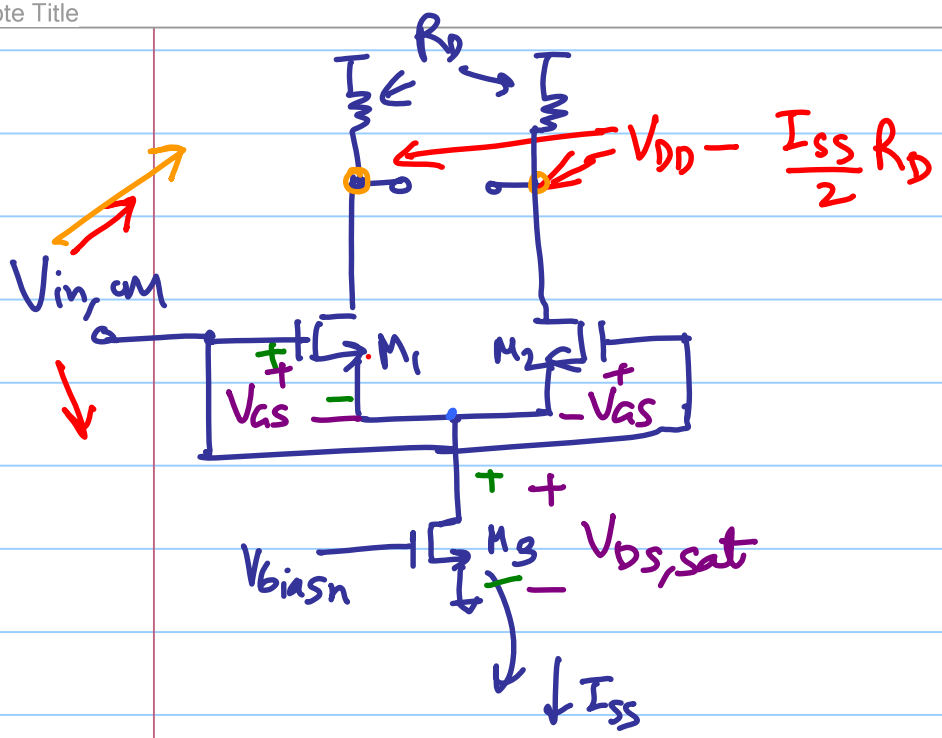
ECE 511 – Lecture 20

Note Title 4/8/2014



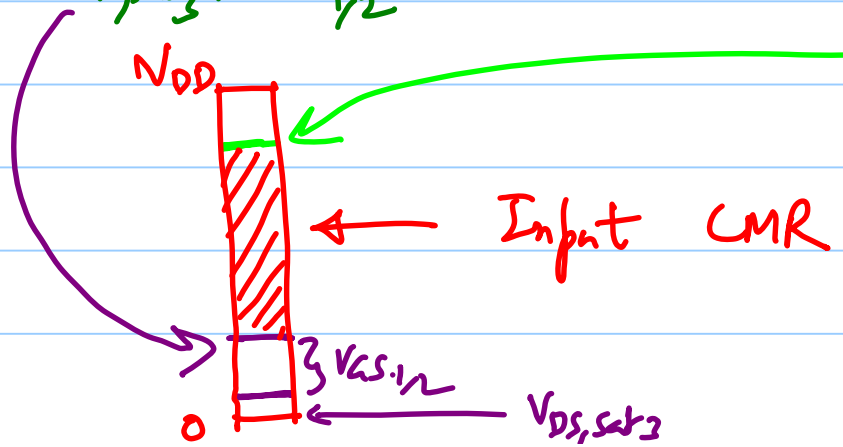
Input Common-Mode Range

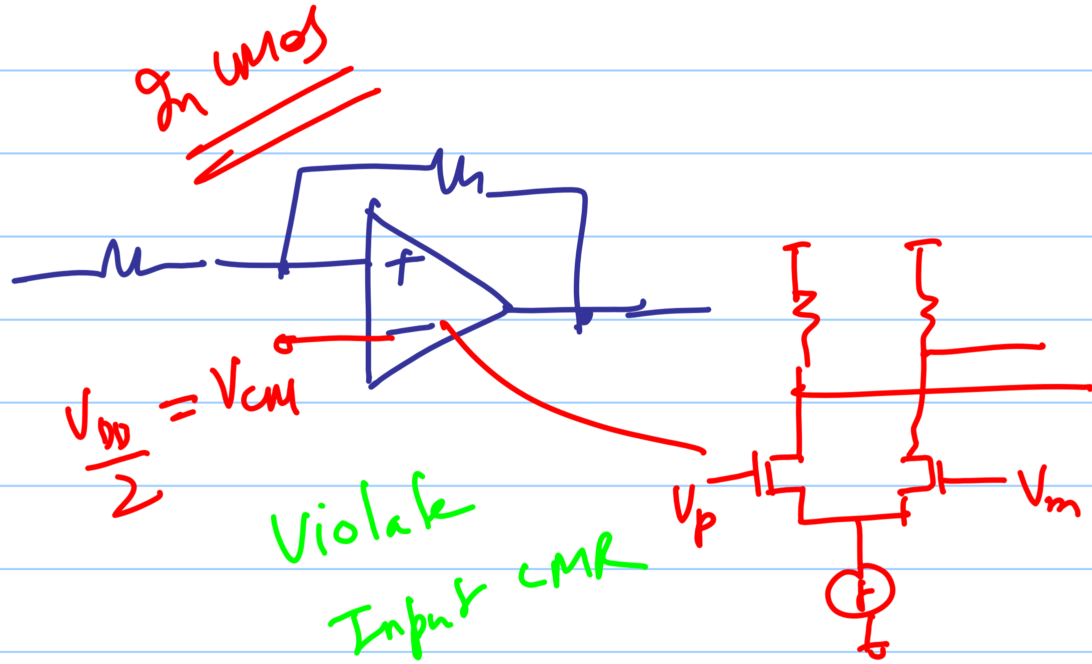
Input CMR

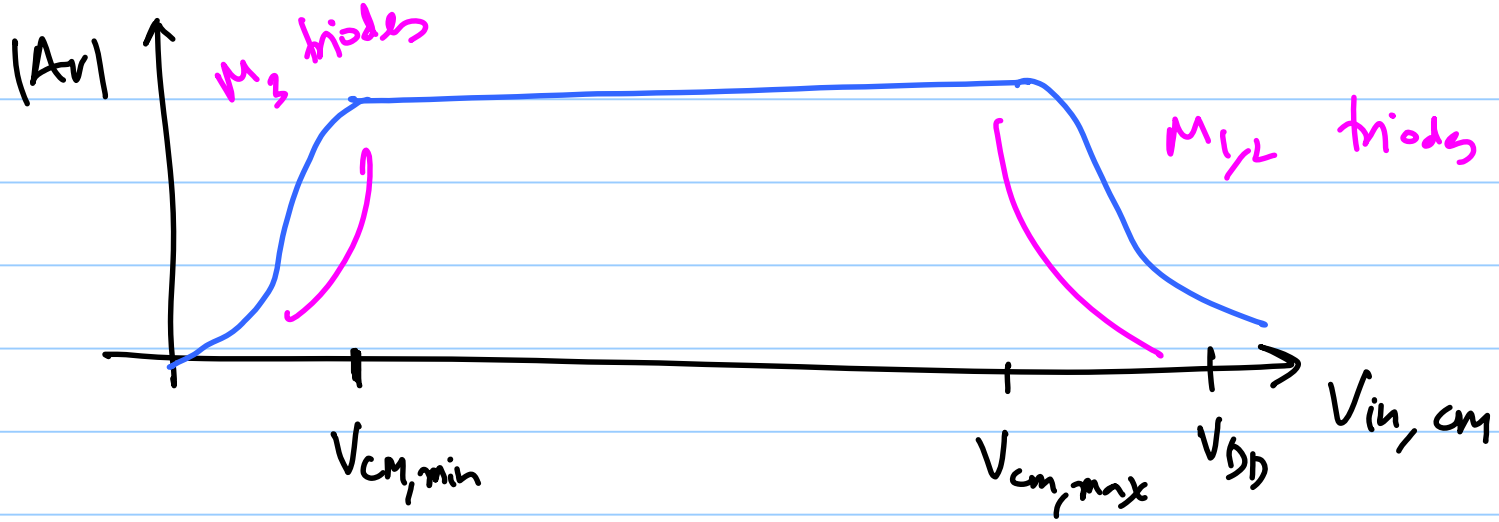
$$V_{in,cm} \geq V_{GS_{1,2}} + V_{DS,sat_3}$$

$$V_{in,cm} \leq \left(V_{DD} - \frac{I_{SS}}{2} R_D\right) + V_{THN}$$

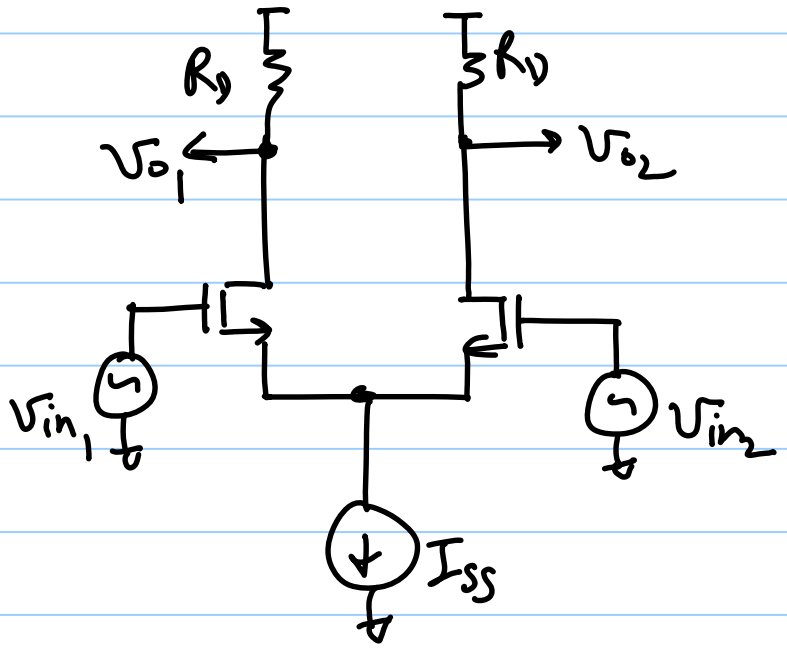
$$V_{DS,sat_3} + V_{GS_{1,2}} \leq V_{in,cm} \leq \left(V_{DD} - \frac{I_{SS}}{2} R_D\right) + V_{THN}$$




gm nmos
+
−
$\frac{V_{DD}}{2} = V_{CM}$
Violate
Input CMR
V_p
V_m

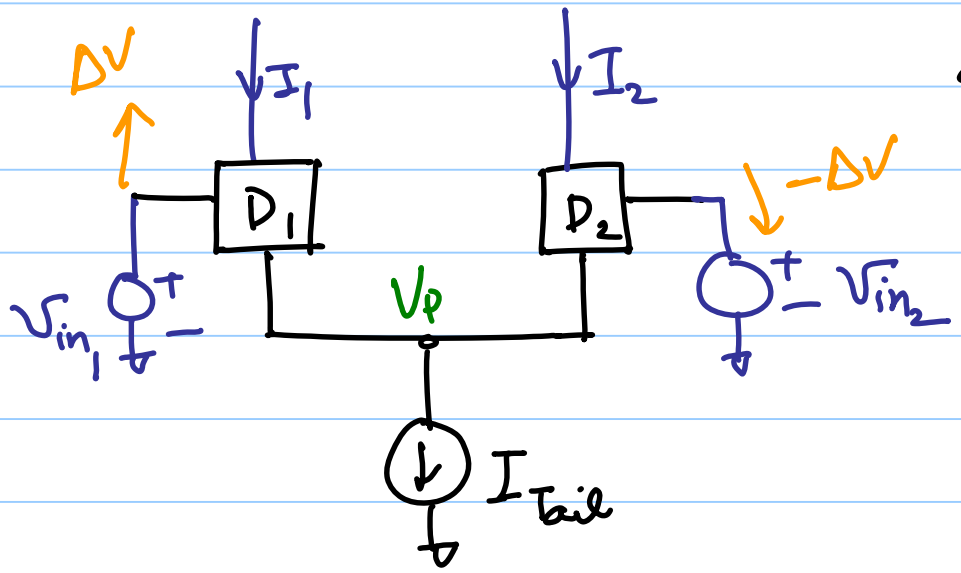

|Av|
M3 triode
M1,2 triode
Vcm,min
Vcm,max
VDD
Vin, cm

Small-Signal Analysis:



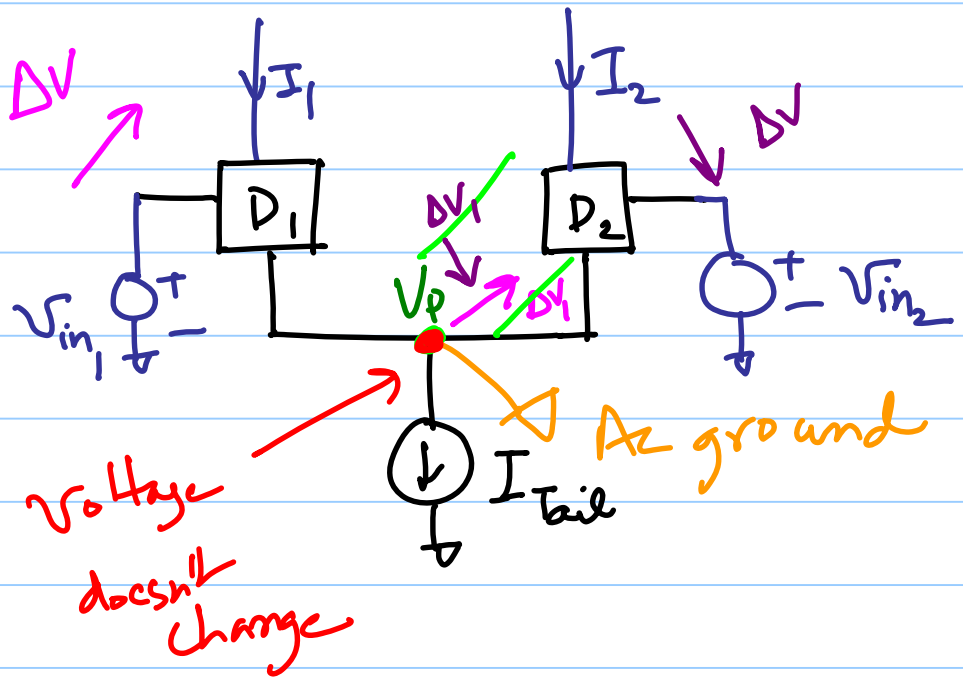
Lemma: In the symmetric circuit shown below where D_1 & D_2 are any 3-terminal devices (i.e a MOSFET)

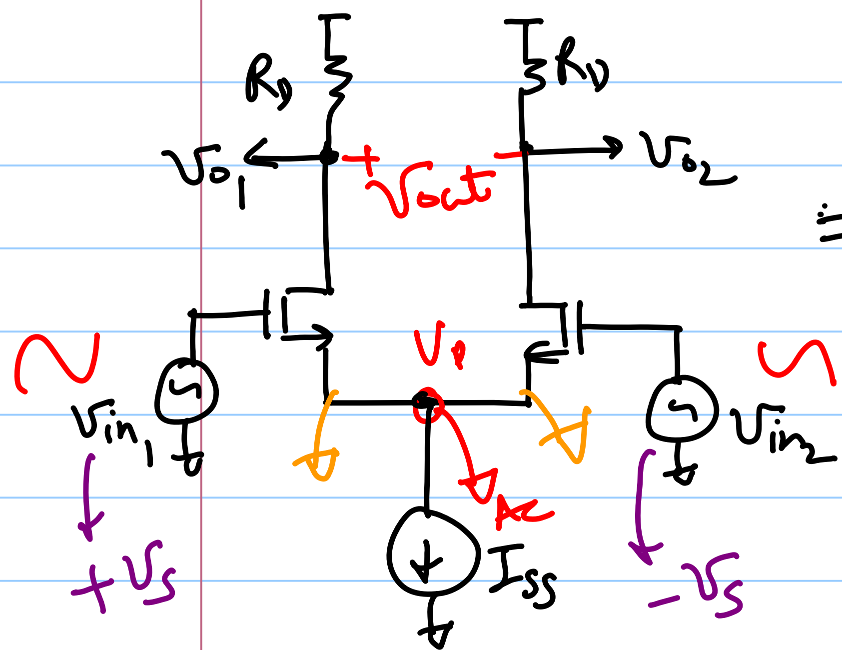
if V_{in_1} changes by $+\Delta V$
& V_{in_2} changes by $-\Delta V$



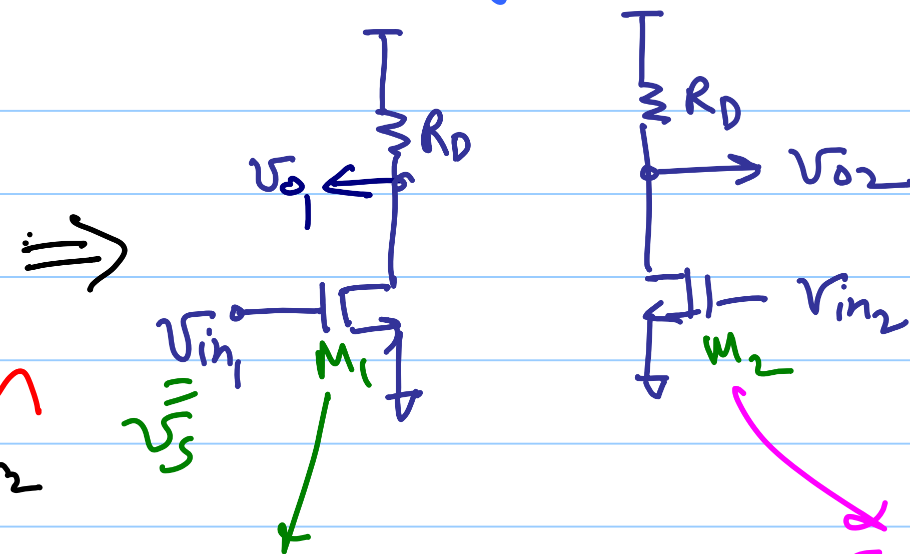
If the circuit is 'linear' then the node V_p doesn't change.

input is fully-differential





2 Half Circuits



$$\frac{v_{o_1}}{v_{in_1}} = -g_{m_1}(r_{o_1} || R_D)$$

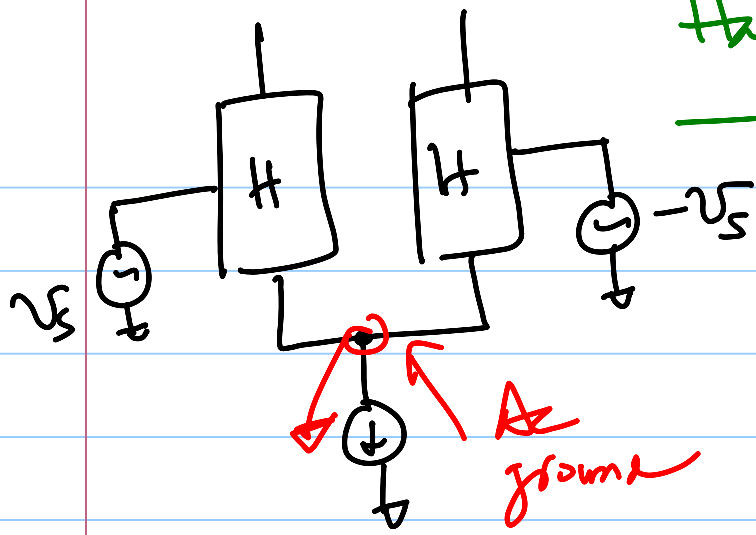
$$\frac{v_{o_2}}{v_{in_2}} = -g_{m_2}(r_{o_2} || R_D)$$

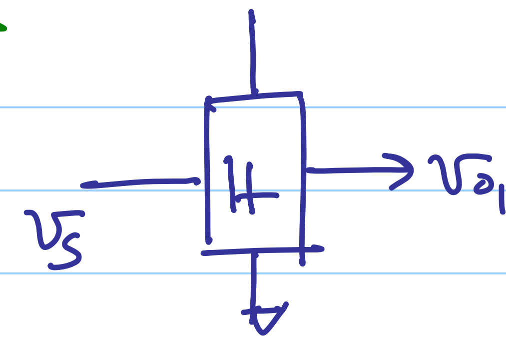
$$A_v = \frac{v_{out}}{v_s} = \left(\frac{v_{o_1}}{v_s}\right) - \left(\frac{v_{o_2}}{-v_s}\right)$$

$$= \left[-g_m(r_o || R_D)\right] - \left[+g_m(r_o || R_D)\right]$$

$$= -2 \times \left(g_m(r_o || R_D)\right)$$

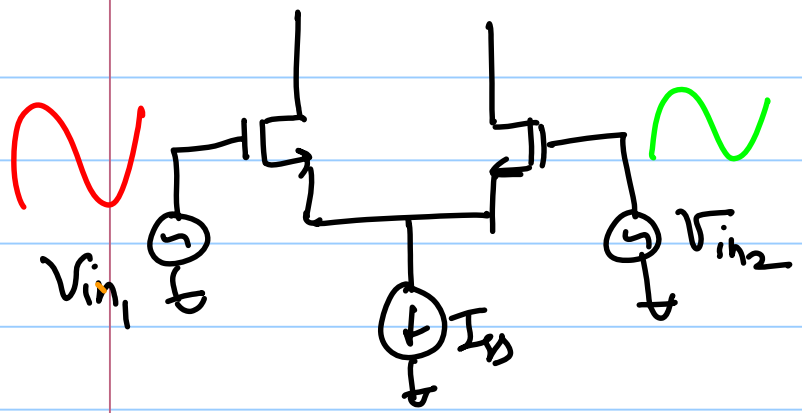
Half Circuit Analysis





$2\times(\quad)$

Q: What if the inputs are not fully-differential, but different

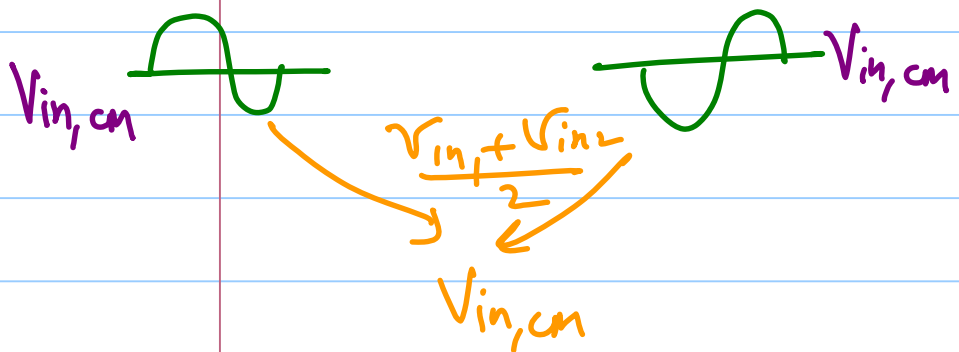


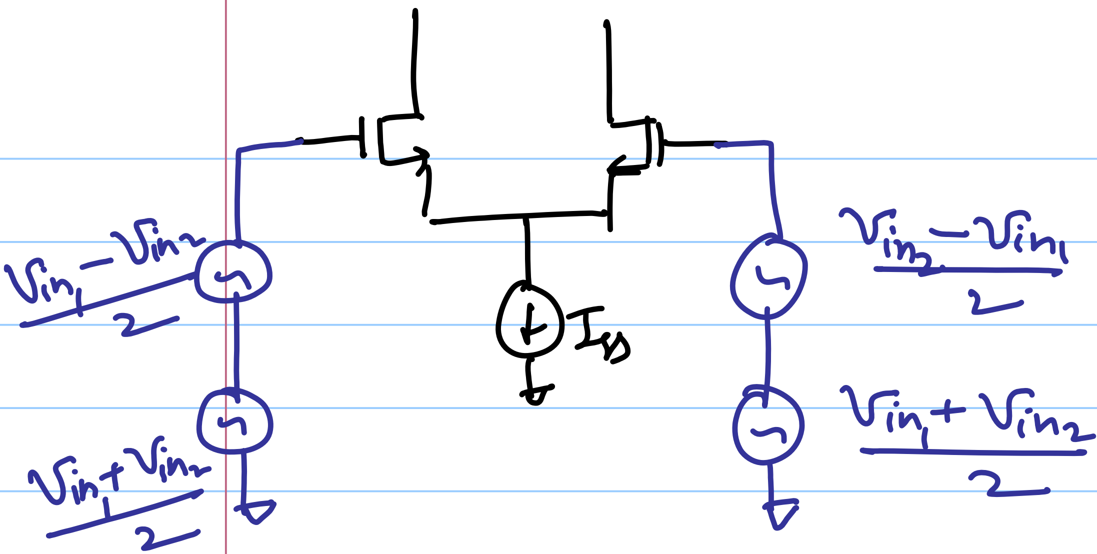
$$V_{in_1} = \left(\frac{V_{in_1} - V_{in_2}}{2}\right) + \left(\frac{V_{in_1} + V_{in_2}}{2}\right)$$

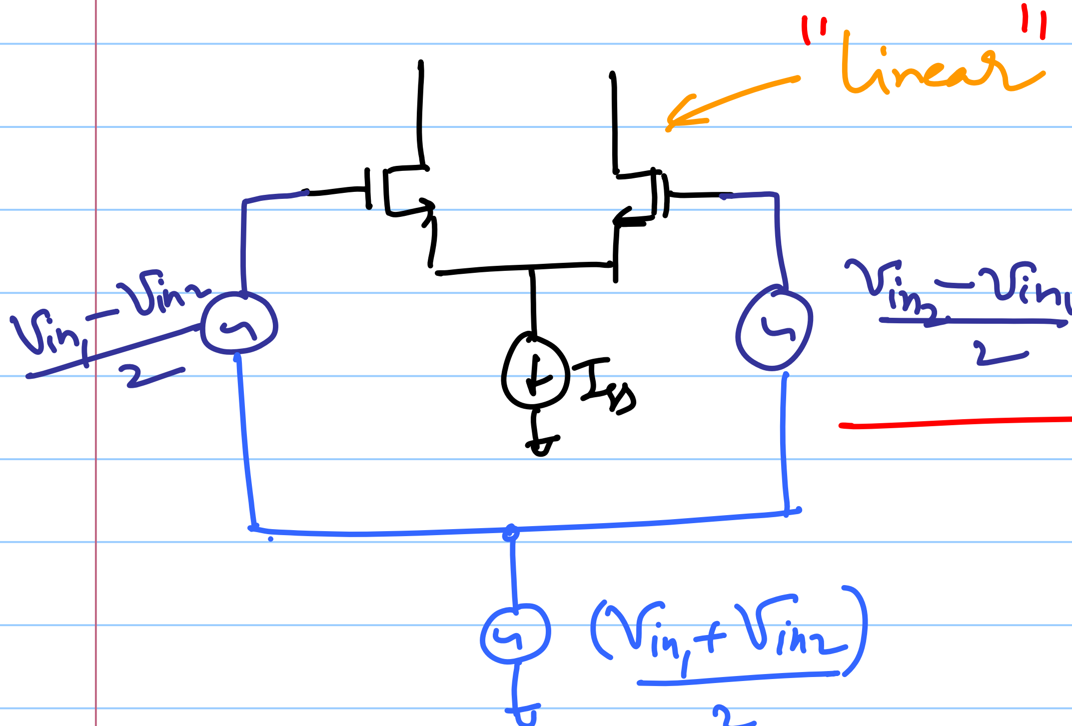
$$V_{in_2} = \left(\frac{V_{in_2} - V_{in_1}}{2}\right) + \left(\frac{V_{in_1} + V_{in_2}}{2}\right)$$

Differential mode signal (Equal & opposite sign)

CM-signal (Not a DC-level anymore)

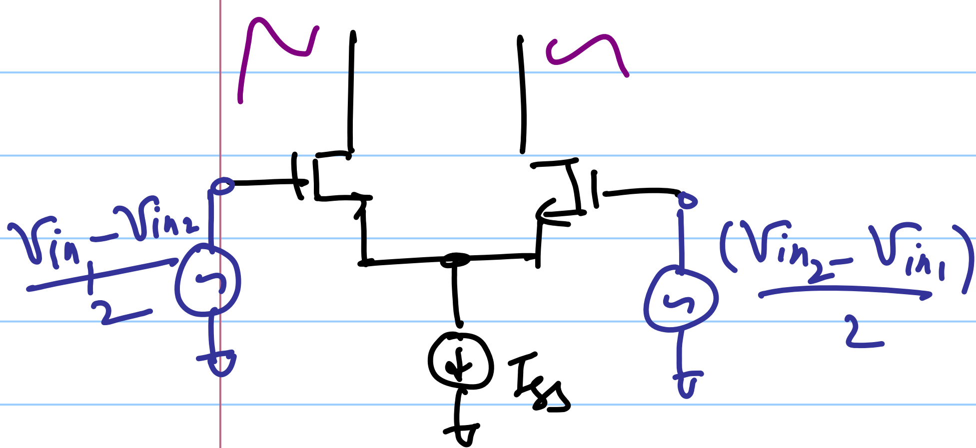






→ Break using superposition

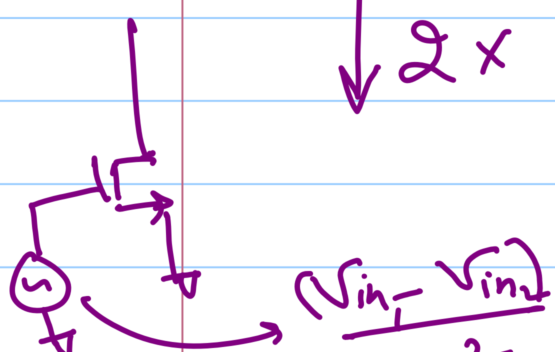
Analyze this



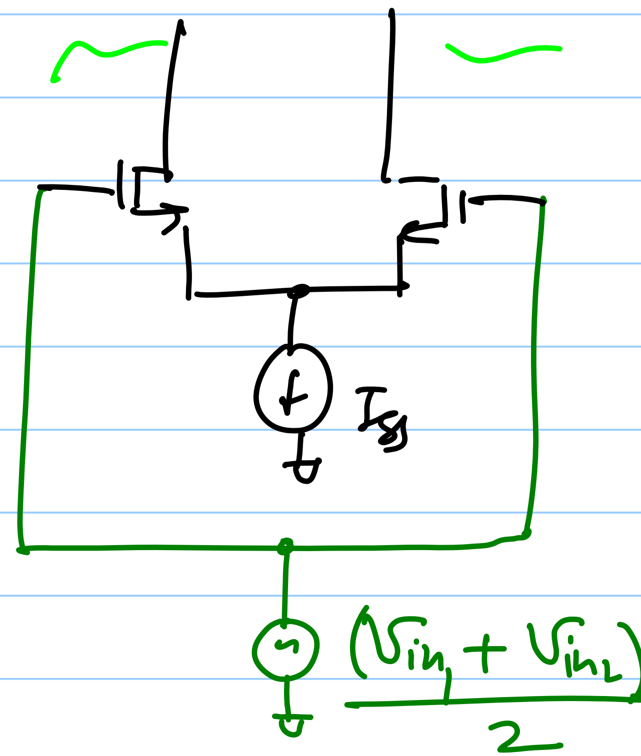
Differential Equivalent Circuit

↓ 2 × Half Circuits

Apply Lemma

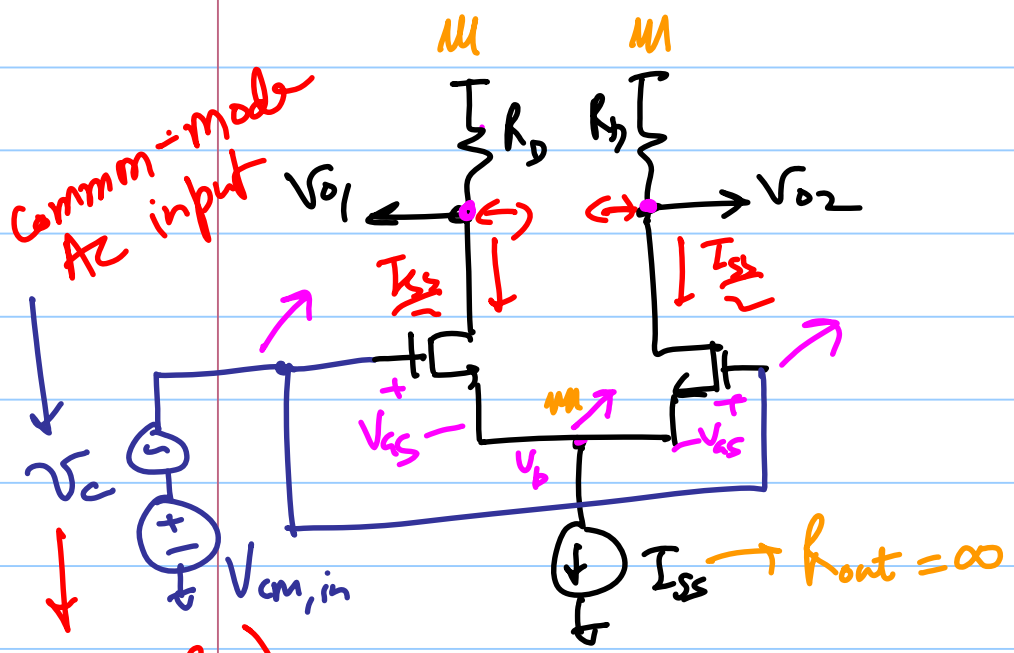


Analyze that

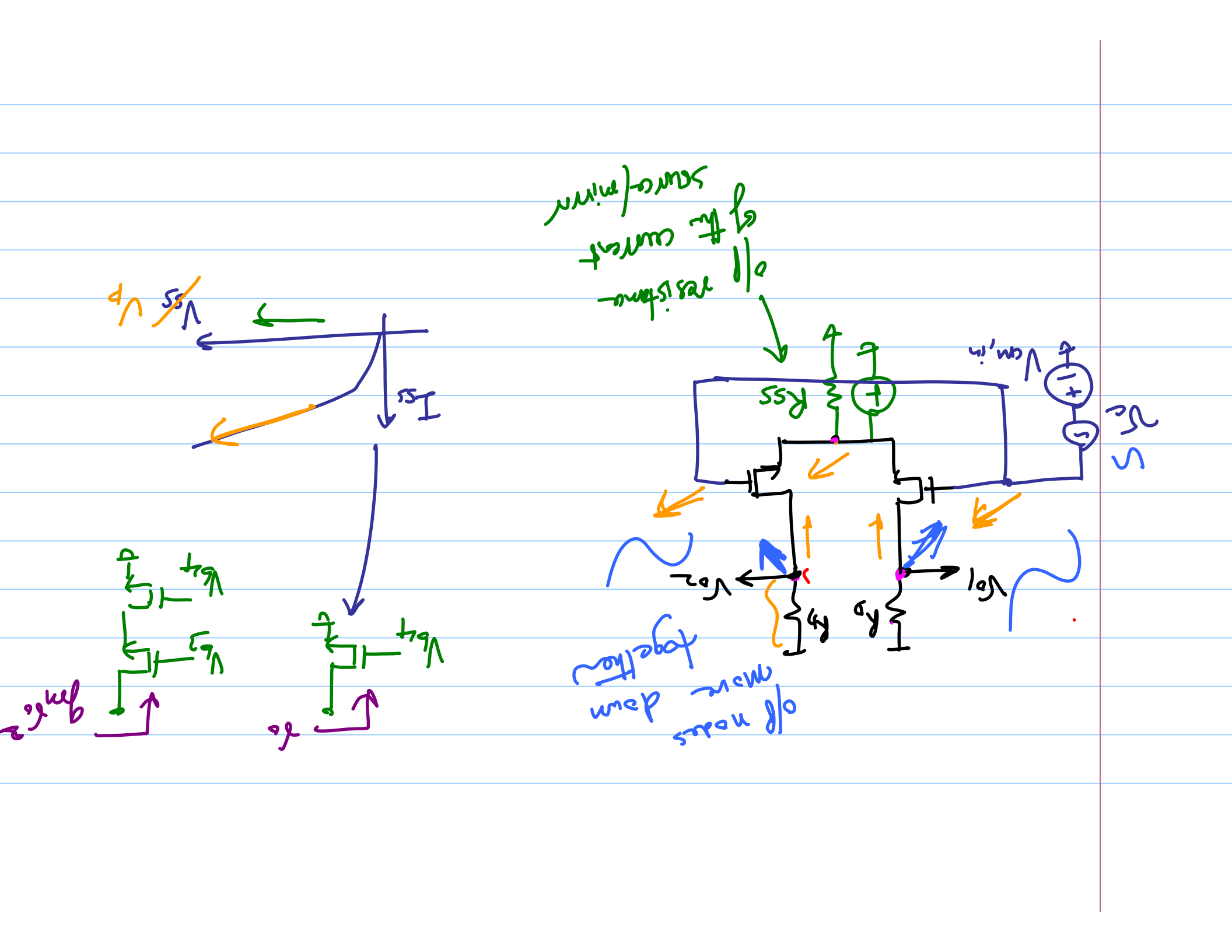


Common-mode Equiv Circuit

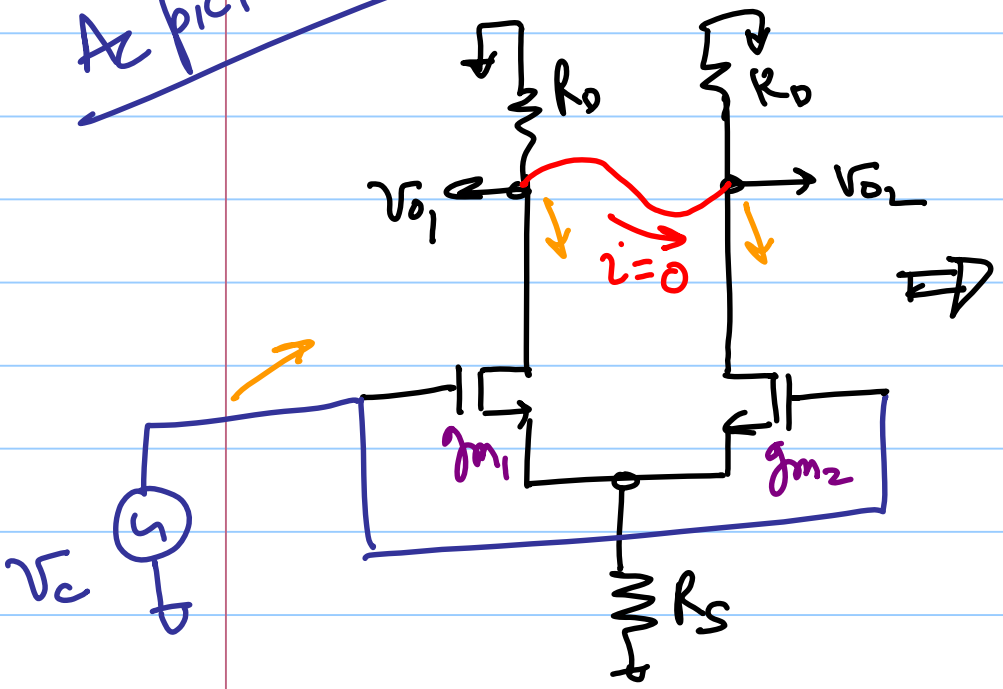
Common-Mode Response / Analysis



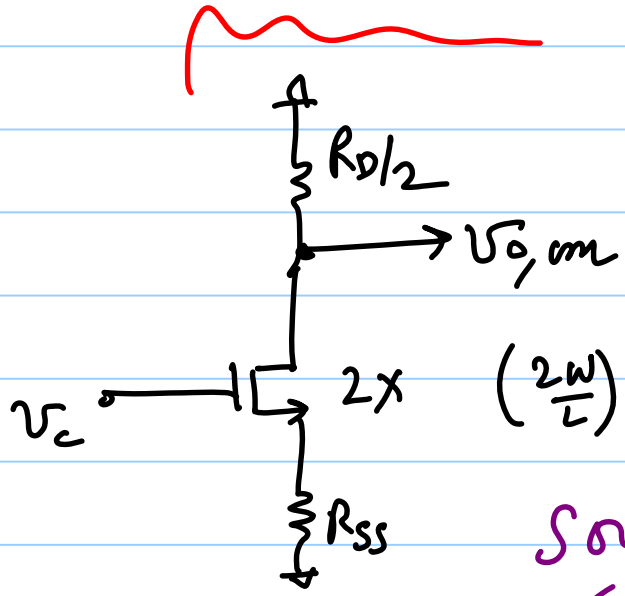
If I_{SS} is ideal the circuit rejects input CM disturbance


V_{SS}
I_{SS}
V_b
V_{b1}
V_{b2}
$g_m r_o$
r_o
o/p resistance of the current source/mirror
R_{SS}
$V_{cm,in}$
V_{in}
V_{o2}
V_{o1}
R_D
R_D
o/p nodes move down together

Common-Mode Ac picture



CM Equivalent Circuit



Looks like degenerated Source CS Amplifier

Common mode Ac gain

$$A_{v,cm} = \frac{V_{o,cm}}{V_c} = -g_m \times \frac{R_D}{2}$$

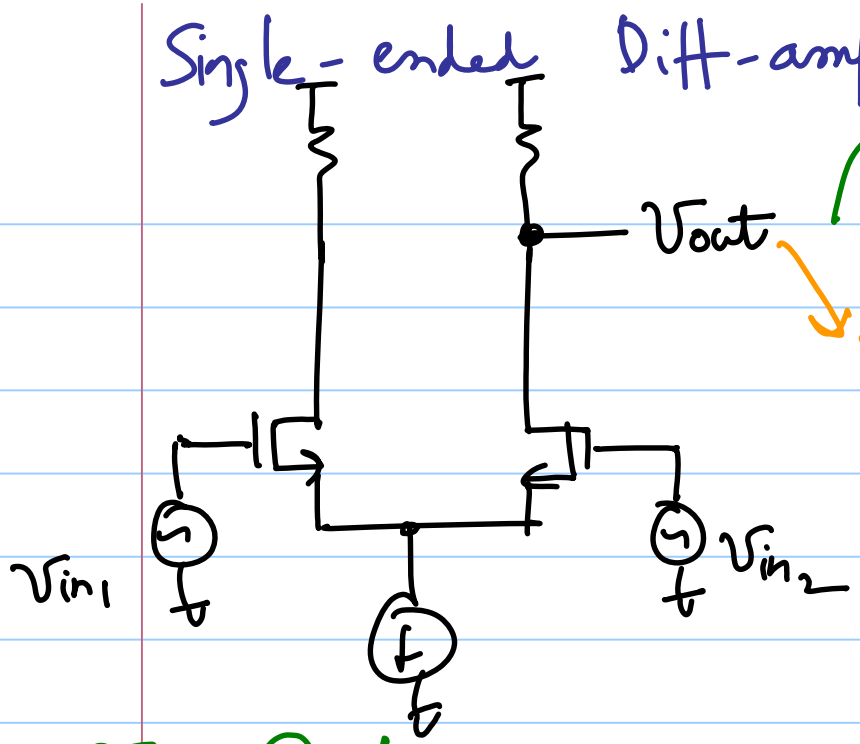
$$= -\left(\frac{2g_{m1,2}}{1+2g_{m1,2}R_{SS}}\right) \cdot \frac{R_D}{2}$$

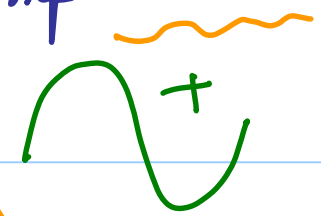
$$= \frac{-R_D/2}{(1/2g_{m1,2}) + R_{SS}}$$

for $R_{SS} \to \infty$, $A_{v,cm} = 0$

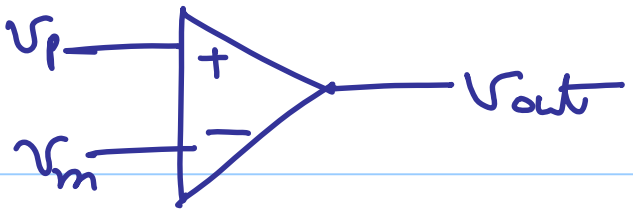
If $R_{SS} >> \frac{1}{2 g_{m1,2}}$

Single-ended Diff-amp





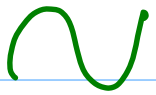
DM + CM



Comm-mode Rejection Ratio

$$CMRR = \left| \frac{A_{v,DM}}{A_{v,CM}} \right|$$

We want a large CMRR

$V_d =$ 

V_c 

Differential Amplifier