Open-loop differential-mode gain $A_o$

Given circuit diagram with labels:

- $R_B = 8.8 \text{ M}\Omega$
- $V_{DD} = 5 \text{ V}$
- $V_{SS} = -5 \text{ V}$
- $I_B = 1 \text{ \mu A}$
- $I_{D1} = 5 \text{ \mu A}$
- $I_{D2} = 5 \text{ \mu A}$
- $I_{B1} = 10 \text{ \mu A}$
- $I_{B2} = 100 \text{ \mu A}$

Transistor labels:

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

Width-to-length ratios:

- $(W/L)_{1,2} = 100$
- $(W/L)_{3,4} = 20$
- $(W/L)_5 = 10$
- $(W/L)_6 = 400$
- $(W/L)_7 = 100$
- $(W/L)_8 = 1$
Basic MOS small-signal model
Basic NMOS small-signal model

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

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

\[ G \quad + \quad i_d \quad D \]

\[ G \quad + \quad g_m v_{gs} \quad + \quad v_{ds} \]

\[ G \quad - \quad r_o \quad - \quad v_{gs} \]

\[ G \quad - \quad s \]

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

\[ r_o = r_{ds} = \left( \frac{\partial i_D}{\partial v_{DS}} \right)^{-1} \bigg|_{V_{SG}, I_D} = \frac{1}{\lambda I_D} \]
Open-loop differential-mode gain $A_o$: $A_2$

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

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

$I_B = 1 \mu\text{A}$

$I_{D1} = 5 \mu\text{A}$

$I_{D2} = 5 \mu\text{A}$

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

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

$(W/L)_8 = 1$

$(W/L)_5 = 10$

$(W/L)_7 = 100$

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

$M_8$

$M_6$

$M_1$

$M_2$

$M_3$

$M_4$

$M_5$

$M_7$
Open-loop differential-mode gain $A_0$: $A_2$
Open-loop differential-mode gain $A_o: A_1$

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

\[ R_B = 8.8 \text{ M}\Omega \]

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

\[ I_{D1} = 5 \mu\text{A} \]

\[ I_{D2} = 5 \mu\text{A} \]

\[ M_1 \]

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

\[ M_2 \]

\[ (W/L)_{3,4} = 20 \]

\[ M_3 \]

\[ M_4 \]

\[ (W/L)_5 = 10 \]

\[ M_5 \]

\[ (W/L)_6 = 400 \]

\[ M_6 \]

\[ (W/L)_7 = 100 \]

\[ M_7 \]

\[ (W/L)_8 = 1 \]

\[ M_8 \]

\[ I_{B2} = 100 \mu\text{A} \]

\[ -V_{SS} = -5 \text{ V} \]
Basic differential amplifier

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

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

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

\[ -V_{SS} \]
Basic differential amplifier: half-circuit analysis

\[
M_1, M_2 (W/L)_{1,2} = 100
\]
Basic differential amplifier: half-circuit analysis

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

\[ \begin{align*}
\text{Input voltage:} & \quad -\frac{v_i}{2} \\
\text{Output voltage:} & \quad \frac{v_i}{2} \\
\text{M1, M2:} & \quad (W/L)_{1,2} = 100
\end{align*} \]
Open-loop differential-mode gain $A_o$: $A_1$

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

$M_1$, $M_2$, $M_3$, $M_4$, $M_5$, $M_6$, $M_7$, $M_8$
Open-loop differential-mode gain $A_0$: $A_1$

![Diagram of a circuit with transistors and resistors labeled with their $W/L$ ratios and current values.]

- $R_B = 8.8 \, \text{M}\Omega$
- $M_1$ and $M_2$: $(W/L)_{1,2} = 100$
- $M_3$ and $M_4$: $(W/L)_{3,4} = 20$
- $M_5$, $M_6$, and $M_7$: $(W/L)_5 = 10$, $(W/L)_6 = 400$, $(W/L)_7 = 100$
- $I_{B1} = 10 \, \mu\text{A}$
- $-v_{id}/2$ and $+v_{id}/2$ sources
Open-loop differential-mode gain $A_o$

![Diagram of an open-loop differential amplifier with labeled components and gains.]

- $R_B = 8.8 \text{ M}\Omega$
- $I_{B1} = 10 \mu\text{A}$
- $(W/L)_8 = 1$
- $(W/L)_{1,2} = 100$
- $(W/L)_{3,4} = 20$
- $(W/L)_5 = 10$
- $(W/L)_6 = 400$
- $(W/L)_7 = 100$