ECEN4827/5827 Lecture 11

- HW3 solutions posted, including tutorial (video clips) solutions
- Lecture 12 today, 12-1pm same room
- All lectures are recorded and available on the CAETE site: do not miss to view all lectures
Open-loop differential-mode gain $A_o = \frac{V_{out}}{V_{id}} = ?$

$V_{DD} = 5 \text{ V}$

$R_B = 8.8 \text{ MΩ}$

$I_{B1} = 10 \text{ µA}$

$I_{B2} = 100 \text{ µA}$

$V_{DD} = 5 \text{ V}$

$V_{SS} = -5 \text{ V}$

$W/L_{1,2} = 100$

$W/L_{3,4} = 20$

$W/L_{5} = 10$

$W/L_{6} = 400$

$W/L_{7} = 100$

$W/L_{8} = 1$

$M_1$, $M_2$, $M_3$, $M_4$, $M_5$, $M_6$, $M_7$, $M_8$

$V_{id} \rightarrow V_{gs} \rightarrow I_{d1} \rightarrow I_{d2} \rightarrow V_i \rightarrow I_{d6} \rightarrow V_{out}$

Stage 1

Stage 2

Keep assumption $V_{out}$ is $st$. $M_6$, $M_7$ are in $AS$ regime
Basic NMOS small-signal model

\[ g_m = \frac{\partial i_D}{\partial v_{GS}} \bigg|_{v_{GS}, i_D} = 2K(v_{GS} - V_{tn}) = 2\sqrt{KI_D} = \frac{2I_D}{(V_{GS} - V_{tn})} \]

\[ r_o = r_{ds} = \left( \frac{\partial i_D}{\partial v_{DS}} \right)^{-1} \bigg|_{v_{GS}, i_D} = \frac{1}{\lambda I_D} \]
Basic PMOS small-signal model

\[ g_m = \frac{\partial i_D}{\partial v_{SG}} \bigg|_{v_{SG}, i_D} = 2K\left(V_{SG} - |V_{tp}|\right) = 2\sqrt{KI_D} = \frac{2I_D}{\left(V_{SG} - |V_{tp}|\right)} \]

\[ r_o = r_{ds} = \left(\frac{\partial i_D}{\partial v_{SD}}\right)^{-1} \bigg|_{v_{SG}, i_D} = \frac{1}{\lambda I_D} \]
Open-loop differential-mode gain $A_o$: 

$$A_2 = \frac{V_o}{V_i} = -g_{m6}$$

**Diagram:**
- $R_B = 8.8 \, \text{M}\Omega$
- $I_D1 = 5 \, \mu\text{A}$
- $I_B = 1 \, \mu\text{A}$
- $(W/L)_{3,4} = 20$
- $(W/L)_{1,2} = 100$
- $(W/L)_5 = 10$
- $(W/L)_6 = 400$
- $(W/L)_7 = 100$
- $V_{DD} = 5 \, \text{V}$
- $V_{SS} = -5 \, \text{V}$
- $M_3$
- $M_4$
- $M_1$
- $M_2$
- $M_5$
- $M_6$
- $M_7$
- $M_8$

**Notes:**
- $I_{B1} = 10 \, \mu\text{A}$
- $I_{B2} = 100 \, \mu\text{A}$
- $g_{m6}(R_x \ || R_{C6} \ || R_{C7})$
- $R_x$
- $-V_{SS} = -5 \, \text{V}$
- $\Gamma_{out} = R_{seen} = R_{C6} \ || R_{C7}$
- $g_m - R_{seen}$
- $V_i \rightarrow \Gamma_{ab} \rightarrow V_o$
- Transconductance part of $\Gamma_{ab}$
Open-loop differential-mode gain $A_0$: $A_2$

\[ A_2 = \frac{v_o}{v_i} = -g_m v_i \left( r_{o6} || r_{o7} \right) \]

\[ v_o = -g_m v_i \left( r_{o6} || r_{o7} \right) \]
Second-stage gain $A_2$

![Circuit diagram]

- **Common-source gain stage**: Input: G, Output: D, Common: S

- **Expression for $A_2$**:
  
  \[ A_2 = -g_{m6} \cdot R_{\text{seen}} \]

  \[ A_2 = -g_{m6} \left( r_{6} || r_{7} \right) \]

- **Numerical example**:
  
  \[ \mu_n \cdot C_{ox} = 60 \mu A/V^2 \]
  
  \[ \mu_p \cdot C_{ox} = 30 \mu A/V^2 \]

  \[ (W/L)_6 = 400 \quad \lambda_n = 0.1 \quad \mu \text{V} \]

  \[ (W/L)_7 = 100 \quad \lambda_p = 0.1 \quad \mu \text{V} \]

- **Calculations**:
  
  \[ g_{m6} = 2 \sqrt{K_6 \cdot I_{B2}} = 1265 \mu A/V \]

  \[ r_{6c} = \frac{1}{I_p \cdot I_{B2}} = 100 \text{k} \Omega \] (large)

  \[ r_{7} = \frac{1}{I_n \cdot I_{B2}} = 100 \text{k} \Omega \]

- **Result**:
  
  \[ A_2 = -63 \quad \text{large negative gain} \]

  \[ r_{O} = r_{6c} || r_{7} = 50 \text{k} \Omega \quad \text{large} \]
Open-loop differential-mode gain $A_o$: $A_1 = \frac{v_1}{v_{id}}.$

The diagram shows a circuit with MOSFETs $M_1$ and $M_2$ connected in a differential configuration. The circuit parameters include:

- $R_B = 8.8 \, \text{M\Omega}$
- $I_B = 1 \, \mu\text{A}$
- $I_{D1} = 5 \, \mu\text{A}$
- $I_{D2} = 5 \, \mu\text{A}$
- $V_{DD} = 5 \, \text{V}$
- $V_{SS} = -5 \, \text{V}$
- $I_{B1} = 10 \, \mu\text{A}$
- $I_{B2} = 100 \, \mu\text{A}$
- $W/L_{3,4} = 20$
- $W/L_{1,2} = 100$
- $W/L_{5} = 10$
- $W/L_{6} = 400$
- $W/L_{7} = 100$

The diagram also includes equations for the current and voltage parameters of the MOSFETs and the biasing resistors.
Basic differential amplifier

\[ V_{DD} = 5 \text{ V} \]

\[ I_{B1} = 10 \mu\text{A} \]

DC current source. \( I_{B1} = \text{bias of the diff amplifier.} \)

\( I_{B1} = \text{"tail current".} \)
Differential amplifier: large-signal characteristic

\[ \frac{V_{ID}}{2} - V_{GS2} + V_{GS1} + \frac{V_{DD}}{2} = 0 \]

\[ V_{ID} = V_{GS2} - V_{GS1} \quad (1) \]

\[ i_{D1} + i_{D2} = I_{B1} \quad (2) \]

Assume:

\[ \frac{W}{L}_{1} = \frac{W}{L}_{2}, \quad k_1 = k_2 \]

Both AS depends on \( V_{DD}, R, I_{B1} \)

ECEN4827/5827 Analog IC Design
Basic differential amplifier: half-circuit analysis

\[(W/L)_{1,2} = 100\]
Basic differential amplifier: half-circuit analysis

\[
\begin{align*}
M_1 & \quad M_2 \\
(W/L)_{1,2} & = 100 \\
\end{align*}
\]

\[
\begin{align*}
R & \\
\end{align*}
\]

\[
\begin{align*}
\text{by symmetry and} & \\
\text{driven by} & \quad +v_{id}/2, \quad -v_{id}/2 \\
\end{align*}
\]
Basic differential amplifier: half-circuit analysis

\[ \frac{v_{x2}}{v_{id}} = -g_{m2} \left( R || r_{o2} \right)^{\frac{1}{2}} \]

\[ v_{d1} = -\frac{g_{m2}}{2} \]

\[ (W/L)_{1,2} = 100 \]

\[ v_{x1} = v_{id} \frac{g_{m2} (R || r_{o2})^{\frac{1}{2}}}{2} \]

\[ v_{x2} = -\frac{v_{id}}{2} \frac{(R || r_{o2})}{2} \]
Open-loop differential-mode gain $A_o$: $A_1 = \frac{v_i}{v_{id}}$?

$R_B = 8.8 \, \text{M}\Omega$

$I_{B1} = 10 \, \mu\text{A}$

$M_8$  
$(W/L)_8 = 1$

$I_{B2} = 100 \, \mu\text{A}$

$M_7$  
$(W/L)_7 = 100$

$I_D1 = 5 \, \mu\text{A}$

$I_D2 = 5 \, \mu\text{A}$

$M_1$  
$(W/L)_{1,2} = 100$

$M_2$  
$(W/L)_{3,4} = 20$

$M_3$

$M_4$  
$(W/L)_6 = 400$

$R_B = 8.8 \, \text{M}\Omega$

$V_{SS} = -5 \, \text{V}$

$V_{DD} = 5 \, \text{V}$

$\frac{v_i}{v_{id}} = -g_{m1}(R_2 || R_4)$