Name: Fall 2017 - Solution

EE303 - Final Exam

Closed Book:
Two 8.5"x11" sheet of handwritten notes permitted
Calculator permitted

Important Notes:

- Read each problem completely and thoroughly
- Summarize all your answers in the boxes provided on these exam sheets
- Make sure to mark the units on your answers!
- Do all your work on the exams sheets provided. If you use any additional sheets, please turn them in, so we can consider all work for partial credit
- Do not forget to put your name in the space above

Problem #	Points	Score
1	20	
2	20	
3	20	
4	20	
TOTAL	**80**	

In the following problems unless otherwise stated, always assume:

$\mu_n C_{ox}$ = 200 μA/V^2, $\mu_p C_{ox}$ = 100 μA/V^2, λ=0 V^{-1}., V_{TH}=0.4 V for NMOS devices and V_{TH}=−0.4V for PMOS devices.

Name: ______________________________

Problem 1 [20 pts=5,10,5]

Consider the circuit of figure 1 with $R_{D1} \neq R_{D2}$ *(i.e. the node P is not at AC ground).* Assume the transistors have the same g_m and channel length modulation is negligible. Calculate the following voltage gains: v_x/v_{in}, v_p/v_{in}, v_y/v_p

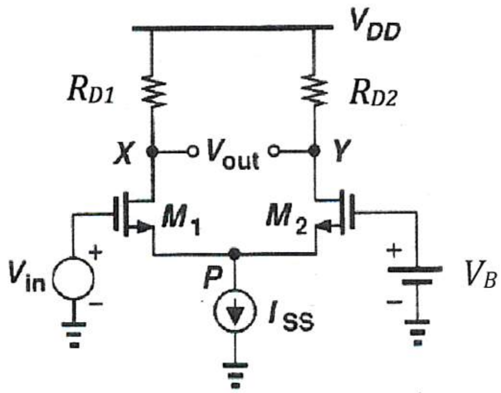
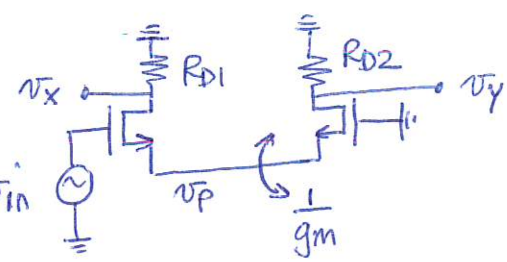


Figure 1

$v_x/v_{in} =$	
$v_p/v_{in} =$	
$v_y/v_p =$	

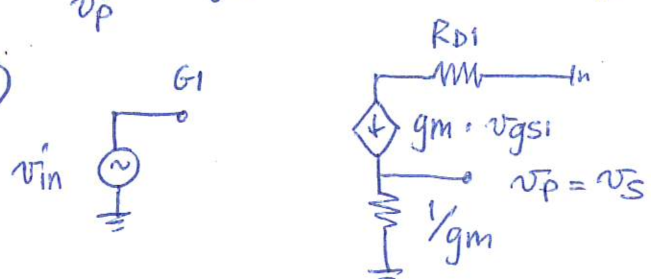


① $\frac{v_x}{v_{in}} = -\frac{g_m R_{D1}}{1 + g_m \frac{1}{g_m}} = -\frac{g_m}{2} R_{D1}$

common source with degeneration $1/g_m$

② $\frac{v_y}{v_p} = g_m R_{D2}$ ← common gate

③



↙ source follower

$$v_{in} = v_{gs1} + v_P = v_{gs1} + \frac{1}{g_m} \cdot g_m v_{gs1} = 2 v_{gs1}$$

$$v_P = \frac{1}{g_m} \cdot g_m v_{gs1} = \frac{1}{g_m} \cdot g_m \cdot \frac{v_{in}}{2}$$

$$\rightarrow \quad \frac{v_P}{v_{in}} = \frac{1}{2}$$

↓ out of curiosity

$$\frac{v_Y}{v_{in}} = \frac{v_Y}{v_P} \cdot \frac{v_P}{v_{in}} = \frac{g_m R_{D2}}{2}$$

$$\frac{v_Y - v_X}{v_{in}} = A_V = \frac{g_m}{2} \left(R_{D1} + R_{D2} \right)$$

Name:

Problem 2 [20 pts=5,10,5]

Calculate the differential voltage gain of the circuits depicted in Figure 2. V_b is a DC bias voltage. Assume perfect symmetry, transistors having the same g_m and r_o, and $g_m r_o >> 1$. State clearly any assumption you make.

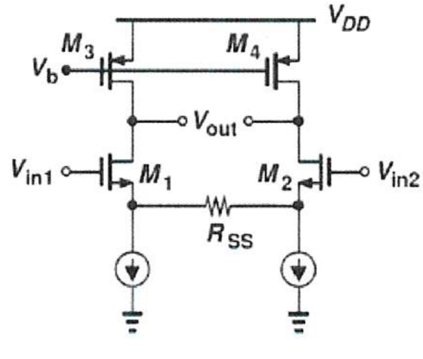
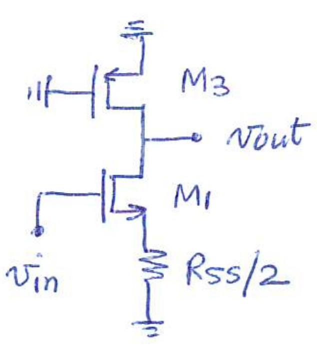


Figure 2

$$A_{dm} = \frac{v_{out2} - v_{out1}}{v_{in1} - v_{in2}}$$

R_{out} =	
G_m =	
$A_{dm} = -G_m R_{out}$	



$M_1 + R_{ss}/2$ is a "super" transistor with:

$$G_m = \frac{g_{m1}}{1 + g_{m1}\frac{R_{SS}}{2}} \quad \text{and} \quad R_o \simeq g_{m1} r_{o1} \frac{R_{SS}}{2}$$

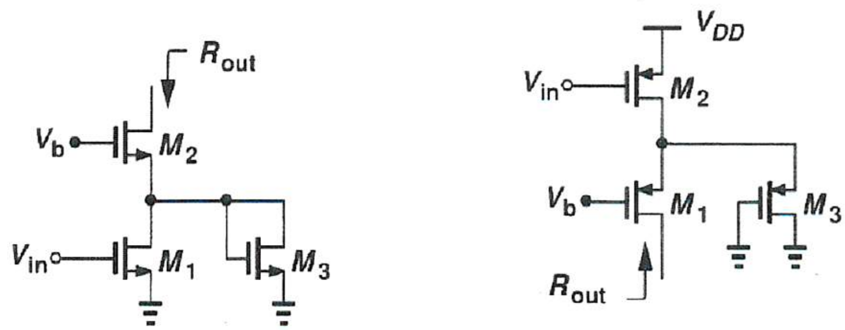
Therefore:

$$A_V = -G_m \cdot \underbrace{(R_o \| r_{o3})}_{= R_{out}}$$

Name: ______________________________

Problem 3 [20 pts]

Determine the output impedance of the circuits shown in Figure 3. Assume $\lambda \neq 0$.



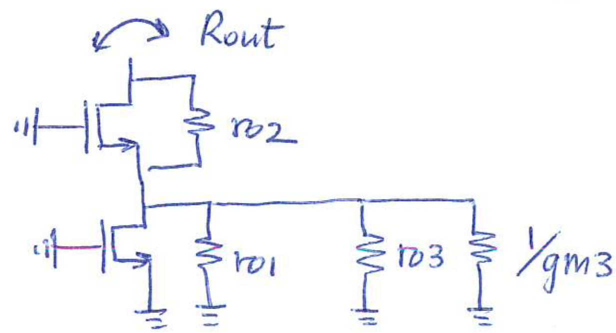
(c) (d)

Figure 3

Vb is a DC bias voltage.

c. R_{out} =	
d. R_{out} =	

(c.)

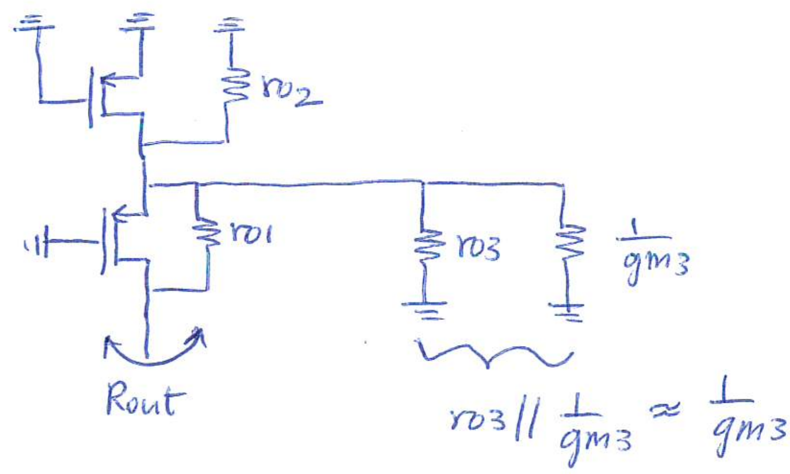


$$r_{o3} \,||\, \frac{1}{g_{m3}} \simeq \frac{1}{g_{m3}}$$

$$R_{out} \simeq g_{m2}\, r_{o2} \cdot R_S$$

with $R_S = r_{o1} \,||\, r_{o3} \,||\, \frac{1}{g_{m3}}$

(d)



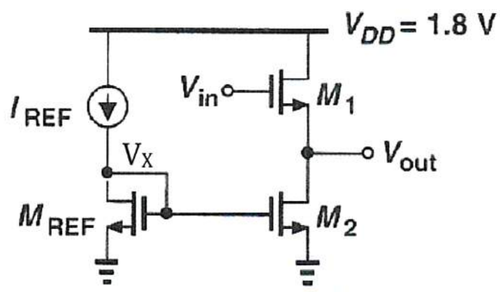
$$R_{out} \approx g_{m1} r_{o1} \cdot R_S$$

with $R_S = r_{o2} \| r_{o3} \| \frac{1}{g_{m3}}$

Name:

Problem 4 [20 pts]

The source follower of figure 4 must achieve a voltage gain of 0.85 and an output impedance of 100 Ω. Assuming $V_X = 1V$, $\lambda_n = 0.1\ V^{-1}$, $I_{REF} = 0.1 I_{D1}$ design the circuit. (Hint: $A_v = g_{m1} R_{out}$)



$\mu_n C_{ox} = 200\ \mu A/V^2$

$V_{TH} = 0.4V$

Figure 4.

$g_{m1} =$	
$r_{o1} = r_{o2} = r_o =$	
$I_{D1} = I_{D2} = I_D =$	
$(W/L)_2 =$	
$(W/L)_{REF} =$	

Since the DC current flowing through M1 and M2 is the same

$r_{o1} = r_{o2} \cong \frac{1}{\lambda I_D} \triangleq r_o$

$R_{out} = r_{o2} \| (r_{o1} \| \frac{1}{g_{m1}}) = \frac{1}{\frac{1}{r_{o2}} + \frac{1}{r_{o1}} + g_{m1}} =$

$= \frac{1}{g_{m1} + \frac{2}{r_o}}$

$A_v = g_{m1} \cdot R_{out} \rightarrow g_{m1} = \frac{A_v}{R_{out}} = \frac{0.85}{100} = 8.5\ mS$

$$R_{out} = \frac{1}{g_{m1} + \frac{2}{r_o}} \longleftrightarrow \frac{2}{r_o} R_{out} + g_{m1} R_{out} = 1 \longleftrightarrow$$

$$\frac{1}{r_o} = \frac{1 - g_{m1} R_{out}}{2\, R_{out}} \Longrightarrow$$

$$r_o = \frac{2\, R_{out}}{1 - g_{m1} R_{out}} = \frac{200}{1 - 0.85} \simeq 1333\,\Omega$$

$$I_D \cong \frac{1}{\lambda_n r_o} = 7.5\,mA$$

$$\left(\frac{W}{L}\right)_2 = \frac{2 \cdot I_D}{\mu_n C_{ox} \left(V_X - V_{TH}\right)^2} \simeq 208$$

$$I_{REF} = 0.1 \times I_D = 0.75\,mA$$

$$\left(\frac{W}{L}\right)_{REF} = \left(\frac{W}{L}\right)_2 \cdot \frac{I_{REF}}{I_D} = \frac{208}{10} \approx 21$$