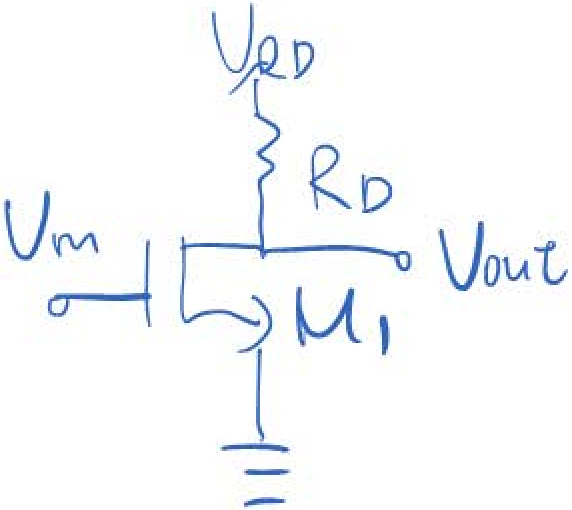
For the final exam:

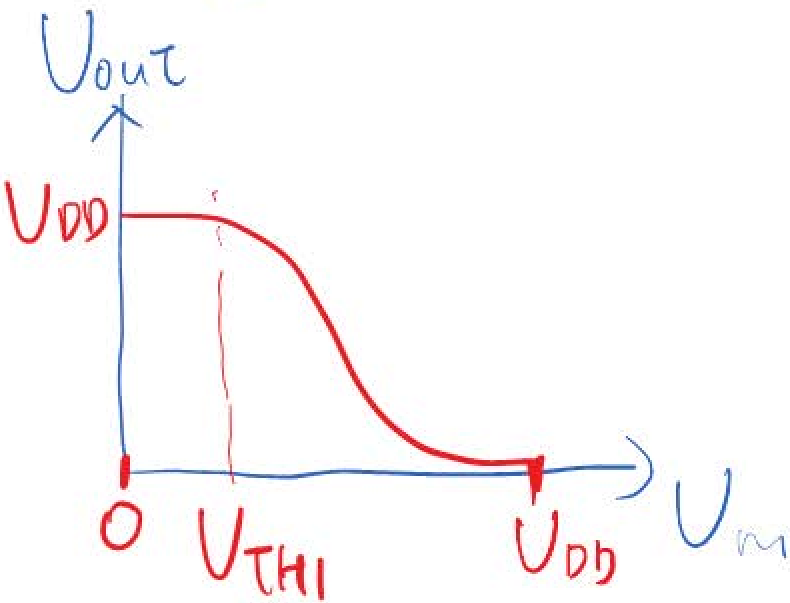
~10% npn BJT (CE, diode-connected load etc.)

~80% single stage amplifiers based on NMOS and PMOS

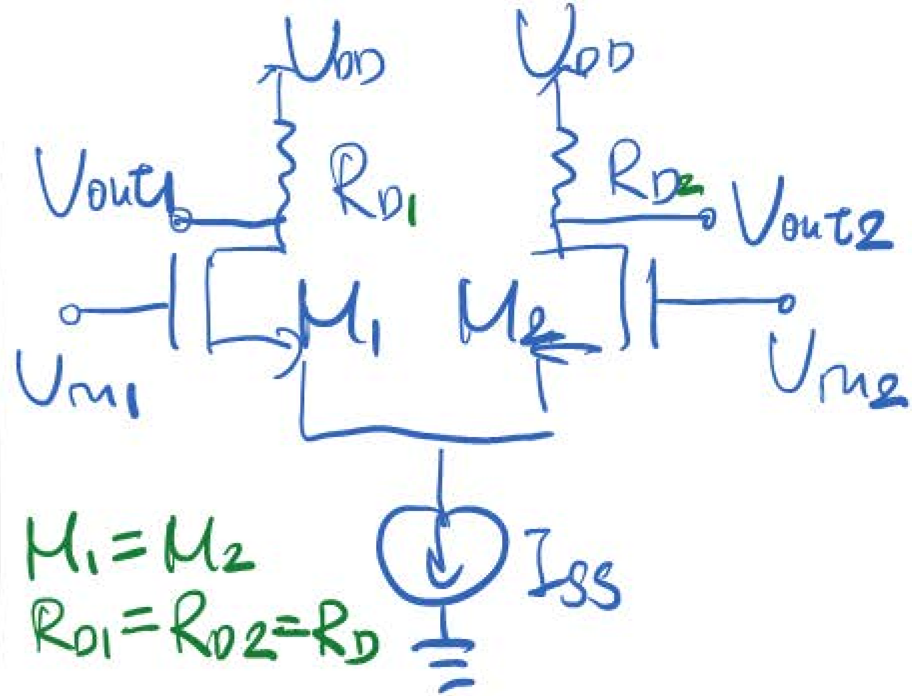
< 10% differential pair



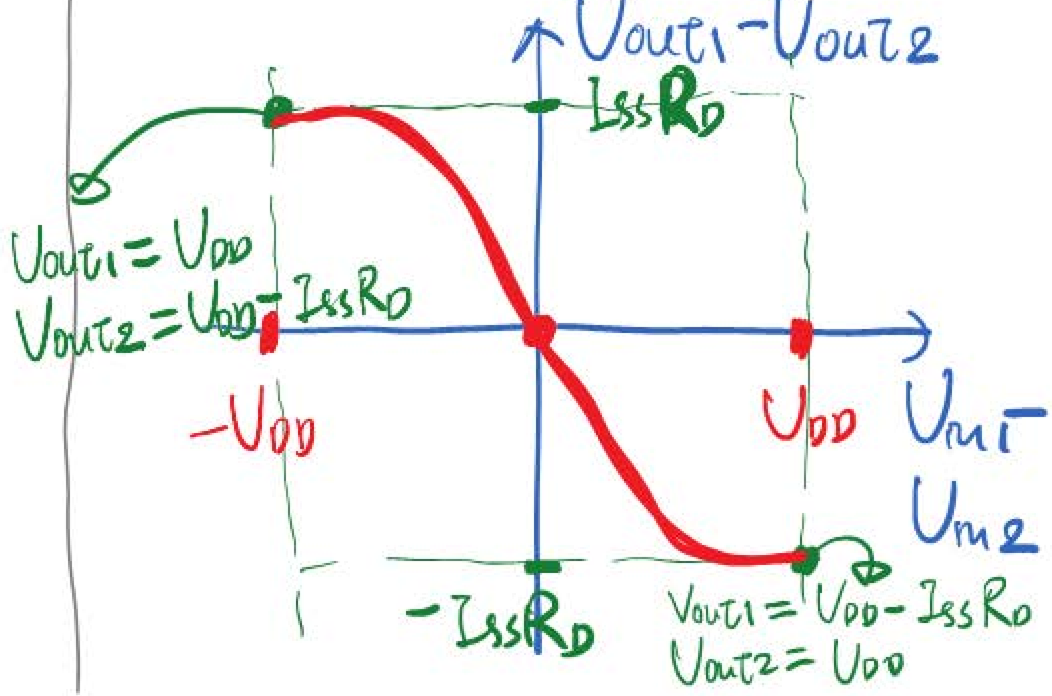
V_{DD}
R_D
V_{in}
V_{out}
M_1



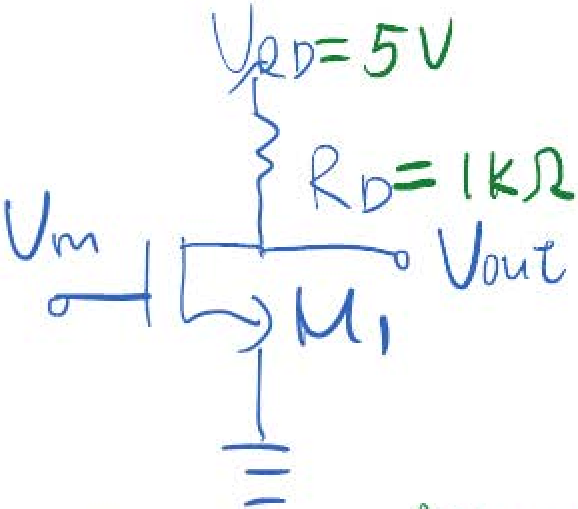
V_{out}
V_{DD}
0
V_{TH1}
V_{DD}
V_{in}



V_{DD}
V_{DD}
V_{out1}
R_{D1}
R_{D2}
V_{out2}
M_1
M_2
V_{in1}
V_{in2}
I_{SS}
$M_1 = M_2$
$R_{D1} = R_{D2} = R_D$



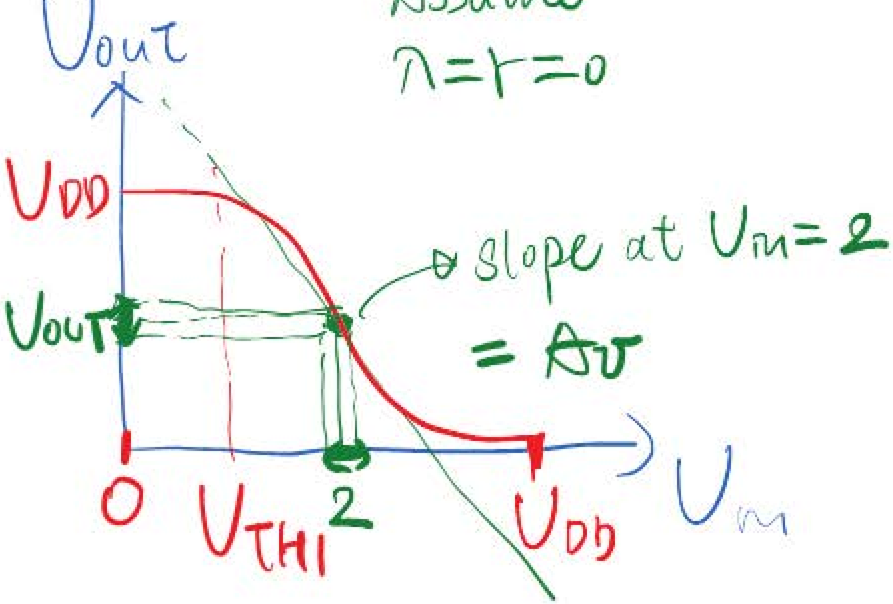
$V_{out1} - V_{out2}$
$I_{SS}R_D$
$V_{out1} = V_{DD}$
$V_{out2} = V_{DD} - I_{SS}R_D$
$-V_{DD}$
V_{DD}
$V_{in1} - V_{in2}$
$-I_{SS}R_D$
$V_{out1} = V_{DD} - I_{SS}R_D$
$V_{out2} = V_{DD}$

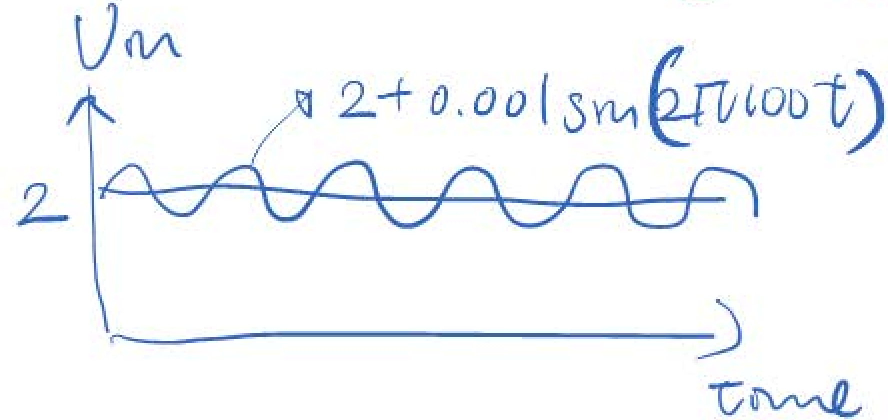


$$V_{in} = 2 + 0.001 \sin(2\pi 100 t)$$

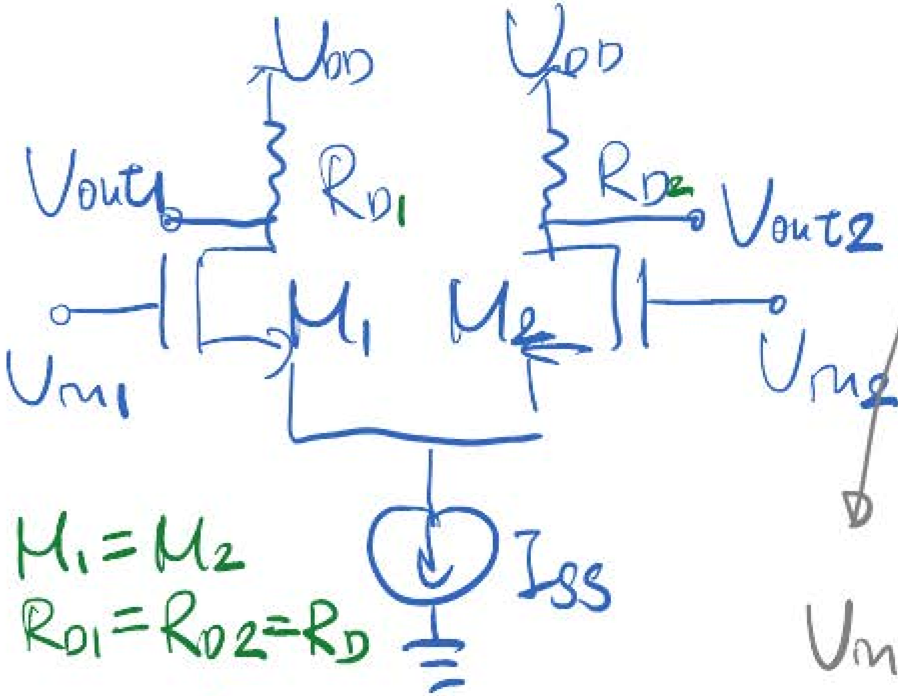
$$V_{out} = V_{OUT} + (0.001 A_v) \sin(2\pi 100 t)$$

Assume
$\lambda = \gamma = 0$



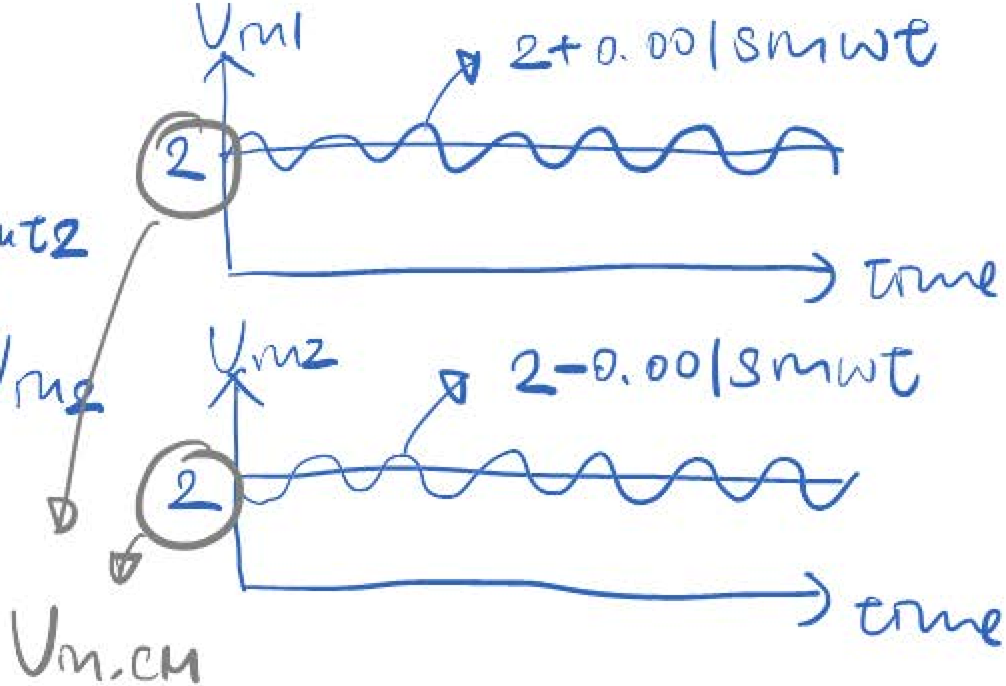


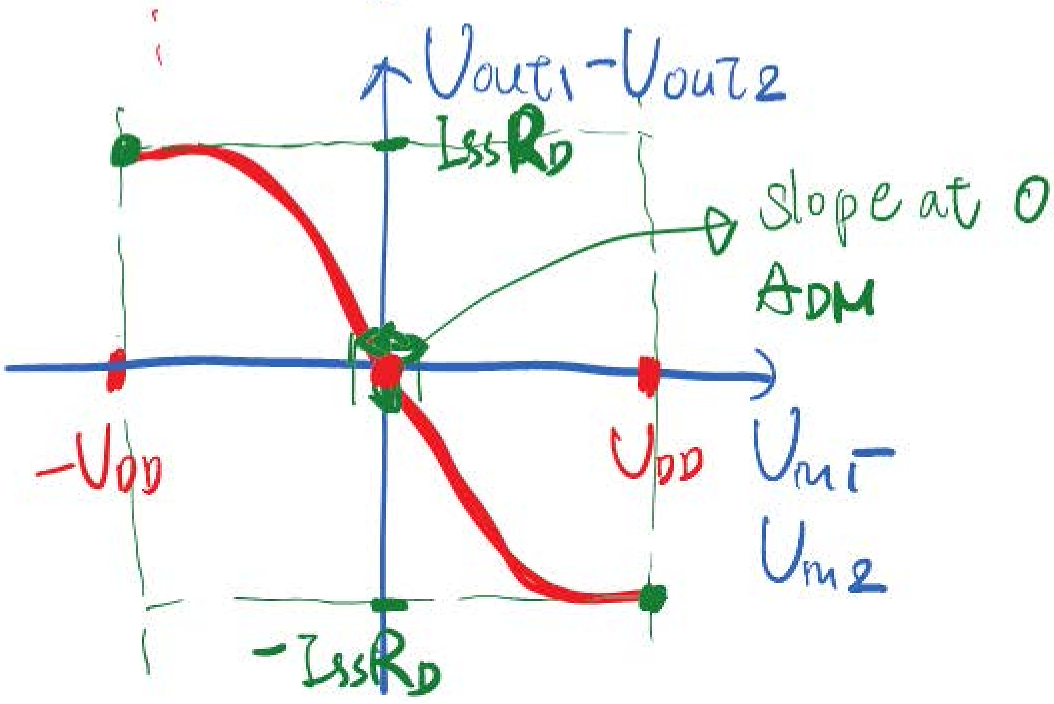
$$V_{OUT} = 5 - (1k) \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L_{eff}}\right)_1 (2 - 0.7)^2$$



$M_1 = M_2$

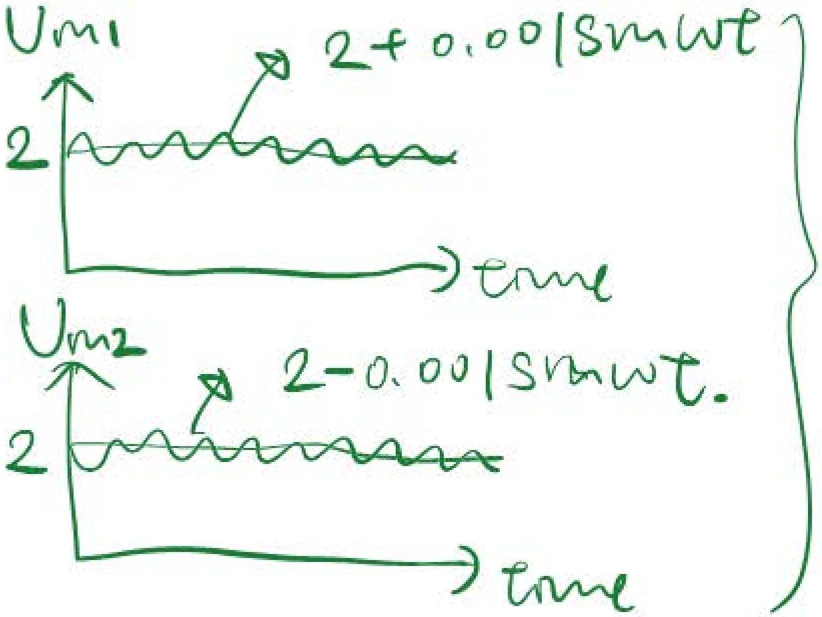
$R_{D1} = R_{D2} = R_D$





$$v_d = V_{in1} - V_{in2} = 0.002$$

$$v_{out} = V_{out1} - V_{out} = 0.002 A_{DM}.$$



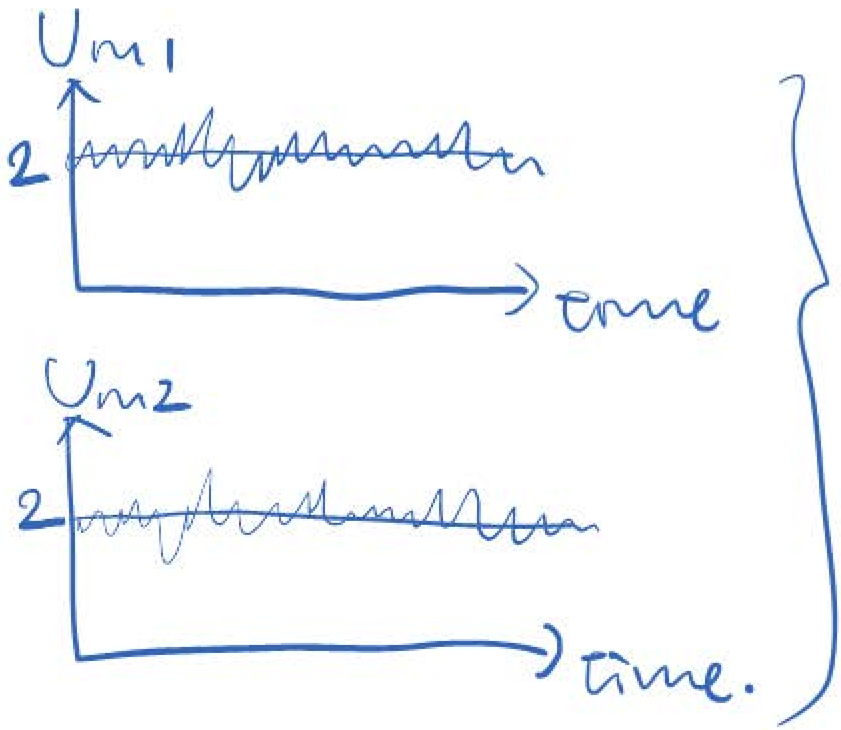
$$V_d = V_{in1} - V_{in2} = 0.002\sin\omega t.$$

AC

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

$$= \underbrace{V_{IN,CM}}_{=2} + \underbrace{v_{in,CM}}_{=0}.$$

fully differential



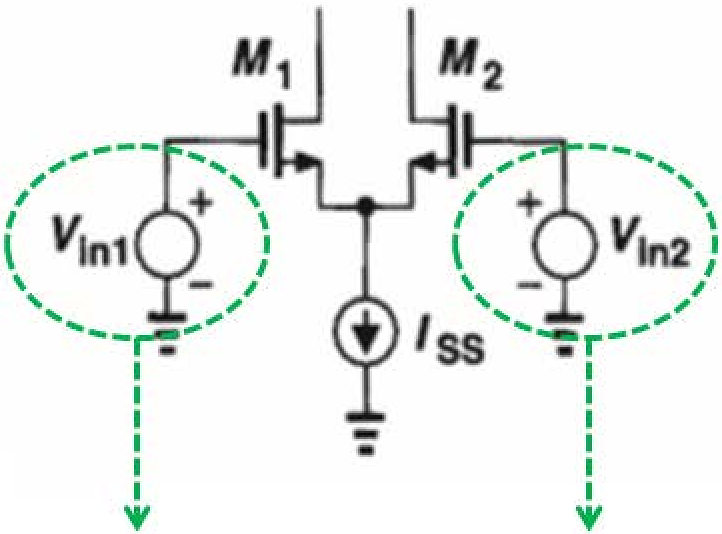
$$V_d = V_{in1} - V_{in2} = AC$$

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

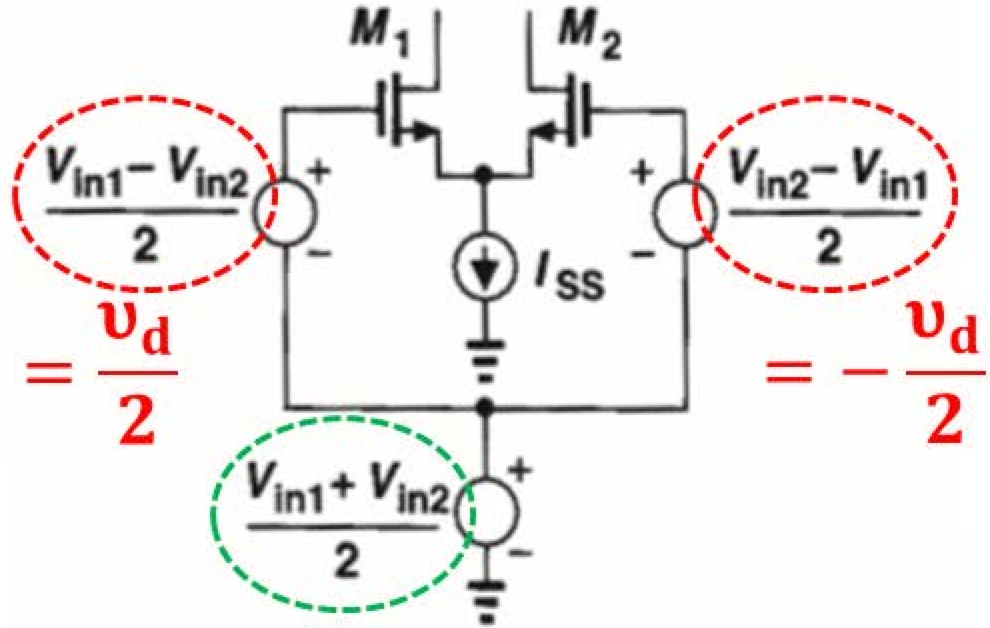
$$= \underbrace{V_{IN,CM}}_{=2} + \underbrace{v_{in,CM}}_{\neq 0}$$

Not fully differential

Common-Mode + Differential-Mode



Not necessarily fully differential



$= \frac{\upsilon_d}{2}$

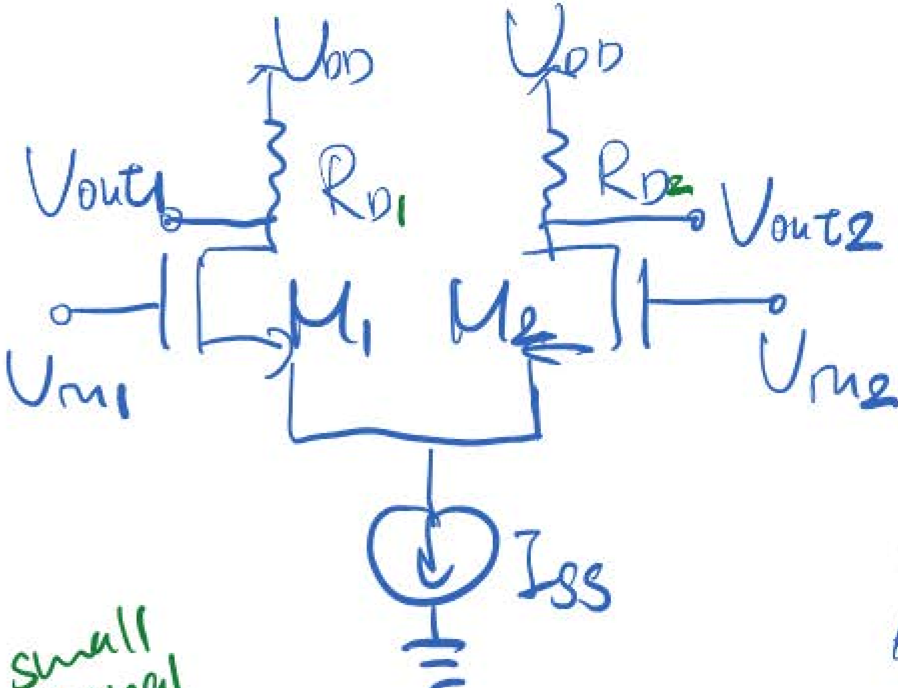
$= -\frac{\upsilon_d}{2}$

$= V_{in,CM}$
$= V_{IN,CM} + \upsilon_{in,CM}$

If fully symmetric
If Iss ideal

$$A_{DM} = \frac{\upsilon_{out1} - \upsilon_{out2}}{\upsilon_d} \qquad A_{CM-DM} = \frac{\upsilon_{out1} - \upsilon_{out2}}{\upsilon_{in,CM}}$$

$$A_{CM} = \frac{\upsilon_{out,CM}}{\upsilon_{in,CM}} = 0 \qquad CMRR = \left|\frac{A_{DM}}{A_{CM-DM}}\right|$$



1° $A_{DM} = \dfrac{v_{out1} - v_{out2}}{\underbrace{v_{in1} - v_{in2}}_{= v_d}}$

$= \dfrac{V_{out1} - V_{out2}}{\underbrace{V_{in1} - V_{in2}}_{= v_d}}$

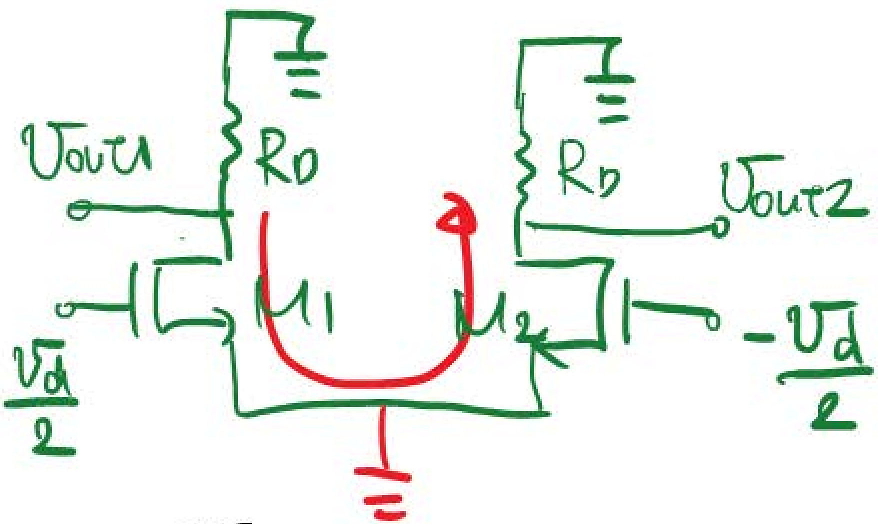
$= \boxed{-g_{m1,2}(r_{o1,2} // R_D)}$

Assume all in sat.

Assume fully symmetric

($R_{D1} = R_{D2} = R_D$, $M_1 = M_2$)

small signal



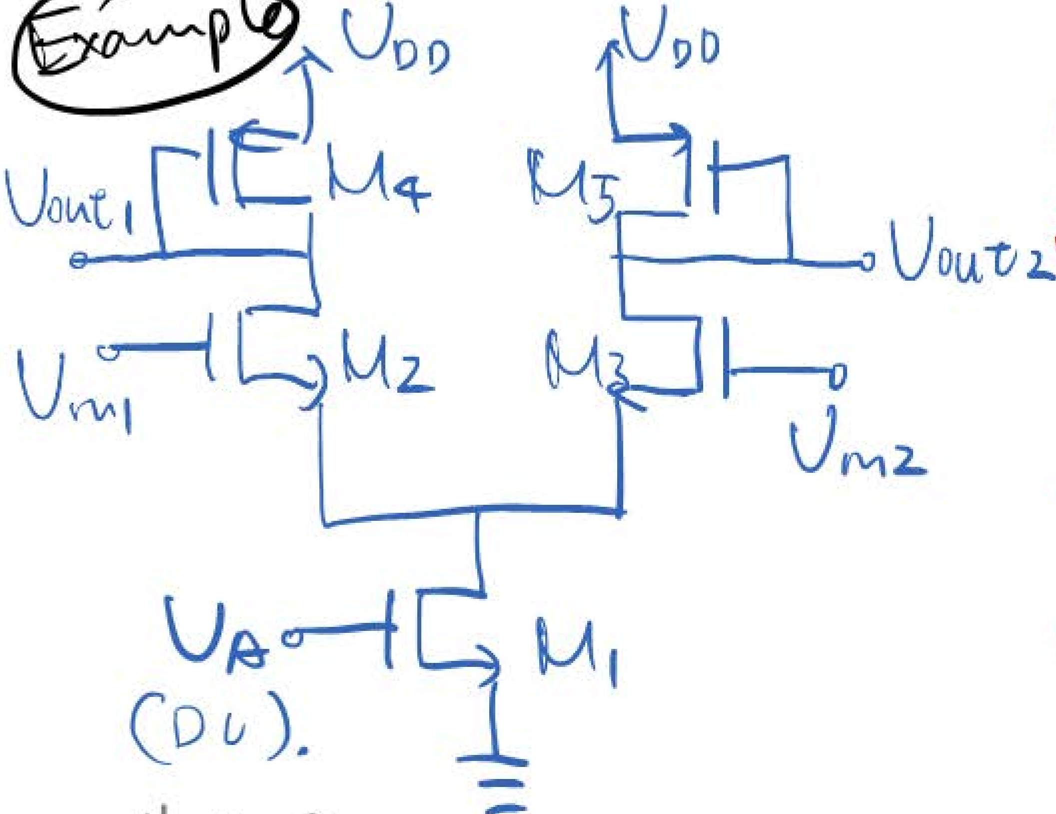
$V_{gs1} = V_{gs2}$

$g_{m1} = g_{m2} = g_{m1,2}$

$r_{o1} = r_{o2} = r_{o1,2}$

$$\begin{cases} v_{out1} = -g_{m1,2}(r_{o1,2} // R_D)\dfrac{v_d}{2} \\ v_{out2} = -g_{m1,2}(r_{o1,2} // R_D)\left(-\dfrac{v_d}{2}\right) \end{cases}$$

Example



1° All in sat.

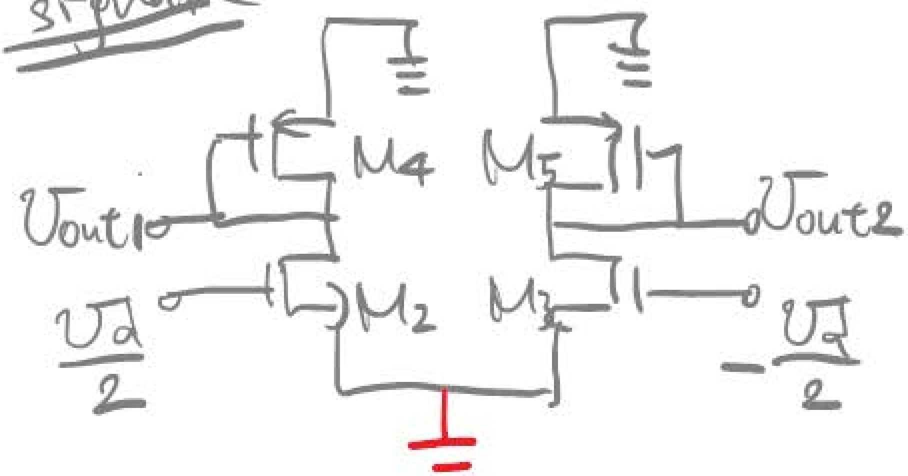
2° Fully symmetric
($M_2=M_3$, $M_4=M_5$)

3° $\lambda=\gamma=0$.

$$A_{DM} = \frac{v_{out1}-v_{out2}}{v_d}$$

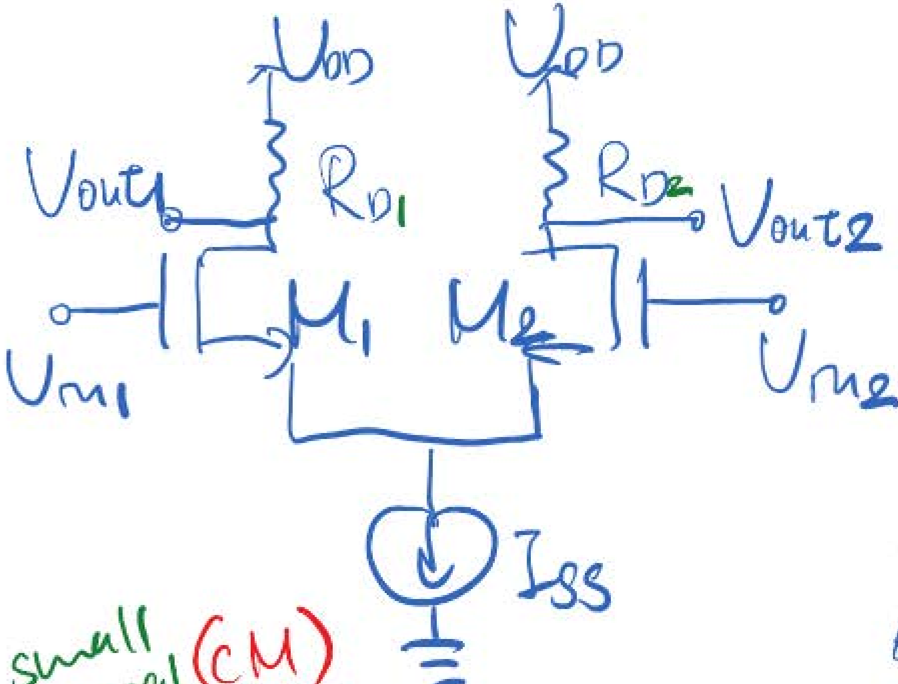
$$= -g_{m2,3}\left(\frac{1}{g_{m4,5}}\right)$$

small signal (DM)



$$g_{m2}=g_{m3}=g_{m2,3}$$

$$g_{m4}=g_{m5}=g_{m4,5}$$



$$2^\circ\ A_{CM} = \frac{v_{out1,2}}{v_{in,CM}} = 0$$

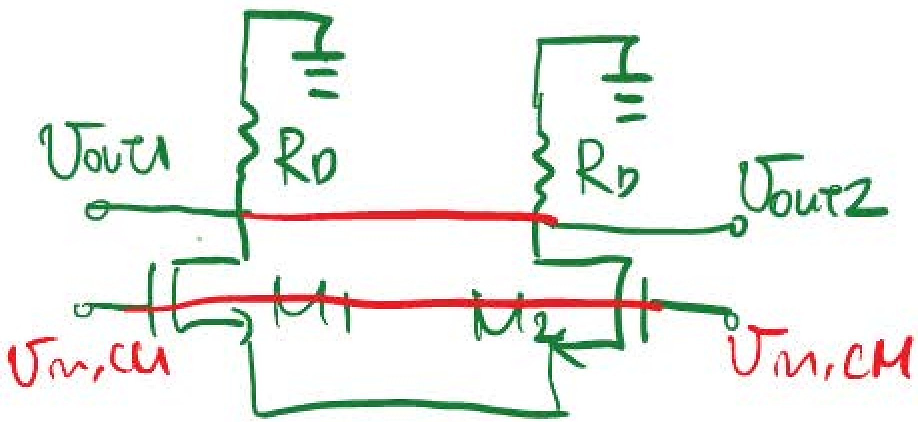
$$v_{out1} = v_{out2} = v_{out1,2}$$

Assume all in sat.

Assume fully symmetric

($R_{D1}=R_{D2}=R_D$, $M_1=M_2$)

small signal (CM)



$\Rightarrow$