Final Exam, ECE 137A

Thursday March 23, 2023, Noon - 3 p.m.

Name: _____

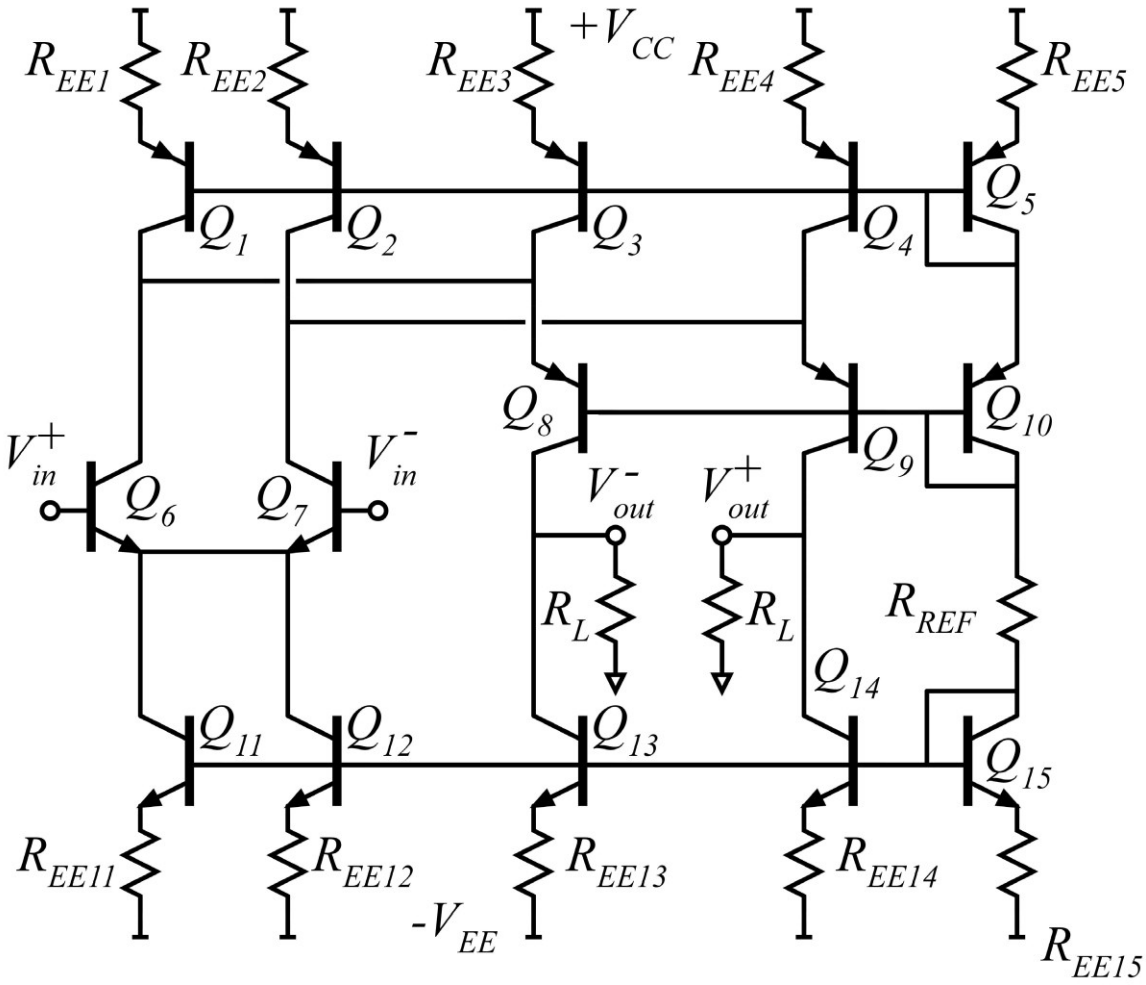
Closed Book Exam:
Class Crib-Sheet and 2 pages (4 surfaces) of student notes permitted
Do not open this exam until instructed to do so. Use any and all reasonable approximations (5% accuracy), ***after stating & justifying them***.
Show your work:
Full credit will not be given for correct answers if supporting work is missing.
Good luck

Part	Points Received	Points Possible	Part	Points Received	Points Possible
1a		5	2c		5
1b		5	2d		15
1c		5	2e		10
1d		10	3a		5
1e		10	3b		10
2a		10	3c		5
2b		5			
total		100			

a

Problem 1, 35 points

This is an NOT an Op-Amp: Analyze under the assumption that the differential and common mode input voltages are at zero volts.



All the transistors have the same (matched) I_S, have $\beta = \infty$, and $V_A = \infty$ Volts.
$V_{CE(sat)} = 0.5\text{V}$. V_{be} is *approximately* 0.7 V, but use the *exact relationship* $V_{be} = (kT/q)\ln(I_E / I_S)$ when appropriate. The supplies are +3 Volts and -3 Volts. All transistors have the same I_S, and all are biased at 1 mA collector current.
The DC voltage drops across REE5 and REE15 are both 300 mV. R_L=1 kOhm.

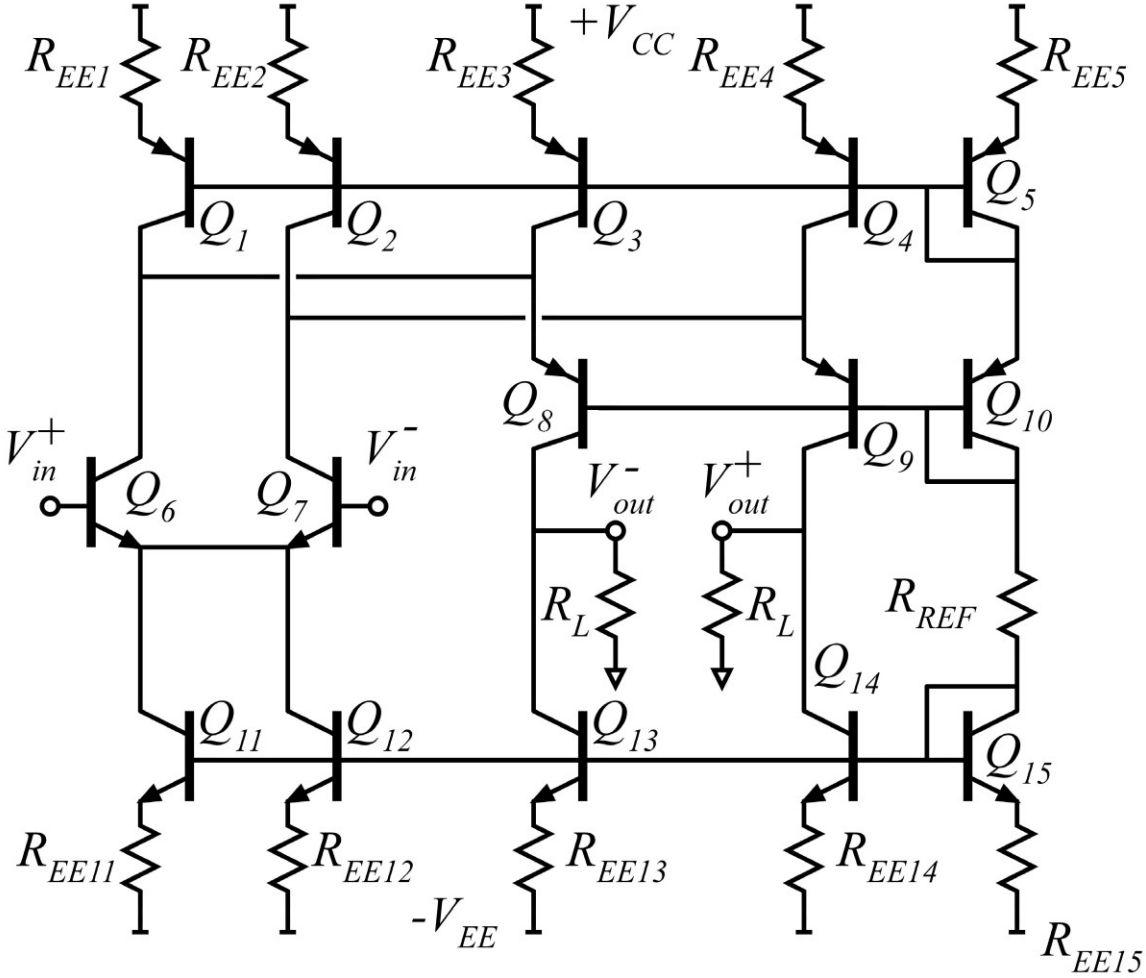
a

Part a, 5 points
DC bias

Find the value of the following resistors:
Ree5=_____ Ree15=_____ R_{REF}=_____
Ree11=_____ Ree12=_____

Part b, 5 points

DC bias



On the circuit diagram above, label the DC voltages at **ALL nodes**.

Part c, 5 points

find the following for all transistors

gm=_____ Rbe=_____ Rce=_____

a

Part d, 10 points.

Find the following

Overall voltage gain $(V_{out}^{+} - V_{out}^{-}) / (V_{in}^{+} - V_{in}^{-})$ = _____

Differential input impedance Rin, Diff = _____

a

a

Part e, 10 points

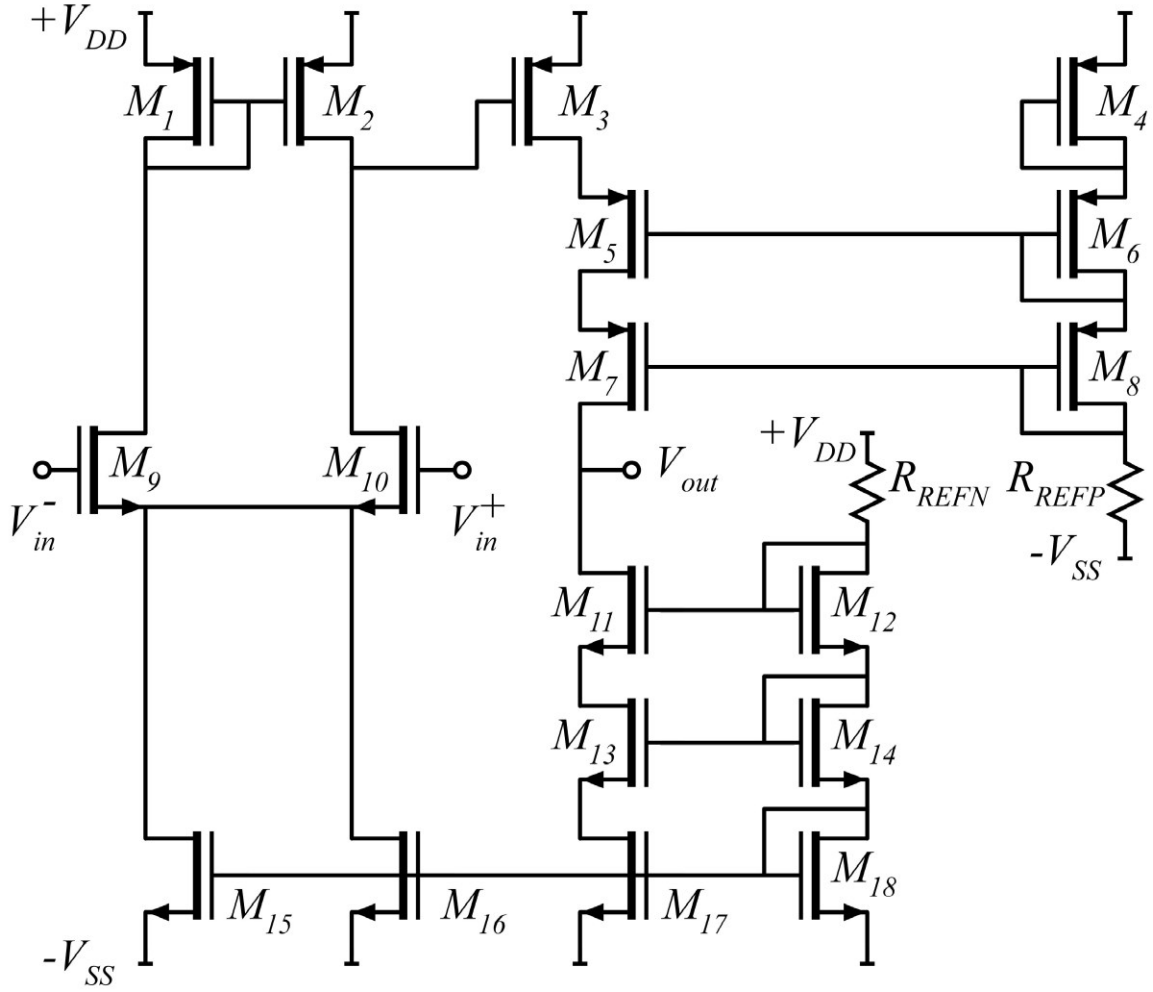
Maximum output voltage swings ***at V_{out}^{+} (not V_{out}^{-})*** (***show all your work***).

	magnitude and sign of maximum output signal swing due to ***cutoff***	magnitude and sign of maximum output signal swing due to ***saturation***
Transistor Q6		Do not calculate
Transistor Q7		Do not calculate
Transistor Q9		
Transistor Q14	Do not calculate	

a

Problem 2, 45 points

This is an Op-Amp---analyze the bias under the assumption that DC output voltage V_{out} is zero volts, that the positive input Vi+ is zero volts, and that we must determine the DC value of the negative input voltage (Vi-) necessary to obtain this.



The NMOSFETs have $K_\mu = 10\text{mA/V}^2 \cdot (W_g / 1\mu\text{m})$ $K_v = 2.0\text{mA/V} \cdot (W_g / 1\mu\text{m})$, $\Delta V = 0.10\text{V}$, $V_{th} = 0.2$ V, $1/\lambda = 5\text{V}$. The PMOS have identical parameters, except, of course, V_{th} is negative. V_{DD} = +0.75 V, $-V_{SS}$ = -0.75 V All transistors have |Vgs|=0.25V and are biased at I_D=50 μA.

Part a, 10 points

DC bias.

Analyze the bias under the assumption that DC output voltage is zero volts, that the positive input Vi+ is zero volts, and that we must determine the DC value of the negative input voltage (Vi-) necessary to obtain this.

(Hint, this should give Vi- = 0V)

Find the following:

Gate widths of M9 and M10 = _____

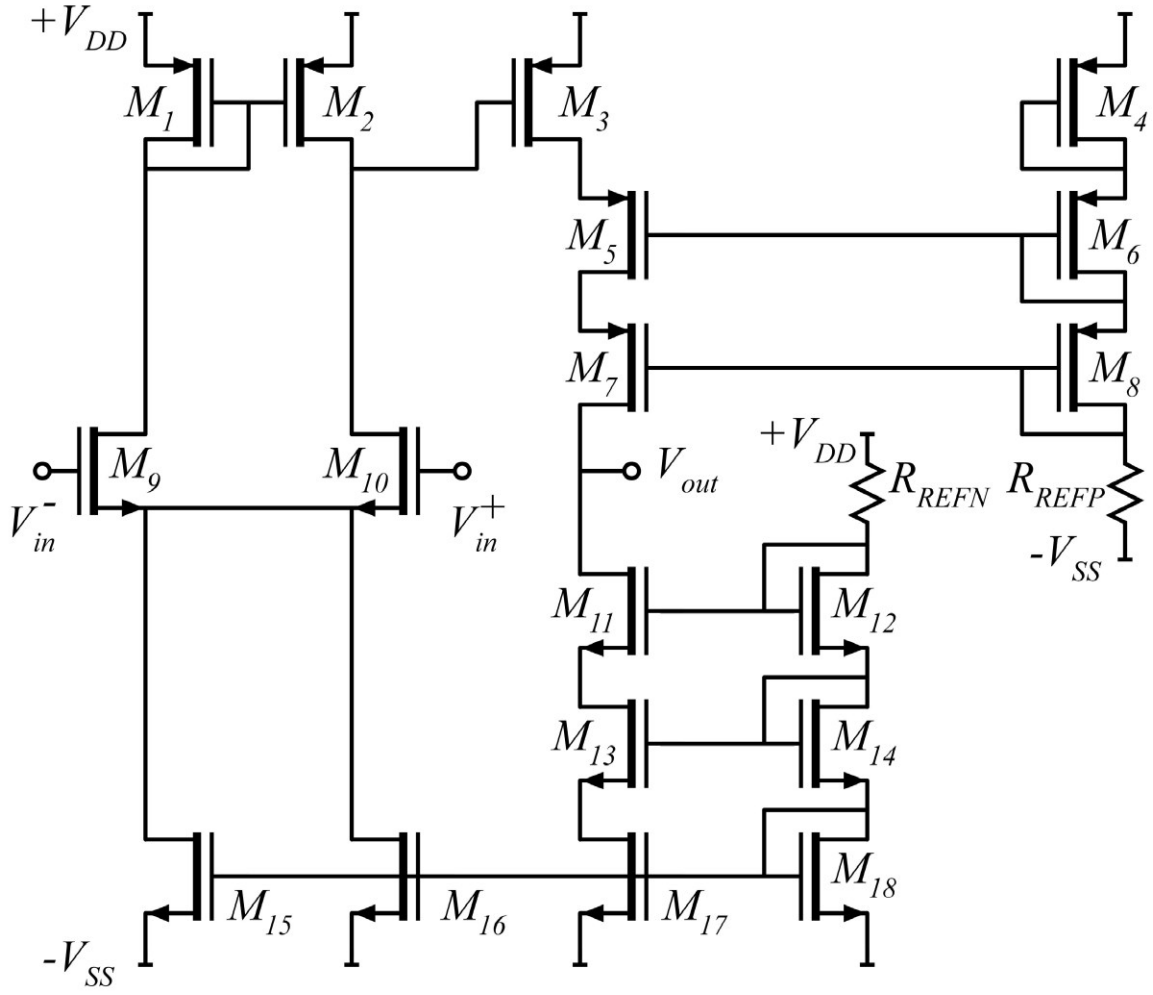
Gate width of M15 and M16 =_____

Gate width of ***all other MOSFETS*** =_____

value of R_{REFN} =_____ value of R_{REFP} =_____

Part b, 5 points

DC bias



On the circuit diagram above, label the DC voltages at **ALL nodes.**

Part c, 5 points.

Find the following

	Voltage Gain	Input impedance
Transistor combination M1,2,9, 10,15, 16		

a

Part d, 15 points.

Find the following

	Voltage Gain	Input impedance
Transistor combination M3,5,7,11,13,17		
Overall op-amp $V_{out} / (V_{in}^{+} - V_{in}^{-})$		

Note

1) You can analyze M3, M5, and M7 as separate stages, or as a combined stage using Norton/Thevenin methods. Don't ask for hints as to how to do this.

a

Part e, 10 points

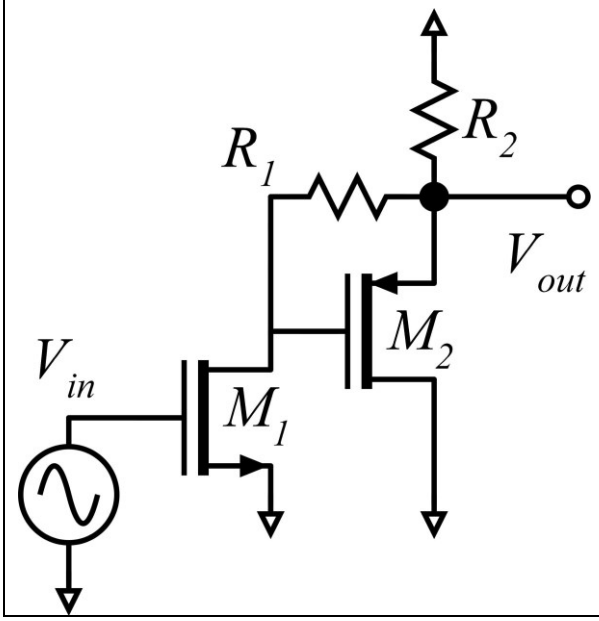
Maximum output voltage swings ***at V_{out}^{+} (not V_{out}^{-})*** (***show all your work***).

	magnitude and sign of maximum output signal swing due to ***knee voltage*** (saturation)
Transistor M7	
Transistor M11	
Transistor M2	

a

a

Problem 3, 20 points



You will be working on the circuit to the left

Ignore DC bias analysis. You don't need it.

M_1 and M_2 have transconductances g_{m1} and g_{m2}.

Both transistors have **infinite** R_{DS}, ...so you don't need to include these elements in the circuit diagram !

Part a, 5 points

Draw a small-signal equivalent circuit of the circuit.

Part b, 10 points

Derive an algebraic expression for V_{out} / V_{in} in terms of g_{m1}, g_{m2}, R_1, and R_2

$V_{out} / V_{in} =$

a

a

Part c, 5 points

Set g_{m1}=1 mS, g_{m2}=2 mS , R_1= 1 kΩ, and R_2 = 2 kΩ.
Find the numerical value of V_{out} / V_{in}

V_{out} / V_{in} =

a