translated

DC Operating Point

\[ V^+ = +2.5 \text{ V} \]

\[ V^- = -2.5 \text{ V} \]

\[ R_{\text{REF}} \]

\[ I_{\text{REF}} = 50 \mu\text{A} \]

\[ V_{\text{BIAS}} = \]

Small-Signal Device Parameters

Transistors \( M_1 \) and \( M_2 \)

\[ g_{m1} = 350 \mu\text{S} \]

\[ r_{o1} = 400 \text{ k}\Omega \]

\[ g_{m2} = 315 \mu\text{S} \]

\[ r_{o2} = 400 \text{ k}\Omega \]

Current supplies \( i_{\text{SUP1}} \) and \( i_{\text{SUP2}} \)

\[ r_{\text{o1}} = r_{\text{o4}} = 400 \text{ k}\Omega \]

\[ r_{\text{o2}} = r_{\text{o6}} = 400 \text{ k}\Omega \]
Two-Port Model

Find $G_m = \frac{i_{out}}{v_{in}} = -9m \cdot 9m \cdot R_{out1} = -22mS$

$R_{in} \rightarrow 0$
$R_{out} = 200mS$
$Gm = -22mS$

Output Voltage Swing

Transistors $M_2$ and $M_6$ will limit the output swing
Limits to Output Voltage

\[ V_{\text{OUT, MIN}} = V^+ + V_{\text{DS6, sat}} = 2.5 + 0.28 = 2.22 \text{ V} \]
\[ V_{\text{OUT, MAX}} = V^- - V_{\text{SO2, sat}} = 2.5 - 0.32 = 2.18 \text{ V} \]

\[ M_6 \text{ will leave saturation when } V_{\text{OUT}} \text{ drops to: } \]
\[ \frac{2I_{D6}}{\mu_n C_{\alpha} (W/L)_6} \]
\[ M_2 \text{ will leave saturation when } V_{\text{OUT}} \text{ rises to: } \]
\[ \frac{2(-I_{D2})}{\mu_p C_{\alpha} (W/L)_2} \]

What about \( M_4 \)?

Output Current Swing

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

Output current: \( i_{\text{OUT}} = -\frac{V_{\text{OUT}}}{R_L} \)

Limits: asymmetrical
\( M_2 \): can increase - \( i_{D2} \)
\( M_6 \): can't increase \( i_{D6} \)
Output Current Limits

- Positive output current (negative \( V_{OUT} \))
  \[ i_{OUT,\text{MAX}} = i_{D,\text{MAX}} - (0) = (50 \mu A) / R_L \]
  \[ V_{OUT,\text{MIN}} = -(50 \mu A)(25 \text{ k}\Omega) = -1.25 \text{ V} \]

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

Transfer Curves (for \( R_L = 25 \text{ k}\Omega \))

Loaded voltage gain

\[ V_{OUT} = V_{IN} \left( g_{mR} R_{OUT} \right) \]
\[ R_{OUT} = 490 \Omega \]
\[ R_D = 19.5 \text{ mS} \]

Loaded transconductance

\[ \left( \frac{g_{mR}}{R_{OUT}} \right) \]
\[ \left( \frac{V_{OUT}}{V_{IN}} \right) \]

\[ \left( \frac{R_{OUT}}{R_D} \right) \]