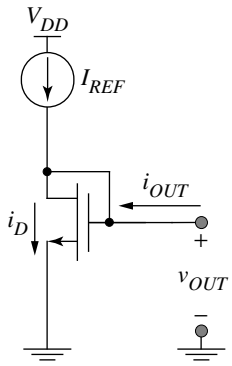
I. Voltage Sources

A. Large Signal Model

- Given a current source force the current through a MOSFET with the drain shorted to the gate



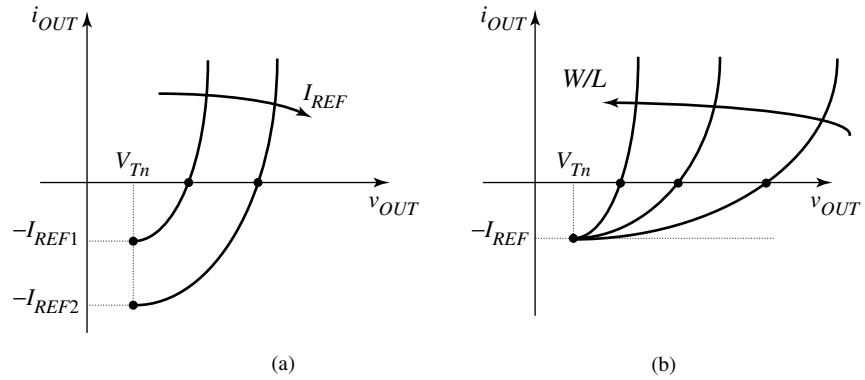
$$i_D = I_{REF} + i_{OUT} = \frac{W}{2L}\mu_n C_{ox}\left(v_{OUT} - V_{Tn}\right)^2\left(1 + \lambda_n v_{OUT}\right)$$

- Neglecting channel length modulation: $\lambda_n v_{OUT} << 1$

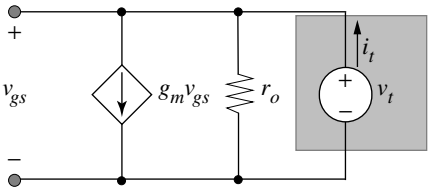
$$v_{OUT} = V_{Tn} + \sqrt{\frac{I_{REF} + i_{OUT}}{\frac{W}{2L}\mu_n C_{ox}}}$$

B. Graphical View of Voltage Sources

- v_{OUT} increases as I_{REF} increases
- v_{OUT} decreases as W/L increases



C. Small Signal View

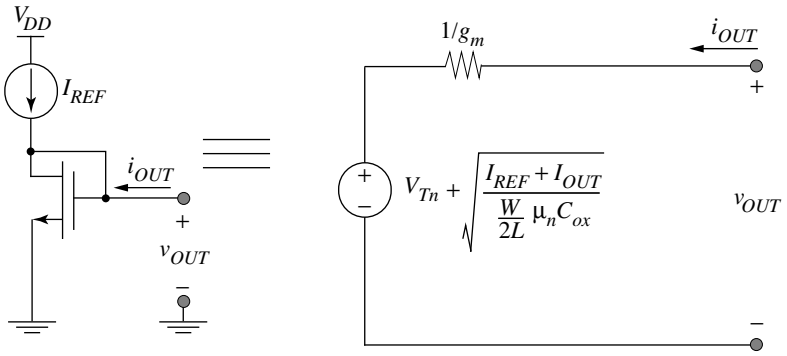


- Since $v_{gs} = v_{out} = v_t$, the tranconductance degenerates into a conductance of g_m. The output resistance is given by:

$$R_{out} = \frac{v_t}{i_t} = \left(\frac{1}{g_m}\right) \Big|\Big| r_o \qquad \approx 1/g_m$$

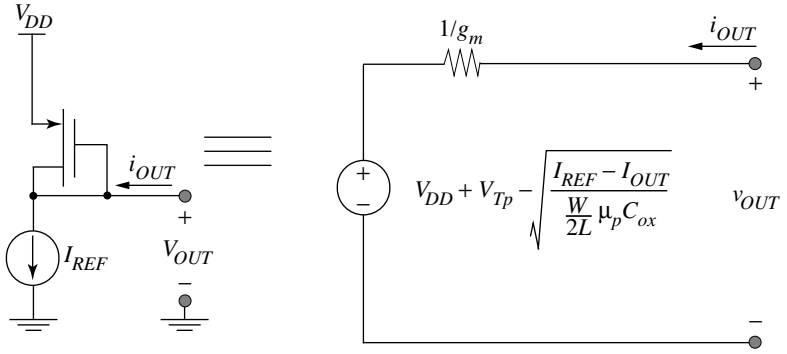
- R_{out} decreases with increasing W/L and I_{REF}

D. Total Voltage Source Model



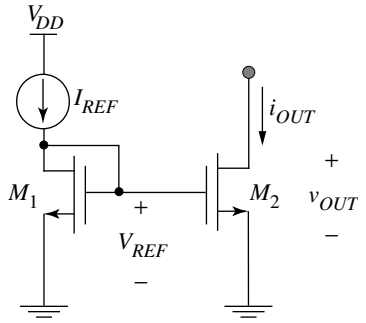
- DC value I_{OUT} is typically very small
- V_{OUT} set by I_{REF} and W/L

E. PMOS Voltage Source



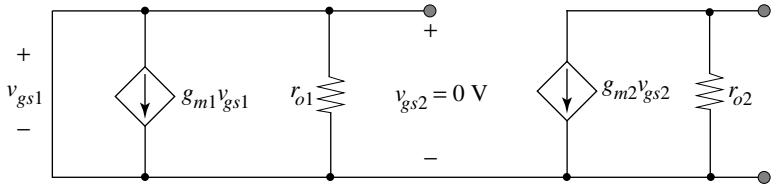
II. MOSFET Current Sources

A. Large Signal View



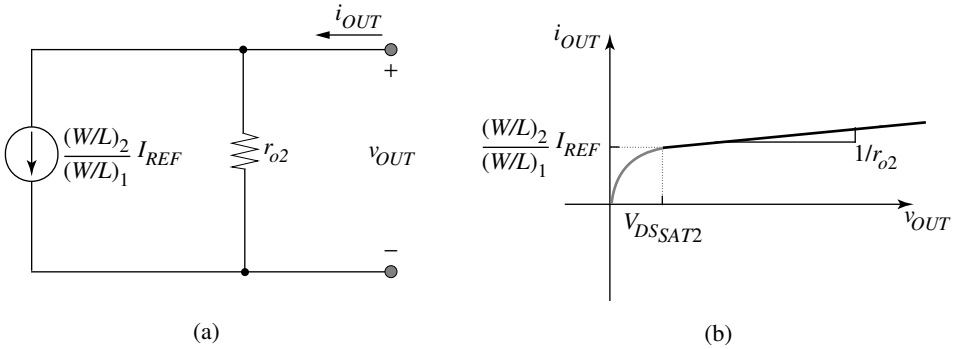
$$I_{OUT} = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1} I_{REF}$$

B. Small Signal View



- $R_{out} = r_{o2}$
- Typical value for r_o is 50 - 250 kΩ, which may be inadequate for many applications

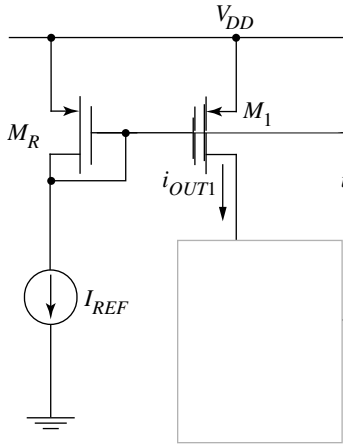
C. Total Current Source Model



- I_{OUT} set by ratio of *W/L*
- R_{out} set by output resistance of transistor

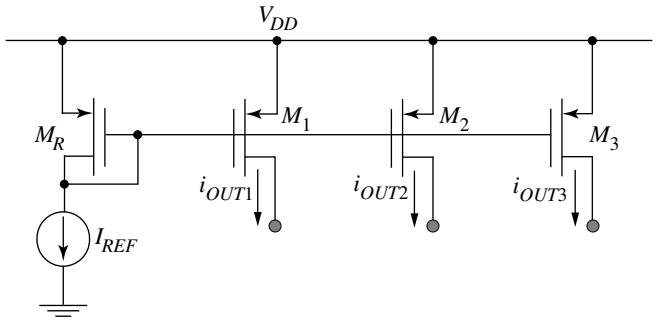
D. P-Channel Current Sources

- n-channel current source *sinks* current to ground
- p-channel current source *sources* current from the positive supply



E. Multiple Current Sources

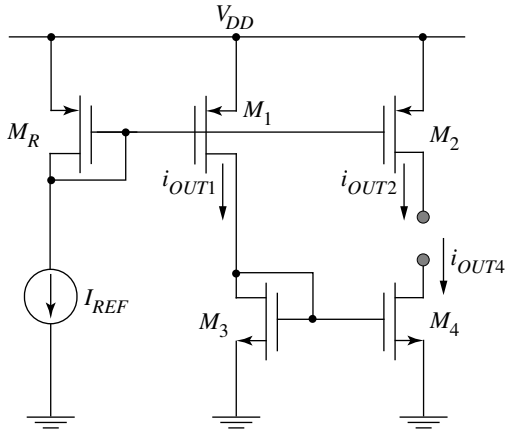
- p-channel current source can use the voltage source, M_R to bias a string of current sources.



$$I_{OUT_n} = \frac{\left(\frac{W}{L}\right)_n}{\left(\frac{W}{L}\right)_R} I_{REF}$$

F. Circuit to Produce both Current Source and Sink

- Output of M_1 is used as reference current for voltage source M_3
- Voltage source M_3 is tied to M_4 to build current sink
- This circuit which forms a current sink from a current source or visa versa is called a *current mirror.*

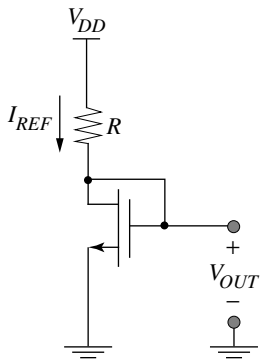


$$I_{OUT1} = \frac{\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_R} I_{REF}$$

$$I_{OUT4} = \frac{\left(\frac{W}{L}\right)_4}{\left(\frac{W}{L}\right)_3} I_{OUT1}$$

G. Generating I_{REF}

- Simple Circuit to generate I_{REF}



$$I_{REF} = \frac{V_{DD} - V_{OUT}}{R}$$

$$V_{OUT} = V_{Tn} + \sqrt{\frac{I_{REF}}{\frac{W}{2L}\mu_n C_{ox}}}$$

- As *W/L* is made large

$$I_{REF} \approx \frac{V_{DD} - V_{Tn}}{R}$$

- Other methods include using an off-chip current source, or generating a power supply and temperature independent reference current. (Beyond scope of 6.012)