

→ Now, for single-ended output (like we will take in the lab):

$$|A_{cm}| = \frac{R_D}{2R_{SS}}, \quad |A_{dm}| = \frac{1}{2} g_m R_D \quad (\text{half of when it is a diff. output})$$

$$\therefore CMRR = \frac{|A_{dm}|}{|A_{cm}|} = g_m R_{SS}$$

→ For differential output: $|A_{cm}| = \frac{V_{O2} - V_{O1}}{V_{in}} = 0$, $|A_{dm}| = g_m R_D$

$$\therefore \boxed{CMRR = \infty}$$

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→ What if there is a mismatch in the loads?

- assume load of M_1 is R_D , load of M_2 is $R_D + \Delta R_D$

$$\text{now, } V_{O1} = -\frac{R_D}{2R_{SS}} \cdot V_{in} \quad \text{and} \quad V_{O2} = -\frac{(R_D + \Delta R_D)}{2R_{SS}} \cdot V_{in}$$

$$\rightarrow \text{now } A_{cm} = -\frac{\Delta R_D}{2R_{SS}}, \quad A_{dm} \approx -g_m R_D \quad (\text{not exactly, but assume } \Delta R_D \text{ is small})$$

$$\text{now } \boxed{CMRR = \frac{2 \cdot g_m R_{SS}}{(\Delta R_D / R_D)}} \quad (\text{check: } \rightarrow \infty \text{ as } \Delta R_D \rightarrow 0)$$

- So a mismatch will lead to a finite CMRR (as will be present in any real circuit).

→ What if there is a mismatch in the transistors?

- results in a mismatch in g_m (remember $g_m = \sqrt{2 \cdot K_n' \cdot \frac{W}{L} \cdot I_D}$)

$$\text{- resulting CMRR is: } \boxed{CMRR = \frac{2 \cdot g_m R_{SS}}{(\Delta g_m / g_m)}}$$

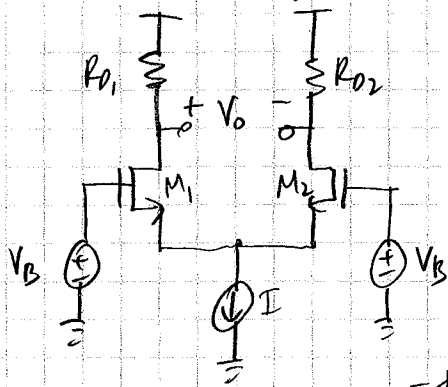
→ see text pg. 703 for a derivation

BJT Differential Pairs

→ Same idea, but different equations due to exponential characteristics of the BJT (unlike square-law MOSFET characteristics)

- also relevant to determine DM & CM input resistance (since ^{S.S.} input resistance of BJT is finite, unlike MOSFET).

Input Offset Voltage



→ for perfect matching, V_O will be zero

- not the case in real circuits.

- for equal inputs, we will have some output V_O ,
→ 3 Called the "Output offset Voltage"

Input Offset Voltage: $V_{os} = \frac{V_O}{A_d}$ ← O/P offset voltage.
↑ diff. gain

- this is the voltage applied at the inputs to zero the output voltage (to compensate for mismatches).

→ 3 sources of mismatch:

- ① Resistor mismatch (R_D)
- ② Transistor size mismatch (W/L)
- ③ Transistor V_t mismatch (due to doping fluctuations)

① R_D Mismatch - assume $R_{D1} = R_D + \frac{\Delta R_D}{2}$, $R_{D2} = R_D - \frac{\Delta R_D}{2}$

→ Currents still split equally since we are ignoring finite O/P resistances.

$$\therefore V_{D1} = V_{DD} - \frac{I}{2} (R_D + \frac{\Delta R_D}{2}), \text{ etc.}$$

$$\therefore V_O = V_{D1} - V_{D2} = \left(\frac{I}{2}\right) \Delta R_D = \frac{I}{V_{ov}}$$

→ divide by diff. gain to refer to the input ($A_D = g_m \cdot R_D$)

$$\therefore V_{os} = \frac{I}{2} \Delta R_D \cdot \frac{V_{ov}}{I \cdot R_D} = \left(\frac{V_{ov}}{2}\right) \frac{\Delta R_D}{R_D}$$

② W/L Mismatch - assume $\left(\frac{W}{L}\right)_1 = \frac{W}{L} + \frac{1}{2} \frac{\Delta(W/L)}{L}$, $\left(\frac{W}{L}\right)_2 = \frac{W}{L} - \frac{1}{2} \frac{\Delta(W/L)}{L}$

→ Can derive that (see text, sort of): $V_{os} = \left(\frac{V_{ov}}{2}\right) \cdot \frac{\Delta(W/L)}{(W/L)}$

③ V_t Mismatch - $V_{t1} = V_t + \frac{\Delta V_t}{2}$, $V_{t2} = V_t - \frac{\Delta V_t}{2}$

→ Can derive that (see text): $V_{os} = \Delta V_t$

→ For total offset, need to consider effects of all three types of offsets:

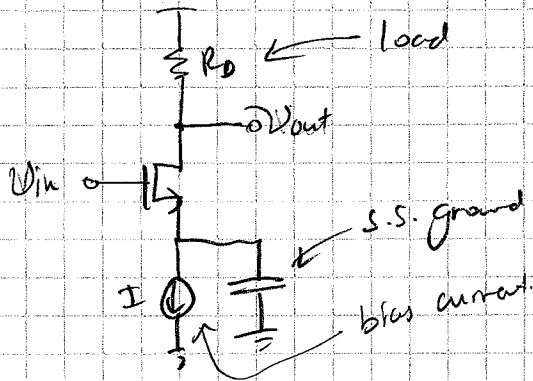
$$V_{os, \text{tot}} = \sqrt{V_{os, R_D}^2 + V_{os, W/L}^2 + V_{os, V_t}^2} \quad (\text{estimate}).$$

↑
independent random variables.

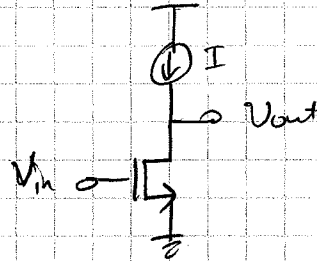
Active Loads

→ So far we have assumed resistive loads for our MOSFET amplifiers
 - we would like to use MOSFETs wherever possible since they are small and easy to integrate.

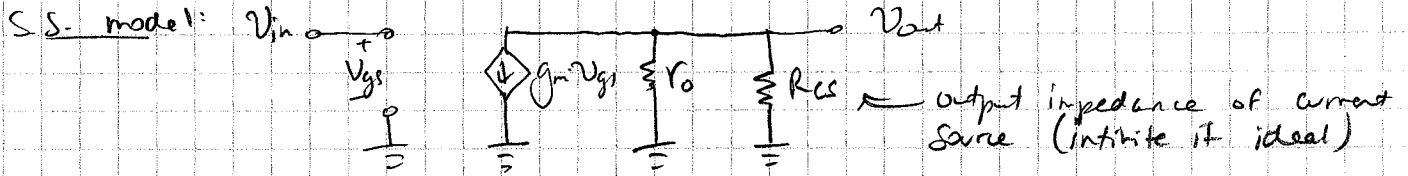
→ Recall an earlier common-source amplifier:



- What if we put the current source at the drain terminal and use it as a load also?



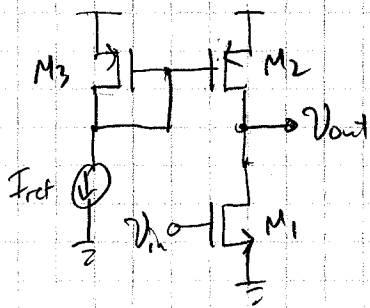
- Can get rid of resistor and coupling capacitor.



→ by inspection, gain: $A = -g_m \cdot (r_{o1} || R_{cs}) \approx -g_m \cdot r_{o1}$

→ How can we implement the current source, I? Current mirror

- a current mirror used like this is called an "Active Load".



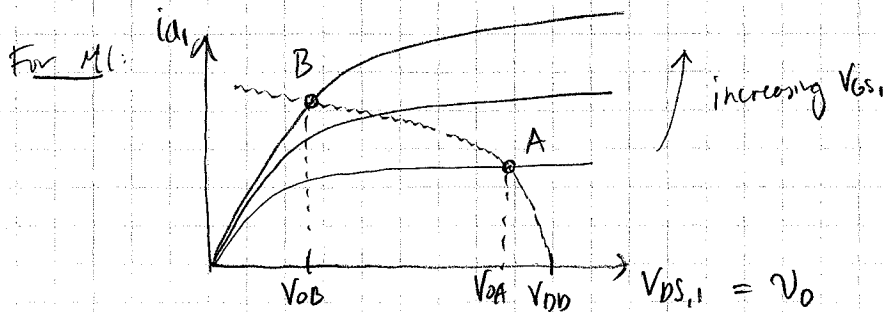
Notes:

- M_1 is NMOS, $M_{2,3}$ are PMOS
- M_1 will be biased with I_{ref} as long as V_{out} keeps both M_1 and M_2 in saturation.
- V_{gs} of M_2 never changes, so it is just like a current source with an output impedance of r_o

$$\therefore \text{gain} = A = -g_m \cdot (r_{o1} || r_{o2})$$

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→ need to pay attention to biasing to insure both M_1 & M_2 remain in saturation:



For M_2 : - Same curves, but $V_{GS,2} = V_{DD} - V_{GS,1}$
 - draw in on M_1 curve.

→ proper operation for V_o between $V_{DS,A}$ and $V_{DS,B}$.