ENGR-2300

Electronic Instrumentation

Quiz 2

Fall 2015

Name Sola.

Section ___

Question I (20 points) __________

Question II (20 points) __________

Question III (20 points) __________

Question IV (20 points) __________

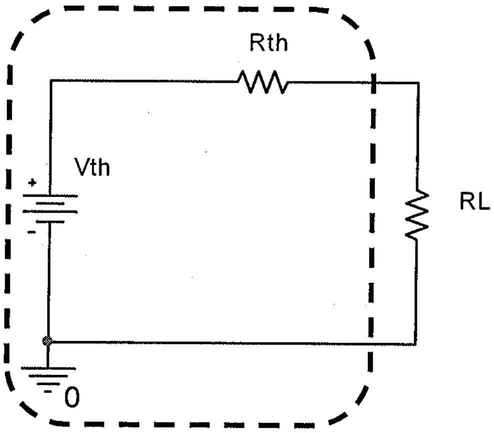
Question V (20 points) __________

Total (100 points) __________

On all questions: SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS. No credit will be given for numbers that appear without justification. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order.

Soln

I. Thevenin Equivalent Voltage Source

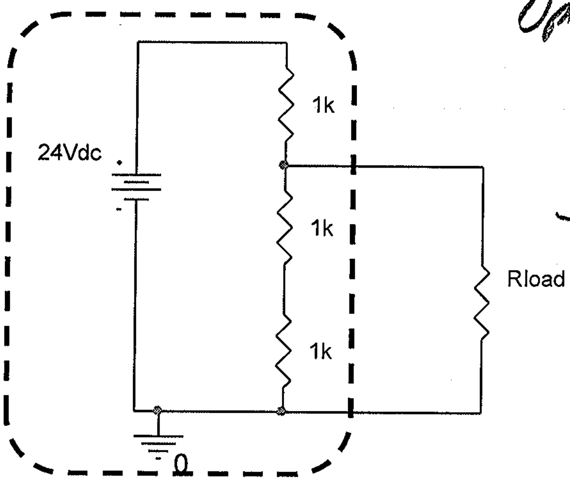


The Thevenin equivalent circuit consists of a voltage source in series with a resistor, which provides a very simple replacement for much more complex circuits. If we have this simple source, analyzing changing loads becomes quite easy.

16V 0.67kΩ

In this problem, you are to find the Thevenin voltage and resistance for various circuits. ***Hint:*** It is often useful to calculate the open circuit voltage (the voltage ~~across RL if RL=∞~~) and the short circuit current (the current in RL if RL=0).

Circuit 1: {4 pts} Find and sketch the Thevenin Equivalent Voltage source for the circuit inside the dashed line.



Open Ckt. $V_{oc} = \frac{2}{3} \cdot 24 = 16V$

$V_{oc} = V_{Th} = 16V$

R_{Th} → set 24V source to 0V

$R_{Th} = 1k \parallel 2k = 0.67k\Omega$

OR I_{sc}

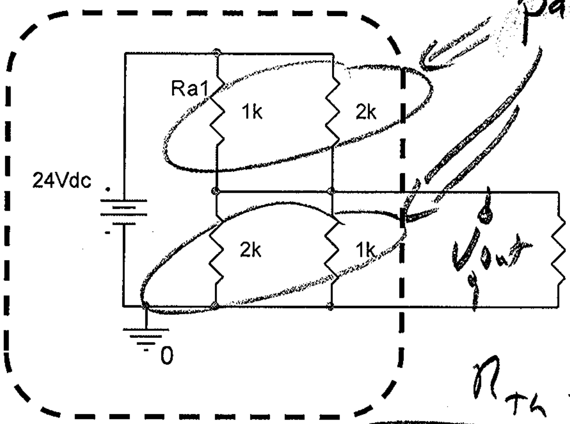
$I_{sc} = \frac{24}{1k} = 24mA = I_{Norton}$

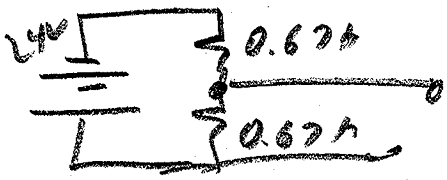
$R_{Th} = \frac{V_{Th}}{I_{sc}} = \frac{16V}{24mA} = 0.667\Omega$

Soln

Circuit 2, part a: {4 pts} Find and sketch the Thevenin Equivalent Voltage source for the circuit inside the dashed line.

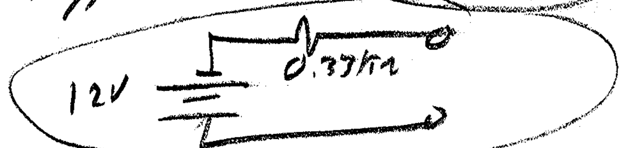
parallel $1k // 2k \Rightarrow 0.67k$



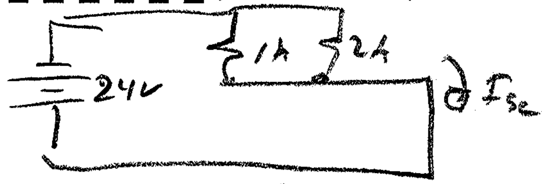


$V_{TH} = V_{open\ circuit} = \left(\frac{1}{2}\right)(24) = 12V$

$R_{TH} = 0.67k // 0.67k = 0.33\,k\Omega$



(OR) I_{sc}

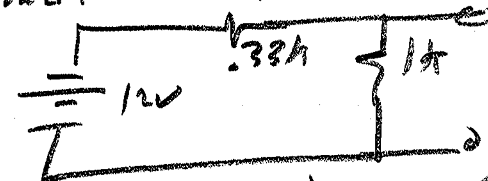


$I_{sc} = \frac{24}{1} + \frac{24}{2} = 36mA$ $R_{TH} = \frac{V_{OC}}{I_{sc}} = \frac{12}{36mA} = 0.33k\Omega$

Circuit 2, part b: {6 pts} For this part, **Rload1=1kΩ**. Find the following:

- Vout, the voltage across Rload1:
- I_{Ra1} the current through Ra1:
- The total power provided by the 24Vdc source:

Rload1 = 1k find Vout



$V_{out} = \frac{1}{1+0.33} \cdot 12 = 9V$

→ Now go back to original ckt

← know this is 9V

$I_{Ra1} = \frac{24-9}{1k} = 15mA$

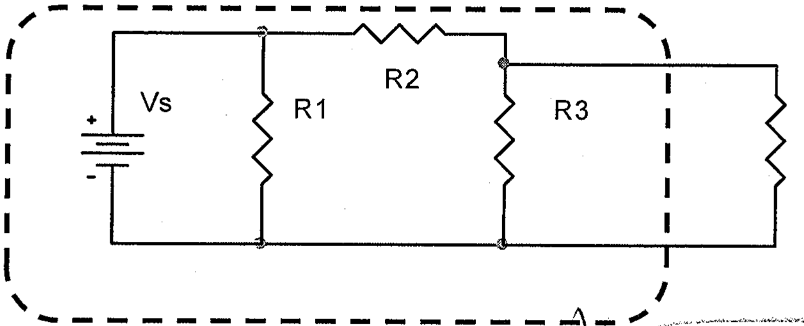
$P = V \cdot I$ $I = I_{R1} + I_{2k}$ ← $I_{2k} = \frac{24-9}{2k} = 7.5mA$

$I = 22.5mA$

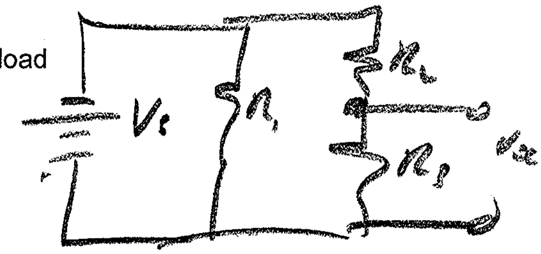
$P = (24V)(22.5mA) = 0.54$ Watts or 540 mW

Soln

Circuit 3: {6 pts} Find and sketch the Thevenin Voltage source for the part of the circuit inside the enlarged dashed line. (V_{Th} and R_{Th} must be given in terms of Vs, R1, R2, and R3.) If stuck: the hint at the beginning of this problem may be useful.

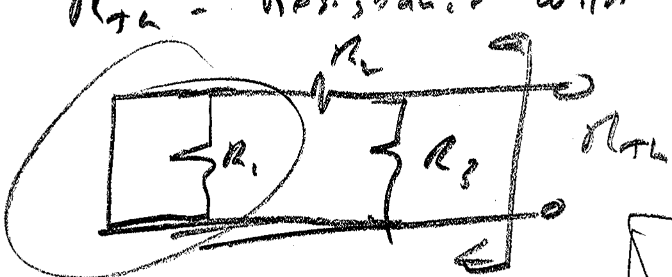


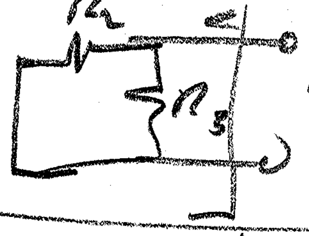
$V_{oc} = V_{Th}$



$$V_{oc} = \frac{R_3}{R_2+R_3} \cdot V_s = V_{Th}$$

R_{Th} = Resistance with source turned off $V_s = 0$

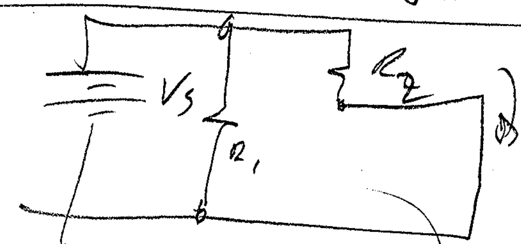




$R_1 // 0 = 0$

$$R_{Th} = R_2 // R_3$$

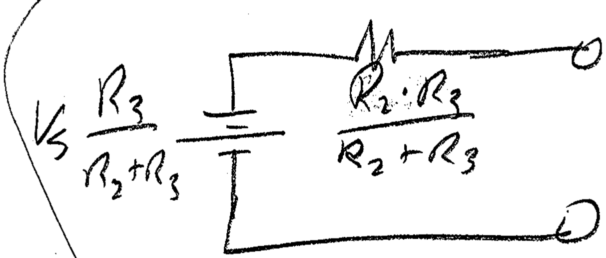
OR I_{sc} ⇒



$I_{sc} = V_s / R_2$

$$R_{Th} = \frac{V_{Th}}{I_{sc}} = \frac{(R_3/(R_2+R_3))V_s}{V_s/R_2}$$

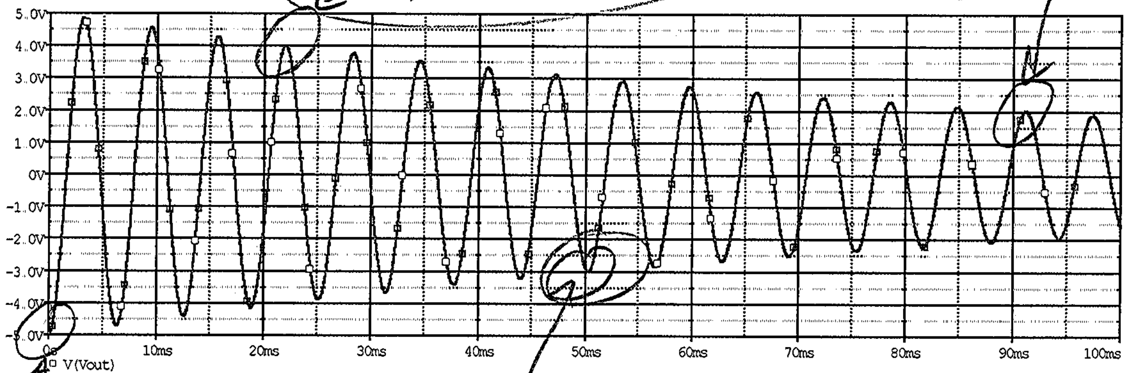
$$R_{Th} = \frac{R_2 \cdot R_3}{R_2+R_3} = R_2//R_3$$



Soln

II. Harmonic Oscillators and Math

4V, t = 22 ms ⟷ 2V, t = +92 ms also works



−5, t = 0   −3, t = 50 ms

The horizontal scale is time (5ms per small division) and the vertical scale is voltage (0.5V per small division). The horizontal scale is from 0s to 100ms. The vertical scale is from -5V to 5V.

a. Find the decay constant α and the angular frequency ω for this data. **You must mark the data points on the plot that you use for your answer.** {4 pts}

Pick any 2 pts

$V_1 = V_0 e^{-\alpha(t_1 - t_0)}$

$\ln \frac{V_1}{V_0} = -\alpha(t_1 - t_0)$

$\ln \frac{-3}{-5} = -\alpha(0.05 - 0)$

$\alpha = 10\ sec^{-1}$ (10.2)

8 cycles in 50 ms $\frac{8}{.05} = 160\ Hz$ $\omega = 2\pi f = 1000$ radians/sec

b. Write the mathematical expression for the voltage in one of the forms $V(t) = Ae^{-\alpha t}\cos\omega t$ or $V(t) = Ae^{-\alpha t}\sin\omega t$, depending on which form fits the data better. Use real values for the constants and provide units where appropriate. {4 pts}

peaks at −5 at t = 0, so use cos ωt

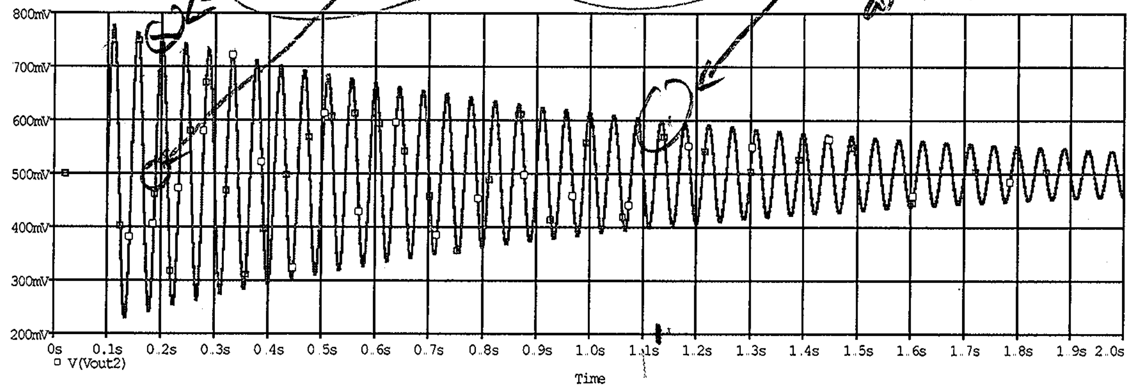
$V(t) = -5e^{-10t}\cos(1000t)$

c. Assume the data used for parts a. and b. are from a stain gauge with an amplifier, as it was for Experiment 5 and Project 2. In this case the ***strain gauge bridge sensitivity is 50mV/cm and the gain of the amplifier is 100***. Write the mathematical expression for the displacement the beam, write it as x(t) = ___ (Note: the gain of this system is different than that of your experiments.) {2pts}

50 mV/cm · 100 = 5V/cm

$x(t) = \frac{V(t)}{5} = -1e^{-10t}\cos(1000t)\ cm$

Soln



d. The plot shown above represents data taken from the accelerometer on a beam after it has been integrated by an op-amp circuit. Note that there is a dc offset, typical of integration. Find the decay constant α and the angular frequency ω for this data. **You must mark the data points on the plot that you use for your answer.**{4 pts}

Same method but must subtract offset.

$V_0 = 250mV$, $V_1 = 100mV$

$t_0 = 0.2 sec$, $t_1 = 1.13 sec$

21 cycles

$\alpha = \frac{-\ln(V_1/V_0)}{t_1 - t_0}$ } Part a

$\alpha = 0.99$ or $\alpha = 1$

$f = \frac{21}{1.13 - 0.2} = 22.6 Hz$ $\omega = 2\pi f = 142 rad/sec = 142 sec^{-1}$

e. You used a strain gauge to measure displacement of a beam. The measured voltage is found to fit: $V(t) = 0.1e^{-0.5t}\sin 100t\ Volts$ Your partner calibrated the total system and told you that displacing the tip of the beam by 1cm resulted in a 50mV signal.

1) Write an expression for the displacement of the beam as a function of time, using your data. As with all problems, include units{1pt}

$x(t) = v(t) \cdot \frac{1cm}{0.05V} = 2e^{-0.5t} \sin 100t\ cm$

2) Estimate the velocity of the tip of the beam as a function of time, using your result above. Keep only the largest terms. Include units {5pts}

$v(t) = \frac{d}{dt} x(t) = (2e^{-0.5t})(+100 \cos 100t) + (2)(-0.5)e^{-0.5t} \sin 100t$ Drop

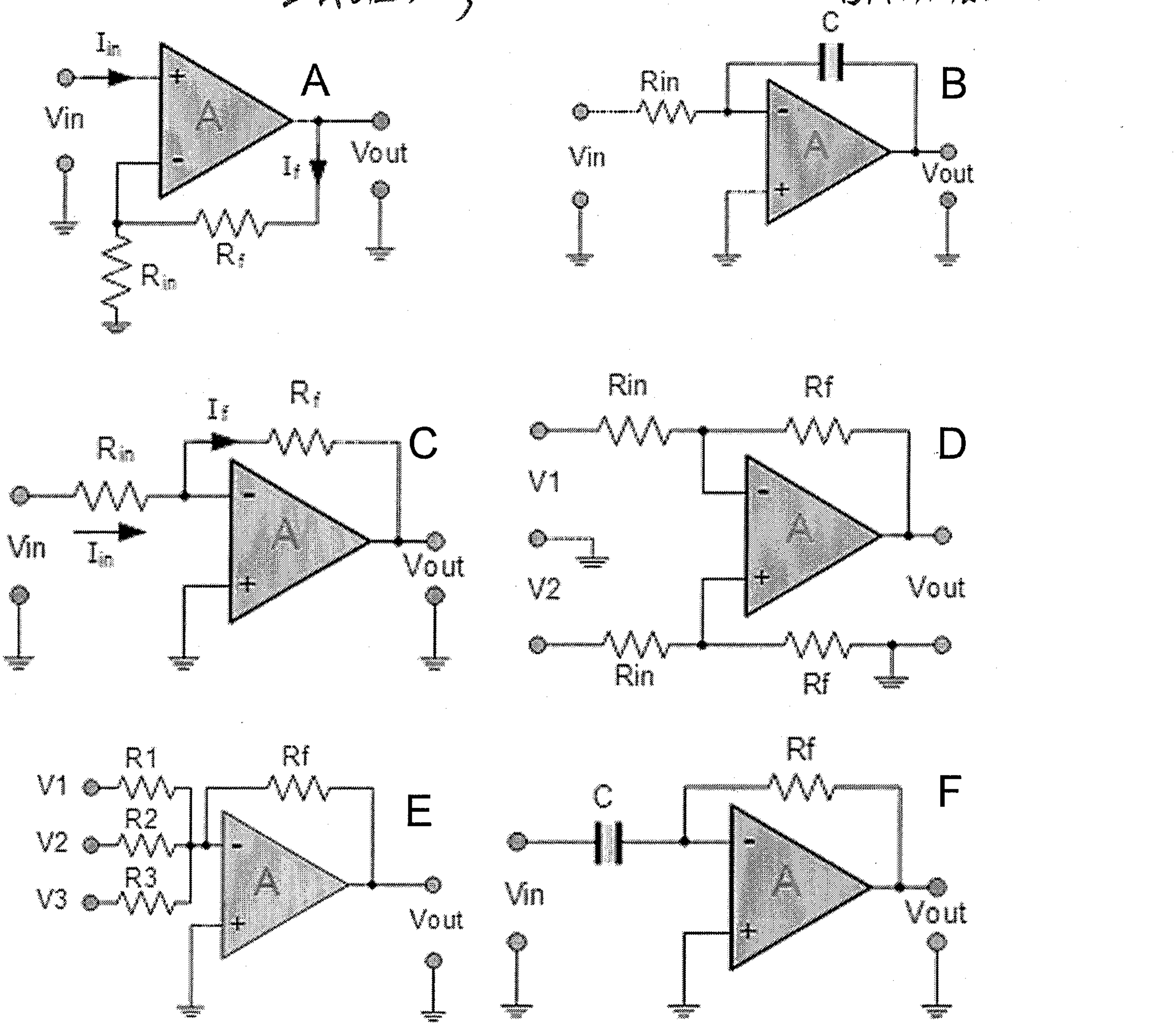
$v(t) \cong 200 e^{-0.5t} \cos 100t\ cm/sec$

Soln

III. Operational Amplifier Applications

a. {3 pts} What type of amplifier is each circuit?

i. A Non-Invertin
ii. B Integrator
iii. C Inverting
iv. D Differential Amp
v. E Adder or Summer
vi. F Differentiator



For the next four parts to this question, you will be asked questions about one or more of these standard configurations.

Soln

b. Circuit D is used with a strain gauge bridge as was done for Experiment 5 and Project 2. There is a circuit diagram for the strain gauge bridge on the Crib Sheet provided.

1. The desired output for circuit D is to be 50 times the Vout of the Strain Gauge Bridge. Your partner has already chosen to use 1k resistors for Rin of circuit D, what is the correct value for Rf? {2pts} $V_{out} = \frac{R_f}{R_{in}} \cdot (V_2 - V_1)$ $\frac{R_f}{R_{in}} = 50$

$R_f = 50 R_{in} = 50k\Omega$

2. Again using the Strain Gauge Bridge circuit on the crib sheet and using circuit D as configured in this problem, Vleft of the bridge is wired to V1 of circuit D and Vright is wired to V2. For the strain gauge bridge on the crib sheet, R1, R2 and R3 are all 200Ω and Rg is 198Ω and Vin=10V, what would be the voltage of output of circuit D? {2pts}

$V_{out}(Bridge) = 10\left(\frac{200}{200+200} - \frac{198}{200+198}\right) = 25mV$

V_{out} of Ckt D $= 50 \cdot V_{out}(Bridge) = 1.26V$ or $1.25V$ or $1.3V$

3. One of the TAs states that if you have completed parts 1) and 2) of this problem as requested, and used the given formulas, then your answer to part 2 is wrong. Is the TA correct? And if so where did we go wrong? Give a brief statement, we don't need a derivation. (Hint: The TAs are usually correct and it just might have something to do with loading effects. Don't redo part 2.) {2pts}

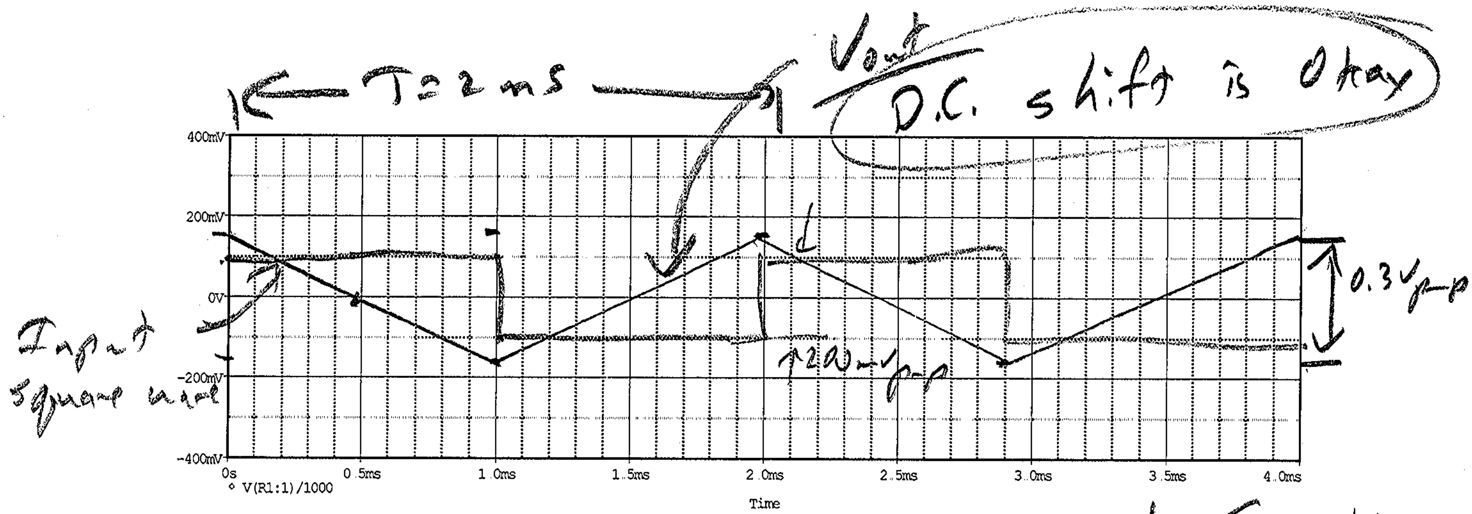
TA is correct, Op-Amp ckt will load the Bridge ckt., Vout of bridge won't match that of the crib sheet

4. Extra credit: Assuming you agree that there is an error in the answer in part 2 above, how would this have changed your analysis for Exp 5 and/or Project 2? {2pts}

Not a problem. Your calibration was a direct measure of Vout of the diff amp vs beam position. Any loading was included in the measurement.

Soln

c. For circuit B: The input is a 500Hz square wave voltage with a 200mV peak to peak amplitude. Sketch the input signal on the graph below. Solve for and sketch the output voltage for circuit B with Rin=1kΩ and C=0.33μF. A second scale can be added to the plot if needed to display the output waveform. {6pts}



B is integrator with $V_0(t) = -\frac{1}{RC}\int V_{in}\,dt$

$RC = (10^3)(0.33\times10^{-6}) = 0.33\times10^{-3}$

$\frac{1}{RC} = 3030$

When input = 100mV $v(t) = (-3030)(0.1)t$

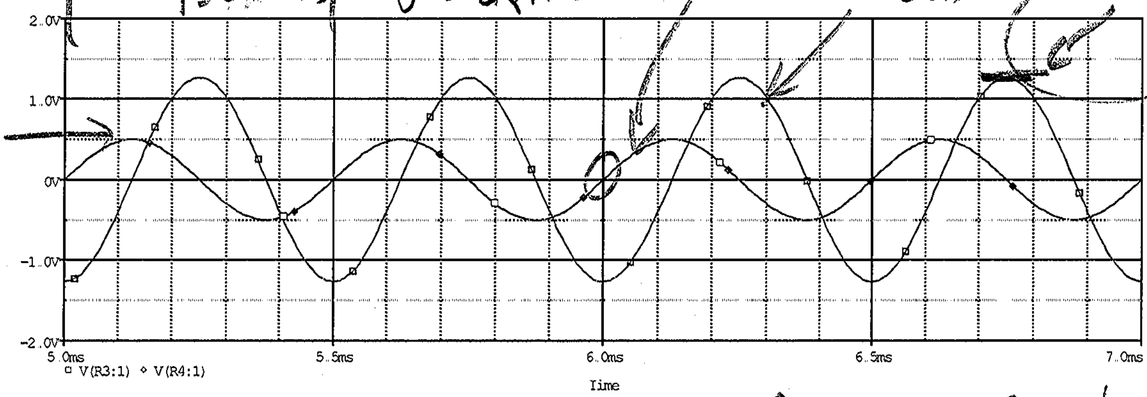
in 1ms, $v(t)$ changes by $(-3030)(0.1)10^{-3}$

$-0.3V$

Soln.

d. {5 pts} Figure F is the circuit used for this problem with Rf=1000kΩ (1kΩ) Below are traces of Vin and Vout. Determine and label which trace is which on the plot. Calculate the value of the capacitor, C in Figure F, that matches this result.

T=0.5mS, f = 2kHz



Differentiator, pick a reference point
I pick 6ms
small amp trace looks like sin
larger trace looks like -cos

try assuming sin wave input.

$V_{out} = -R_f C \frac{d(A\sin\omega t)}{dt} = -R_f C \omega A \cos \omega t$

sin — small trace input

− cos — larger trace output

$A = 0.5$, $\omega = 2\pi f = 2\pi \cdot 2000 = 1.26 \times 10^4$ sec^{-1}

Amp of $V_{out} = 1.3V$ $R_f C \omega A \cong 1.3V$

$(1000K C)(1.26 \times 10^4)(0.5) \cong 1.3V$

$C = 0.2 \mu F$

$0 - 0.21 \mu F$

Soln

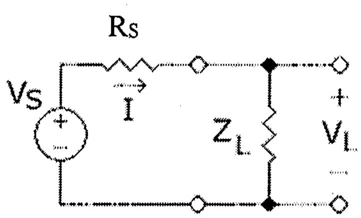
IV. Operational Amplifier and Circuit Fundamentals

a. {4 pts} **The Inverting and Non-Inverting Amp** configurations are different. One way in which they are different is the effective input resistance. Look at both configurations on the crib sheet.
What is the effective input resistance for each configuration? By effective resistance, simple determine the amount of input current that would occur for a given Vin. R is simply the ratio Vin/Iin. Use the resistor labels as given on the crib sheet and assume the op-amps are ideal.

Inverting —W— (R_{in}) or Input Resistance = R_{in}

Non-Inverting ($i = 0$) No Current Input Resistance = ∞

b. {4 pts} **Finding Input Impedances Z_{in}** One of the early experiments you did was to find the impedance of the Analog Discovery board. The same experiment can be used to measure the input impedance of an op-amp circuit. What was done with the Analog Discovery was to connect a known voltage source (with known voltage and resistance) to the unknown resistance (Discovery or op-amp circuit), in the experiment it was channel 1 of the Analog Discovery.



This forms a voltage divider. In the circuit at the above, assume we know Vs and Rs and are able to measure V_L. From the known quantities V_S, R_S, and V_L, write an equation to find the value of $Z_L = f(V_S, R_S, V_L) = ?$
(Note #1: for this case Z_L can be replaced with R_L. For AC steady state it is important to know effective input resistance and capacitance, in that case the impedance is complex and one must use Z. This is true for high frequency signals connected to the Analog Discovery or op-amp circuits.)

$$V_L = \frac{Z_L}{Z_L + R_S} \cdot V_S$$

$$V_L \cdot Z_L + V_L R_S = Z_L \cdot V_S$$

$$Z_L (V_S - V_L) = V_L R_S$$

$$Z_L = \frac{V_L R_S}{V_S - V_L}$$

OR

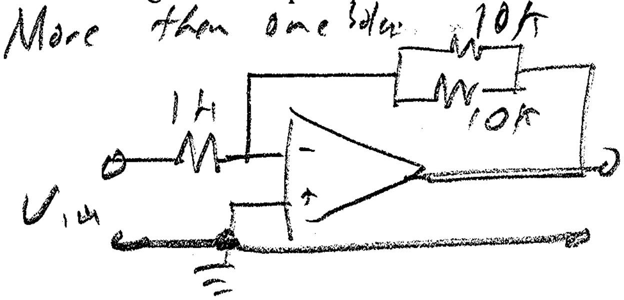
$$R_L = \frac{V_L R_S}{V_S - V_L}$$

53/2

c. **Inverting and Non-Inverting Amps** You only have 1kΩ and 10kΩ resistors available, 10 of each.

i. {4pts}Draw an op-amp circuit that has a transfer function of -5, Vout/Vin=-5, using an ideal op-amp and available resistors. Be sure to label Vin and Vout.

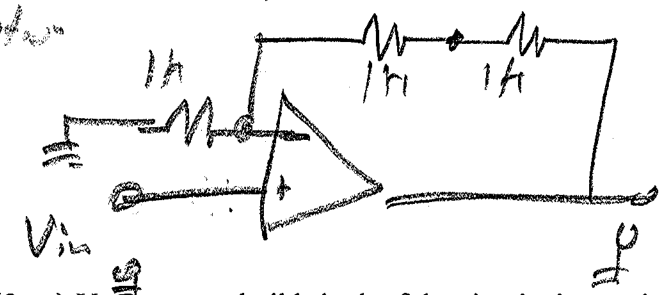
More than one idea



$V_{out} = -\frac{R_f}{R_1} V_{in} = \frac{-5V_{in}}{1} = -5V_{in}$

ii. {4pts}Again only using 1kΩ and 10kΩ resistors, draw a op-amp circuit with a transfer function of +3, Vout/Vin=3.

One option



$V_{out} = V_{in}\left(\frac{2k}{1k} + 1\right) = 3V_{in}$

iii. {2pts} Your partner builds both of the circuits in part i. and ii. above. She/he uses 9V batteries to power the op-amps, and claims that each circuit only works if the magnitude of Vin is less than specific values. What are those values for both circuits above, (this means 2 answers.)

Vout saturates at V_{batt} for part i) $|V_{in}| = \frac{9}{5} = 1.8V$

$|V_{in}| < 1.8V$

Part ii) $|V_{in}| = \frac{9}{3}$ $|V_{in}| < 3V$

d. {2 pts} Power sources: Professors Connor and Schoch disagree on how best to power the op-amps used in EI. Prof. Connor says that the 9V batteries are best. Prof. Schoch is suggesting that the +5V and -5V outputs on the Analog discovery are best. Who do you feel is correct and why.

Connor
- Can use Higher voltages
- has greater current capability

Schoch
- Don't need to buy batteries

~~Both~~ Either answer is correct

Soln.

V. **Concepts, Troubleshooting and Data Analysis**

a. **Resistor Color Code** {6 pts} Today's date is 10-28-2015. Because the date consists of three numbers, how would you represent each number with the resistor color code, if indeed it can be done? If it can be, give the color code. If it cannot be, cross out the number.

i. 10 Brown, Black, Black

ii. 28 Red, Gray, Black

iii. ~~2015~~

b. **Classroom Knowledge** {2pts} True or False

i. Resistors needed for the experiments were provided in the bag of parts handed out at the beginning of the semester. False – bins on table

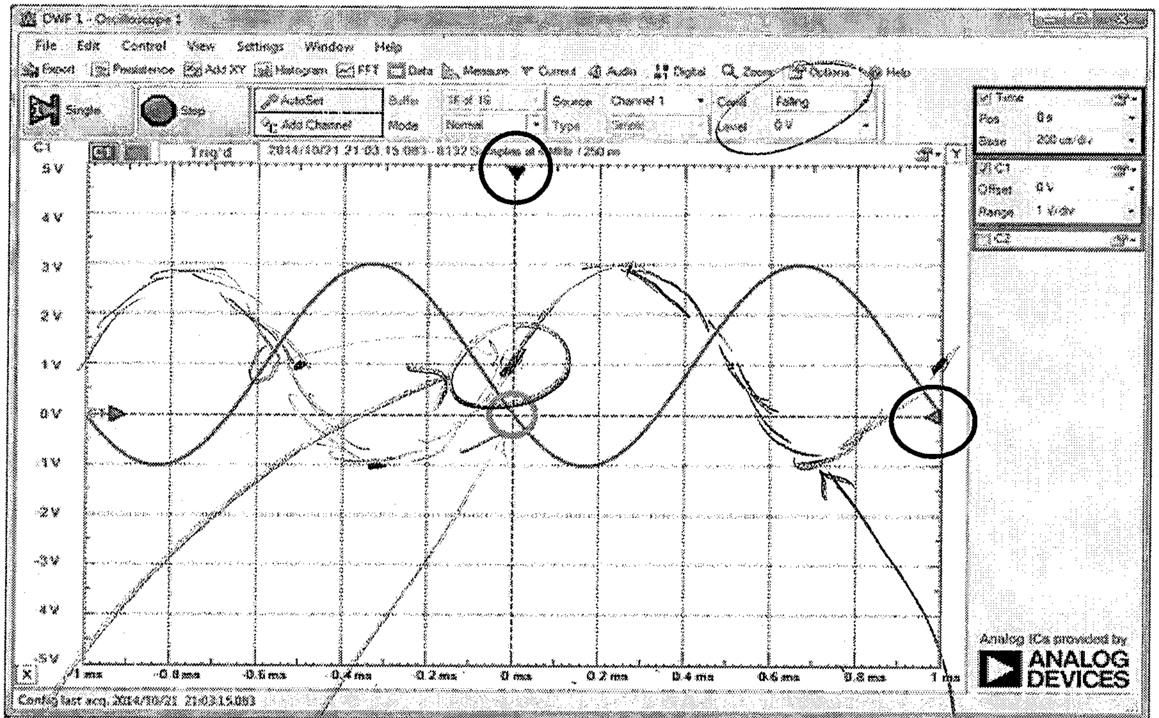
ii. There is no reasonable need to ever calibrate the Analog Discovery board. False ⇒ otherwise DC offsets and gain errors

c. **Experiment and Project Tasks** {2 pts} True or false?

- Before beginning a lab, at least one team member must read over and be generally acquainted with the experiment or project write-up and the other **required reading** materials listed on the EILinks page. True
- Before beginning a lab, hand-drawn circuit diagrams must be prepared for all circuits either to be analyzed using PSpice or physically built and characterized using your Analog Discovery board. True

Soln.

d. **Triggering** {4 pts} Shown below is an example Analog Discovery Oscilloscope display showing a sinusoidal voltage signal. The vertical scale is 1V/div and the horizontal scale is 0.2ms/div. Analog Discovery shows the trigger voltage level and time with solid triangles at the right side and top of the scope window, respectively. Both of the triangles are circled to make them easier to find. The triggering for this particular display is set to occur when the signal level is falling. Redraw the signal as it will be observed if the triggering is **changed to a trigger level of 1V and rising**. Please draw neatly and explain your answer.



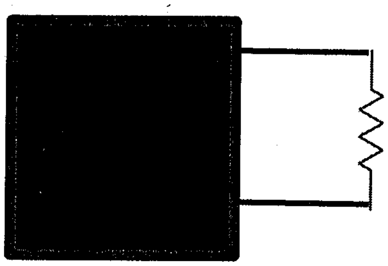
Clearly falling & trigger at 0V

at 0ms, signal at 1V rising

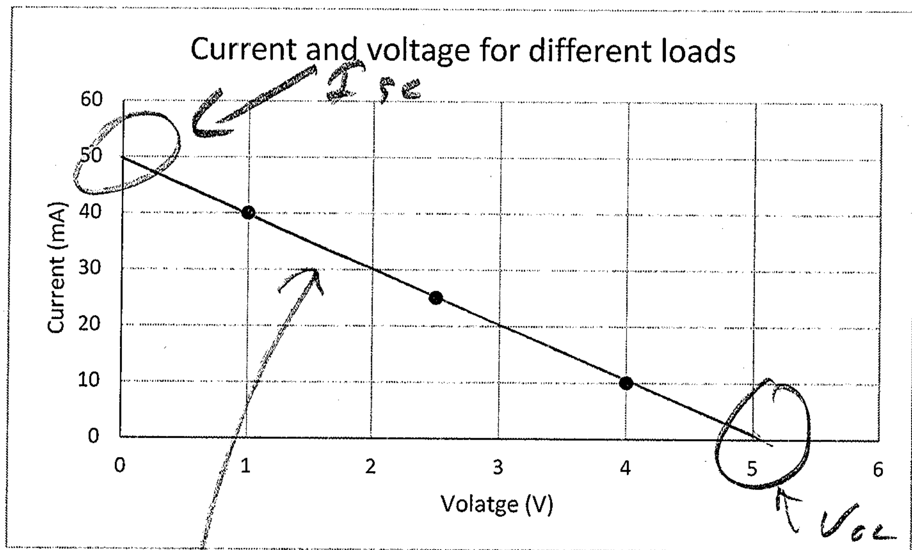
Same amplitude
Same frequency
V_{max} is same
V_{min} is same

Soln.

e. **Black Box Circuit** {6 pts} There is a circuit in a black box that produces an output voltage when turned on. We expect that it can be represented by a Thevenin Equivalent source with voltage V_{th} and resistance R_{th}. To test it out, different load resistors were connected to the box. In this case it was possible to measure both the voltage across the load resistor and the current through that resistor. The data is plotted.



Data collected:



i. It appears that a straight line fits this data, draw a straight line through the data points.{1pt}

ii. What is V_{oc} the open circuit voltage? {2pt} $\Rightarrow V_{oc}$, $I = 0$

$V_{oc} = 5V$

iii. What is I_{sc} the short circuit current? {2pt} $I_{sc} \Rightarrow V = 0$

$I_{sc} = 50mA$

iv. Determine the values for V_{th} and R_{th}. {1pt}

$V_{Th} = V_{oc} = 5V$ $R_{th} = \frac{V_{oc}}{I_{sc}} = \frac{5}{0.05} = 100\Omega$