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:

$$v_{OUT,MIN} = V^- + V_{DS,MIN} = -2.5 + \frac{2I_D}{\mu C_m (W/L)_6}$$

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

$$v_{OUT,MAX} = V^+ - V_{DS,MAX} = 2.5 - \frac{2(-I_D)}{\mu C_m (W/L)_2}$$

What about $M_4$?

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

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

Output Current Swing

Load resistor: pick $R_L = 25$ kΩ

Output current:

$$i_{OUT} = -v_{OUT} / R_L$$

Limits: asymmetrical

$M_2$: can increase $i_D$

$M_6$: can’t increase $i_D$

Output Current Limits

- Positive output current (negative $v_{OUT}$)

$$i_{OUT,MAX} = i_D = 50\mu A = -v_{OUT,MIN} / R_L$$

$$v_{OUT,MIN} = -(50\mu A)(25kΩ) = -1.25V$$

(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

$$i_{OUT,MIN} = -v_{OUT,MAX} / R_L = -(2.18V / 25kΩ) = -87.2\mu A$$
Transfer Curves (for $R_L = 25$ kΩ)

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

Loaded transconductance $= \frac{i_{out}}{v_{in}}$

$$= (g_{m1} R_{out}) (g_{m2} R_{out} / (R_{out} + R_L)) = -19.5 \text{ mS}$$