Lecture 36: MOS Inspection Analysis

• Announcements:
  • HW#11 online and due Friday, 12/4
  • Lab#6 online and due Friday, 12/11 (last day of RRR week)
  • 1st Lab#6 Checkpoint due next week (spice)
  • Today is the only lecture this week, since Wednesday is a non-instructional day and Friday is during Thanksgiving Break
  • You should have received an email with your Z score; I will make some general comments regarding this at today’s lecture

• Lecture Topics:
  • Output Stage
  • MOS Inspection Analysis

• Last Time:
  • Designed a cascade amplifier and considered the small-signal criterion for the output stage
  • Now, continue with this ...

⇒ in the S.S. sense, we want:

⇒ add biasing:

Big picture:

$V_{BE1}$: $f_m$ stability from $V_{BE1} > 10I_{B1}$

neglect $I_{B1}$

$V_{BE1} = V_{CC} - V_{BE1}$

$I_{C1} = I_{E1}$

$V_{E2} = V_{E1} - V_{B1} - V_{BE1} - V_{B2} - V_{BE2}$

$I_{C2} = I_{E2}$

$V_{E3} = V_{E2} - V_{BE3} - I_{C2}R_{E2}$

$I_{E3} = I_{E3} = I_{E3}$

$V_{E3} = V_{B3} - V_{BE3} - I_{E3}R_{E3}$

$R_o = \frac{V_{CC}}{I_{O}}$

$|\text{gain}| = g_{m2}R_{E2}$
Large Output Swing:

\[ V_{\text{omax}} < \text{This can be volts (e.g., 2V, 10V, ...)} \]

Does this violate our small-signal design criterion? \[ V_{\text{be}} < V_t = 2.5 \text{mV} \]

Emitter Follower Output Stage:

\[ V_{E2\text{max}} = V_{CC} \]
\[ V_{E3\text{max}} = V_{E2\text{max}} - V_{BE3(m)} \]
\[ = V_{CC} - V_{BE1(m)} \]

\[ V_{E2} \text{ set by biasing} \]

\[ V_{E2\text{min}} = V_{E2} + V_{ES2(500)} \]
\[ V_{E3\text{min}} = V_{E3} + V_{ES3(500)} \]
\[ = 1 \text{mV} \]

Case: Max Voltage

\[ = Q_3 \text{ sources enough current to push } V_{No} \text{ up across } R_{SE} \]
\[ = \text{max voltage limit determined by } Q_3 \text{ stage} \]

\[ V_{\text{omax}} = \frac{V_{E3\text{max}} - V_{E3\text{min}}}{2} \]
**EE 105: Microelectronic Devices & Circuits**

**Lecture 36w: MOS Inspection Analysis**

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**Compare BJT and MOS Small-Signal Models**

**BJT:**

\[ V_{bc} \]

\[ i_c = \beta i_b \]

**MOS:**

\[ V_{gs} \]

\[ i_d = \begin{cases} 0 & \text{for } \beta \to 0 \\ \beta V_{gs} & \text{for } \beta \to \infty \end{cases} \]

**MOS Inspection Analysis \to Generalized Loadings**

- For now, ignore body effect (i.e., ignore \( g_m \)).
- Use the same inspection formulas as bipolar, but use \( \beta \to \infty, \quad r_{th} = \frac{g_m}{f_m} \to \infty \).

**Bipolar**: \[ R_b = \left( \frac{g_m}{\beta+1} \right) (\beta+1) \to R_b \to 0 \]

**MOS**: \[ R_g = 0 \quad \rightarrow \quad R_s = \frac{1}{g_m} \]

\[ R_e = r_o \left[ 1 + \frac{g_m R_e}{1 + \frac{R_g}{R_f}} \right] \quad \rightarrow \quad R_d = r_o (1 + g_m R_g) \]

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\[
\frac{N_d}{N_s} = -G_m R_S, \quad G_m = \frac{g_m}{1 + g_m R_s} \\
\frac{N_i}{N_s} = -G_m R_S, \quad G_m = -g_m \\
\frac{N_s}{N_g} = \frac{g_m R_s}{1 + g_m R_s} = \frac{R_s}{1/g_m + R_s} \\
\text{Fn } V_{SB} = 0V.
\]

MOS Inspection Analysis

Problem: Suppose via SPICE the gain will be 80-90% of what is calculated using the model.

The problem is \( g_{mb} \) in the source follower.

Suggestion: Substrate Ground, i.e., \( V_{SB} = 0V \)

\[
N_{gs} = N_i - N_o \quad \text{and} \quad N_{bs} = -N_o \\
g_m(N_i - N_o) = N_o(g_{ds} + C_s + g_{mb}) \\
A_N = \frac{g_m}{N_o} = \frac{g_m}{g_{mb} + g_{ds} + C_s}
\]
MOS Inspection Formulas with Substrate Grounded

The only difference from substrate tied to source is that $g_m$ is replaced by $g_{m_t}+g_{m_b}$ in some of the formulas, particularly over where the source is involved.

$$R_s = \frac{1}{g_{m_t}+g_{m_b}}$$

$$R_d = R_b \left[ 1 + (g_{m_t}+g_{m_b})R_b \right]$$

$$\frac{N_d}{N_s} = -g_m R_b, \quad G_m = \frac{g_m}{1 + (g_{m_t}+g_{m_b})R_b}$$

$$N_s = -g_m R_b, \quad G_m = -g_{m_t}$$

$$\frac{N_s}{N_b} = \frac{g_m R_b}{1 + (g_{m_t}+g_{m_b})R_b}$$

Remark: When the substrate is tied to the source, $g_{m_b} = 0$. 
MOS High Frequency Inspection Analysis

\[ T_0 = \left[ C_{gs1} + C_{gd1}(1 + g_{m1}R_P) \right] R_S \]

\[ T_1 = \left[ C_{gd1} + C_{gs1} + C_{gs2} \right] \left( R_{in}R_P \right) \]

\[ T_2 = C_{gs2} \left( R_{in1} + 1 \right) \left( \frac{1}{g_{m2} + g_{m3}} \right) \]

\[ \times T_{gs2} = C_{gs2} \left( \frac{R_{in1} + R_{B2}}{1 + (g_{m2} + g_{m3})R_{B2}} \right) \]

\[ \Omega_f = \frac{1}{T_0 + T_1 + T_2 + T_{gs2}} \]

because very little signal occurs \( C_{gs2} \) is large stage gain \( \approx 1 \)

\[ \text{Sec} \rightarrow \text{Sec} \sim \text{ak} \]