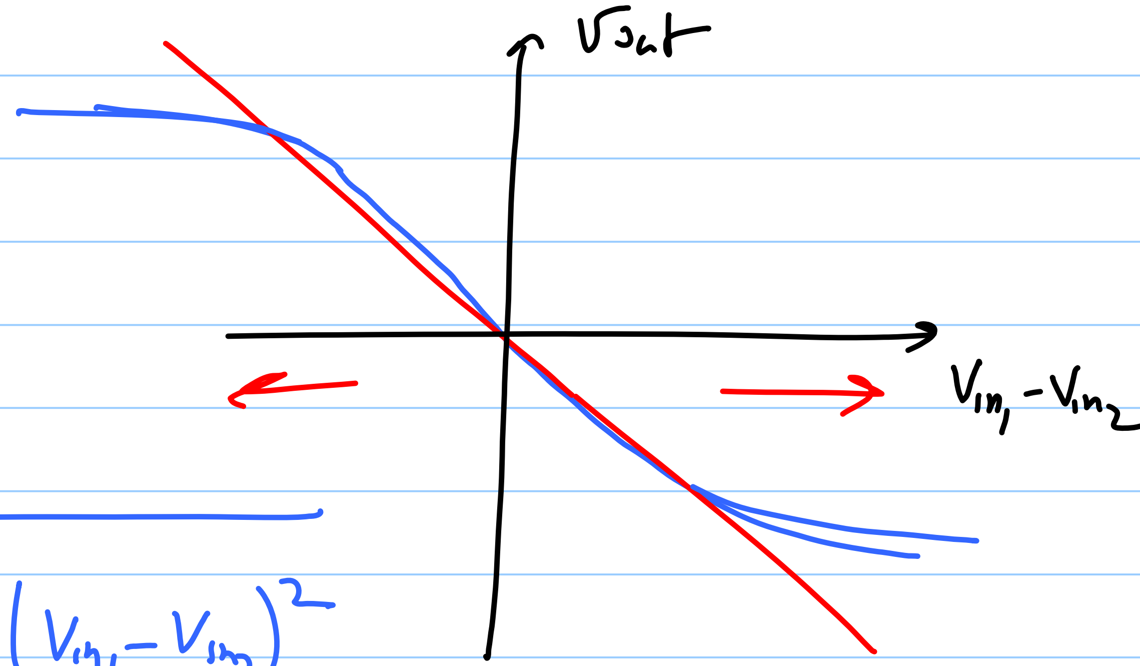
ECE 511 - Lecture 21

Note Title 4/7/2015

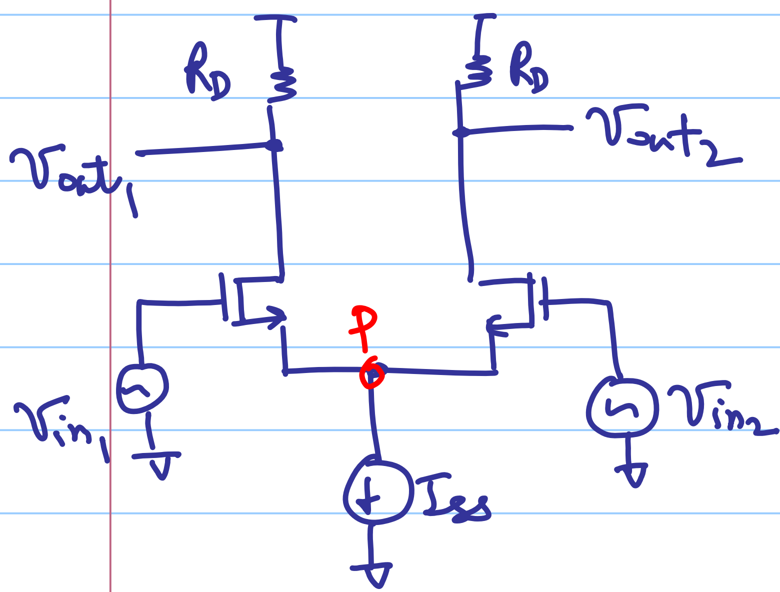


$$I_{D_1} - I_{D_2} = \frac{\beta}{2}\underbrace{(V_{in_1} - V_{in_2})}_{V_{in}}\sqrt{\frac{4I_{SS}}{\beta} - \underbrace{(V_{in_1} - V_{in_2})}_{V_{in}}^2}$$

compressive non linearity

for linearity $\frac{I_{SS}}{\beta} \uparrow$

Small-signal Analysis

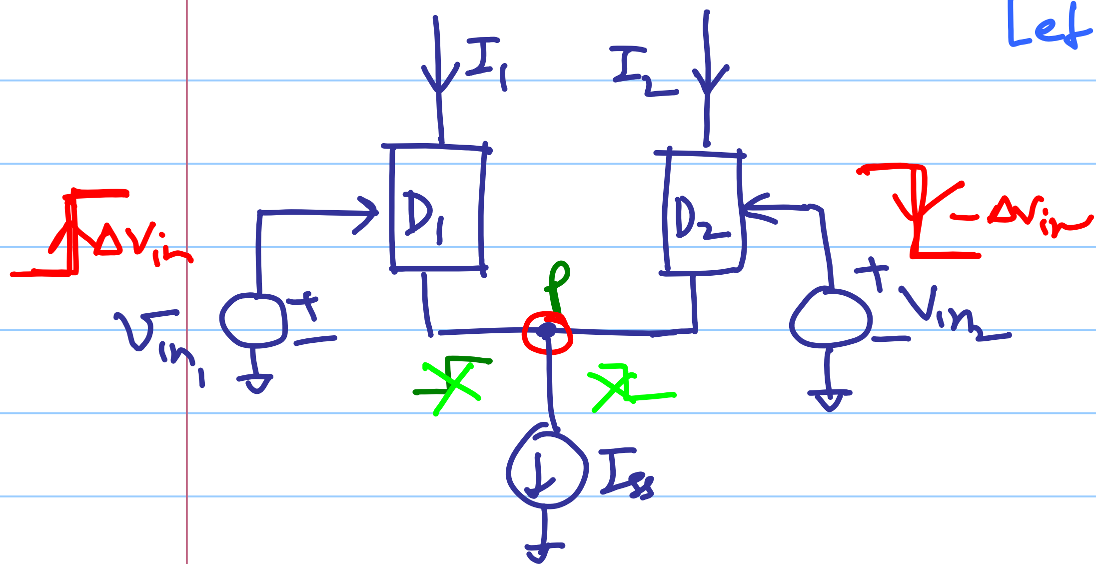


Lemma:

Consider the "symmetric circuit" shown below where D_1 + D_2 are any 3-terminal devices

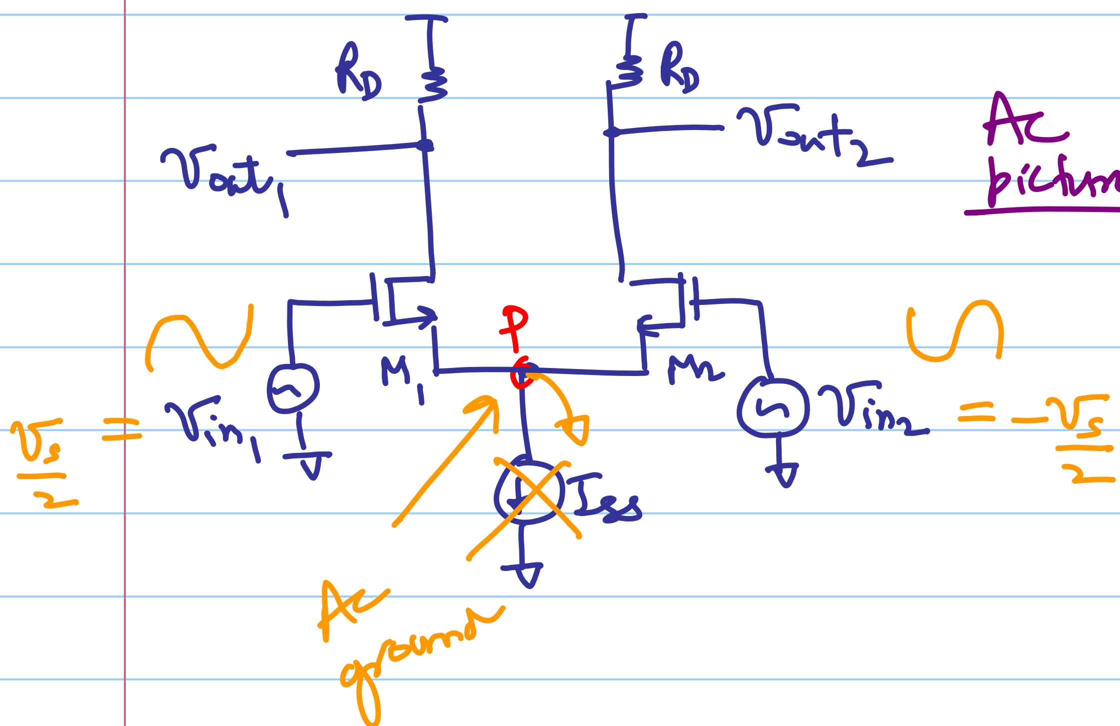
Let V_{in_1} change from V_0 to $V_0 + \Delta V_{in}$

V_{in_2} " " V_0 to $V_0 - \Delta V_{in}$



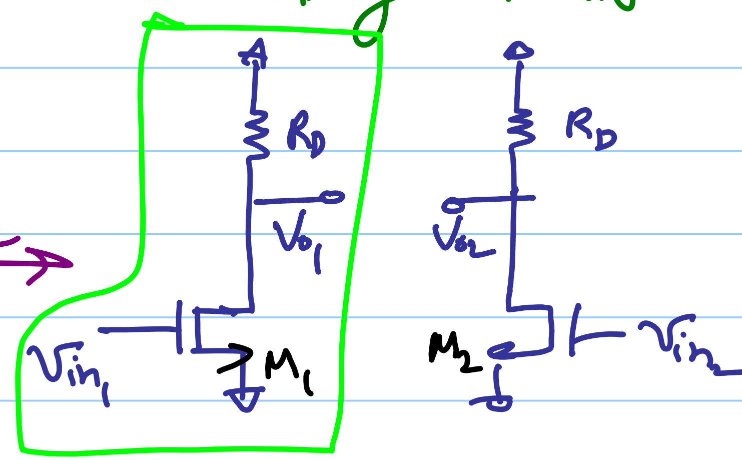
Then if, circuit remains "linear", "V_p doesn't change".

V_{in_1} & V_{in_2} are differential inputs



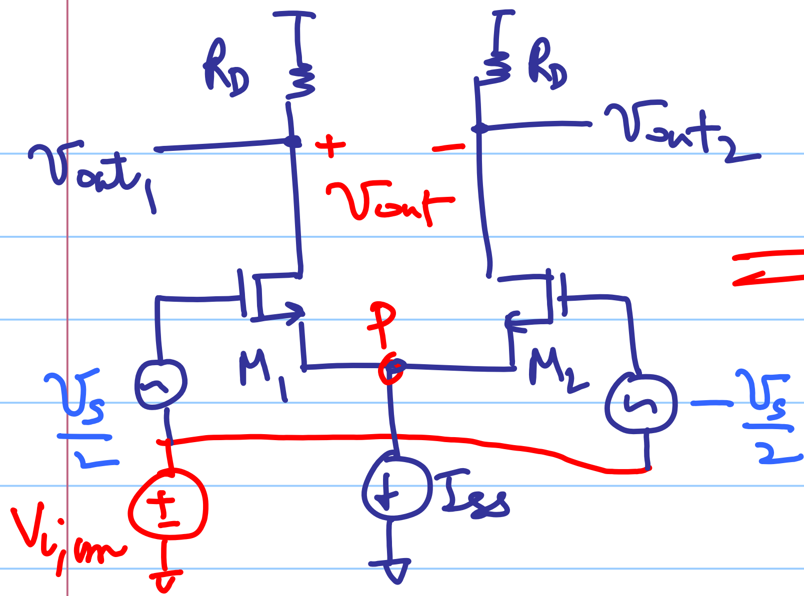
AC picture →

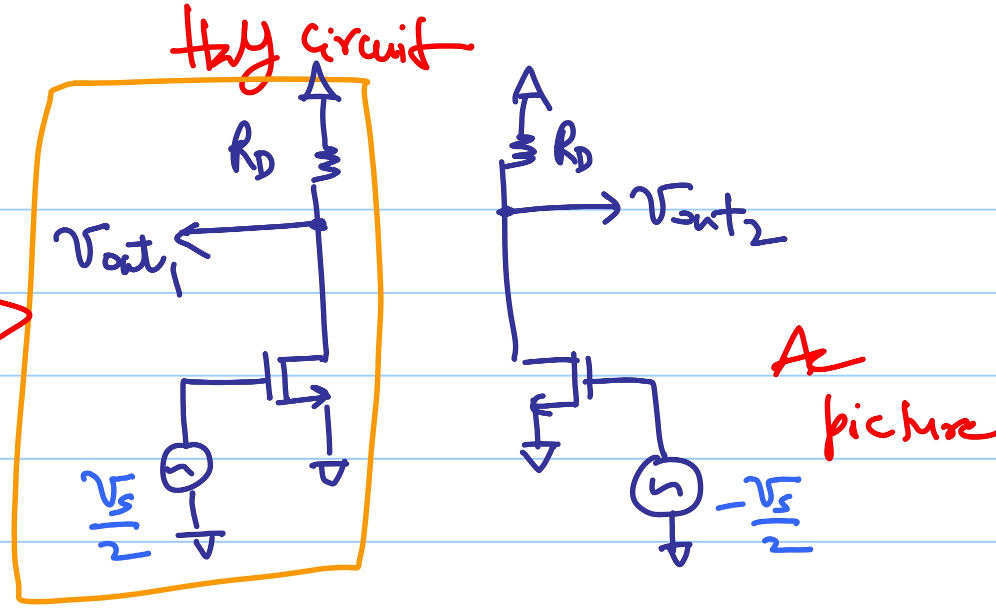
Half - Circuit



Linearity ⇒ signals are "small"

* Half Circuit (small-signal) Analysis





$$v_{out_1} = -g_m(r_o \| R_D)\cdot \frac{v_s}{2} \qquad v_{out_2} = \cancel{-}\, g_m(r_o \| R_D)\cdot\left(\cancel{-}\frac{v_s}{2}\right)$$

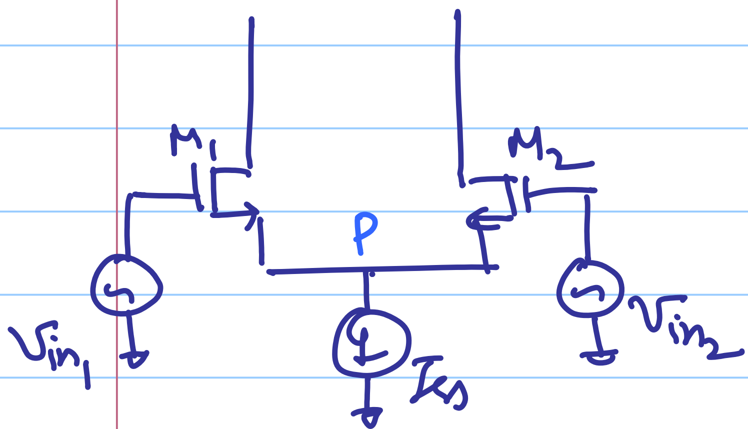
Diff. o/p $\Rightarrow$ $$(v_{out_1} - v_{out_2}) = -\frac{g_m(r_o \| R_D)\cdot v_s}{2} - \frac{g_m(r_o \| R_D)\cdot v_s}{2}$$

$$= -g_m(r_o \| R_D)\cdot v_s$$

$$\Rightarrow \frac{v_{out_1} - v_{out_2}}{v_s} = -g_m(r_o \| R_D)$$

$$v_s \triangleq v_{in_1} - v_{in_2}$$

* What if the inputs are not fully-differential, but single-ended



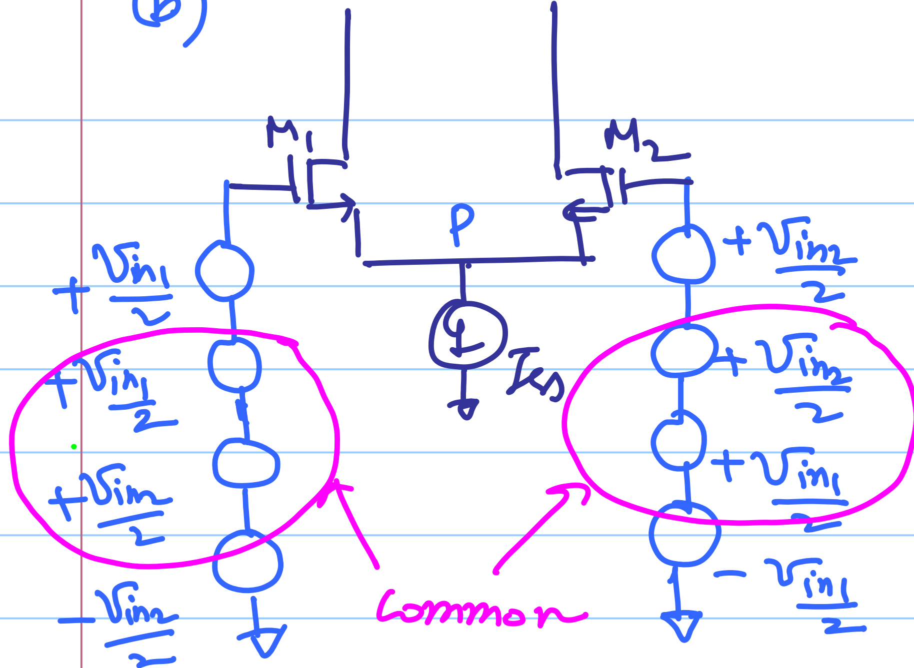
$$v_{in_1} = \underbrace{\left(\frac{v_{in_1} - v_{in_2}}{2}\right)}_{v_s/2} + \left(\frac{v_{in_1} + v_{in_2}}{2}\right)$$

common v_c

$$v_{in_2} = \underbrace{\left(\frac{v_{in_2} - v_{in_1}}{2}\right)}_{-v_s/2} + \left(\frac{v_{in_1} + v_{in_2}}{2}\right)$$

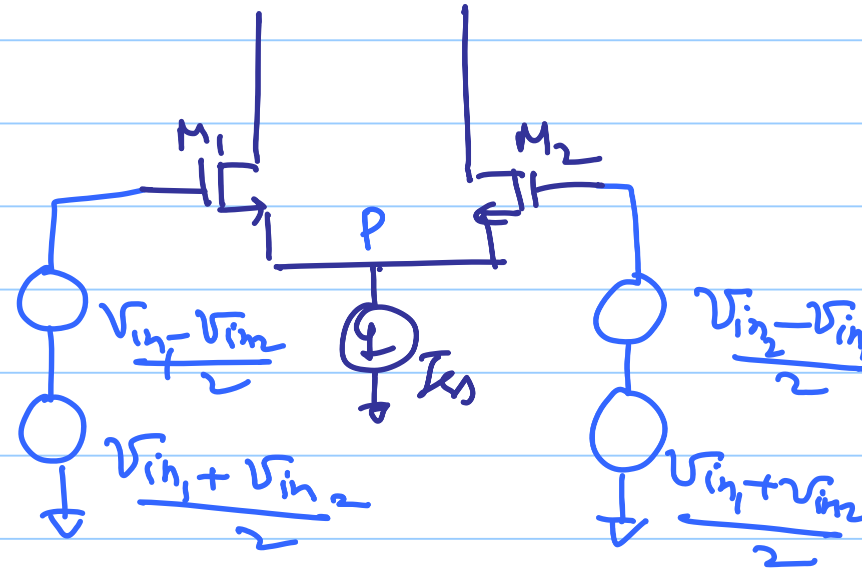
May Not be DC

(b)



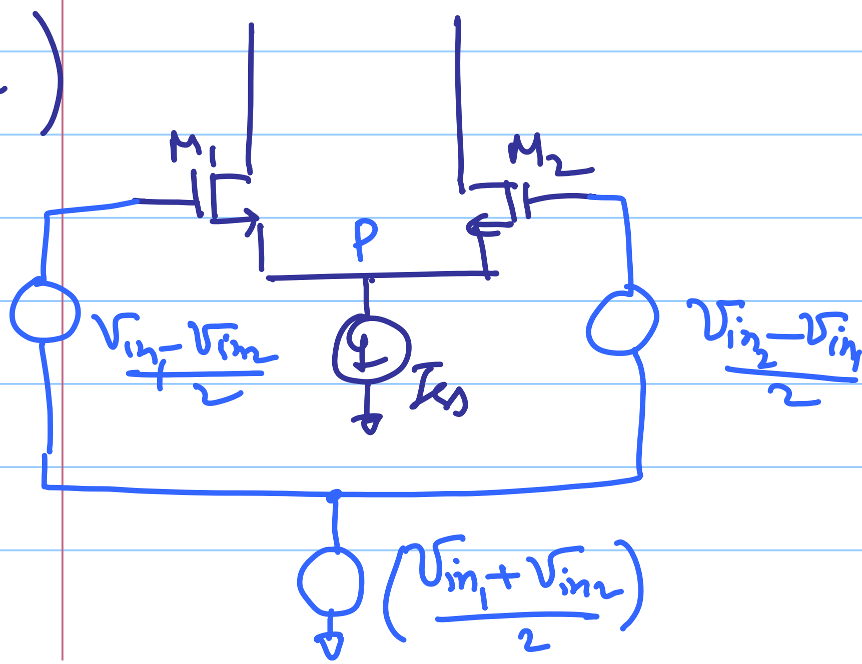
M1
M2
P
Iss
+Vin1/2
+Vin1/2
+Vin2/2
-Vin2/2
+Vin2/2
+Vin2/2
+Vin1/2
-Vin1/2
common

(c)



M1
M2
P
Iss
(Vin1-Vin2)/2
(Vin1+Vin2)/2
(Vin2-Vin1)/2
(Vin1+Vin2)/2

(d)

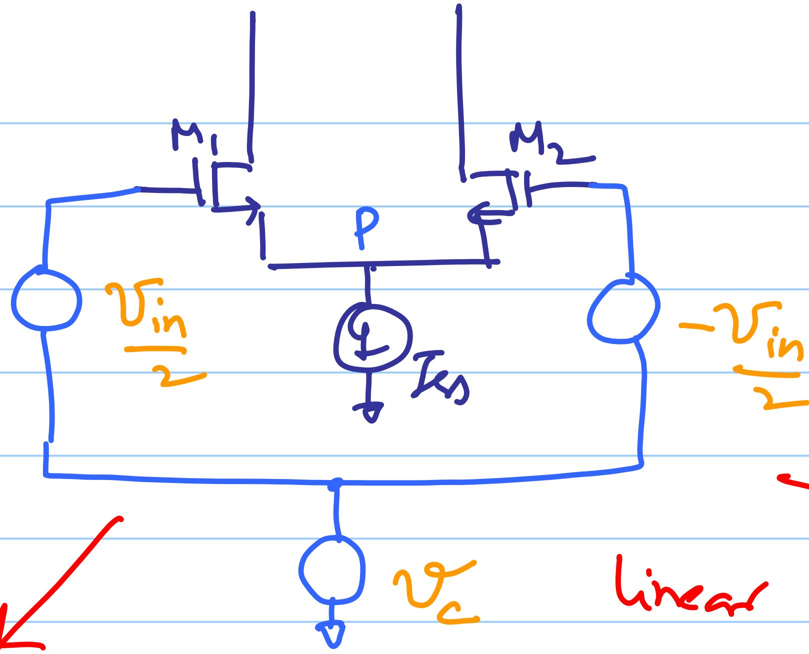


M1
M2
P
Iss
(Vin1-Vin2)/2
(Vin2-Vin1)/2
((Vin1+Vin2)/2)

$$v_{in} = v_{in_1} - v_{in_2}$$

$$v_c = \frac{(v_{in_1} + v_{in_2})}{2}$$

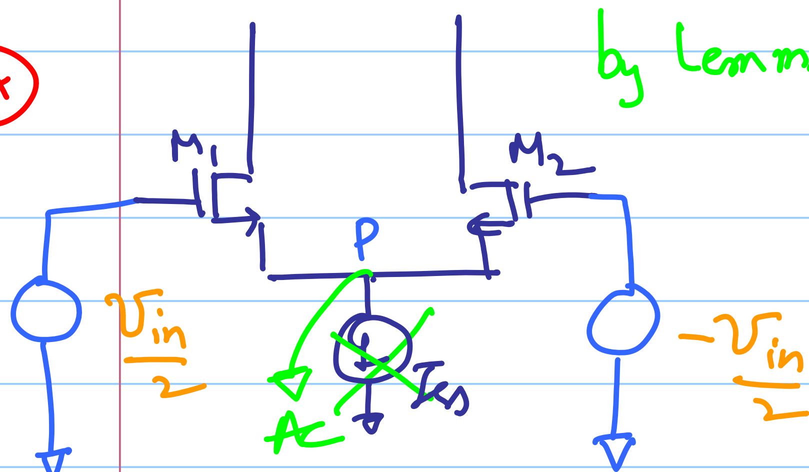
average of the 2 inputs ⇒ Common-mode signal



linear superposition

by Lemma

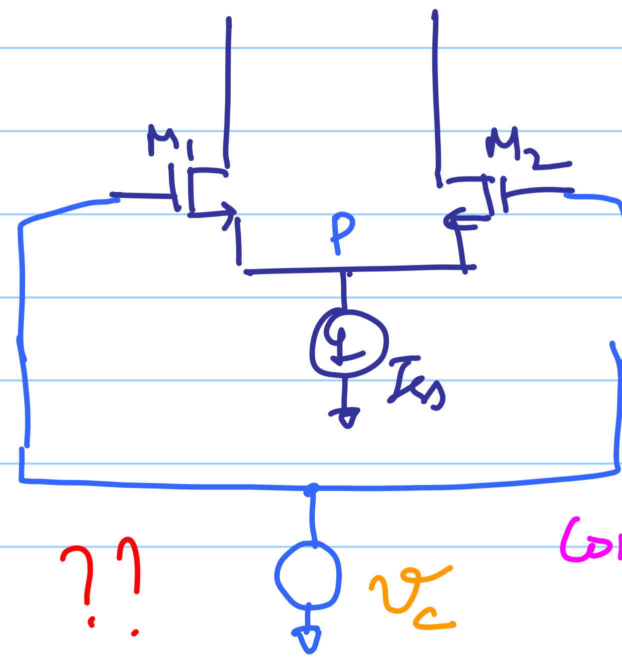
A



DIFFERENTIAL

(Half Circuit Analysis)

B



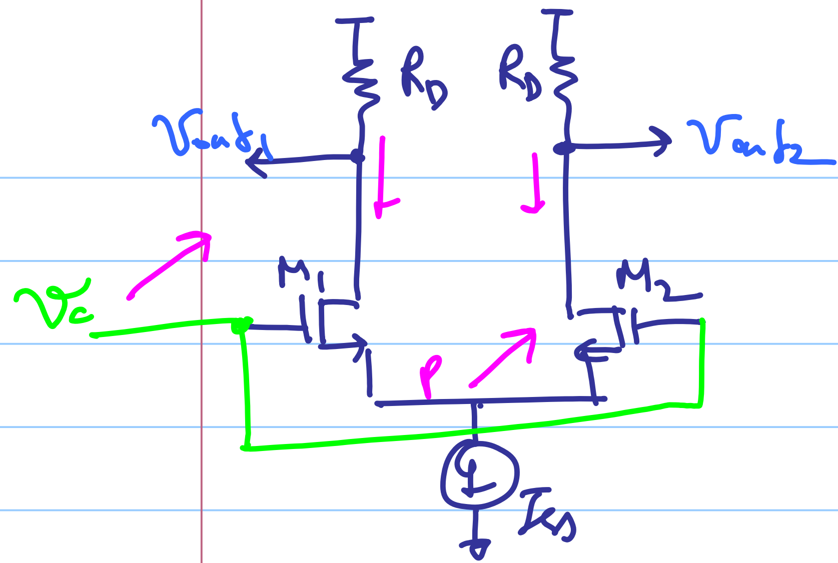
??

COMMON-MODE

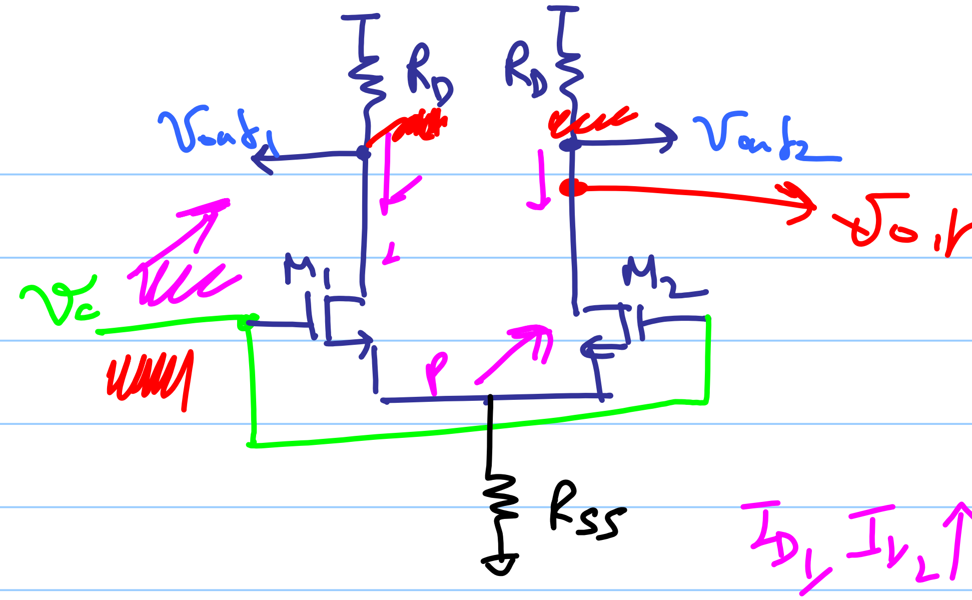
Common Mode Response of Diff-pair

* Diffamp should ideally suppress the effect of CM disturbances, including a CM input (v_c)

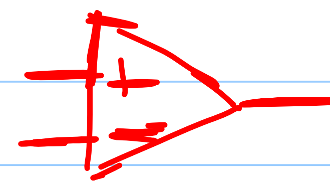
* In reality the tail current source is not ideal
  - ↳ finite output resistance
    - ↳ CM variations at the output



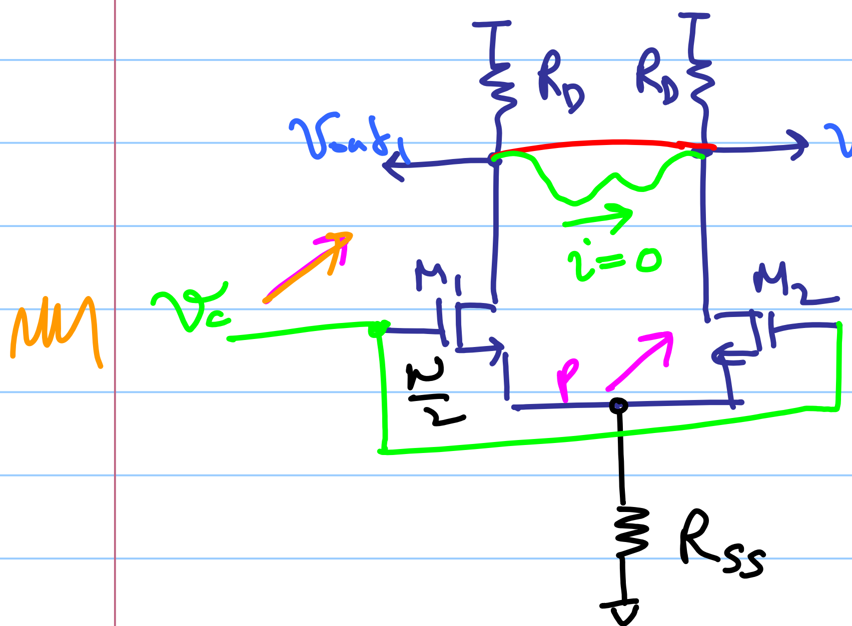
$v_C \uparrow \Rightarrow V_P \uparrow$



$V_{out} \downarrow$

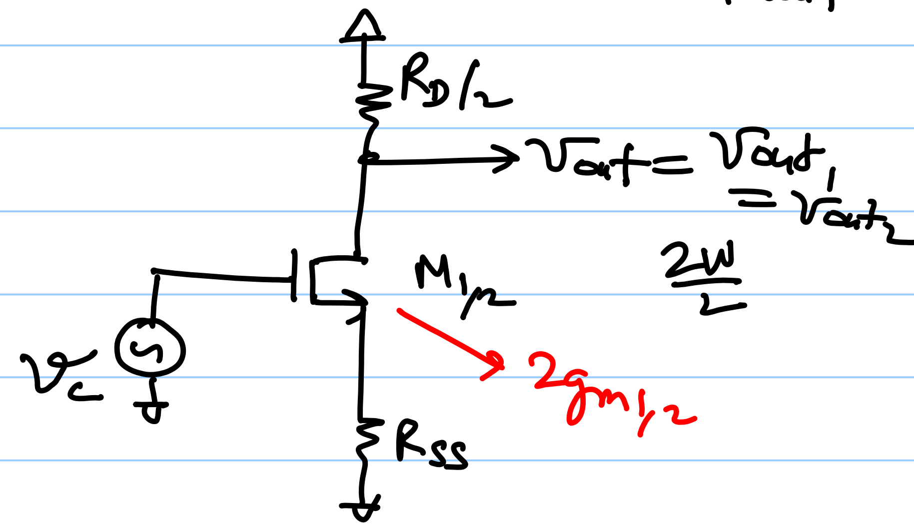


Common-Mode Equivalent Circuit



$\Rightarrow$

CM-Equivalent (A_c) circuit



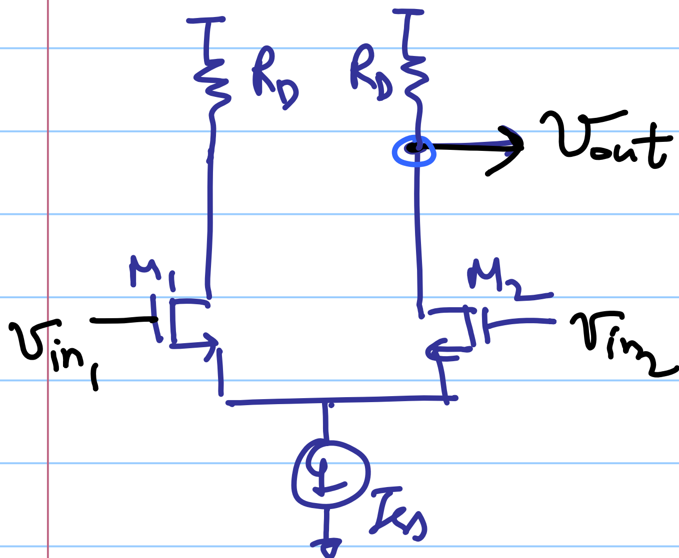
Common mode small-signal gain $= A_{vCM} = \dfrac{v_{out}}{v_c} = -\dfrac{R_D/2}{\frac{1}{(2g_m)} + R_{SS}}$

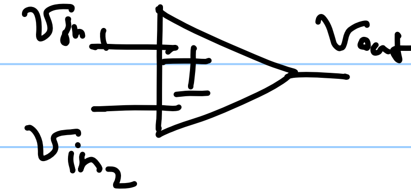
$\lambda = 0, \gamma = 0$

We want $|A_{vCM}| \to 0$

$\Rightarrow R_{SS} \to \infty$

Let's say we have single-ended output





$$v_{out} = v_{out_2} = A_{v,DM} \cdot (v_{in_1} - v_{in_2}) + A_{v,CM} \cdot \left(\frac{v_{in_1} + v_{in_2}}{2}\right)$$

$$= A_{v,DM} \cdot v_{in} + A_{v,CM} \cdot v_c$$

DM gain

CM gain

$$A_{v,DM} = -\frac{g_m R_D}{2}$$

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

We want $|A_{v,DM}| \uparrow$ & $|A_{v,cm}| \to 0$

Common-mode rejection ratio

$$(CMRR) = \left|\frac{A_{v,DM}}{A_{v,cm}}\right|$$

expressed in dB

$$20\log_{10}\left|\frac{A_{v,DM}}{A_{v,cm}}\right|$$

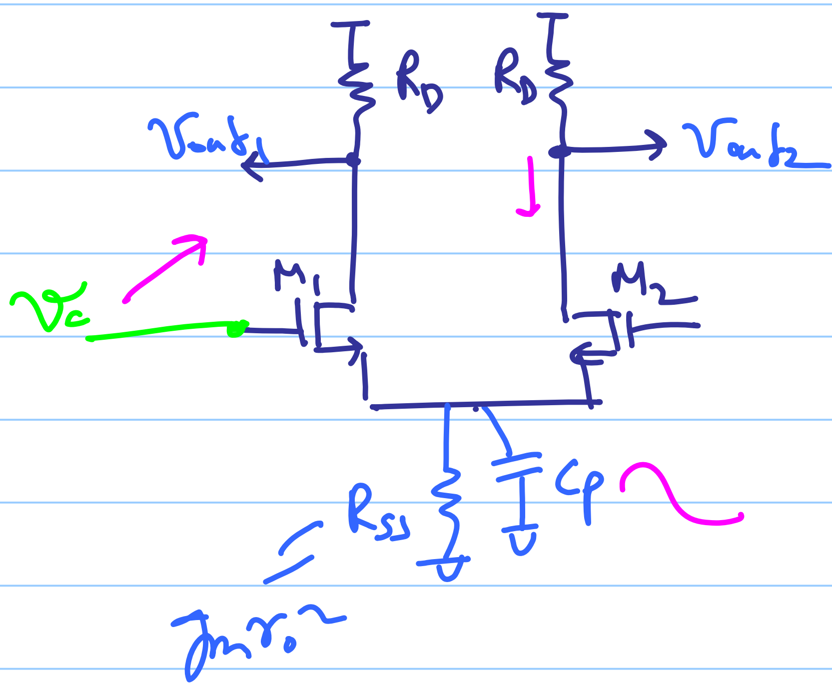
ideally CMRR $\to \infty$

CMRR for the above diffpair

$$CMRR = \frac{\cancel{\frac{g_m R_D}{2}}}{\frac{\cancel{g_m R_D}}{1+2g_m R_{SS}}} = \frac{1}{2} + g_m R_{SS}$$

mismatch b/w M_1 & M_2 limits CM rejecti

$$CMRR = \frac{g_m}{\Delta g_m}\left(1 + 2 g_m R_{SS}\right)$$



$$\left|\frac{1}{j\omega C_p}\right| \simeq R_{SS}$$