Lecture 13: SCP & Current Mirror Load

- Announcements:
  - Pre-Lecture materials online
  - Midterm will be on the date specified in your syllabus: Thursday, March 21, 3:30-5 p.m. in 390 Hearst Mining Building

- Lecture Topics:
  - Emitter Coupled Pair (ECP) w/ Degeneration
  - Source Coupled Pair (SCP)
  - Current Mirror Loads

- Last Time:
  - Going through Op Amps & ECP using the Pre-Lecture handout
  - Continue w/ ECP w/ degeneration example

Ex: \[ V_{CC} \]

\[ Q_1 = Q_2 \quad R_{C1} = R_{C2} = R_C \]

\[ V_{i1} \quad V_{i2} \quad V_{o1} \quad V_{o2} \]

\[ I_{EE} \]

\[ 2R_{EE} \]

\[ V_EE \]

\[ R_{C1} \quad R_{C2} \]

\[ R_F \]

\[ R_F^+ \]

\[ R_F^- \]

\[ R_E \]

\[ N_{01} \quad N_{02} \]

\[ N_{0d} \]

\[ V_{o1} \quad V_{o2} \]

\[ V_{o1}' \quad V_{o2}' \]

\[ V_C \]

\[ V_{E1} \quad V_{E2} \]

\[ V_{E1}' \quad V_{E2}' \]

\[ N_{01} = N_{02} = N_{0d} \]

(1) Find the differential mode gain: \( A_{dm} \)

\[ \frac{(N_{01} - N_{02})}{(N_{01} + N_{02})} \]

\[ A_{dm} = \frac{g_m(R_F/R_E)}{1 + g_mR_E} \]

\[ \frac{N_{01} - N_{02}}{V_{o1} - V_{o2}} = \frac{N_{0d}}{V_{i1}} \]

\[ 2R_{EE} \]

\[ Q \]

\[ V_{i1} \quad V_{i2} \]

\[ I_{EE} \]

\[ 2R_{EE} \]
(2) Find the common-mode gain, $A_{cm}$:

$$A_{cm} = \frac{V_{oc}}{V_{ic}}$$

We like this because it suppresses common-mode noise!

If there is a mismatch in the def., e.g., $R_{c1} \neq R_{c2}$, then we can define:

$$A_{cm, dm} = \frac{\text{common-mode input to differential-mode output gain}}{V_{oc}} = \frac{V_{id}}{V_{ic}} \cdot \frac{V_{o1}}{V_{o2}}$$

$$A_{dm, cm} = \frac{\text{differential-mode input to common-mode output gain}}{V_{oc}} = \frac{V_{oc}}{V_{id}} \cdot \frac{V_{o1} - V_{o2}}{V_{o1} - V_{o2}}$$

You will experiment these in a future HW.
What is $R_o$?

$i_o = \frac{N_x}{2r_{o2}}$

$i = \frac{N_x}{r_{o1}}$

$r_{o2} (= r_{o2}(1 + g_{m2}g_{m1}))$

\[ i_x = \frac{N_x}{r_{o1}} + \frac{N_x}{2r_{o2}} \]

\[ \frac{V_x}{r_{o1}} + \frac{N_x}{2r_{o2}} \]

\[ \text{mirrored} \]

\[ \frac{V_x}{r_{o1}} + \frac{N_x}{r_{o2}} \]

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MOS Source-Coupled Pair

Assume: $V_t, V_a, V_b$ are identical.

Find $\Delta I_d = I_{dL} - I_{dS} = f(V_{dd})$.

\[ I_d = \frac{I_{dL} + I_{dS}}{2} \]

\[ V_{dd} = \frac{2(\frac{I_{dL} + I_{dS}}{2}) - \sqrt{2(\frac{I_{dL} + I_{dS}}{2})^2 - 2(\frac{I_{dL} + I_{dS}}{2})^2 - (\frac{2I_{dL}}{2})^2 + I_{dL} - \frac{2I_{dS}}{2}}}{\frac{2}{k}} \]

Solve for $\Delta I_d$:

\[ \Delta I_d = \frac{k}{2} V_{dd} \left( \frac{2I_{dL}}{2} - V_{dd} \right) \]

Large Signal Equation for Differential Output Current

\[ V_{dd} \leq \frac{2I_{dL}}{k} = \frac{2I_{dL}}{kC_{ox}V_{dd}} = \frac{1}{2} (V_{dd} - V_t) \]

Thus, to extend the linear input range:

1. $I_{dL} \rightarrow (V_{dd} - V_t)\uparrow$
2. $W \uparrow$
3. $L \uparrow$

To choose $V_{dd}$:

\[ V_{dd} = \frac{V_{dd}}{2} = \frac{V_{dd}}{2} \]

When $V_{dd} > V_{dd_{Sat}} = V_{dd} - V_t$ then $V_{dd}$ will cut-off

\[ V_{dd} \leq 2(V_{dd} - V_t) \rightarrow \text{to maintain saturation} \]

\[ V_{dd_{Sat}} = \frac{2I_{dL}}{kC_{ox}V_{dd}} = \frac{2I_{dL}}{kC_{ox}V_{dd}} \]

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Diff. Pair w/ Current Mirror Load

Common-Mode Input Range: Range of input voltages in which all devices remain in saturation.

Common-Mode Input Range: $V_{CM} = \frac{2E_{CO}}{I_{FS} + V_{OSS} + V_{CEO1,2}}$

Common-Mode Range: $CMRR = \frac{V_{CM1,2}}{V_{CM1,2}}$

$CMRR = \frac{1}{1 + 2A_{in}(1 + 2g_{m1,2}r_{os})}$

Amplifier Gain: $A_{v} = -\frac{1}{2g_{m1,2}r_{os}}$

Bias Current: $I_{B} = \frac{V_{CC}}{2g_{m1,2}r_{os}}$

$V_{CM1,2} = \frac{2g_{m1,2}(r_{os}2)g_{m3,4}}{g_{m3,4} + (1 + 2g_{m1,2}r_{os})g_{m3,4} + (1 + 2g_{m1,2}r_{os})g_{m3,4}}$

$A_{in} = \frac{g_{m1,2}(r_{os}2)g_{m3,4}}{1 + 2g_{m1,2}r_{os}}$

$V_{CM1,2} = \frac{2g_{m1,2}r_{os}}{1 + 2g_{m1,2}r_{os}}$

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Diff. Pair w/ Current Mirror Load

\[ V_{\text{com}(\text{tri})} = V_{\text{BD}} \pm \left| V_{\text{GZ1,2}} \right| - V_{\text{out}} + V_{GZ1,2} \]

\[ V_{\text{com}(\text{tri})} = V_{\text{BD}} - \frac{I_{FB}}{g_{m1}(W/L)_{1,2}} \left| V_{\text{G1,2}} \right| - 2V_{\text{G1,2}} \]