Lecture 36

• Last time:
  – Cascode amplifiers, totem pole voltage supplies
  – Start: two-stage CMOS transconductance amp

• Today:
  – Complete “lecture design” of two-stage CMOS transconductance amplifier

DC Bias: Find Operating Points

Find $V_{BIAS}$ such that $V_{OUT} = 0 \text{ V}$

Device parameters:

\[
\begin{align*}
\mu_n C_{ox} &= 50 \, \mu\text{A/V}^2 \\
\mu_p C_{ox} &= 25 \, \mu\text{A/V}^2 \\
V_{Tn} &= 1 \, \text{V} \\
V_{Tp} &= -1 \, \text{V} \\
\lambda_n &= 0.05 \, \text{V}^{-1} \\
\lambda_p &= 0.05 \, \text{V}^{-1}
\end{align*}
\]

Device dimensions (for “lecture” design):

\[
\begin{align*}
(W/L)_n &= 50/2 \\
(W/L)_p &= 80/2
\end{align*}
\]
Finding $R_{REF}$

Require $I_{REF} = -I_{D3} = 50 \mu A$

$$V_{SG3} = -V_{T_P} + \sqrt{\frac{-2I_{D3}}{\mu_p C_{ox} (W/L)_3}}$$

$I_{REF} =$

DC Operating Point

$I_{REF} = 50 \mu A$

$V_{BIAS} =$
Small-Signal Device Parameters

Transistors $M_1$ and $M_2$

$g_{m1} = 350 \, \mu S \quad r_{o1} = 400 \, k\Omega$

$g_{m2} = 315 \, \mu S \quad r_{o2} = 400 \, k\Omega$

Current supplies $i_{SUP1}$ and $i_{SUP2}$

$r_{oc1} = r_{oc2} = 400 \, k\Omega$

Two-Port Model

Find $G_m = \frac{i_{out}}{v_{in}}$
Output Voltage Swing

Transistors $M_2$ and $M_6$ will limit the output swing

Limits to Output Voltage

$M_6$ will leave saturation when $v_{OUT}$ drops to:

$$v_{OUT,MIN} = V^- + V_{DS6,sat} = -2.5 + \sqrt{\frac{2I_{D6}}{\mu_n C_{ox}(W/L)_6}}$$

$$v_{OUT,MIN} = -2.5 + 0.28 = -2.22 \text{ V}$$

$M_2$ will leave saturation when $v_{OUT}$ rises to:

$$v_{OUT,MAX} = V^+ - V_{SD2,sat} = 2.5 - \sqrt{\frac{2(-I_{D2})}{\mu_p C_{ox}(W/L)_2}}$$

$$v_{OUT,MAX} = 2.5 - 0.32 = 2.18 \text{ V}$$

What about $M_4$?
Output Current Swing

Load resistor: pick \( R_L = 25 \, \text{k}\Omega \)

Output current: \( i_{OUT} = -v_{OUT} / R_L \)

\[
i_{OUT} = i_D - (-i_{D2})
\]

Limits: asymmetrical

- \( M_2 \): can increase \(-i_{D2} \)
- \( M_6 \): can’t increase \( i_{D6} \)

Output Current Limits

- Positive output current (negative \( v_{OUT} \))
  \[
i_{OUT,\text{MAX}} = i_D - (0) = 50 \mu A = -v_{OUT,\text{MIN}} / R_L
  \]
  \[
v_{OUT,\text{MIN}} = -(50 \mu A)(25k\Omega) = -1.25V
  \]
  (less negative than limit set by saturation of \( M_6 \))

- Negative output current (positive \( v_{OUT} \))
  No limit on current from \( M_2 \), so voltage swing sets current limit
  \[
i_{OUT,\text{MIN}} = -v_{OUT,\text{MAX}} / R_L = -(2.18V / 25k\Omega) = -87.2\mu A
  \]
Transfer Curves (for $R_L = 25 \, \text{k}\Omega$)

Loaded voltage gain $= \frac{v_{\text{out}}}{v_{\text{in}}} = (g_{m1}R_{\text{out}1})(g_{m2}R_{\text{out}2}\|R_L) = 490$

Loaded transconductance $= \frac{i_{\text{out}}}{v_{\text{in}}} = (-g_{m1}R_{\text{out}1})(g_{m2})(R_{\text{out}}/(R_{\text{out}} + R_L)) = -19.5 \, \text{mS}$