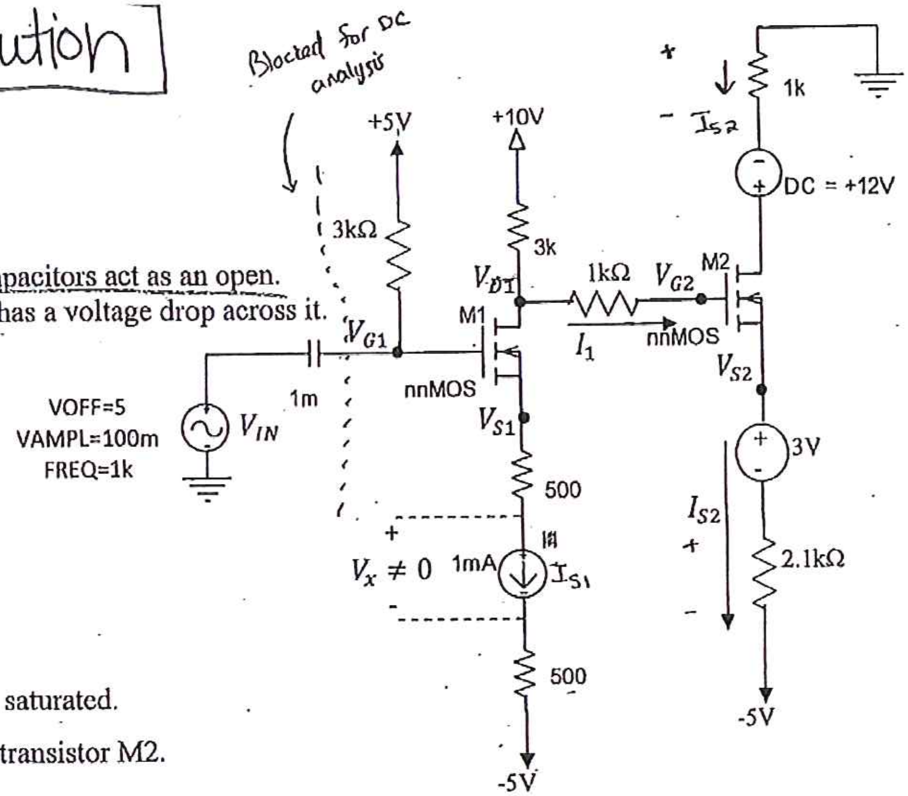
Exam 2 Solution

Problem 1 – (40 points)

Use: V_t=1V
$k_n'(W/L)$=2mA/V^2
λ=0

For DC analysis, assume that the capacitors act as an open.
The current source is not ideal and has a voltage drop across it.



(a) Solve for the DC currents:
  a. I_1 = 0A
  b. I_{S2} = 2.97mA

(b) Solve for the DC voltages:
  a. V_{G2} = 7V
  b. V_{S2} = 4.24V
  c. V_{S1} = 3V

(c) Verify that transistor M1 is saturated.

(d) State the DC bias point for transistor M2.

(e) Assuming that the transistor amplification is V_{S2}/V_{IN} = -4V/V. Assume the input frequency is operating within the circuits operating range. Assume that the amplification does not pull the transistors out of saturation. Will V_{S2} ever be 3V? Why or why not?

Parts (a) and (b): Assume saturation mode for M_1, M_2. Open up capacitors.

$I_1 = 0A$ (no current through gate)

M_1 transistor: $V_{G1} = 5V$ (no current through gate)

$I_{S1} = 1mA$

$I_{S1} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)(V_{GS1} - V_t)^2$

$\therefore 1m = \frac{1}{2}(2m)(V_{GS1} - 1)^2$

$\therefore 1 = V_{GS1}^2 - 2V_{GS1} + 1$

$\therefore V_{GS1}^2 - 2V_{GS1} = 0 = V_{GS1}(V_{GS1} - 2) = 0$

$\rightarrow V_{GS1} = 0V, 2V$

Need $V_{GS1} > V_t$, so $V_{GS1} = 2V$.

$V_{GS1} = V_{G1} - V_{S1}$, so $V_{S1} = V_{G1} - V_{GS1} = 5V - 2V = 3V = V_{S1}$.

$V_{D1} = 10V - (1mA \cdot 3k\Omega) = 10V - 3V = 7V$

Need $V_{D1} > V_{G1} - V_t$: $(V_{D1} = 7V) > (V_{G1} - V_t = 5V - 1V = 4V)$. ✓

$\therefore M_1$ is saturated

$V_{D1} = V_{G2} = 7V$ (no current through gate)

M_2 transistor: $V_{G2} = V_{D1} = 7V$

$V_{S2} = -5V + I_{S2}(2.1k) + 3V = -2V + I_{S2}(2.1k)$

$I_{S2} = \frac{1}{2}k_n'(\frac{W}{L})(V_{GS2} - V_t)^2 = \frac{1}{2}k_n'(\frac{W}{L})(V_{G2} - V_{S2} - V_t)^2$

$\therefore\ I_{S2} = \frac{1}{2}k_n'(\frac{W}{L})(7 - (-2 + I_{S2}(2.1k)) - 1)^2$

$I_{S2} = \frac{1}{2}k_n'(\frac{W}{L})(8 - I_{S2}(2.1k))^2$

$I_{S2} = \frac{1}{2}(2m)(64 - 2(I_{S2} \cdot 16.8k) + I_{S2}^2(2.1k)^2)$

$I_{S2} = (1m)(64 - 33.6k\, I_{S2} + 4.41M\, I_{S2}^2)$

$I_{S2} = 64m - 33.6\, I_{S2} + 4.41k\, I_{S2}^2$

$0 = 64m - 34.6\, I_{S2} + 4.41k\, I_{S2}^2$

$$I_{S2} = \frac{34.6 \pm \sqrt{(34.6)^2 - 4(4.41k)(64m)}}{2(4.41k)} = \frac{34.6 \pm \sqrt{68.2}}{8.82k}$$

$= 4.86mA,\ 2.97mA$

Try $I_{S2} = 2.97mA$. $V_{D2} = 0V - (2.97mA \cdot 1k\Omega) + 12V = 9.03V$

$V_{S2} = -2V + (2.97mA \cdot 2.1k) = 4.24V$

Need $V_{GS2} > V_t$: $(V_{GS2} = V_{G2} - V_{S2} = 7V - 4.24V = 2.76V) > (V_t = 1V)$ ✓

Need $V_{D2} > V_{G2} - V_t$: $(V_{D2} = 9.03V) > (V_{G2} - V_t = 7V - 1V = 6V)$. ✓

$\therefore$ saturated

$I_{S2} = 2.97mA,\ V_{S2} = 4.24V$

Part (c): Need $V_{GS1} > V_t$: $(V_{GS1} = 2V) > (V_t = 1V)$. ✓

Need $V_{D1} > V_{G1} - V_t$: $(V_{D1} = 7V) > (5V - 1V = 4V)$. ✓ $\therefore$ Saturated

Part (d): DC bias point for M_2 is $V_{GS2} = V_{G2} - V_{S2} = 7V - 4.24V = 2.76V$ or $I_{S2} = 2.97mA$

Part (e): $V_{S2} = V_{S2DC} + V_{S2AC}$

$V_{S2DC} = 4.24V$

$V_{S2AC} = -4\frac{V}{V} \cdot 100mV\sin(\omega t) = -400mV\sin(\omega t)$

$V_{S2} = 4.24V - 0.4V\sin(\omega t)$

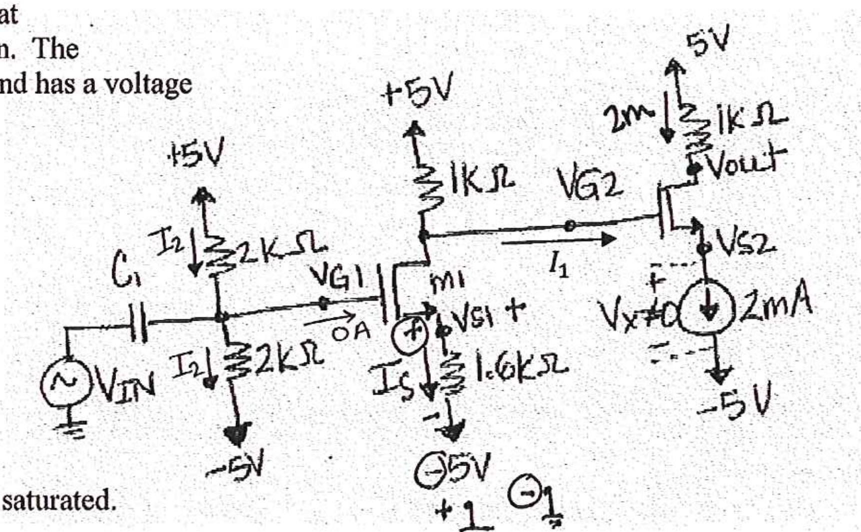
Peak values of V_{S2} are $4.24V + 0.4V = 4.64V$

$4.24V - 0.4V = 3.84V$

So V_{S2} will never be 3V.

Problem 1 – **(40 points)** Solution

Use: V_t=1V
$k_n'(W/L)$=1mA/V^2
λ=0
V_{IN} = (5+10msin(20t))V
For DC analysis, assume that the capacitors act as an open. The current source is not ideal and has a voltage drop across it.



(a) Solve for the DC currents:
  a. I_1=0
  b. I_S=1.4m

(b) Solve for the DC voltages:
  a. V_{G2} = 3.6V
  b. V_{S2}=0.6 V
  c. V_{S1}=-2.7V

(c) Verify that transistor M2 is saturated.

(d) State the DC bias point for transistor M1.

(e) Assuming that the transistor amplification is V_{out}/V_{IN} = +5V/V. Assume the input frequency is operating within the circuits operating range. Assume that the amplification does not pull the transistors out of saturation. Draw a rough sketch of the **total instantaneous value** seen at V_{out} using the V_{IN} value stated above.

a) $I_1 = 0$

b) $I_S = \frac{1}{2} k_n'\left(\frac{W}{L}\right)(V_{GS1}-V_t)^2 = \frac{1}{2}(1m)(V_{G1}-V_{S1}-1)^2$

$V_{G1}=0$ OR $+5 - I_2(2k) - I_2(2k) + 5 = 0$

$I_2 = \frac{10}{4k} = 2.5mA$

$-5 + I_2(2k) = V_{G1} = 0$

$V_{S1} = -5 + I_S(1.6K)$

$\frac{2I_S}{1m} = (0+5-I_S(1.6K)-1)^2 = (4-I_S(1.6K))^2 = 16 - 12800I_S + I_S^2(1.6K)^2$

$0 = I_S^2(1.6K)^2 - 14{,}800I_S + 16$

$I_S = \frac{14{,}800 \pm \sqrt{14{,}800^2 - 4(16)(1.6K)^2}}{2(1.6K)^2} = 4.3m \text{ and } 1.4mA$

If $I_s = 4.3m$ then $V_{S1} = -5 + I_s(1.6k) = +1.88$

$V_{GS1} = 0 - 1.88 = -1.88 < V_t$ × NO

$\boxed{I_s = 1.4mA}$

$V_{S1} = -5 + (1.4m)(1.6k) = \boxed{-2.7V = V_{S1}}$

$\therefore V_{GS1} = 2.7V > V_t$ ∴ ON

$V_{D1} = V_{G2} = 5 - 1K(1.4m) = \boxed{3.6V = V_{G2}}$

$3.6 = V_{D1} - \cancel{V_{S1}} > V_{G1} - \cancel{V_{S1}} - V_t = 0 - 1$ ✓ TRUE, SAT

$I_{D2} = I_{S2} = 2mA = \frac{1}{2}(1m)(3.6 - V_{S2} - 1)^2$

$4 = (2.6 - V_{S2})^2$

$\pm\sqrt{4} = 2.6 - V_{S2}$

$\therefore V_{S2} = 2.6 \pm 2 = 4.6$ OR 0.6

If $V_{S2} = 4.6$ then $V_{GS2} = 3.6 - 4.6 = -1 < V_t = 1$ ∴ NOT ON!

$\boxed{V_{S2} = 0.6V}$

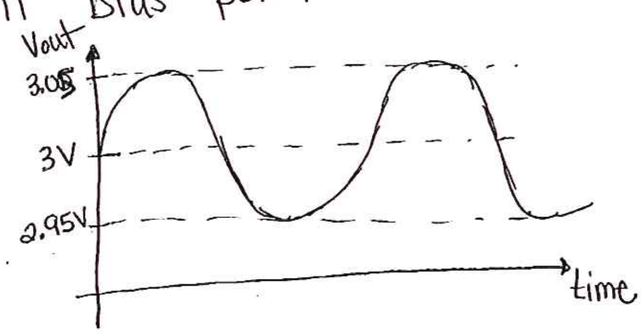
c) $V_{GS2} = 3.6 - 0.6 = 3V > V_t = 1$ ∴ ON

$V_{D2} = 5 - 1K(2m) = 3V$

$3V = V_{D2} - \cancel{V_{S2}} > V_{G2} - \cancel{V_{S2}} - V_t = 2.6V$ ✓ SATURATED

d) m1 bias point is $I_D = 1.4m$ OR $V_{GS1} = 2.7V$

e)



$V_{out_{total}} = V_{out_{DC}} + V_{out_{AC}}$

$V_{out_{total}} = 3 + 5(10m\sin(20t))$

ECE2280
Quiz #3
(open book/notes)

NAME:____

I certify that the work below is my own.

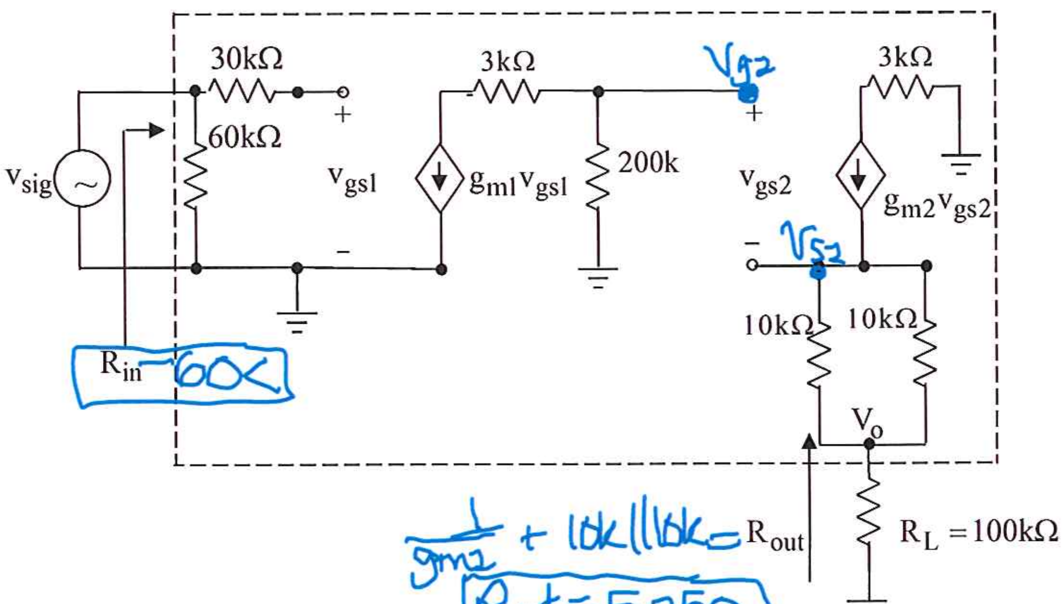
Signature:____

Let V_t=1V, $k_n'(W/L)$=1mA/V^2, v_{sig} is an AC source, λ=0 (for all transistors) and assume all transistors are saturate
Transistor 1 has DC values: V_{GS}=3V, I_D=2mA.
Transistor 2 has DC values: V_{GS}=5V, I_D=8mA.

$g_{m1} = (m)(3-1)$
$= 2m$
OR
$g_{m1} - \sqrt{2(1m)(2m)} - 2m$
$g_{m2} = (1m)(5-\ ) - \sqrt{2(m)(8m)} = 4$

For the following hybrid-π equivalent circuit, find the following values:

(a) R_{in} (input resistance –ignore the input source, Vsig)
(b) R_{out} (output resistance-ignore R_L{no load is connected})
(c) ideal midband gain, $\frac{Vo}{Vsig}$



$\frac{1}{g_{m2}} + 10k \| 10k = R_{out}$

$\boxed{R_{out} = 5{,}250}$

$V_o = g_{m2} V_{gs2} (100k)$

$V_{gs2} - V_{g2} \quad V_{s2} - -g_{m1} V_{gs} (200k) - g_{m2} V_{gs2} (05k)$

$V_{gs2}(+ g_{m2}(105k)) = -g_m V_{gs} (200k)$

$V_{gs2} - \frac{g_m V_{gs} (200k)}{(1 + g_{m2}(105k))}$

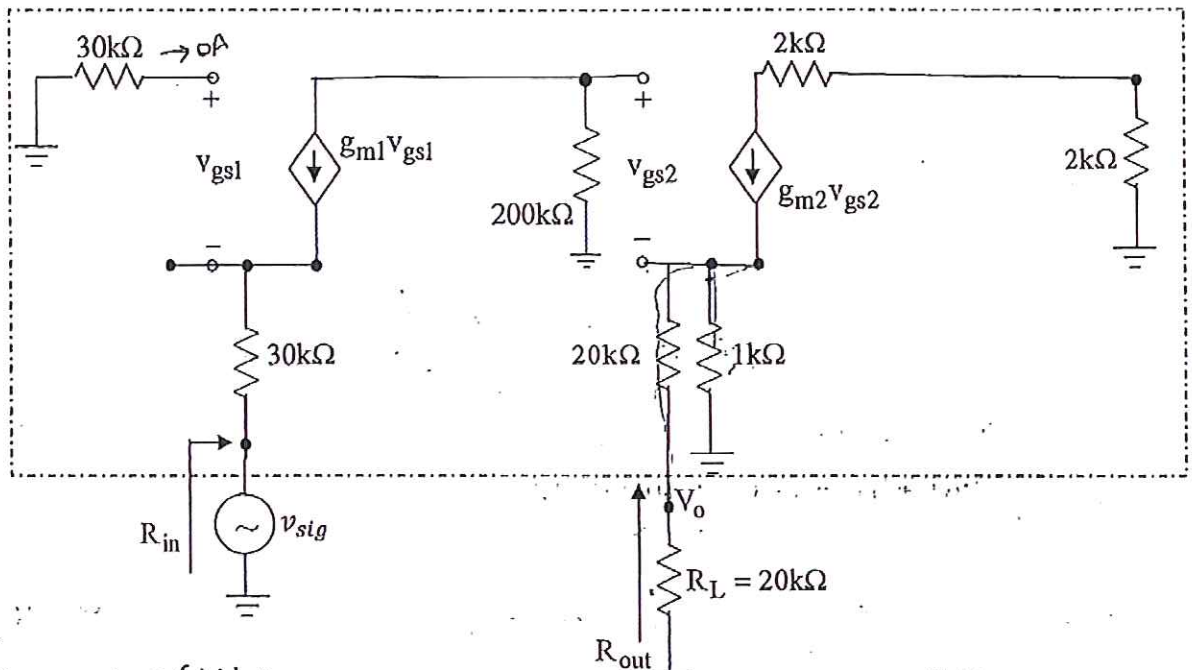
$V_{gs1} - V_{sig}$

$V_o = g_{m2}(100k)\left[\frac{-g_{m1} V_{sig}(200k)}{\ldots}\right] \Rightarrow \boxed{\frac{V_o}{V_{sig}} = -380\ V/V}$

Problem 2 – (35 points)

Use: V_t=1V
$k_n'(W/L)$=2mA/V^2
V_{sig} is an AC source
Transistor 1 has DC values: V_{GS}=1.5V, I_D=0.25mA
Transistor 2 has DC values: V_{GS}=13.5V, I_D=156.25mA
λ=0 (for all transistors) and assume all transistors are saturated

For the following hybrid-π equivalent circuit, find the following values:
(a) R_{in} (input resistance –ignore the input source, v_{sig})
(b) R_{out}(output resistance – ignore the load resistor, R_L)
(c) ideal overall midband gain, $\frac{V_o}{v_{sig}}$.



$g_{m1} = k_n'\left(\frac{W}{L}\right)(V_{GS1} - V_t)$
$= (2m)(1.5-1) = (2m)(0.5) = 1m$

$g_{m2} = k_n'\left(\frac{W}{L}\right)(V_{GS2} - V_t)$
$= (2m)(13.5-1)$
$= (2m)(12.5) = 25m$

a) $R_{in} = 30k\Omega + \frac{1}{g_{m1}} = 30k\Omega + \frac{1}{1m} = 30k\Omega + 1k\Omega = 31k\Omega$

b) $R_{out} = 20k\Omega + 1k\Omega \| \frac{1}{g_{m2}} = 20k\Omega + \frac{1}{\frac{1}{1k\Omega} + g_{m2}} = 20k\Omega + \frac{1}{1m + 25m}$

$= 20k\Omega + \frac{1}{26m} = 20.038\,k\Omega$

c) $V_o = 0V + \left(\frac{g_{m2} V_{gs2} \cdot 1k\Omega}{1k\Omega + 20k\Omega + 20k\Omega}\right) \cdot 20k\Omega = \frac{g_{m2} V_{gs2}}{41} \cdot 20k\Omega = \frac{g_{m2} V_{gs2} \cdot 20k}{41}$

$V_{gs2} = V_{g2} - V_{s2} = (0V + -g_{m1} V_{gs1} \cdot 200k\Omega) - (g_{m2} V_{gs2} \cdot 40k\Omega \| 1k\Omega)$

$\therefore V_{gs2} = -g_{m1} V_{gs1} \cdot 200k - g_{m2} V_{gs2} \cdot 0.98k\Omega$

$\therefore V_{gs2}(1 + g_{m2} \cdot 0.98k\Omega) = -g_{m1} V_{gs1} \cdot 200k$

$\therefore V_{gs2} = \frac{-g_{m1} V_{gs1} \cdot 200k}{1 + g_{m2} \cdot 0.98k}$

$V_{gs1} = V_{g1} - V_{s1} = 0V - (V_{sig} + g_{m1} V_{gs1} \cdot 30k)$

$\therefore V_{gs1} = -V_{sig} - g_{m1} V_{gs1} \cdot 30k$

$\therefore V_{gs1}(1 + g_{m1} \cdot 30k) = -V_{sig}$

$V_{gs1} = \frac{-V_{sig}}{1 + g_{m1} \cdot 30k}$

All together: $V_o = \frac{20k \cdot g_{m2}}{41}\left(\frac{+g_{m1} \cdot 200k}{1 + g_{m2} \cdot 0.98k}\left(\frac{+V_{sig}}{1 + g_{m1} \cdot 30k}\right)\right)$

$V_o = \frac{g_{m1} g_{m2} \cdot 20k \cdot 200k}{41(1 + g_{m2} \cdot 0.98k)(1 + g_{m1} \cdot 30k)} V_{sig}$

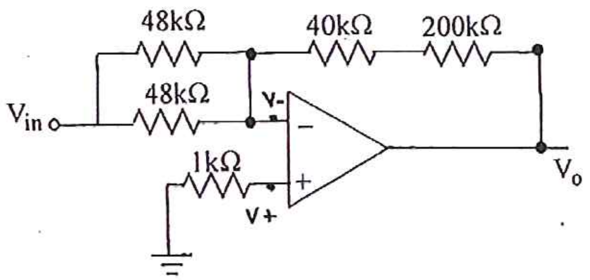
$\frac{V_o}{V_{sig}} = \frac{(1m)(2.5m) 20k \cdot 200k}{41(1 + (2.5m)(0.98k))(1 + (1m)(30k))} = \frac{100000}{32410.5} = 3.09 \frac{V}{V}$

Problem 4 – (20 points)

You are given the following characteristics for a real amplifier:

Input offset voltage,	V_{ios}=2mV
Input Resistance,	R_i=2MΩ
Unity-gain bandwidth,	f_T=40MHz
Output swing limits,	within 2Volts of power supply
Slew Rate,	SR=5 $\frac{V}{\mu sec}$

The following circuit is powered at ±9V:



a) (3 points) What value is the ideal gain?

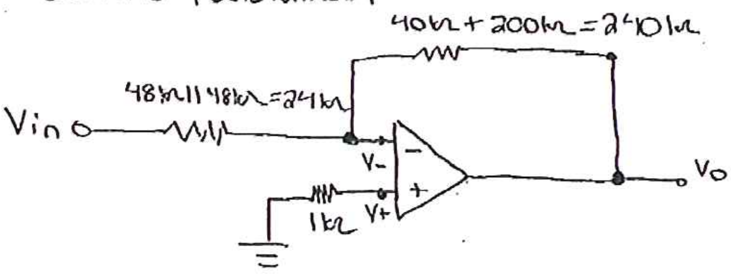
b) (10 points) What is the bandwidth of the circuit considering both the Unity-gain bandwidth limitations and the slew rate effect for an input of V_{in}=0.001sin(ωt)?

c) (4 points) For V_{in}=0.001sin(ωt), what is the maximum and minimum values seen at the output considering only the input offset voltage?

d) (3 points) How should the circuit above be modified(do not remove any resistors) to minimize the effect of the input bias current? Draw the schematic of the modified circuit and state values of added component(s).

a) Ideal op-amp: V+ = V- (see schematic), no current into op-amp.

Combine resistances:



This is just an inverting amplifier, so the gain is $\frac{V_o}{V_{in}} = \frac{-240k\Omega}{24k\Omega} = -10\frac{V}{V}$, or ($10\frac{V}{V}$, inverting).

b) Effect due to unity-gain bandwidth:

$f_c \cdot gain = f_t \rightarrow f_c = \frac{f_t}{gain} = \frac{40MHz}{10} = 4MHz$

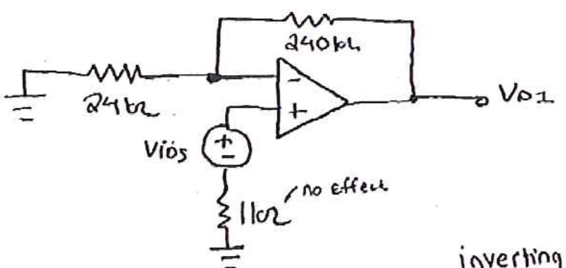
Effect due to slew rate: $f_{max} = \frac{SR}{V_{pp} \cdot \pi}$, where SR = slew rate, V_{pp} = 2 · amplitude of output signal

Amplitude of output signal: $\text{gain} \cdot \underbrace{0.001\text{ V}}_{\text{amplitude of input signal}} = 10 \cdot 1\text{mV} = 10\text{mV}$

So, $V_{pp} = 2(10\text{mV}) = 20\text{mV}$

$f_{max} = \dfrac{5\text{V}}{1\mu s \cdot 20\text{mV} \cdot \pi} \approx 79.6\text{ MHz}$. Smaller frequency determines the bandwidth, so bandwidth is 4 MHz.

c) Use superposition. Vios on, Vin off.



This is just a noninverting amplifier.

$\dfrac{V_{o1}}{V_{ios}} = \left(1 + \dfrac{240k\Omega}{24k\Omega}\right) = (1+10) = 11$

$\therefore V_{o1} = 11 \cdot V_{ios} = 11 \cdot 2\text{mV} = 22\text{mV}$

Vin on, Vios off: $V_{o2} = \underbrace{\text{gain}}_{\text{inverting gain}} \cdot V_{in} = -10 \cdot (0.001\sin(\omega t))$

$= -10\text{mV} \cdot \sin(\omega t)$

Combine results: $V_o = V_{o1} + V_{o2} = 22\text{mV} - 10\text{mV}\sin(\omega t)$

Max value: $22\text{mV} + 10\text{mV} = 32\text{mV}$,
Min value: $22\text{mV} - 10\text{mV} = 12\text{mV}$

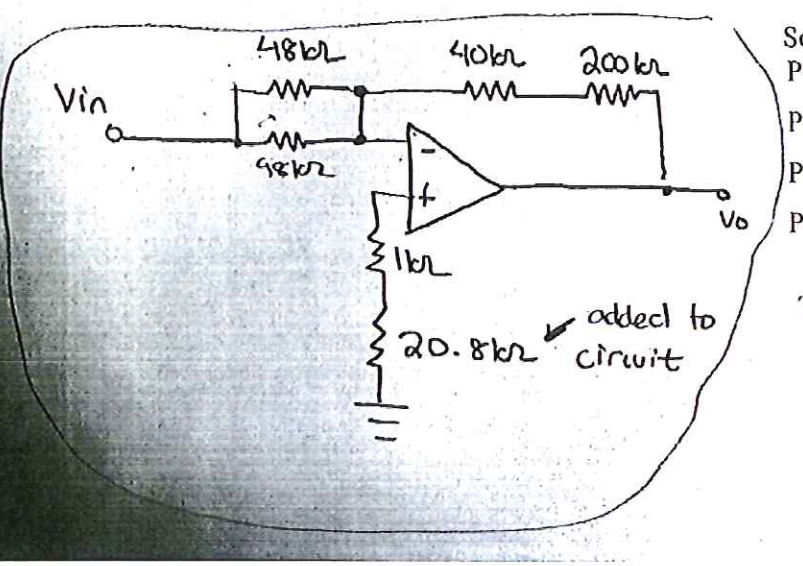
d) Match the impedance seen by each terminal of the op-amp.

− terminal sees impedance $R_{TH} = 24k\Omega \,||\, 240k\Omega = 24k\Omega \cdot 1||10$

$= 24k\Omega \cdot \frac{10}{11} \approx 21.8k\Omega$

+ terminal sees impedance 1kΩ. If we add a 20.8 kΩ resistor in series with this 1kΩ resistor, then the impedances will match.

Circuit:



ECE 2280 Midterm #1

Name________

Scores:

Prob 1 ________ of a possible 25pts
Prob 2 ________ of a possible 25pts
Prob 3 ________ of a possible 30pts
Prob 4 ________ of a possible 20pts

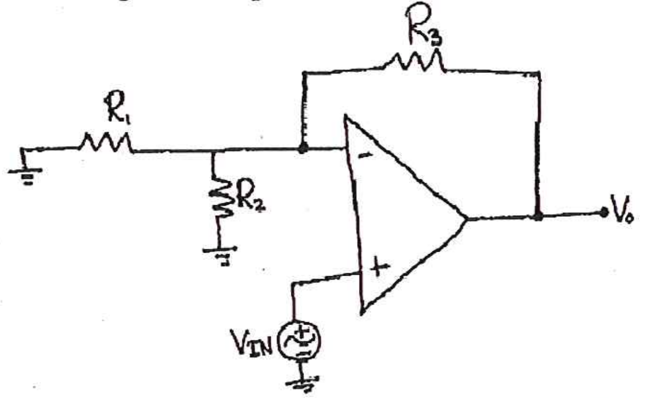
Total ________ of a possible 100 pts

Problem 4 – (20 points)

You are given the following characteristics for a real amplifier:

Input offset voltage,	V_{ios}=4mV
Input Resistance,	R_i=2MΩ
Unity-gain bandwidth,	f_T=10MHz
Output swing limits,	within 2Volts of power supply
Slew Rate,	SR=$5\frac{V}{\mu sec}$

The following circuit is powered at ±12V:



a) State the equation for Vo. Include no more than V_{IN}, R_1, R_2, and R_3.

b) If R_1= R_2=10k and R_3=100k, what is the bandwidth of the circuit. Consider both the effect due to slew rate (use the maximum output value possible) compared to the effect due to the unity gain bandwidth.

c) For V_{in}=0.001sin($2\pi 90kt$), what is the PEAK(not peak to peak) value at the output considering the input offset voltage?

d) How should the circuit above be modified to minimize the effect of the input bias current? Draw the schematic of the modified circuit and state values of added component(s).

a) $\boxed{V_o = \left[\frac{R_3}{R_2 \| R_1} + 1\right] \cdot V_{IN}}$

b) $V_o = \left[\frac{100k}{5k} + 1\right] \cdot V_{IN}$

$$\frac{V_o}{V_{IN}} = 21 \Rightarrow f_{3dB} = \frac{10M}{21} = 476KHz$$

$$f_{max} = \frac{5}{1\times10^{-6}} \cdot \frac{1}{(+20\cdot\pi)} \cong \boxed{80KHz}$$

c) $V_{out\,peak} = 21m + 4m(21) = \boxed{105mV_{peak}}$

d)