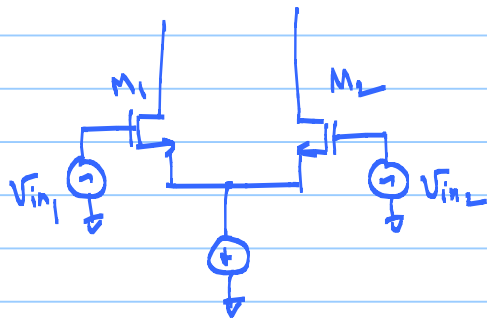


ECE 511 - Lecture 19

Note Title

4/4/2013



$$V_{in1} = \left(\frac{V_{in1} - V_{in2}}{2} \right) + \left(\frac{V_{in1} + V_{in2}}{2} \right)$$

$$V_{in2} = \left(\frac{V_{in2} - V_{in1}}{2} \right) + \left(\frac{V_{in1} + V_{in2}}{2} \right)$$

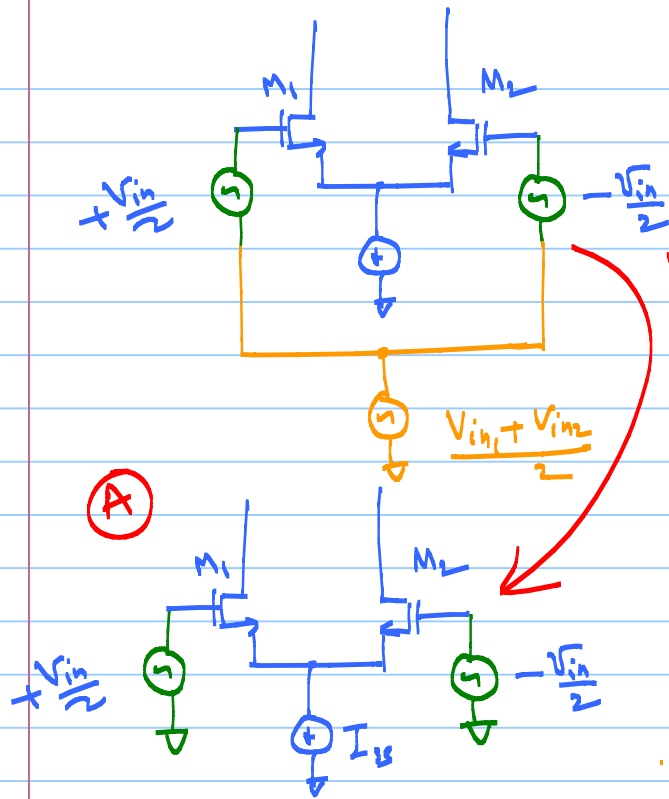
A circuit diagram of a differential pair, similar to the one above, but with differential and common-mode input signals. The gates of M_1 and M_2 are connected to nodes labeled $\frac{V_{in1} - V_{in2}}{2}$ and $\frac{V_{in2} - V_{in1}}{2}$ respectively. These nodes are also connected to a common-mode input node labeled $\frac{V_{in1} + V_{in2}}{2}$. The sources of M_1 and M_2 are connected to a common node that is connected to ground. The drains of M_1 and M_2 are connected to a common output node, which is marked with a '+' sign.

$$\frac{V_{in2} - V_{in1}}{2} = - \left(\frac{V_{in1} - V_{in2}}{2} \right) = - \frac{V_{in}}{2}$$

↑ differential input signal

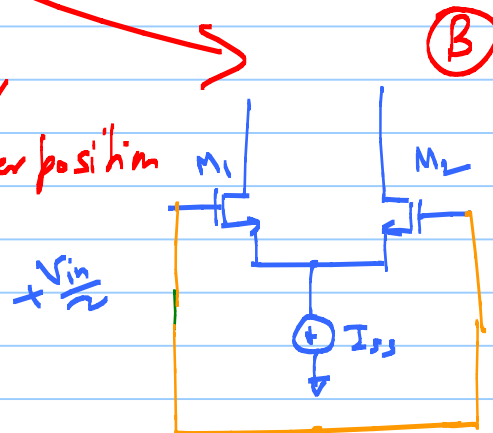
common-mode input signal

$$V_{in} = V_{in1} - V_{in2}$$



Differential Mode

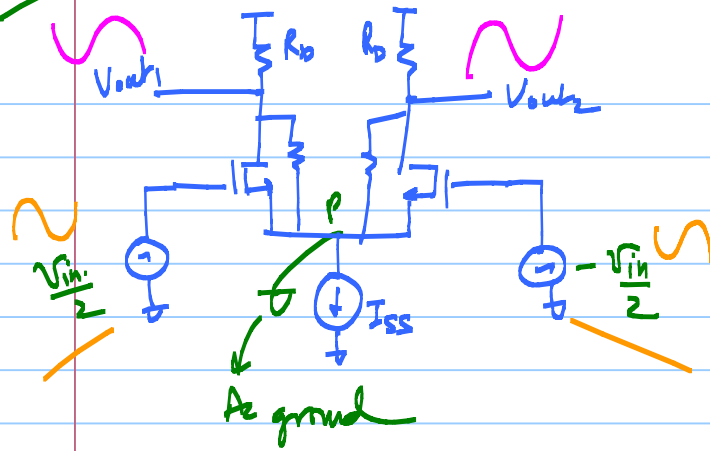
Linear
Superposition



Common
Mode

$$\frac{V_{in1} + V_{in2}}{2} = V_{in,cm}$$

Example: DM circuit



$$v_{out1} = -g_m(R_D \parallel r_o) \frac{v_{in}}{2}$$

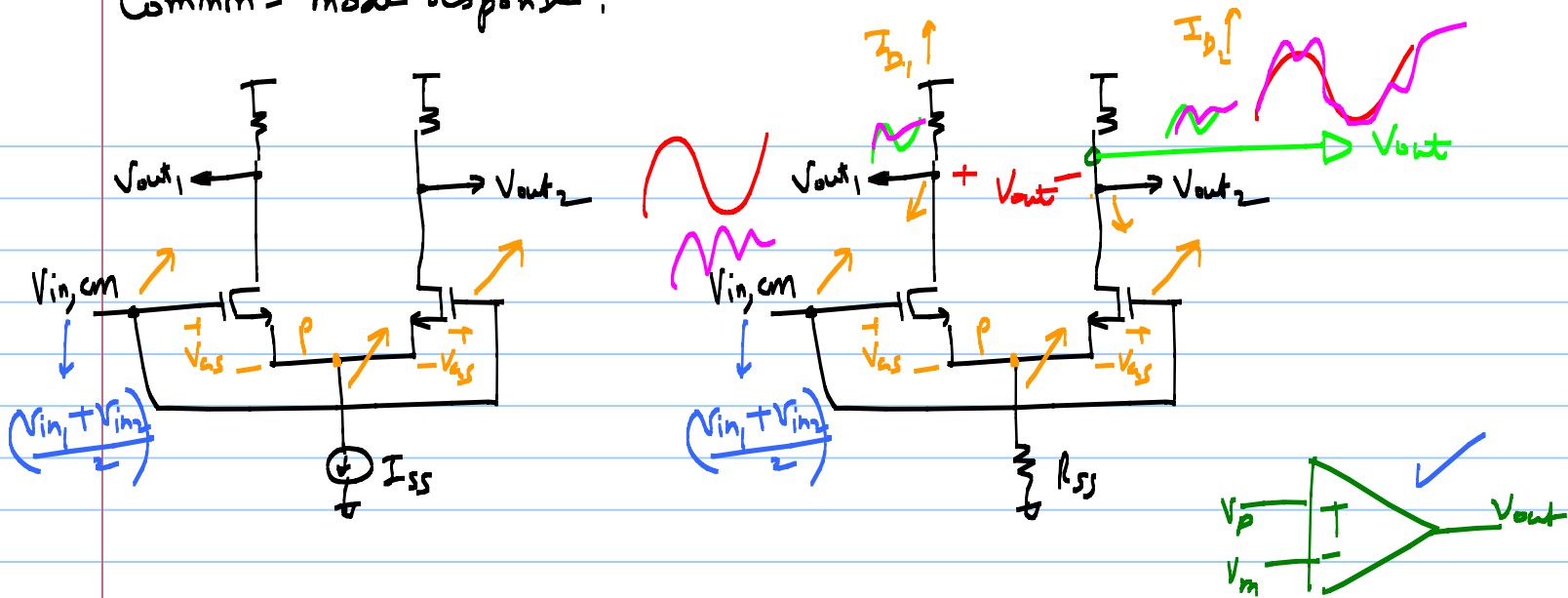
$$v_{out2} = +g_m(R_D \parallel r_o) \frac{v_{in}}{2}$$

$$v_{out} = v_{out1} - v_{out2} = \boxed{-g_m(R_D \parallel r_o)} v_{in}$$

Differential
mode gain

$A_{v, DM}$

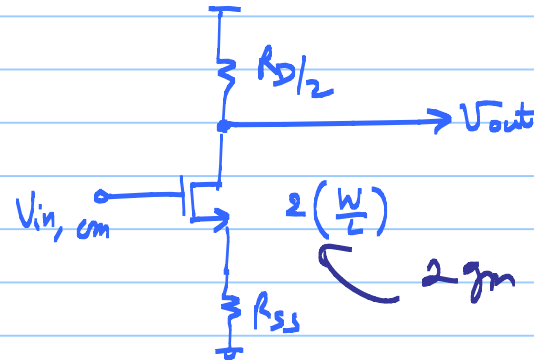
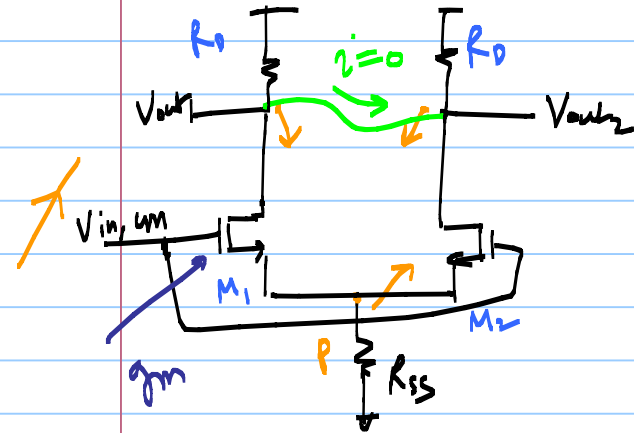
Common-mode response:



* Current source is not ideal

↳ CM variations will appear at the outputs

"CM Equivalent Circuit"



$$A_{v,cm} = \frac{V_{out}}{V_{in,cm}} = - \frac{2g_m}{1 + 2g_m R_{ss}} \cdot \frac{R_0}{2}$$

$$A_{v,cm} = - \frac{g_m R_0}{1 + 2g_m R_{ss}}$$

$$A_{v, cm} = - \frac{(g_m R_D)}{1 + 2g_m R_{SS}}$$

$$R_{SS} \rightarrow \infty$$

Single-ended output

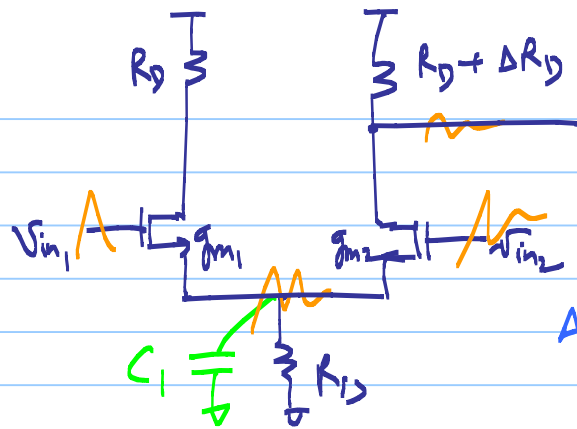
$$V_{out1} = \underbrace{A_{v, dm}}_{-\frac{g_m R_D}{2}} \cdot \underbrace{V_{in}}_{V_{in1} - V_{in2}} + \underbrace{A_{v, cm}}_{-\frac{R_D/2}{(\frac{1}{2g_m}) + R_{SS}}} \cdot \underbrace{V_{in, cm}}_{\frac{V_{in1} + V_{in2}}{2}}$$

* We want large $A_{v, dm}$ and small $A_{v, cm} \Rightarrow R_{SS} \uparrow$ for rejecting CM disturbance

metric

$$CMRR = \left| \frac{A_{v, DM}}{A_{v, CM}} \right| = \frac{\frac{g_m R_D}{2}}{\frac{g_m R_D}{1 + 2g_m R_{SS}}} = \frac{1}{2} + g_m R_{SS}$$

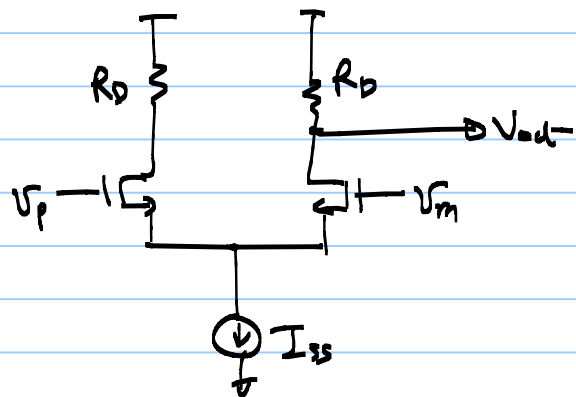
In a FD circuit $V_{out} = V_{out1} - V_{out2}$
CMRR is irrelevant



$$g_{m2} = g_{m1} + \Delta g_m$$

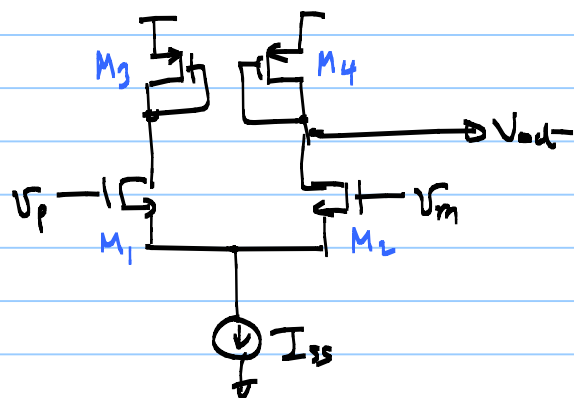
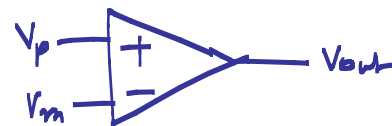
Asymmetry in the diff pair causes
CM mode to appear as differential
noise at the output

$$CMRR \approx \left(\frac{g_m}{\Delta g_m} \right) (1 + \underline{2g_m R_{SS}}) \rightarrow \text{worse at high frequency}$$



$$A_{v,DM} = + \frac{g_m (R_D \parallel r_o)}{2}$$

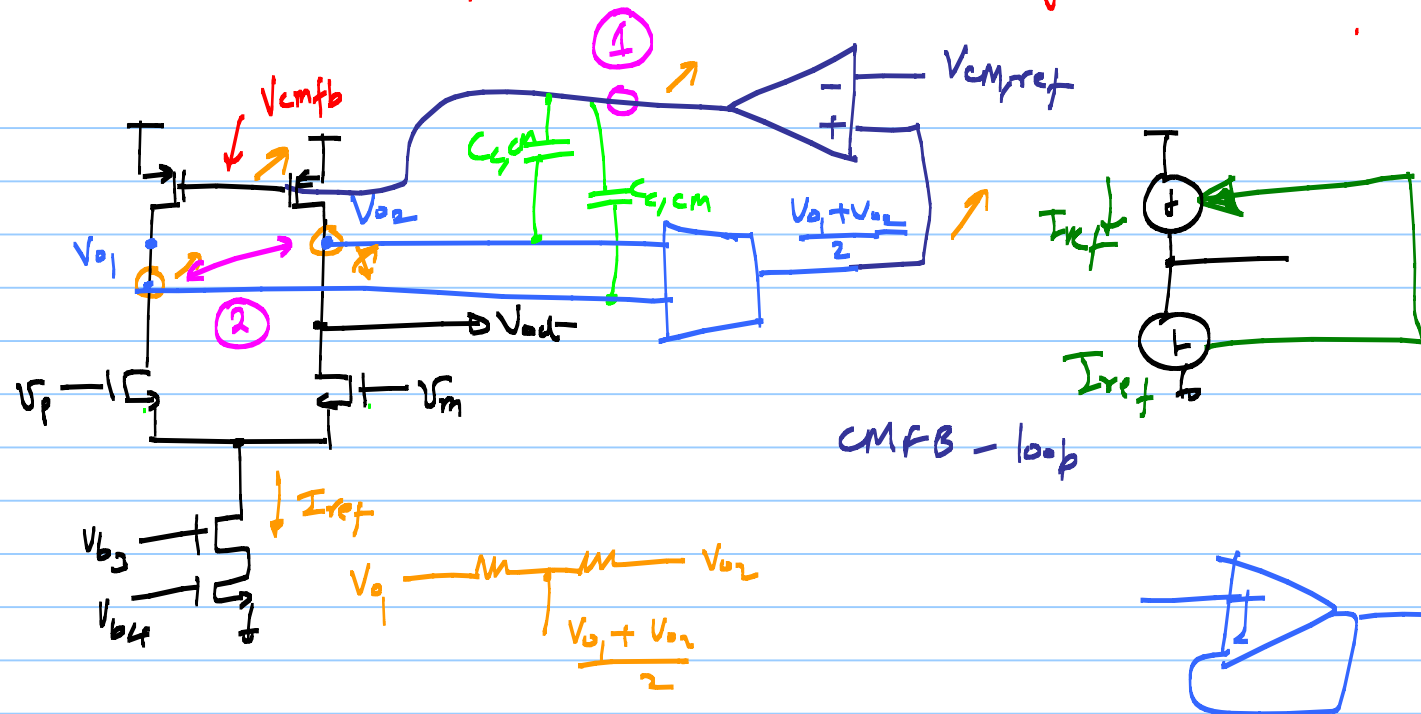
$$A_{v,CM} = - \frac{R_D/2}{\frac{1}{2}g_m + R_{SS}}$$

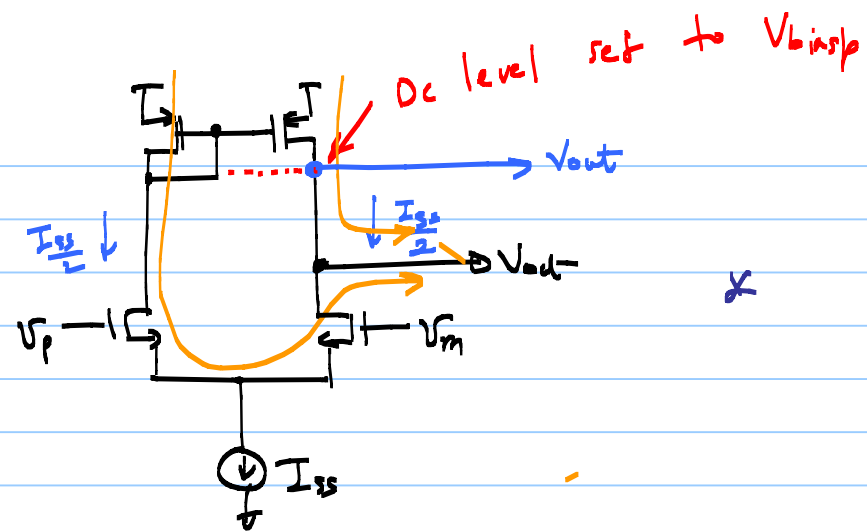


$$A_{v,DM} = + \frac{g_{m1,2}}{2} \left(\frac{1}{g_{m3,4}} \parallel r_{o2} \parallel r_{o3} \right)$$

$$\approx \frac{1}{2} \frac{g_{m1,2}}{g_{m3,4}}$$

* Output CM-level is undefined $\rightarrow$ BAD!





"By symmetry"