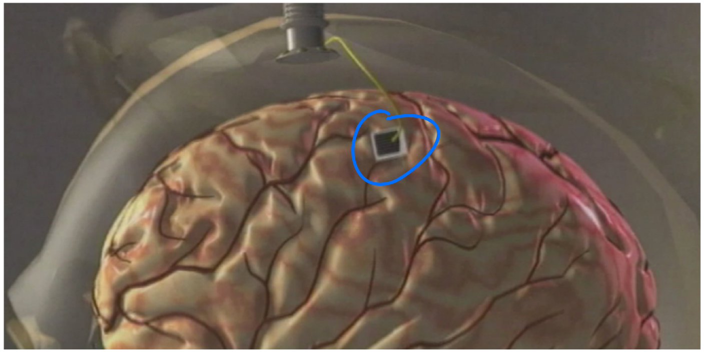
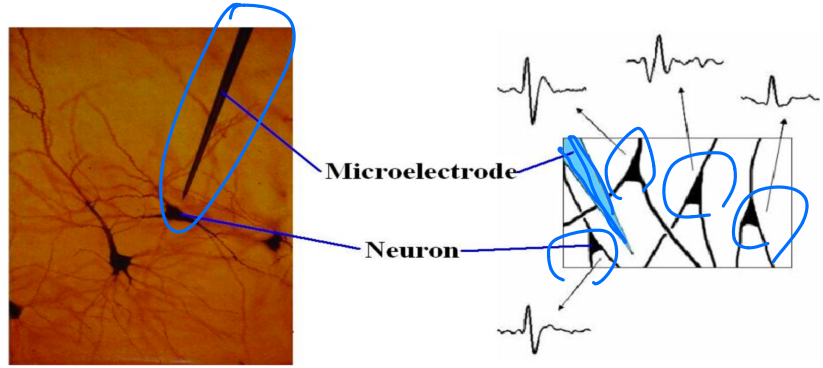
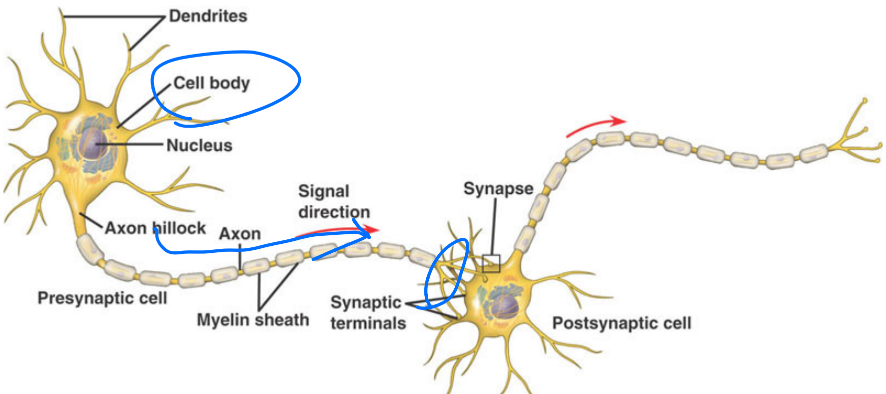
* HW 9 Posted. due next Wed 5/8
  Last HW
* Last lecture on Thursday 5/2
* RRR week, OH: 5/7 (Tue) 11-12
* Final Exam: 5/15/2019 (Wed)
  11:30 – 2:30
    - Closed book
    - 6 pages of cheat sheet
* Turn in ALL your Lab Report
* Please do course survey

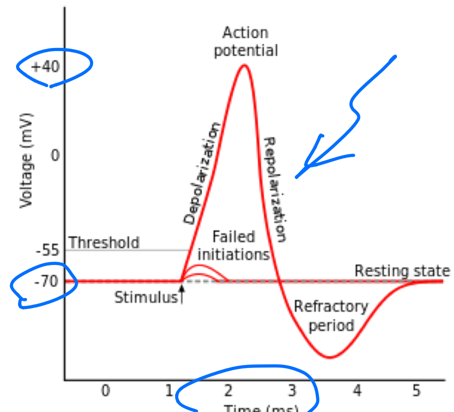
Neural Recording





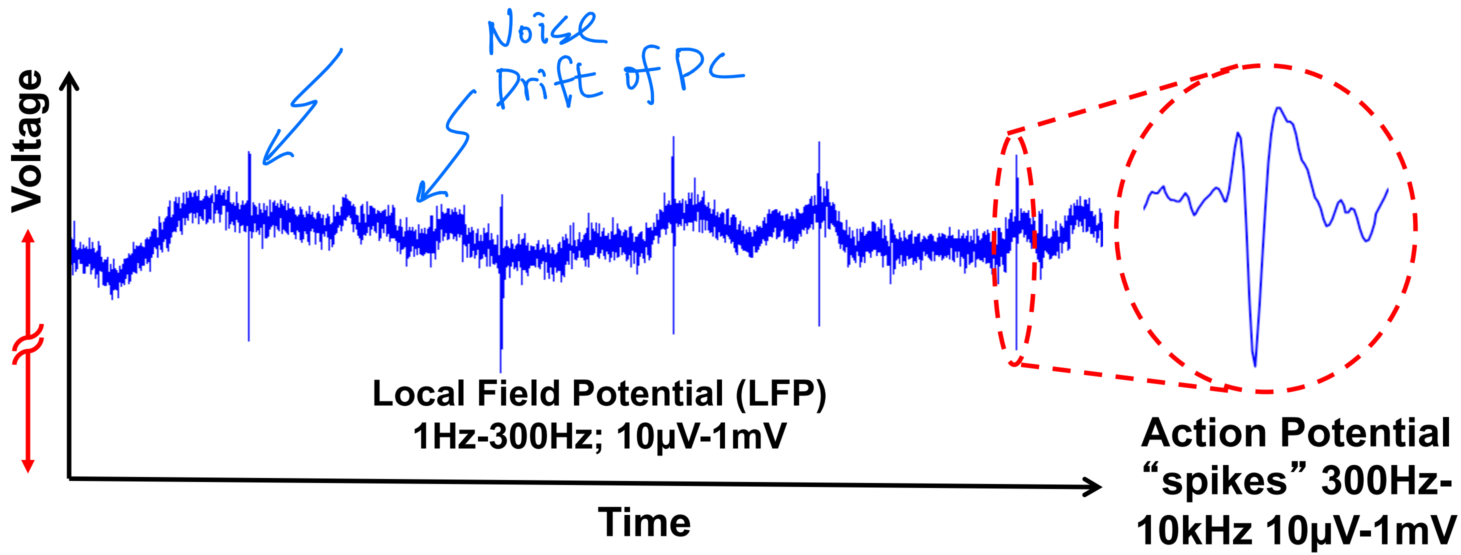
An array of electrodes is implanted in the motor cortex and senses extracellular signals that include firing from nearby neurons





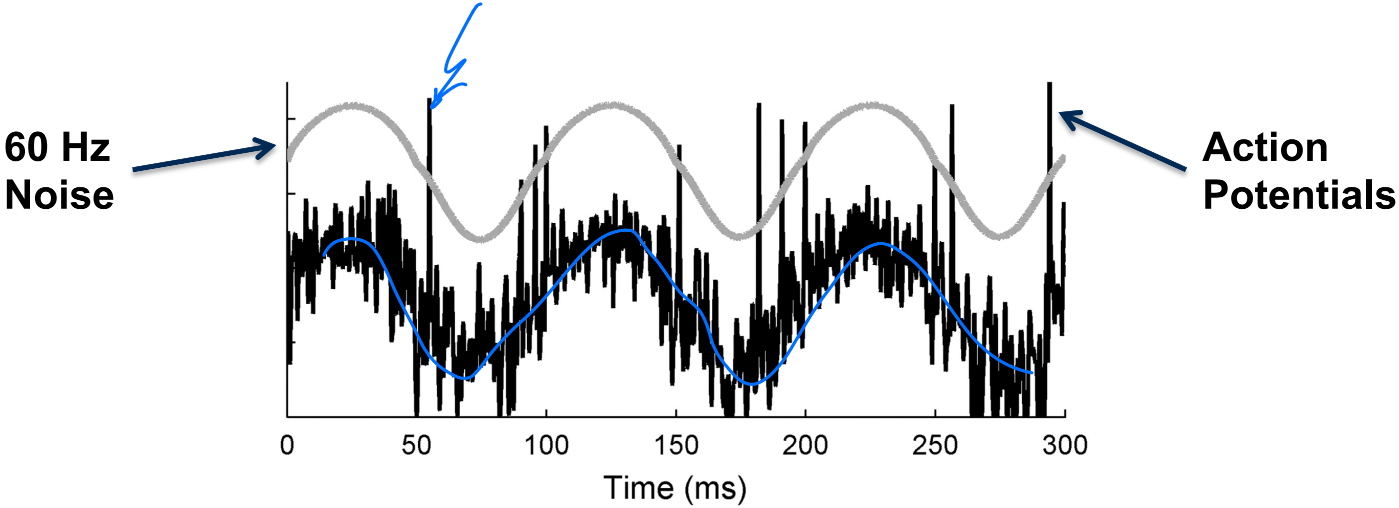
The propagation of signals from neuron to neuron is called an Action Potential, which is analogous to a digital "pulse"

Extracellular Neuronal Signals

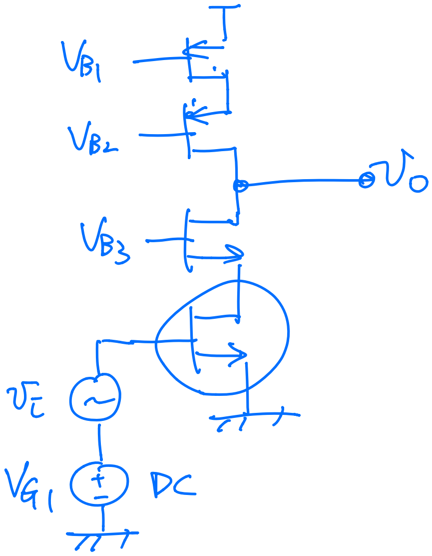


- The goal of a neural recording device is to record the small-amplitude neural signals and pick out the meaningful signals from the "noise".
- These signals are then decoded to create trajectories, movements, and speeds for controlling prostheses, computers, etc.

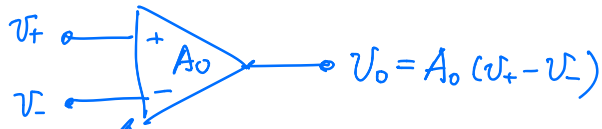
60Hz and Other Interferers



- In reality, the tiny signals recorded from the brain can get corrupted by numerous interferers.
- Ambient 60Hz noise couples into electrical signals in and on the body
- Motion can cause voltage artifacts from the movement of the electrodes relative to the neurons



Op Amp



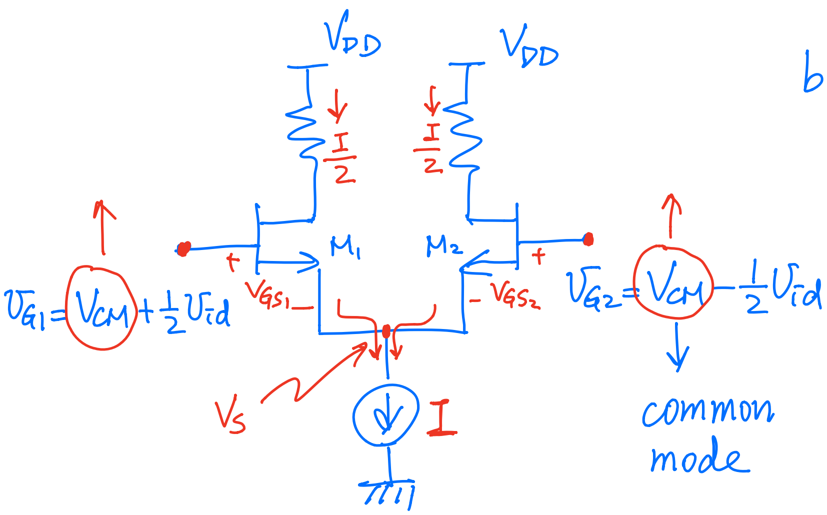
What is the input circuit?

Differential Pair

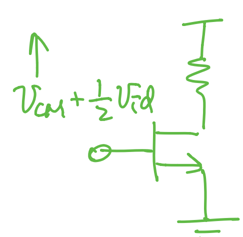
a, b

$$a = \frac{a+b}{2} + \frac{a-b}{2}$$

$$b = \frac{a+b}{2} - \frac{a-b}{2}$$



CS

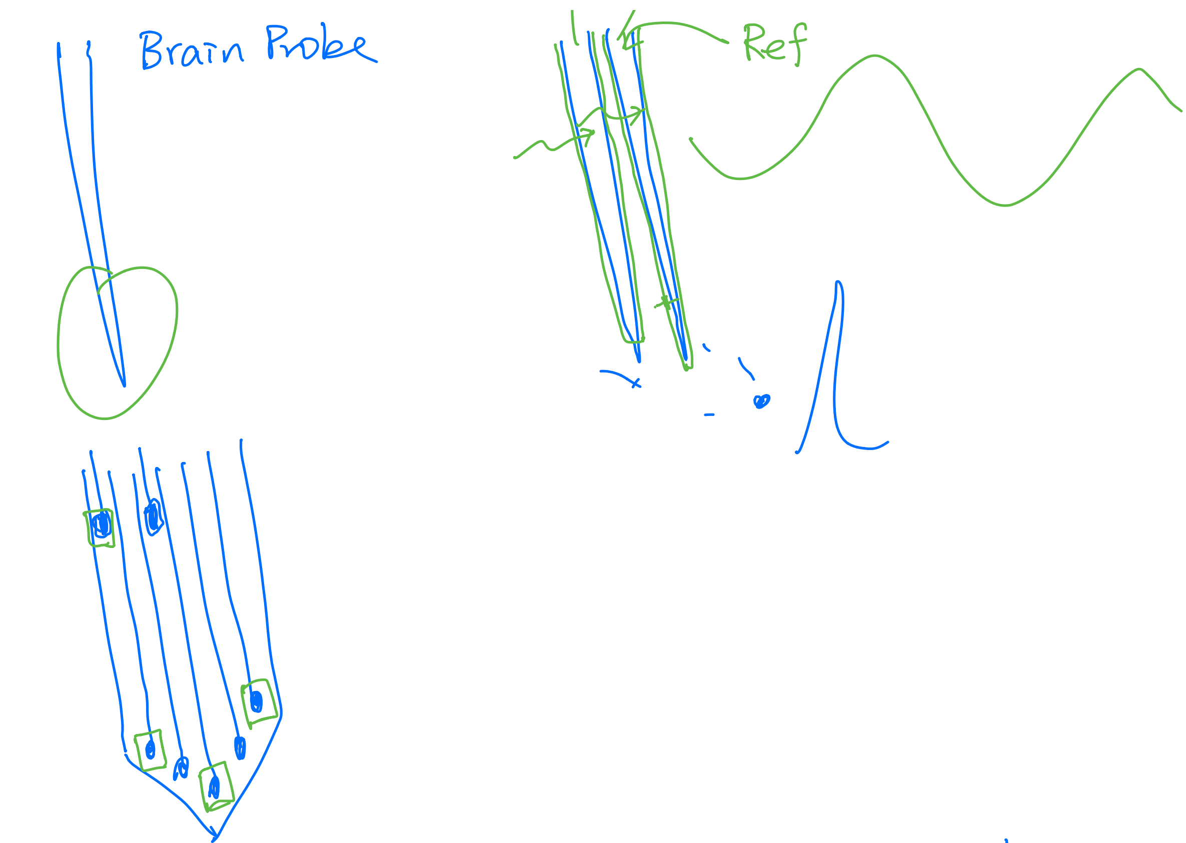


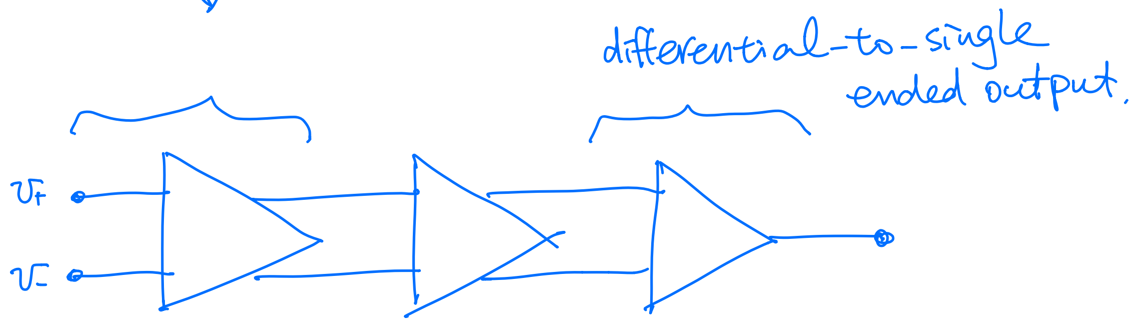
M_1, M_2 are biased for $\frac{I}{2} = \frac{1}{2}k_n V_{ov}^2$

V_{ov} is fixed. $\Rightarrow V_{ov} = V_{GS} - V_{t,n} \Rightarrow V_{GS1} = V_{GS2}$

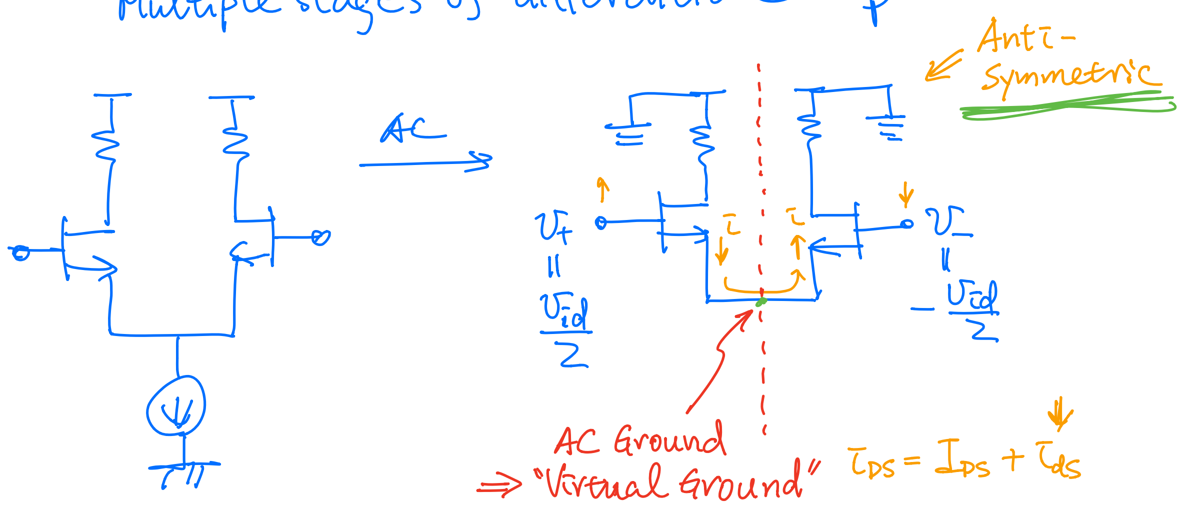
V_S is "following" V_{CM} so that V_{GS} stay fixed

$v_+ \quad v_- \Rightarrow v_{id} = v_+ - v_-$



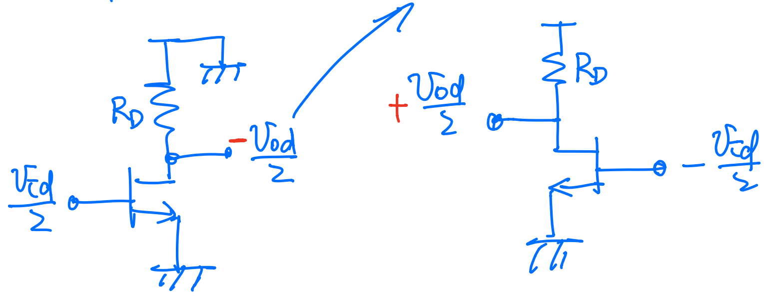


Multiple stages of differential amp



Half-Circuit

v_o, differential



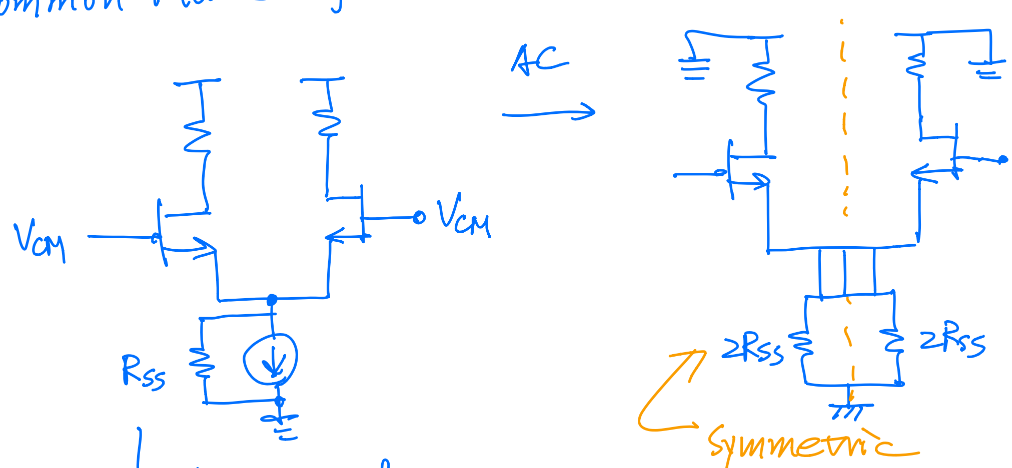
↑ CS Amp.

$$A_d = \frac{\left(\frac{v_{od}}{2}\right)}{\left(\frac{v_{id}}{2}\right)} = A_{v,cs} = g_m(R_D // r_o)$$

Total differential Gain

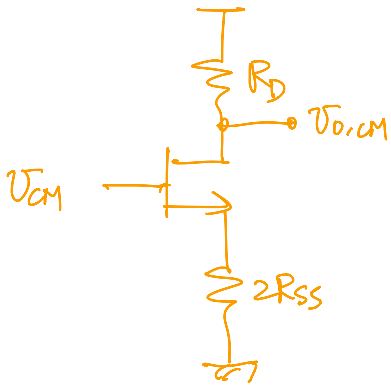
$$A_v = \frac{v_{od}}{v_{id}} = g_m(R_D // r_o)$$

Common Mode Signal (Noise or drift, or interference)



↳ large, but $< \infty$

Symmetric Half-Circuit



$$A_{CM,1/2} = \frac{v_{o,CM}}{v_{CM}} = \frac{-g_m R_D}{1 + 2R_{SS} \cdot g_m}$$

$$A_{CM} = \frac{v_{o,CM,right} - v_{o,CM,left}}{v_{CM}} \rightarrow 0$$

$$CMRR = \frac{A_d}{A_{CM}} = \infty$$

CS with source degeneration

Due to mismatch, $R_{D1} = R_D$, $R_{D2} = R_D + \Delta R_D$

$$A_{CM} = \frac{-g_m \Delta R_D}{1 + 2R_{SS} \cdot g_m} \qquad \frac{\Delta R_D}{R_D} < 1\%$$

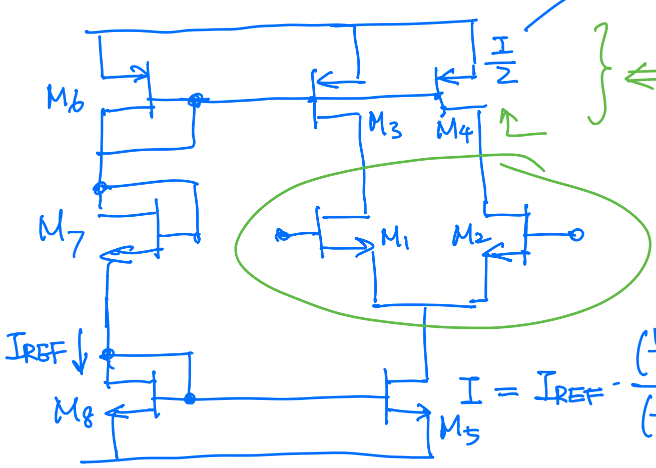
$$CMRR = \left|\frac{A_d}{A_{CM}}\right| = \frac{g_m R_D}{\left(\frac{g_m \Delta R_D}{1 + 2R_{SS} g_m}\right)} = \left(\frac{R_D}{\Delta R_D}\right)(1 + 2R_{SS} g_m)$$

$\frac{R_D}{\Delta R_D} \sim 100$

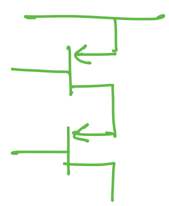
$2R_{SS} g_m \rightarrow \sim g_m r_o \sim 100$

"Real" Differential Pair in IC

$I_{REF} \cdot \frac{(W/L)_4}{(W/L)_6}$

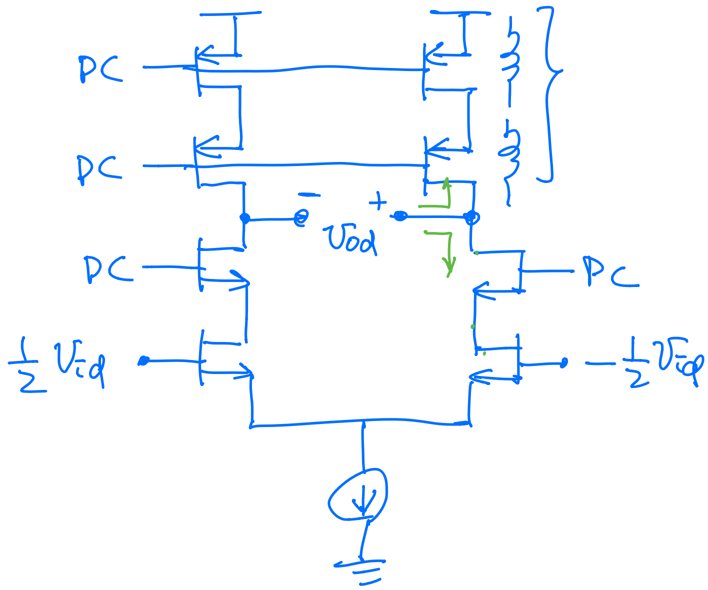


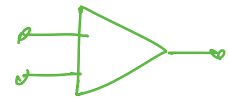
} ⇐ Cascode



} ⇒ Cascode

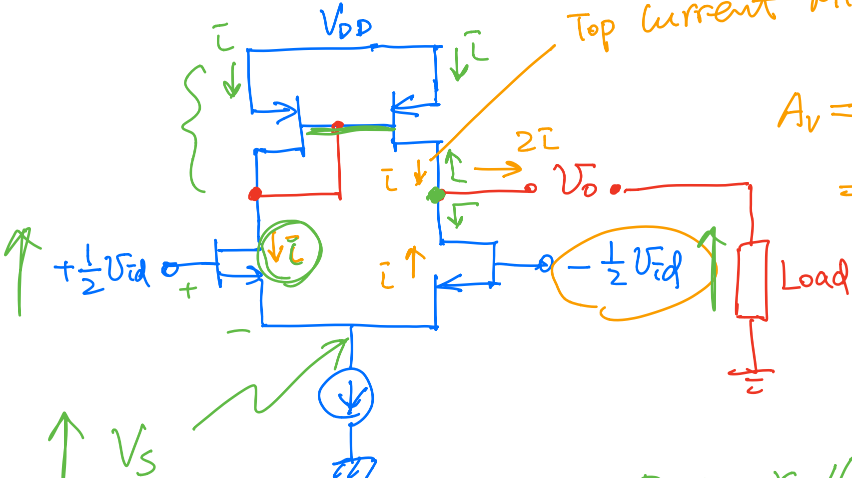
$$I = I_{REF} \cdot \frac{(W/L)_5}{(W/L)_8}$$





✓ CMRR
✓ High gain
— BW
✗ Low R_o
✗ Single-ended output

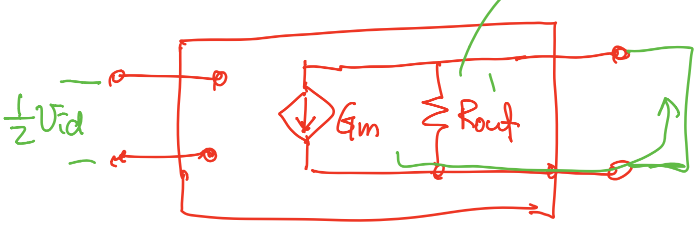
Single-ended Output.



$A_v = g_m (r_o // r_o)$

$= \frac{1}{2} g_m r_o$

$R_{out} = r_o // r_o$



$2i = 2 \cdot g_m (\frac{1}{2} v_{id})$

$$v_o = G_m R_{out} = g_m v_{id} \cdot (r_o // r_o) = \frac{1}{2} g_m v_{id} r_o$$

$$A_v = \frac{v_o}{v_{id}} = \frac{1}{2} g_m r_o$$