frac{N_0}{N_f} \left[ \frac{R_{gb}l(C_{ht} + (\beta+1)R_E)}{R_f + R_{gb}l(C_{gt} + (\beta+1)R_E)} \right] \frac{g_m R_E}{1+g_m R_E} = \frac{N_0}{N_f} \]

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
  - Determining the total capacitance $C_{node}$ from that node to ground
  - Determining the total resistance $R_{node}$ from that node to ground
  - Time constant = $R_{node} \cdot C_{node}$
- 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 $\omega_H$
High Freq Analysis

Using OCTC Analysis: $V_{in}^*$

$$V_H = \frac{C_{m1} R_A + C_{m2} R_A + C_{m3} R_A}{C_{m1} + C_{m2} + C_{m3}}$$

Do it for the general case:

$$KCL: i_x = \frac{N_x}{R_T} + \frac{N_0 + N_x}{R_B} = \frac{N_x}{R_T} + \frac{N_x}{R_B} + \frac{N_x}{R_B}$$

$$V_e = R_E \left( \frac{N_x}{R_T} - i_x + g_m N_x \right)$$

$$i_x = \frac{N_x + R_E}{R_B} \left( \frac{N_x}{R_T} - i_x + g_m N_x \right)$$

$$I_x (1 + \frac{R_E}{R_B}) = N_x \left( \frac{1}{R_T} + \frac{1}{R_B} + \frac{R_E}{R_B} \right) + g_m \frac{R_E}{R_B}$$

$$R_{eq} = \frac{V_{in}}{I_x} = \frac{R_T (R_E + R_B)}{1 + gmR_E}$$

$$R_{eq} \approx \frac{1}{g_m}$$

If $\frac{g_m}{r} \gg 1$, can be neglected.
Now, let's work to get $V_{TH}$:

$C_0 = C_{mu}(1+gm_{RE})$

$C_0 = C_{mu}(1 + \frac{gm_{RE}}{gm_{RE} + RE})$

$R_0 = R_s || R_{BB} \parallel (\frac{gm_{RE}}{gm_{RE} + RE} \frac{RE}{R_s}) \approx R_s || R_{BB} \approx R_s$

$z_0 = C_{mu}(1 + \frac{gm_{RE}}{gm_{RE} + RE}) R_s$

$V_{TH} = \frac{1}{\beta_2 + 1} \left( \frac{gm_{RE}}{gm_{RE} + RE} \right) \left( \frac{RE}{R_s} \right)$

$R_3 = R_d || R_{of} \left( 1 + \frac{gm_{RE}}{gm_{RE} + RE} \right) || \left( \frac{gm_{RE}}{gm_{RE} + RE} \right) \left( \frac{RE}{R_s} \right)$

$\approx R_d || R_{of} \left( \frac{gm_{RE}}{gm_{RE} + RE} \right) \left( \frac{RE}{R_s} \right)$

$T_0 = \left( C_{mu} || R_s \right) R_d$