ENGR4300
Spring 2006
Test 2B

Name________<u>solution</u>____________

Section_____________________________

Question 1 (25 points)____________

Question 2 (15 points) ____________

Question 3 (20 points)____________

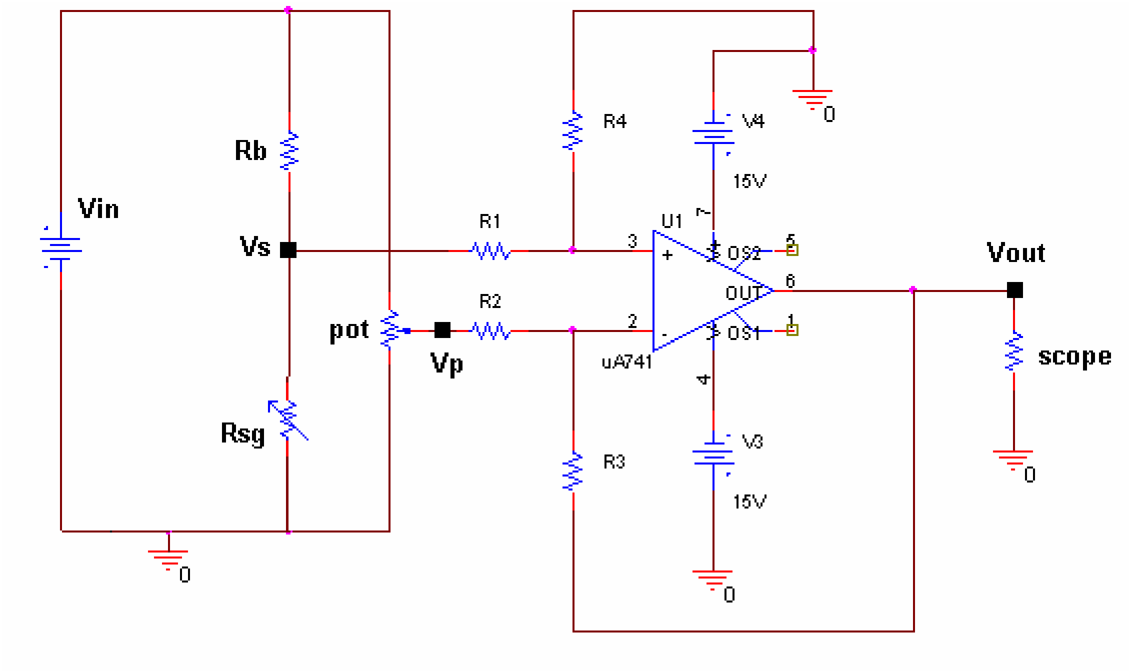
Question 4 (20 points)____________

Question 5 (20 points)____________

Total (100 points): _______________

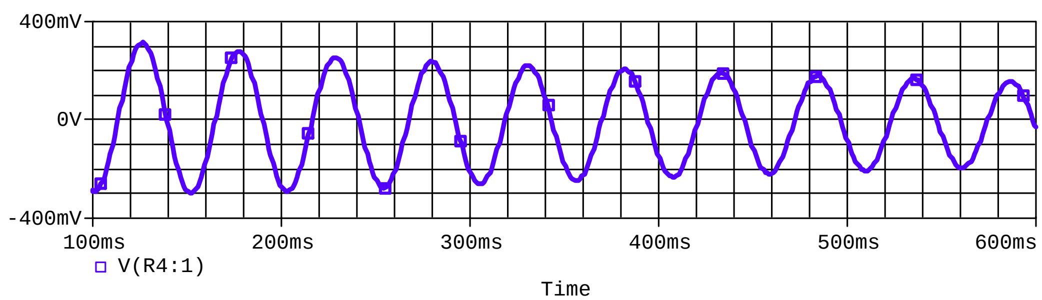
On all questions: SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES <u>AND UNITS</u>. No credit will be given for numbers that appear without justification.

Question 1 – Bridges and Damped Sinusoids (25 points)

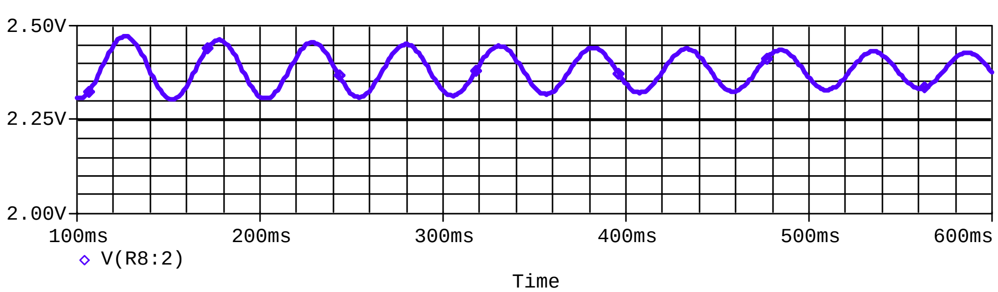


Above is figure of an amplified strain gauge bridge similar to the one you are using for project 2. The circuit has the following values: Vin = 5V, Rb=1K ohms, R1 = 2K ohms, R2 = 2K ohms, R3=10k ohms, R4=10k ohms, and the pot is a 2k pot.

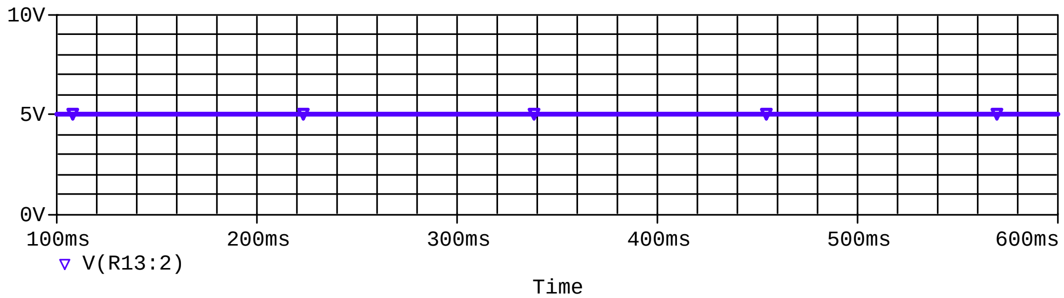
a) Assuming the bridge is ideal and that it has been properly balanced, which of these four plots is correct for each of the following four voltages on the figure: Vin, Vs, Vp, and Vout. (Indicate the signal in the box below the plot). (8 points)



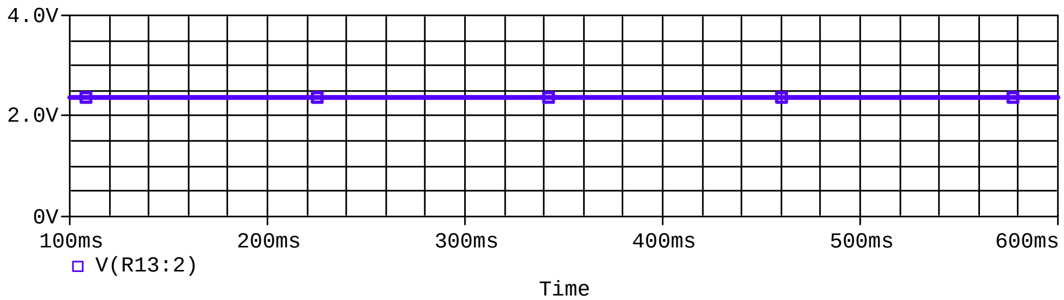
Vout



Vs



Vin



Vp

b) What is the resonant frequency of the output signal in Hertz? (3 points)

T=(560m-100m)/9 = 51.1ms f=1/51.1m

f = 19.6 Hz

c) What is the damping constant of the output signal? (4 points)

From below:

(t0,v0) = (0.1s,300mV)   (t1,v1) = (0.56s,200mV)

200m = 300m e^[-α(.56-.1)]

α = 0.9/s

From above:

(t0,v0) = (0.125s,310mV)   (t1,v1) = (0.585s,150mV)

150m = 310m e^[-α(.585-.125)]

α = 1.6/s

d) Write an equation for Vout in terms of Vs and Vp. Do not substitute numerical values for the resistors. (2 points)

$$Vout = \left(\frac{R4}{R1}\right)(Vs - Vp)$$ *[Allowable variations: R4=R3, R1=R2]*

e) If R_{pot} is the total resistance of the potentiometer, R_{top}, is the resistance between the center of the pot and the source voltage, R_{bottom} is the resistance between the center of the pot and ground, R_{sg} is the resistance of the strain gauge, and Rb is as shown in the figure, which of the following are true statements? Assume the bridge is balanced and in its rest position. (4 points) (Circle T or F for each statement.)

$\frac{Rb}{Rb + R_{sg}} = \frac{R_{top}}{R_{pot}}$	***T***	F
$\frac{Rb}{R_{sg}} = \frac{R_{top}}{R_{bottom}}$	***T***	F
$R_{top} + R_{bottom} = R_{pot}$	***T***	F
$\frac{R_{bottom}}{R_{sg}} = \frac{R_{pot} - R_{bottom}}{Rb}$	***T***	F

f) Starting with the equation from part d, derive an equation for Vout in terms of Vin for this circuit. Use the resistor naming conventions we used in part e ($R_{pot,}$ R_{top}, R_{bottom}, R_{sg}, and Rb) and the other resistors in the circuit (R1, R2, R3, and R4). You will not need all of these resistors in the answer. You cannot assume the bridge is balanced. You cannot substitute numerical values for the resistors. You cannot express your answer in terms of Vs and Vp. Your answer should be expressed as Vout = K*Vin, where K is a constant based on some combination of the resistor values. (4 points)

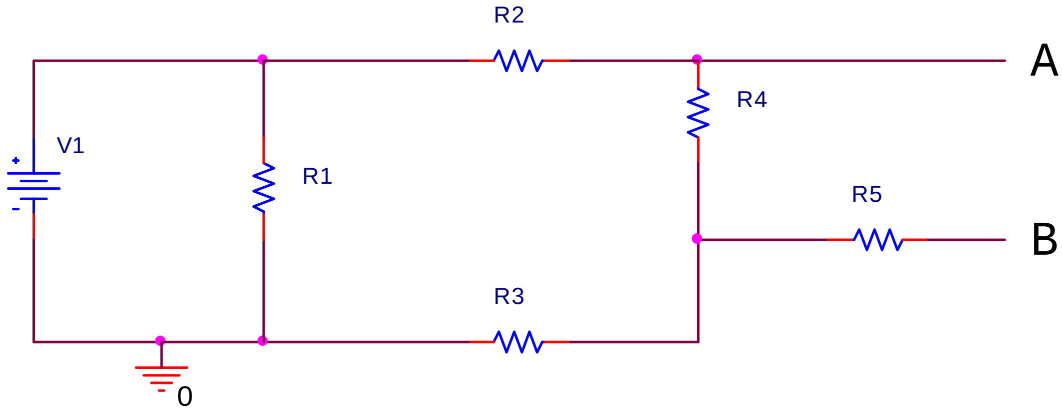
$$Vout = \left(\frac{R4}{R1}\right)(Vs - Vp) \quad Vs = \frac{R_{sg}}{R_{sg} + Rb}Vin \quad Vp = \frac{R_{bottom}}{R_{pot}}Vin$$

$$Vout = \left(\frac{R4}{R1}\right)\left(\frac{R_{sg}}{R_{sg} + Rb}Vin - \frac{R_{bottom}}{R_{pot}}Vin\right)$$

$$Vout = \left(\frac{R4}{R1}\right)\left(\frac{R_{sg}}{R_{sg} + Rb} - \frac{R_{bottom}}{R_{pot}}\right) * Vin$$

[Allowable variations: R1=R2, R3=R4, $R_{pot} = R_{top} + R_{bottom}$]

Question 2 – Thevenin Equivalents (15 points)



V1=8V, R1=3k ohms, R2=400 ohms, R3=2k ohms, R4=1k ohms, R5=2k ohms

a) Find the Thevenin equivalent voltage with respect to A and B for the circuit shown above. (5 points)

$Vth = V1(R4)/(R2+R3+R4) = 8(1k)/(400+2k+1k) = 2.35\ V$

Vth = 2.35V

b) Find the Thevenin equivalent resistance with respect to A and B for the circuit shown above. (5 points)

```
           +-----(R4)---------+
A -------+                     +----(R5)------B
           +---(R2)---(R3)---+
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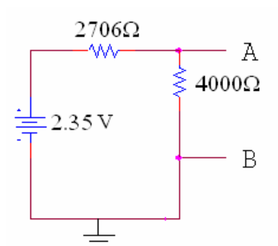
$R23 = 400+2000 = 2400 \quad R234 = (2400*1000)/(2400+1000)=706\ ohms$

$Rth = 706+2000 = 2706\ ohms$

Rth = 2706 ohms

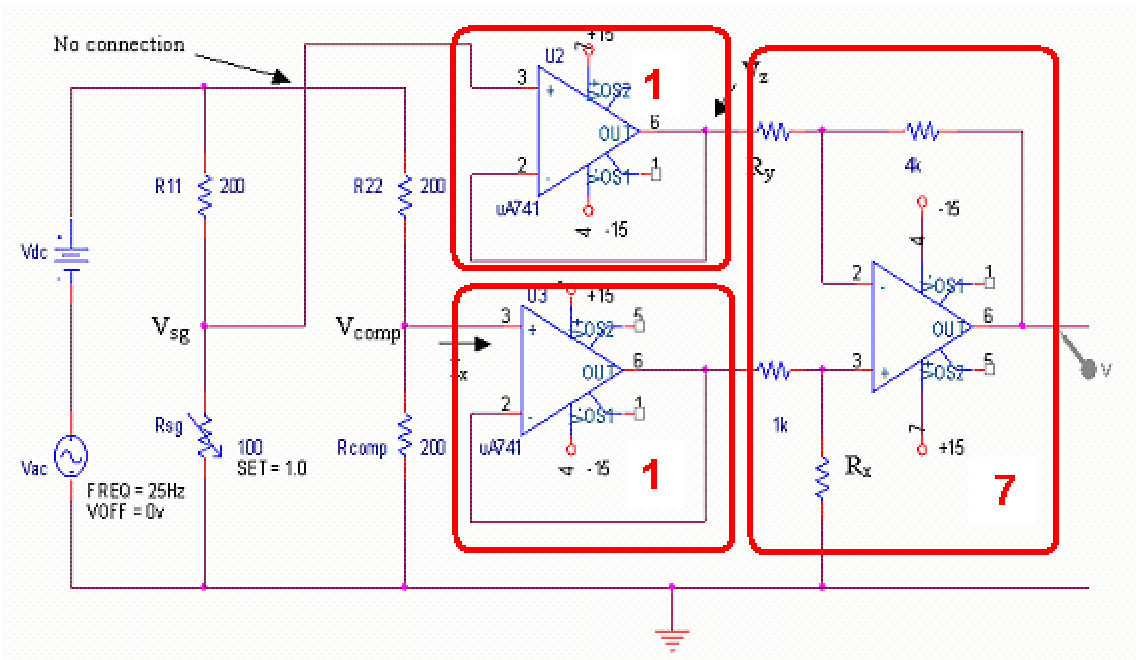
c) Draw the Thevenin equivalent circuit with a load resistor of 4K between points A and B. (3 points)



d) What is the current through the 4K load resistor in the circuit you drew in part c? (2 points)

$I = Vth/(Rth+4k) = 2.35/(2706+4000) = 0.35mA$ ***I = 0.35mA***

Question 3 – Op-Amp Applications (20 points)



For the circuit above, the variable resistor, Rsg, will be equal to 100 ohms when SET=1. The op-amps are ideal. The Vac source creates a sine wave and the Vdc source adds a DC offset to it. When Vac=0, this is equivalent to replacing the Vac source by a short, leaving only the Vdc source as input to the circuit.

a) What is the voltage V_{sg} in the circuit above if Vac=0 and Vdc = 9v? (3 points)

$V_{sg} = 9V(100)/(100+200) = 3V$ **$V_{sg} = 3V$**

b) What is the voltage V_{comp} in the circuit above if Vac=0 and Vdc = 9v? (3 points)

$V_{sg} = 9V(200)/(200+200) = 4.5V$ **$V_{sg} = 4.5V$**

c) With Vdc = 6v and Vac = 0v, and assuming the op-amp is ideal, what is I_x? (3 points)

$I_x = 0mA$

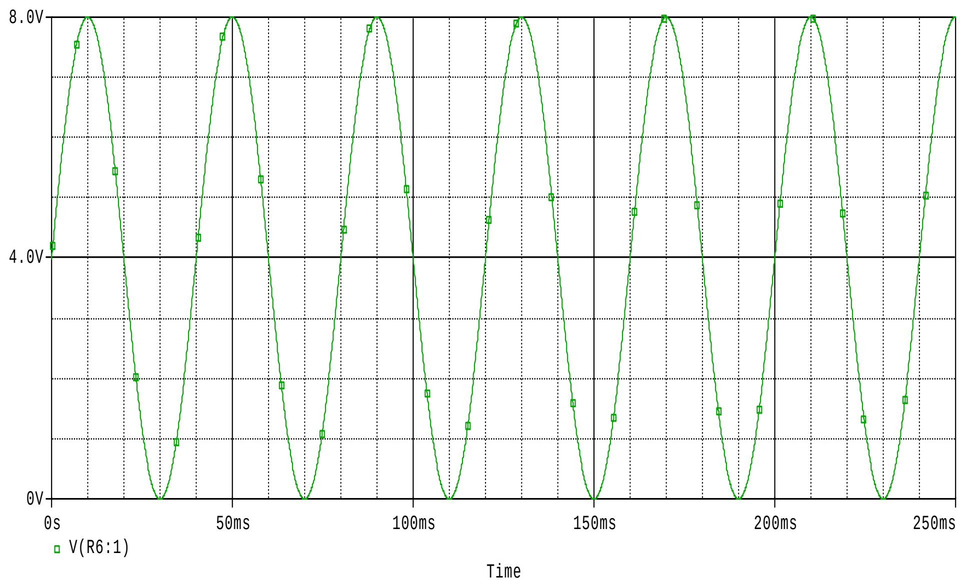
d) What is the voltage V_z if Vdc = 6v and Vac = 0v? (3 points)

Vz = V_{sg} =6V(100)/(100+200) = 2V **Vz = 2V**

e) Circle and label the op amp configurations on the schematic above, choosing from the following types. (Not all are in the circuit and there can be more than one of a single type.) (3 points)

1. Follower/Buffer
2. Inverting Amp
3. Non-inverting Amp
4. Differentiator
5. Integrator
6. Adding (Mixing) Amp
7. Difference (Differential) Amp

f) What values of R_x and R_y would you use to produce the following plot with Vdc = 6v and the amplitude of Vac = 6v, if the probe's output appeared as follows? (5 points)



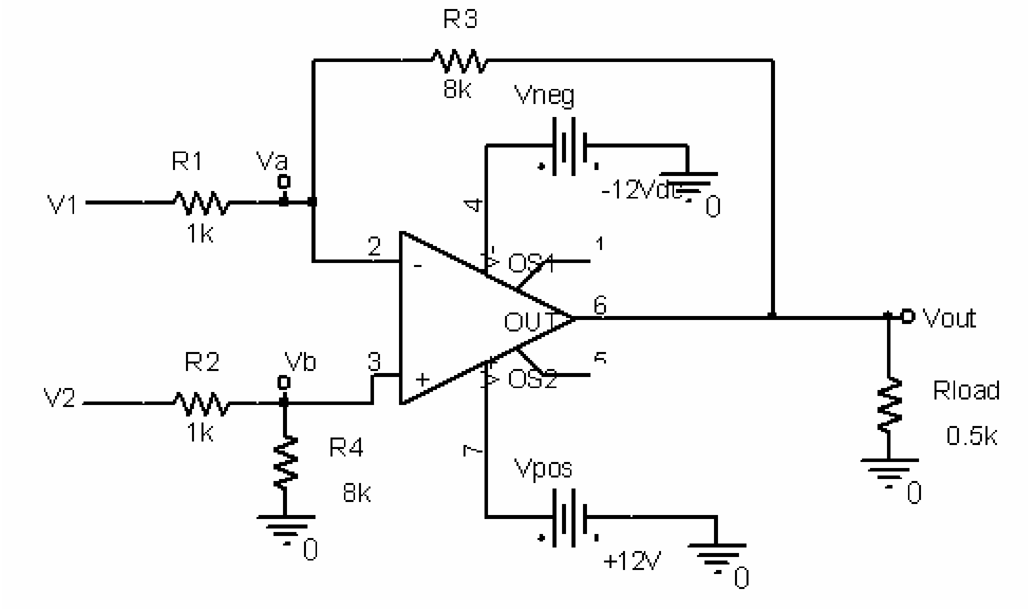
We know that the circuit will operate on the amplitude and the offset in a mutually exclusive manner. We could use either to solve the problem. The input amplitude is 6V and the DC offset is also 6V. They are the same, so we will use 6V as the input. The output amplitude and DC offset are both 4V.

If the circuit with Rx and Ry is actually a functioning differential amplifier, then Rx and Ry can be found easily by looking at the circuit. Ry must match the other input resistor and Rx must match the feedback resistor. This would mean that Rx=4k ohms and Ry=1k ohms. If this is not the case, then we will have to do more work.

Let's check and see if our assumption is correct :
Vout = (Rf/Rin)(Vx-Vz) Vx=6V(200/400) = 3V Vz=6V(100/300)=2V
Vout = (4k/1k)(3V-2V)=4V. This is the Vout that we want. Therefore,

Rx = 4K ohms and Ry = 1k ohms

Question 4 – Op-Amp Analysis (20 points)



Part A: Assume the op-amp is ideal.

1) Above is a Capture schematic of an op-amp circuit that you should recognize. What type of circuit is it? (1 point)

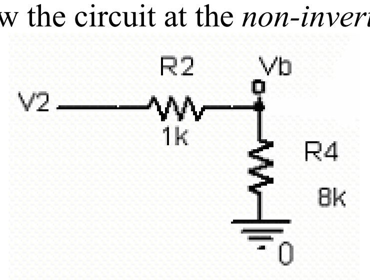
differential amplifier

2) We assume that the op-amp is ideal. What are the two "golden rules" that we then use to analyze the circuit? (2 points)

1) Va = Vb   2) Ia = Ib = 0

(where Ia is the current entering at pin 2 of the op amp and Ib is the current entering at pin 3 of the op amp.)

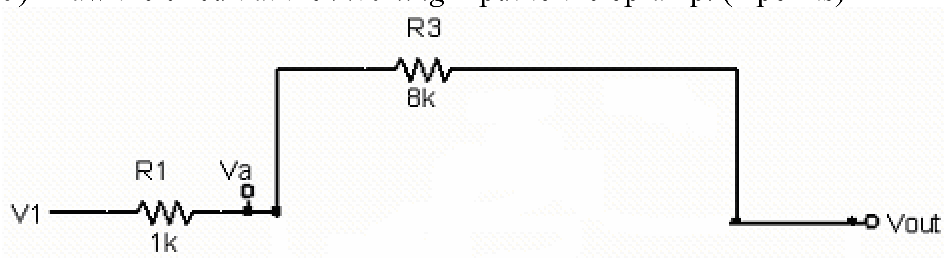
3) Draw the circuit at the *non-inverting* input to the op-amp. (2 points)



4) If V1 = 1.2 V, V2 = 0.5V what is the value of Vb in Volts? (2 points)

Vb =V2(R4)/(R2+R4)= (0.5)(8k)/(1k+8k)=0.444V   ***Vb=0.44V***

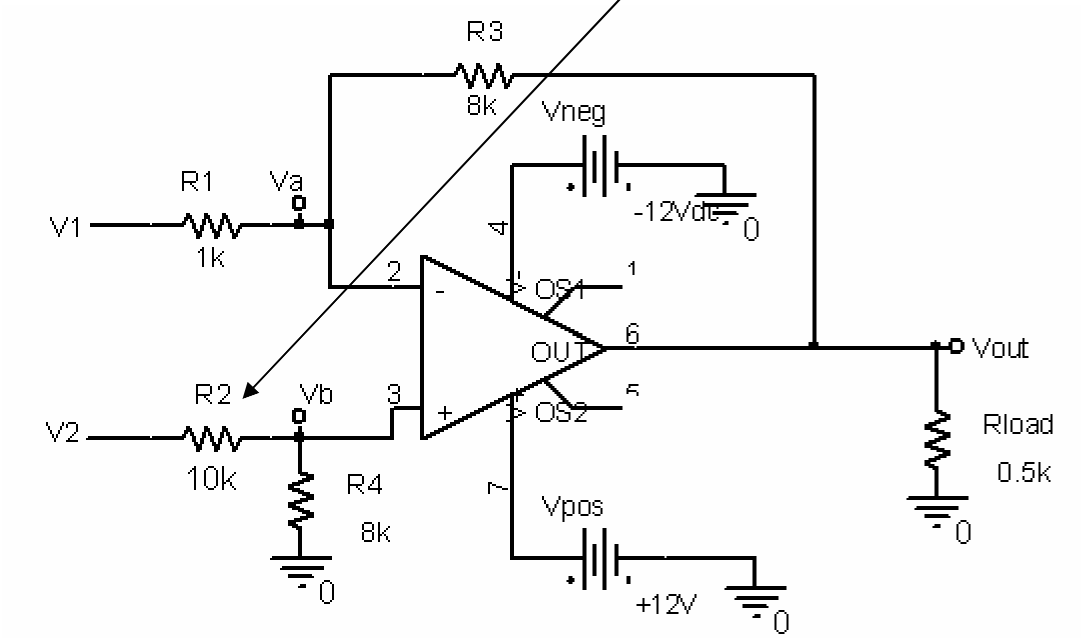
5) Draw the circuit at the *inverting* input to the op-amp. (2 points)



6) Still using V1 = 1.2 V, V2 = 0.5V what is the value of Vout in Volts? Show your work. (3 points)

Vout = (R3/R1)(V2-V1) = (8k)/(1k)(0.5-1.2) = -5.6V ***Vout = -5.6V***

Part B: This is the same circuit except that one of your partners wired this circuit and made a mistake. She/he used a 10kΩ resistor for R2 rather than the 1kΩ value called for in the schematic.



1) Still using V1 = 1.2V, V2 = 0.5V, what is the value of Vb in Volts for the improperly wired circuit? (2 points)

Vb = V2(R4)/(R2+R4) = 0.5(8k)/(8k+10k) = 0.22 V ***Vb = 0.22V***

2) Still assuming the circuit is wired incorrectly as stated in part 1B, and using V1 = 1.2V, V2 = 0.5V what is the value of Va in volts? What is the current through R1, in mA? Assume that the op-amp is ideal. (3 points)

According to the op-amp analysis rules, Va = Vb, therefore

Va = 0.22 V

I_{R1} = (V1-Va)/R1 = (1.2-0.22)/(1k) = 0.98mA

I(through R1) = 0.98mA

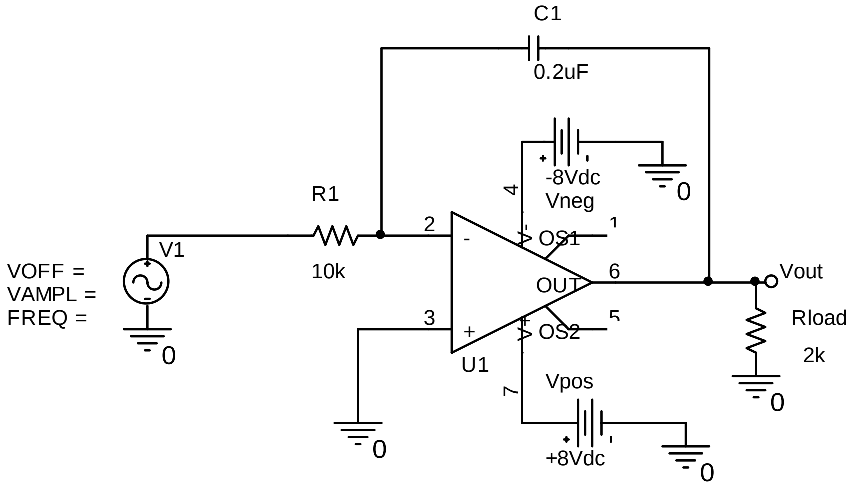
3) Use the results from part B2 and determine Vout for the incorrect circuit, again using V1=1.2V and V2=0.5V. Give Vout in volts. (3 points)

I know that the current through R3 must be the same as the current through R1.

I_{R1} = (Va-Vout)/R3   0.98m = (0.22 – Vout)/8k   7.84 = 0.22-Vout Vout=-7.62V

Vout = -7.62V

Question 5 – Op-Amp Integrators and Differentiators (20 points)



Part A: Assume the op-amp in the circuit above is ideal.

1) Above is a Capture schematic of an op-amp circuit that you should recognize. What type of circuit is it? (1 point)

ideal integrator

2) For this circuit, the input is sinusoidal. What is H(jω), the transfer function for this circuit? H(jω) = **Vout/V1**. You must use the component values, don't leave the answer in terms of R1 or C1. Simplify your answer. (3 points)

$H(j\omega) = -1 / (j\omega RinCf) = -1 / (j\omega(10k)(0.2\mu) = -1 / (j\omega 0.002) = +500j/\omega$

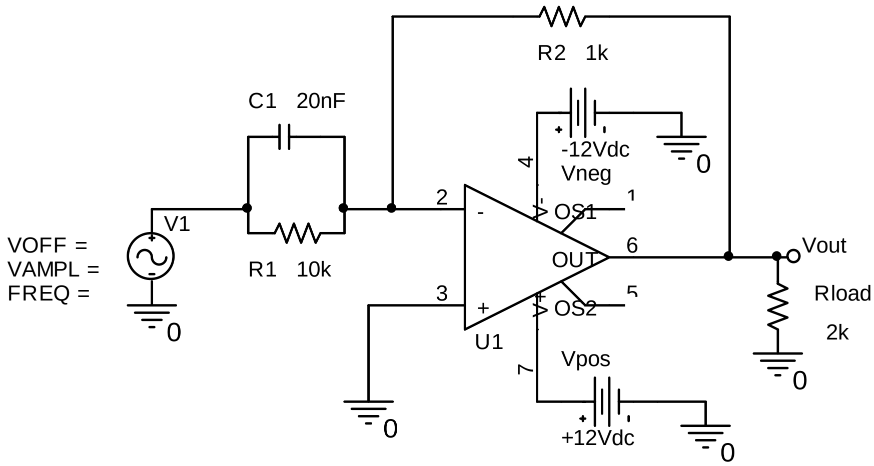
$\mathbf{H(j\omega) = 500j/\omega}$

3) V1 = 2V sin(100t + 0 rad), and Vout is expressed as a sine wave of the form: Vout = $A_{out}\sin(\omega_{out}t + \Phi_{out})$. What are the values for A_{out}, ω_{out}, and Φ_{out}? Include units (6 points)

$\omega_{out} = 100$ rad/sec $|H| = 500/100 = 5$ $\angle H = \pi/2$

$A_{out} = |H| * A_{in} = 5*2V = 10V$ $\Phi_{out} = \angle H + \Phi_{in} = 1.57 + 0 = 1.57$ rad

$\mathbf{A_{out} = 10V}$ $\mathbf{\omega_{out} = 100}$ **rad/sec** $\mathbf{\Phi_{out} = 1.57}$ **rad**



Part B: You are given the circuit pictured above. Assume the op-amp is ideal.

1) Assume that the input is sinusoidal and we want to find H(jω), the transfer function, for this circuit. We know that when the non-inverting terminal of an op-amp circuit is grounded, H(jω) = **-Zf/Zin**. Find Zf. Substitute values for the components. (1 point)

Zf = R2 = 1k ***Zf = 1k***

2) Find Zin. Substitute values for the components. Simplify your answer. (2 points)

$$Zin = \frac{\frac{1}{j\omega C1}\cdot R1}{\frac{1}{j\omega C1}+R1} = \frac{R1}{1+\omega R1C1} = \frac{10k}{1+\omega(10k)(20n)} = \frac{10k}{1+j\omega(0.2m)}$$

$$Zin = \frac{10k}{1+j\omega(0.0002)}$$

3) Using 1) and 2), determine the transfer function, H(jω), for the circuit. Substitute component values. Simplify your answer. (3 points)

$$H(j\omega) = \frac{-Zf}{Zin} = \frac{1k}{10k/1+j\omega(0.0002)} = \frac{1k}{10k}\left(1+j\omega(0.0002)\right)$$

$$H(j\omega) = -0.1 - j\omega(0.02m) = -0.1 - j\omega(0.00002)$$

4) At high frequency, this circuit acts like a ***differentiator***
Fill in the blank using one of the following: a) Inverting Amplifier, b) Non-inverting Amplifier, c) Differential Amplifier, d) Adder, e) Integrator, f) Differentiator, g) none of a thru e. (2 points)

*We also accepted "**none of a through e**" because although the circuit is differentiating at high frequencies, the transfer function approaches infinity. It won't be a useful differentiator.*

5) Now assume that Vin is a 0.1V DC source. What is Vout? (2 points)

$$H(j\omega) = -0.1 - j\omega(0.00002)$$

DC input is zero frequency. The transfer function at zero frequency (ω approaches zero) is H(jω) = -0.1. The phase is π, so the signal is inverted.

*Aout = |H| * Vin |H| = 0.1 Vin = 0.1 Aout = (0.1)(0.1) = 0.01*

The signal is inverted, so Vout = - 0.01V

A simpler way to find the answer, is to realize that the capacitor behaves like an open circuit at low frequency. The circuit turns into an inverting amplifier.

Vout = -R2/R1(Vin) = -(1k)/(10k)(0.1) = -0.01V

Vout = -0.01V