Lecture 33: Multi-Transistor Circuit

- Announcements:
- No homework this week
- Lab#5 2nd checkpoint due in lab this week
  - Show your breadboard on Zoom to your GSI and show that an input gives an output
  - This is meant to ensure that you have not procrastinated till the end; but hopefully you have much more done than just a functional breadboard circuit
- 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 will post today or tomorrow to give you an early look
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- Lecture Topics:
  - Generally-Loaded Transistor
    - Terminal Resistances
    - Terminal-to-Terminal Gains
    - Inspection Analysis Sheet
  - Multi-Transistor Inspection Analysis Example
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- Last Time:
- Went through inspection analysis sheet
- Now, use this to analyze a multi-transistor ckt. …

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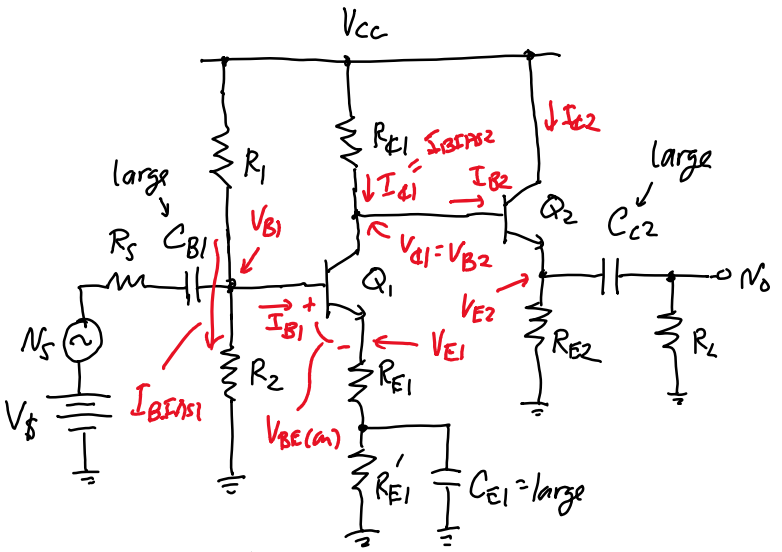
Example. Multi-Transistor Amplifier Inspection Analysis

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



Find R_i, R_o, $A_v = \frac{V_o}{V_s}$, and f_H.

First, find the DC operating point.

Good Design, $I_{BIAS} > 10 I_{B1}$

$V_{B1} = \frac{R_2}{R_1+R_2} V_{CC}$ (neglecting I_{B1}) $\rightarrow V_{E1} = V_{B1} - \underbrace{V_{BE(on)}}_{0.7V}$

$I_{C1} \approx I_{E1} = \frac{V_{E1}}{R_{E1}+R'_{E1}} = \frac{V_{B1}-V_{BE(on)}}{R_{E1}+R'_{E1}}$

$V_{C1} = V_{CC} - I_{C1} R_C = V_{B2} \rightarrow V_{E2} = V_{B2} - \overbrace{V_{BE(on)}}^{0.7V}$

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$I_{E2} \doteq I_{E2} = \frac{V_{E2}}{R_{E2}}$

$[\alpha \approx 1]$

Remarks.

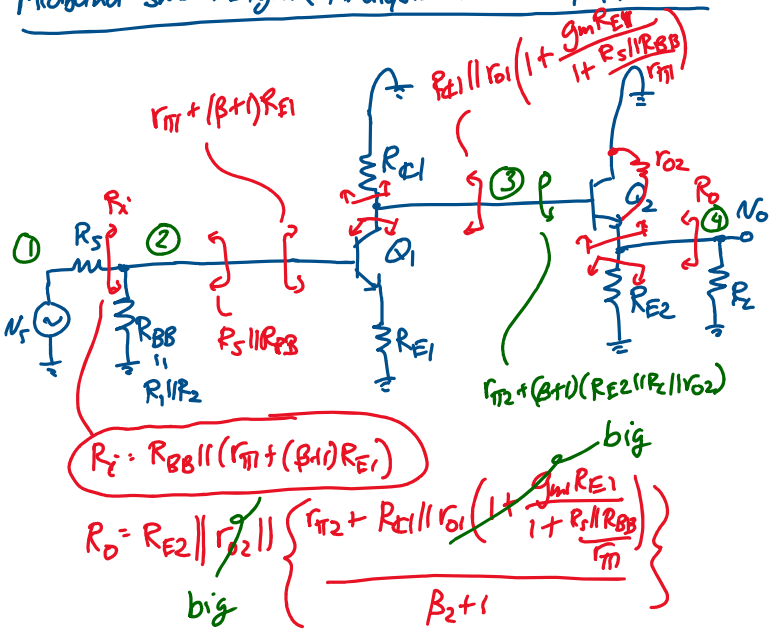
① look for $V_{BE(on)}$'s → well-defined voltage

② Currents usually determined by $\frac{V_E}{R_E}$'s.

For Bias Stability:

$I_{BIAS1} > 10 I_{B1}$ also $I_{BIAS2} = I_{E1} \geq 10 I_{B2}$

Midband Small-Signal Analysis for Gain, R_i, and R_o:



$\therefore R_o = R_{E2} \| \frac{r_{\pi 2} + R_{C1}}{\beta+1}$

Get gain $= \frac{V_o}{V_s}$: (gain from ① to ④)

$\frac{V_o}{V_s} = \frac{V_②}{V_①} \cdot \frac{V_③}{V_②} \cdot \frac{V_④}{V_③}$

$\frac{V_②}{V_①} = \frac{V_②}{V_s} = \frac{R_i}{R_S + R_i} = \frac{R_{BB} \| (r_{\pi 1} + (\beta+1)R_{E1})}{R_S + R_{BB} \| (r_{\pi 1} + (\beta+1)R_{E1})}$

(voltage divider)

$\frac{V_③}{V_②} \doteq -G_{m1} R_{C1}$

$= -\left(\frac{g_{m1}}{1 + g_{m1}R_{E1}}\right)\left\{R_{C1} \| r_{O1}\left(1 + \frac{g_{m1}R_{E1}}{1 + \frac{R_S \| R_{BB}}{r_{\pi 1}}}\right) \| \infty\right\}$

large

$r_{\pi 2} + (\beta+1)(R_{E2} \| R_L \| r_{O2})$

large

$\frac{V_③}{V_②} = -\frac{g_{m1}R_{C1}}{1 + g_{m1}R_{E1}}$

$\frac{V_④}{V_③} = \frac{R_{E2} \| R_L \| r_{O2}}{r_{e2} + R_{E2} \| R_L \| r_{O2}} \approx 1$

$r_{e2} = \frac{1}{g_{m2}} \sim 25\Omega$

$$\therefore \frac{v_o}{v_s} = \frac{v_2}{v_0}\cdot\frac{v_3}{v_2}\cdot\frac{v_4}{v_3}$$

$$= -\frac{R_{BB}\,\|\,(r_{\pi 1}+(\beta+1)R_{E1})}{R_S + R_{BB}\,\|\,(r_{\pi 1}+(\beta+1)R_{E1})}\cdot\frac{g_{m1}R_{C1}}{1+g_{m1}R_{E1}} = \frac{v_o}{v_s}$$

$$[R_S = \text{small}] \Rightarrow \frac{v_o}{v_s} = -\frac{g_{m1}R_{C1}}{1+g_{m1}R_{E1}}$$

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

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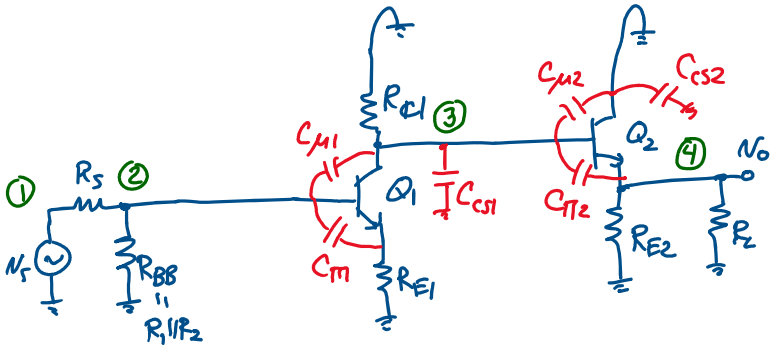
Procedure for High Frequency Inspection Analysis:

- 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 = $R_{node}*C_{node}$
- Handle each feedback capacitor separately using knowledge of its driving point R equation (or derive the equation from scratch using the hybrid-π model
- Add up all the time constants and take the reciprocal to get the ω_H



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