EE 332 Circuits and Devices II Autumn 2021
Midterm Exam Exam Date: Nov. 15 (5-7pm)

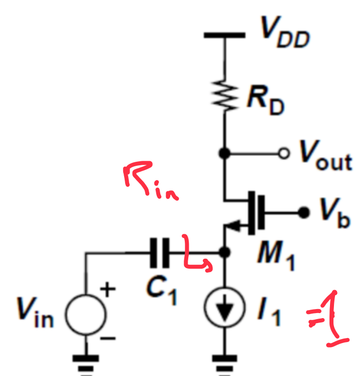
Full Name: .... **Grade:** ...... **/100**
SID : ....

Assume: VDD=1.2V, |Vth$_{n,p}$|=0.3V, $\mu_n C_{ox} = \frac{0.5mA}{V^2}$, $\mu_n = 2\mu_p, \lambda_p = \lambda_n = 0.1V^{-1}$, $\gamma = 0$ for both NMOS and PMOS devices.

$\Rightarrow \mu_p C_{ox} = \frac{0.25\,mA}{V^2}$

1. (~~30~~ 35 pts) Assuming $I_1 = \cancel{0.2}\,1\,mA$ (ideal current source), and C_1 is an AC-coupling capacitor (will be shorted in small-signal models and open for DC/bias analysis):

a) Find $(W/L)_1$ such that the input impedance will be 50Ω.
b) Write down the small-signal gain equation in terms of small-signal parameters and R_D.
c) Find R_D such that V_{out} bias point will be $V_{DD}/2$.
d) Find ~~V_{GS}-V_{th} to achieve~~ a gain ~~of 50~~ (you can assume $\lambda = 0$ for this part). for that R_D.
e) If we realize I_1 current-source with a single NMOS device at a fixed gate bias of $V_{DD}/2$, what would be the W/L for that device?
f) What can be minimum V_b to make sure all transistors are in saturation?
g) Assuming $V_{in} = 0.5 + 0.01sin(\omega t)\ V$, what is the overall (bias and small-signal) V_{out} ?



$= 1\,mA$

a) $R_{in} \approx 1/g_m \Rightarrow g_m = \frac{1}{50} = 20\,mS = \frac{2 I_D}{V_{od}} = \frac{2\,mA}{V_{od}}$

$\Rightarrow V_{od} = \frac{2\,mA}{20\,mS} = \underline{0.1\,V}$

$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{od}^2 \Rightarrow 1\,mA = \frac{1}{2} \times \frac{0.5\,mA}{V^2} \times \frac{W}{L} \times (0.1)^2$

$\Rightarrow \boxed{(W/L) = 400}$

b) $A_v = \frac{V_{out}}{V_{in}} = g_m R_D$

c) $V_{out,DC} = V_{DD} - I_D . R_D = V_{DD}/2$

$$\Rightarrow R_D . I_D = \frac{V_{DD}}{2} \Rightarrow R_D = \frac{V_{DD}}{2I_D} = \boxed{\frac{1.2V}{2 \times 1mA} = 600\Omega}$$

d) $A_v = g_m R_D = 20mS \times 0.6k\Omega = \boxed{12}$

e) $I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{OD})^2$

$V_{OD} \to V_{gs} - V_{th}$

$$1mA = \frac{1}{2} \times \frac{0.5mA}{V^2} \times \frac{W}{L} \underbrace{(0.6 - 0.3)^2}_{0.09}$$

$$\Rightarrow \boxed{\frac{W}{L} = \frac{400}{9} \sim 40}$$

f) $V_{b\,min} = V_{gs} + V_{od,\,\text{Current Source}}$

$$= \underbrace{V_{OD_1}}_{0.1} + \underbrace{V_{th}}_{0.3} + \underbrace{V_{OD,CS}}_{0.3} = \boxed{0.7V}$$

from part a ← from part e

g) $V_{out} = \underbrace{V_{out,DC}}_{V_{DD}/2 = 0.6V} + \underbrace{v_{out}}_{A_v \times (0.01 \sin(\omega t))}$

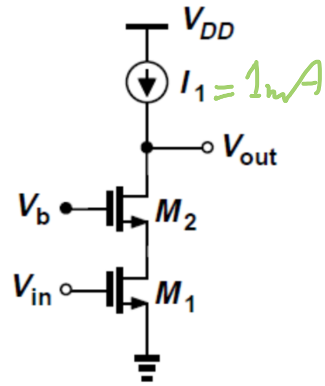
12 from part d

$$\Rightarrow \boxed{V_{out} = 0.6 + 0.12 \sin(\omega t)}$$

30

2. (~~40~~ pts) Design a Cascode amplifier as shown in figure below to achieve a gain of ~~100~~. 10^4
Assume an ideal current source of $I_1 = 1mA$ and $g_m r_o \gg 1$.

a) If $V_{GS1}=V_{GS2}$, what should be the value of V_{GS1}?
b) Find R_{out} and R_{in} values for this amplifier.
c) Calculate optimal V_b to maximize the output swing.
d) To realize the current source load, we will use a PMOS active load with W/L=~~40~~ 800. Assume the bias current will remain at 1mA, what would be the V_{OD} (=V_{GS}-V_{th}) for this device?
e) What's the output swing range?
f) ~~If I_1 will be doubled, how does the gain will change? Find the new gain value.~~



a) $$A_v \approx \underbrace{g_{m_1} r_{o_1}}_{\frac{2}{V_{od_1}\lambda}} \times \underbrace{g_{m_2} r_{o_2}}_{\frac{2}{V_{od_2}\lambda}} = \left(\frac{2}{V_{od}\cdot\cancel{\lambda}_{0.1}}\right)^2 = \left(\frac{20}{V_{od}}\right)^2$$

$$\frac{2I}{V_{od}} \times \frac{1}{\lambda I}$$

For $A_v = 10^4 \implies \dfrac{20}{V_{od}} = 100 \implies \boxed{V_{od} = 0.2V}$

b) $\boxed{R_{in} = \infty}$

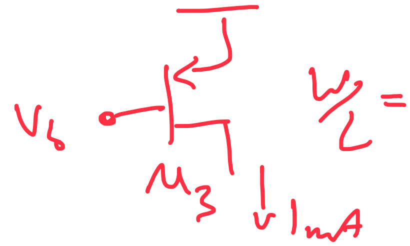
$$\frac{1}{0.1 \times 1mA} = 10k\Omega$$

$$R_{out} \approx r_{o_1} \times \underbrace{(g_{m_2} r_{o_2})}_{100} = \frac{1}{\cancel{\lambda} I_D} \times 100 = \boxed{1M\Omega}$$

c) $$V_{b_{min}} = V_{OD_1} + V_{GS_2} = 2V_{OD} + V_{Th} = 2\times 0.2 + 0.3$$

$$= \boxed{0.7V}$$

d)



$$1mA = \frac{1}{2} \times \frac{0.25mA}{V^2} \times \cancel{\frac{W}{L}}^{\,800} \times |V_{od}|^2$$

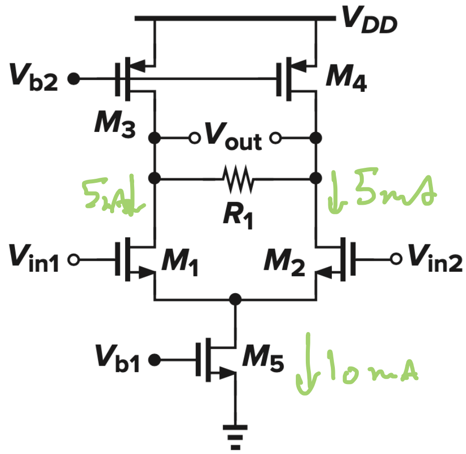
$$\Rightarrow \boxed{|V_{od}| = 0.1V}$$

e) $V_{out,max} = V_{DD} - V_{od_3} = 1.2 - 0.1 = 1.1V$

$V_{out,min} = V_{OD_1} + V_{OD_2} = 0.2 + 0.2 = 0.4V$

$V_{out\ swing\ pp} = V_{out,max} - V_{out,min} = 1.1 - 0.4 = \boxed{0.7V}$

3. (35 pts) For the differential amplifier shown below:



a) Assuming the target over-drive voltage (V_{od}) for *all the transistors* is 0.2V, find the V_{b1}, V_{b2}, ~~and $V_{CM,in}$~~ values.
b) Find $(W/L)_{1,2}$, $(W/L)_{3,4}$, & $(W/L)_5$ such that current tail will be 10mA.
c) Draw the differential-mode half circuit and calculate the differential gain ($\frac{v_{o2}-v_{o1}}{v_{id}}$) in terms of small-signal parameters (g_ms, r_os, and R_1)?
d) Draw the common-mode half circuit and calculate single ended common-mode gain ($\frac{v_{o1/2}}{v_{cm}}$) in terms of small-signal parameters (g_ms, r_os, and R_1)?
e) For a differential gain of -10, what should be the value of R_1?
f) Find differential output peak-to-peak swing.
g) Find the acceptable min. input common-mode ($V_{CM,in}$) ~~range~~ for this amplifier.

a) $V_{b_2} = V_{DD} - |V_{GS_{2,4}}| = 1.2 - (0.2+0.3) = \boxed{0.7V}$

$V_{b_1} = V_{GS_5} = V_{OD_5} + V_{Th} = 0.2 + 0.3 = \boxed{0.5V}$

b) $10mA = \frac{1}{2} \times \frac{0.5mA}{V^2} \times \left(\frac{W}{L}\right)_5 \times (0.2)^2$

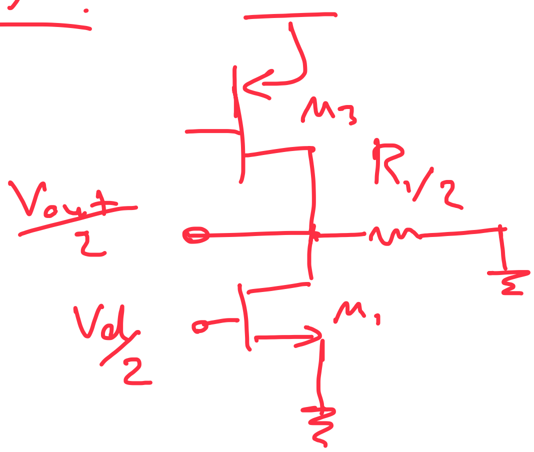
$\Rightarrow \boxed{(W/L)_5 = 1000}$

$M_{1,2}$ have half current & same $V_{OD} \Rightarrow \boxed{(W/L)_{1,2} = 500}$

$M_{3,4}$ have half current, same V_{od}, but $\mu_p = \frac{\mu_n}{2}$

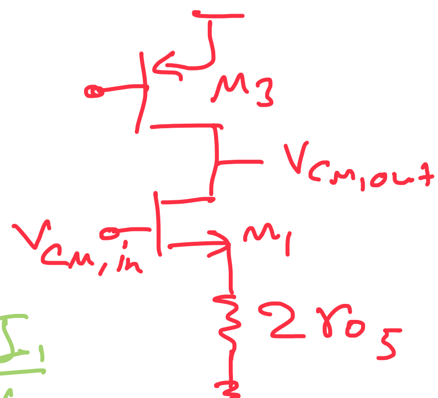
$$\Rightarrow \boxed{(W/L)_{3,4} = 1000}$$

c) D.M.



$$\boxed{A_v = -g_{m_1} \times \left(\frac{R_1}{2} \| r_{o_1} \| r_{o_3}\right) \approx -g_{m_1}\frac{R_1}{2}}$$

d)



$$\boxed{A_v = \frac{V_{out,cm}}{V_{in,cm}} = \frac{-g_{m_1} r_{o_3}}{1+g_{m_1}\times 2r_{o_5}}}$$

$\frac{2I_1}{V_{od}}$

e) $A_v \approx -g_{m_1}\frac{R_1}{2} \Rightarrow \frac{\cancel{2}\times 5mA}{0.2}\times\frac{R_1}{\cancel{2}} = 10$

$$\Rightarrow \boxed{R_1 = \frac{2}{5mA} = 400\Omega}$$

f) Single-ended $\rightarrow \begin{cases} V_{max} = V_{DD} - V_{od_3} = 1.2-0.2 = 1V \\ V_{min} = V_{OD_1}+V_{OD_2} = 0.2+0.2 = 0.4V \end{cases}$

$\Rightarrow$ Diff. swing range $= 2\times(1-0.4) = \boxed{1.2V}$

g) $V_{in,cm} > V_{gs_1} + V_{od_5} = 0.2+0.3+0.2 = \boxed{0.7V}$