EE 332 Circuits and Devices II Autumn 2022

Midterm Exam Exam Date: Nov. 14 (5-7pm)

Full Name: ……………………… **Grade:** …… **/100**

SID : ………………………

Assume for all the problems: 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.

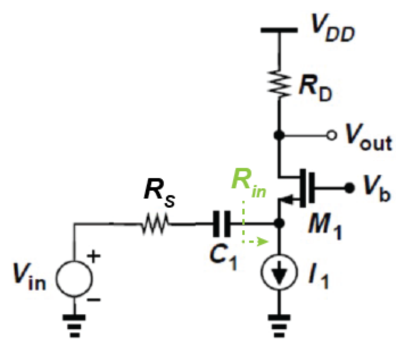
Useful Equations:

$$I_D = \frac{1}{2}\mu_{n,p}C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_{TH})^2$$

$$g_m = \mu_{n,p}C_{ox}\frac{W}{L}(V_{GS} - V_{TH}) = \sqrt{2\mu_{n,p}C_{ox}\frac{W}{L}I_D} = \frac{2I_D}{V_{GS} - V_{TH}}$$

$$r_o = \frac{1}{\lambda I_D}$$

1. (40 pts) If $I_1 = 1mA$ (ideal current source), and C_1 is an AC-coupling capacitor (will be shorted in small-signal models and open for DC/bias analysis) answer following questions assuming $\underline{\lambda = 0 \text{ for this problem}}$. Notice that input voltage source has an impedance of $R_S = 50\Omega$.



a) Find $(W/L)_1$ such that the input impedance (R_{in}) 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 small-signal gain using R_D from part c.
e) If we realize I_1 current-source with a single NMOS device at a fixed gate bias of 0.5V, 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}? (C1 will be shorted at all frequencies)
h) What's the output voltage swing range (peak-to-peak)?

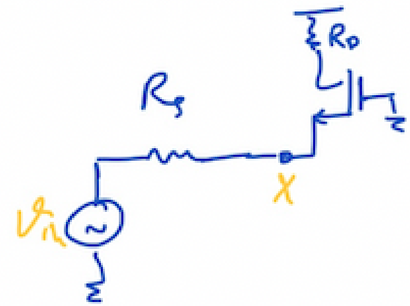
a) $R_{in} = 1/g_m \Rightarrow g_m = \frac{1}{50} = 20\,mS$

$\Rightarrow \frac{2\cancel{I_D}^{\,1mA}}{V_{OD}} = 20\,mS \Rightarrow \boxed{V_{OD} = 0.1\,V}$

$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{OD}^2 \Rightarrow \boxed{W/L = 400}$

b) $\dfrac{v_{out}}{v_{in}} = \dfrac{v_{out}}{v_x} \times \dfrac{v_x}{v_{in}}$

$g_m R_D \qquad \dfrac{R_{in}}{R_{in}+R_S} = 1/2$



$\Rightarrow \quad \boxed{A_v = \tfrac{1}{2} g_m R_D}$

c) $v_{out,DC} = V_{DD} - I_D R_D = V_{DD}/2 \quad \Rightarrow \quad \boxed{R_D = 600\,\Omega}$

d) $A_v = \tfrac{1}{2} g_m R_D \quad \Rightarrow \quad \boxed{A_v = 6}$

e) $I_D = \tfrac{1}{2} \mu_n C_{ox} \tfrac{W}{L} V_{OD}^2 \quad \Rightarrow \quad \boxed{W/L = 100}$

$0.5V - 0.3V = 0.2V$

f) $V_{b,min} = V_{OD,tail} + V_{GS,1}$

part a $\qquad V_{th}$

$= 0.2V + 0.1V + 0.3V$

$\Rightarrow \quad \boxed{V_{b,min} = 0.6V}$

g) $V_{out} = V_{out,DC} + V_{out,AC,SS}$

$= 0.6V + A_v \times v_{in}$

$\boxed{V_{out} = 0.6V + 0.06\sin(\omega t)}$

h)

$V_{out,Max} = V_{DD}$

$V_{out,Min} = V_b - V_{th}$

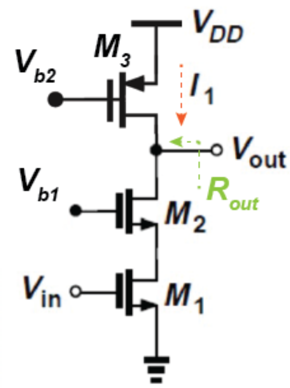
$\Rightarrow V_{sw,pp} = 1.2 - (0.3)$

$\boxed{V_{sw,pp} = 0.9V}$

2

2. (25 pts) For the Cascode amplifier shown in figure below all transistors are biased to have a V_{OD} (V_{GS}-V_{th}) of 0.2V with the drain current of current $I_1 = 1mA$ and $g_m r_o \gg 1$.

a) Find R_{out} and R_{in} values for this amplifier.
b) What is the gain of this amplifier?
c) Calculate optimal V_{b1} to maximize the output swing.
d) What's the output swing range (peak-to-peak)?



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

$R_{out} = [r_{o1} + \cancel{r_{o2} + g_{m2} r_{o2} r_o}] \parallel r_{o3}$

$\sim g_{m2} r_{o2} r_{o1}$

$= \underbrace{\frac{2I_1}{V_{OD}} \times \frac{1}{\lambda I_1}}_{100} \times \frac{1}{\lambda I_1} \parallel \frac{1}{\lambda I_1}$

$\Rightarrow R_{out} \approx r_{o3} = \frac{1}{\lambda I_1} = \frac{1}{0.1 \times 1mA} = \boxed{10k\Omega}$

b) $A_v = -g_{m1} \times R_{out}$

$= -\frac{2\cancel{I_1}}{\cancel{V_{OD}}} \times \cancel{R_{out}}$ $10k\Omega$ $= \boxed{-100}$

$10mS$

c) $V_{b1} = V_{OD1} + V_{GS2} = V_{OD1} + V_{OD2} + V_{th} =$

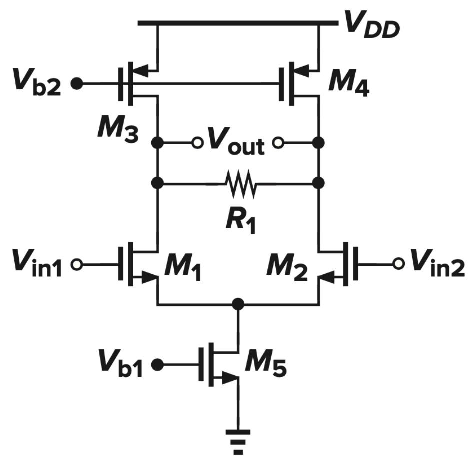
$0.2V + 0.2V + 0.3V = \boxed{0.7V}$

3

d) $\begin{cases} V_{out,max} = V_{DD} - V_{OD_3} = 1.2 - 0.2 = 1V \\ V_{out,min} = V_{OD_1} + V_{OD_2} = 0.2 + 0.2V = 0.4V \end{cases}$

$$\boxed{V_{sw,pp} = 1 - 0.4 = 0.6V}$$

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} values.
b) Find $(W/L)_{1,2}$, $(W/L)_{3,4}$, & $(W/L)_5$ such that current tail will be 8mA.
c) Draw the differential-mode half circuit and calculate the differential gain ($\frac{v_{out}}{v_{in1}-v_{in2}}$) in terms of small-signal parameters (g_m, r_o, and R_1)?
d) Draw the common-mode half circuit and calculate single ended common-mode gain ($\frac{v_{out1/2}}{v_{in,cm}}$) in terms of small-signal parameters (g_m, r_o, 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 minimum input common-mode ($V_{in,cm}$) for this amplifier.

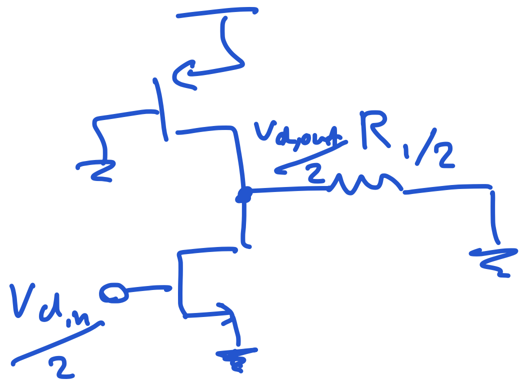
a) $V_{b_2} = V_{DD} - V_{GS_{3,4}} = 1.2 - (0.2+0.3) = \boxed{0.7V}$

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

b) using I_D equ.:

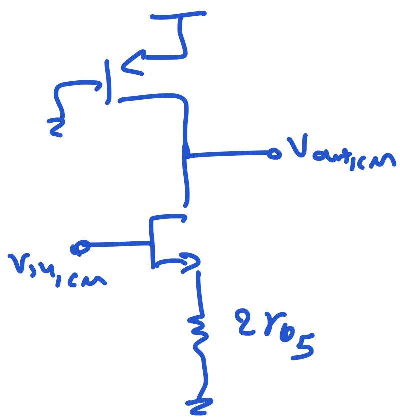
$\boxed{\left(\frac{W}{L}\right)_{1,2} = 400}$ $\boxed{\left(\frac{W}{L}\right)_{3,4} = 800}$ $\boxed{\left(\frac{W}{L}\right)_{5} = 800}$

c) D.M



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

d) C.M



$$\boxed{A_v = \frac{-g_{m_1} r_{o3}}{1+g_{m_1} \times 2r_{o5}}}$$

e) $A_v \simeq -g_{m_1}\frac{R_1}{2} = -10$ $\quad g_{m_1} = \frac{2I_1}{V_{od}}$

$= -\frac{2\times 4mA}{0.2V} \times \frac{R_1}{2} = -10$ $\Rightarrow \boxed{R_1 = 500\Omega}$

f) Single-ended Swing: $\begin{cases} V_{max} = 1.2 - 0.2 = 1V \\ V_{min} = 0.2 + 0.2V = 0.4V \end{cases}$

$$\boxed{\text{Diff pp swing} = 2\times(1-0.4) = 1.2V}$$

g) $V_{in,cm} \geq V_{GS_1} + V_{OD_1} \Rightarrow \boxed{V_{in,cm} \geq 0.7V}$