Lecture 34: Cascade Amplifier

- **Announcements**:
- HW#10 online and due Friday Nov. 22
- Lab 6 online and due 5 p.m., Friday, Dec. 13
- Graded Midterm 2 passed back last time
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- Lecture Topics:
  - Purposeful Design
  - Cascade Amplifier
  - Differential Pair
- -----------------------------------
- **Last Time**:
- Explored amplifier stages and cascading
- Now, continue with an example ...

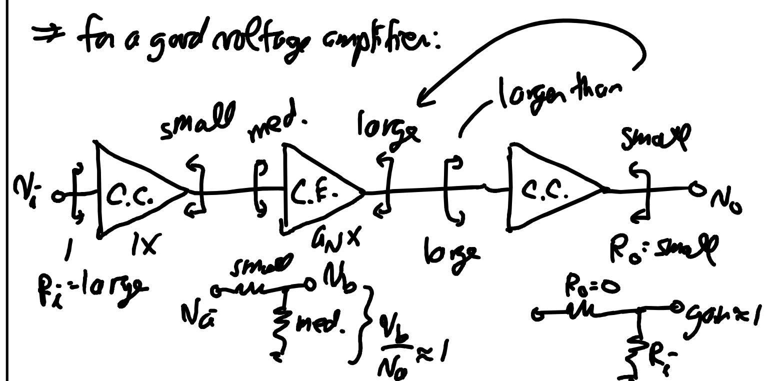
Multi-Stage Amplifier Design Guidelines

(for voltage amplifiers) (i→i amps, etc., would have different charts)

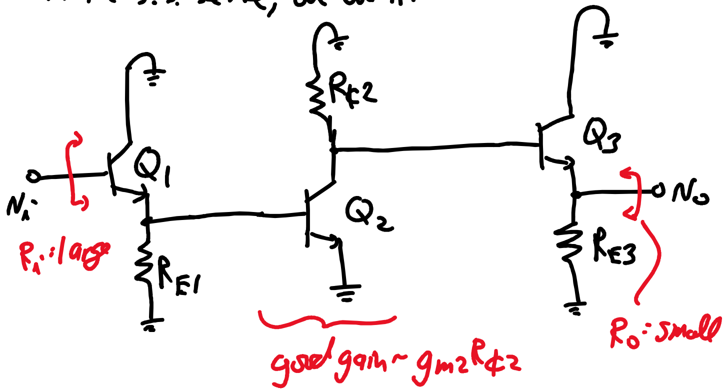
	Ideal Voltage Amp	C.E.	C.E. w/ R_E	C.C.	C.B.
R_i	∞	med. ✗	large ✓	large ✓	small ✗
R_o	0	large ✗	large ✗	small ✓	large ✗
a_v	∞	large ✓	med ✗	small ✗	large ✓
f_H	∞	small ✗	med. ✗	large ✓	large ✓

To Get Better Performance → Cascade Amplifiers

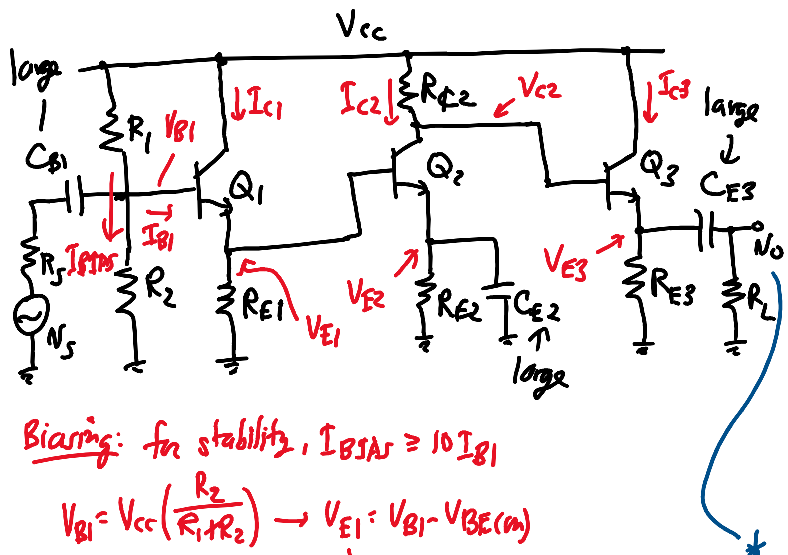
⇒ for a good voltage amplifier:



⇒ in the S.S. sense, we want:



⇒ add biasing:



Biasing: for stability, $I_{BIAS} \geq 10 I_{B1}$

$V_{B1} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right) \rightarrow V_{E1} = V_{B1} - V_{BE(on)}$

$I_{C1} \cong I_{E1} = \frac{V_{E1}}{R_{E1}}$

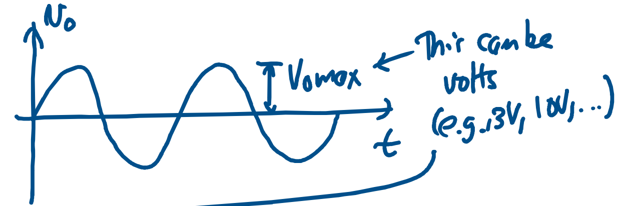
↓ $V_{E2} = V_{E1} - V_{BE(on)}$

$= V_{B1} - 2V_{BE(on)}$

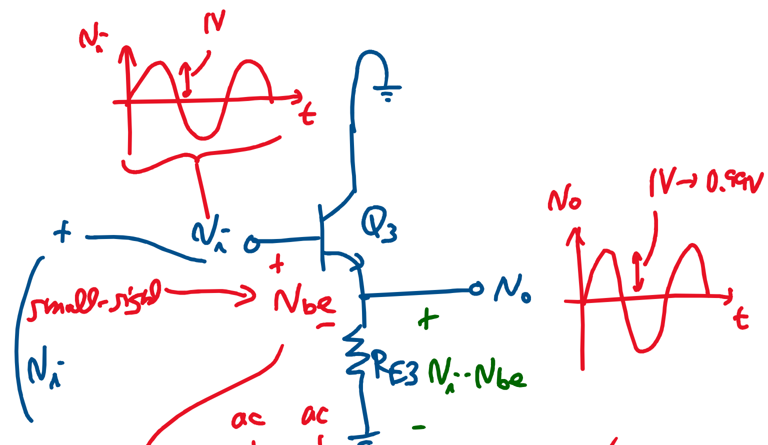
$I_{C2} \cong I_{E2} = \frac{V_{E2}}{R_{E2}} \rightarrow V_{C2} = V_{CC} - I_C R_{C2} = V_{B3}$

$V_{E3} = V_{C2} - V_{BE(on)} \rightarrow I_{C3} \cong I_{E3} = \frac{V_{E3}}{R_{E3}}$

* → Large Output Swing:



Does this violate our small-signal design criterion? → $v_{be} \ll V_T = 25mV$

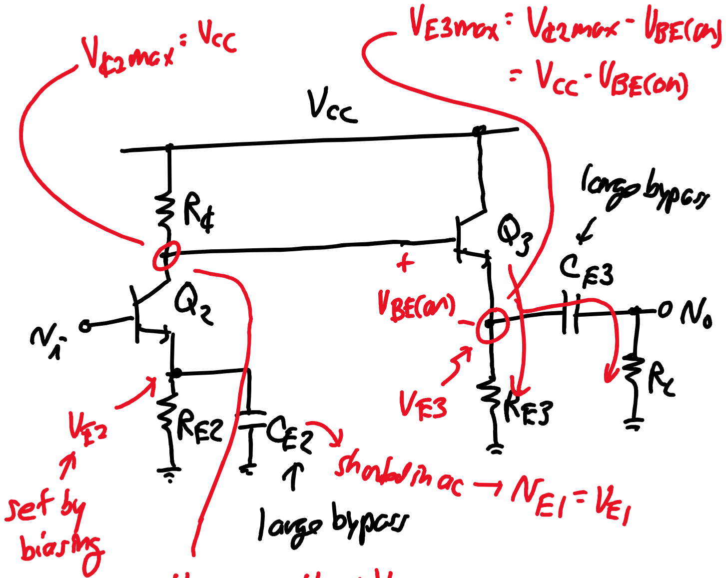


$v_{be} \approx 1V - 0.99V = 10mV < 25mV$ ✓ satisfies small-signal

Emitter Follower Output Stage

⇒ What is the max voltage swing @ the output?

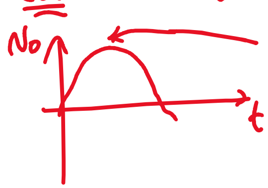
⇒ Need to think in both large & small signal domains!



$V_{E2min} = V_{E2} + V_{CE2(sat)}$

↳ $V_{E3min} = \begin{cases} V_{E2} + V_{CE2(sat)} - V_{BE(on)} \\ \text{or } 0V \end{cases}$

Case: max voltage

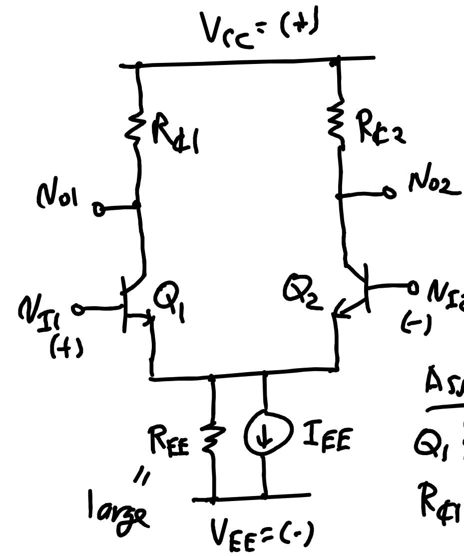


⇒ Q_3 sources enough current to push v_o up across $R_{E3} \| R_L$

⇒ max voltage limit determined by Q_2 stage

$\therefore V_{omax} = \dfrac{V_{E3max} - V_{E3min}}{2}$ ⟶ $V_{swing} = 2 \times V_{omax}$

Differential Pair → A Simple Op Amp



Assumption:
Q_1 & Q_2 identical
R_{C1} & R_{C2} identical

Purpose: Amplify the difference between two signals regardless of their common-mode values.

Definitions.

$v_{ID} = v_{I1} - v_{I2}$ (differential input)

$v_{ICM} = \dfrac{v_{I1} + v_{I2}}{2}$ (common-mode input)

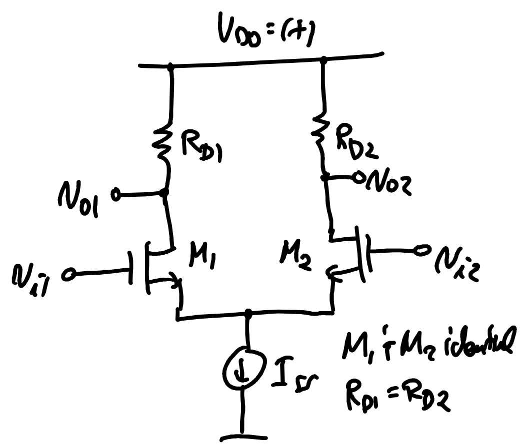
$v_{I1} = v_{ICM} + \dfrac{v_{ID}}{2}$

$v_{I2} = v_{ICM} - \dfrac{v_{ID}}{2}$

Differential Gain: $A_d = \frac{v_{o1} - v_{o2}}{v_{id}} = \frac{v_{od}}{v_{id}}$ (want BIG)

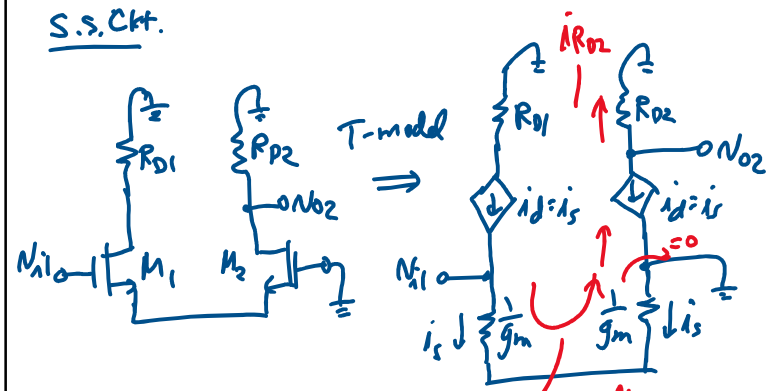
Common-Mode Gain: $A_{cm} = \frac{v_{o1}}{v_{icm}} = \frac{v_{o2}}{v_{icm}}$ (want SMALL)

Common-Mode Rejection Ratio = CMRR = $\frac{A_{dm}}{A_{cm}}$ (want BIG)



Want $A_d = \frac{v_{o1} - v_{o2}}{v_{i1} - v_{i2}}$:

S.S. Ckt.



$i_{R_{D2}} = \frac{v_{i1}}{\frac{2}{g_m}} = \frac{1}{2} g_m v_{i1}$

$v_{o2} = i_{R_{D2}} R_{D2}$

$= +\frac{1}{2} g_m v_{i1} R_{D2} \rightarrow \therefore \frac{v_{o2}}{v_{i1}} = \frac{1}{2} g_m R_D$

$[R_D = R_{D1} = R_{D2}]$

$[g_m = g_{m1} = g_{m2}]$