ENGR-2300

Electronic Instrumentation

Quiz 2

Fall 2016

Name Soln

Section ___

SOLN

Question I (20 points) ________

Question II (20 points) ________

Question III (20 points) ________

Question IV (20 points) ________

LMS Question is worth an additional 20pts

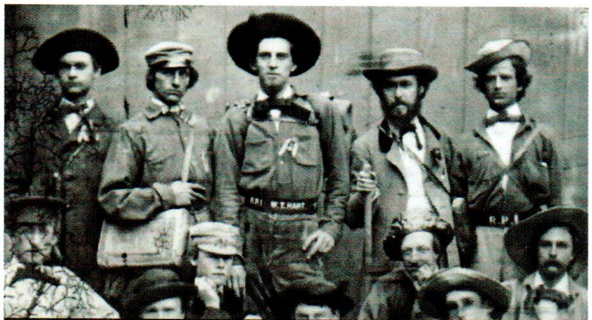
Total (80 points) ________

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.

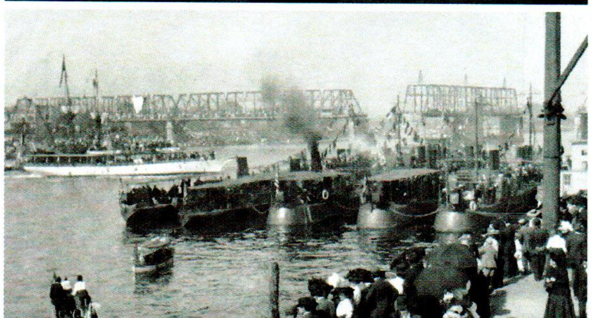
Today in History Soln

Events:

- 1774 – The First Continental Congress adjourned in Philadelphia
- 1825 – The Erie Canal opened

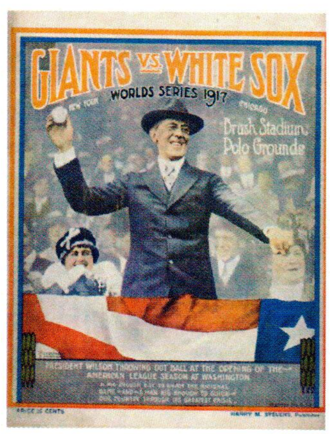


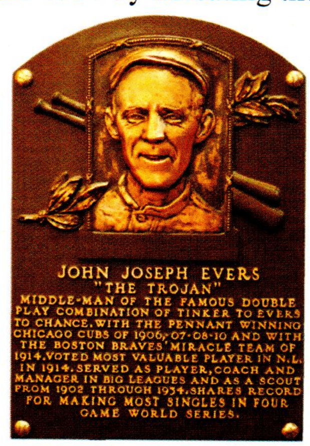
RPI engineering students have a long history of surveying major projects across the world, including the enlargements to the Erie Canal and the Panama Canal. Famous RPI graduates were Washington Roebling, who completed his father's design for the Brooklyn Bridge, George Washington Gale Ferris, who designed the Ferris Wheel that was first used at the Chicago Worlds Fair in 1893, and Garnett Douglas Baltimore, first African American graduate who designed Troy's Prospect Park



Flotilla of Ships. Hudson Fulton Celebration, Troy, NY. 1909. The ceremonies commemorated Henry Hudson's 1609 discovery of the Hudson River and Robert Fulton's invention of the first steamboat, were some of the largest celebrations in New York State. On October 9, 1909 a flotilla of ships sailed up the Hudson River to Troy passing thousands of cheering Trojans lining the shores between Broadway and Ferry Streets.

- 1881 – The Gunfight at the OK Corral
- 1962 – American UN Ambassador Adlai Stevenson asked his Soviet counterpart during a Security Council debate if the USSR has placed missiles in Cuba
- 2005 – The Chicago White Sox won their first World Series since 1917 by defeating the Houston Astros 1-0 in game 4



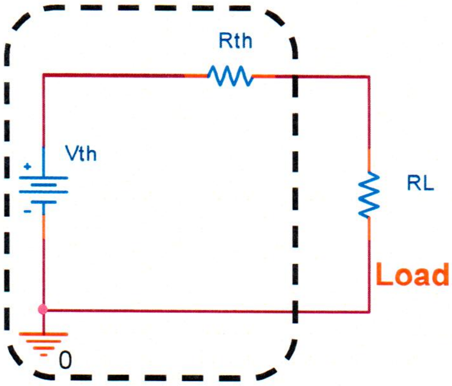


Births:

- 1911 – Mahalia Jackson
- 1919 – Edward W. Brooke
- 1947 – Hillary Clinton
- 1962 – Cary Elwes
- 1973 – Seth MacFarlane
- 1984 – Sasha Cohen

Solu.

1. Thevenin Equivalent And Circuit Concepts



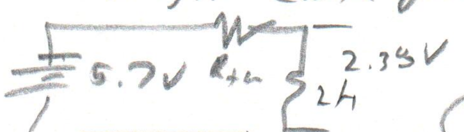
The Thevenin Equivalent Circuit consists of a voltage source in series with a resistor, which provides a very simple replacement for much more complex circuits. If we have this simple source, analyzing changing loads becomes quite easy.

a) (4pts) For an unknown circuit, the voltage across RL was measured for different values of RL. The results are displayed in the table. Find and sketch the Thevenin Equivalent Circuit, determine Vth to the nearest 0.1V and Rth to the nearest 0.1kΩ

RL	Vload
0.5kΩ	0.86
2kΩ	2.38
10kΩ	4.45
500kΩ	5.67
1MegΩ	5.68

Method 1: V_{load} ~ constant for 500k & 1Meg so assume $V_{open\ circuit} \approx 5.68$, $\boxed{\text{use } 5.7}$

$V_{th} = V_{open\ circuit} = 5.7$, then use a single data point.



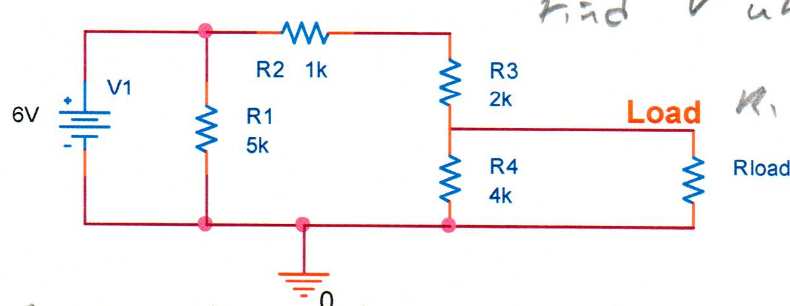
$2.38V = 5.7\left(\frac{2k}{2k + R_{th}}\right)$

$R_{th} = 2.8k$

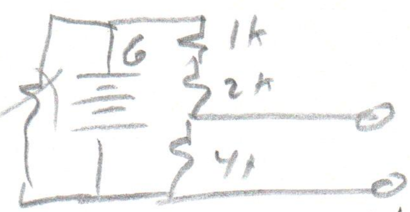
Method 2: Solve using any 2 points, 2 equations, 2 unknowns

$0.86 = V_{th}\left(\frac{0.5k}{0.5k + R_{th}}\right)$ & $4.45 = V_{th}\left(\frac{10k}{10k + R_{th}}\right)$

b) {6 pts} Find and sketch the Thevenin Equivalent Circuit for the following circuit.



Find V when $R_{load} \Rightarrow \infty$

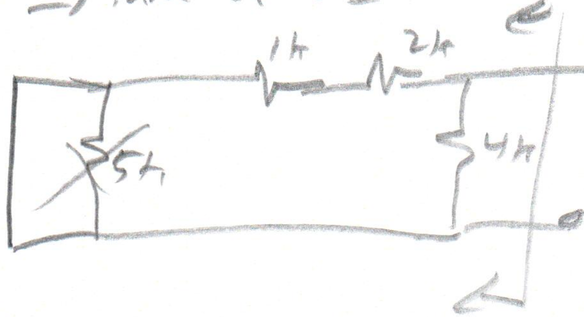


$V_{open} = V_{th}$

$V_{th} = 6\left(\frac{4}{4+2+1}\right)$

$\boxed{V_{th} = 3.43V}$

$R_{th} \Rightarrow$ turn off V1



$R_{th} = 4k // (1k + 2k)$

$\boxed{R_{th} = 1.71 k\Omega}$

c) Circuit concepts: Strain Gauge. A quick note – most teams measured about 1Ω change in resistance across one of the 4 connected bridge resistors when moving the instrumented beam over the full range of motion. This was out of ~ 262Ω, or about 0.75% change.

i. {2pts} The crib sheet has a formula for a strain gauge bridge. For a typical bridge with no stress the resistor values are all the same, R1=R2=R3=Rg. Use the figure and formula from the crib sheet and determine Vleft, Vright, and Vout if the strain gauge is stressed enough to increase Rg by 0.5%, Rg=1.005*R1. Let Vin=9V, and R1=R2=R3. – keep 4 significant digits for Vleft & Vright

$V_{left} = \frac{R_1}{R_1+R_2} \cdot V_{in} = 0.5 V_{in} = 4.5V$

Vleft = 4.500 V

$V_{right} = \frac{R_g}{R_g+R_3} \cdot V_{in} = \frac{1.005 \cdot R1}{1.005 \cdot R1 + R1} \cdot 9 = \frac{1.005}{2.005} \cdot 9$

Vright = 4.511 V

Vout = −11 mV

$V_{out} = 4.500 - 4.511 = -11\,mV$

ii. {4pts} Now modify the figure for the strain gauge bridge on the crib sheet and replace R3 with an identical strain sensor as Rg but it is on the opposite side of the instrumented beam. As the beam is stressed, if Rg increases in value, R3 will decrease by the same percentage, one is under tension and one is under compression. Again determine Vleft, Vright and Vout but now R1=R2, R3=R1 decreased by 0.5%, Rg=R1 increased by 0.5%. Vin=9V

V_{left} = unchanged

Vleft = 4.5 V

$V_{right} = \frac{1.005 R1}{1.005 R1 + 0.995 R_1} \cdot 9 = \frac{1.005}{2} \cdot 9 = 4.523$

Vright = 4.523 V

Vout = −23 mV

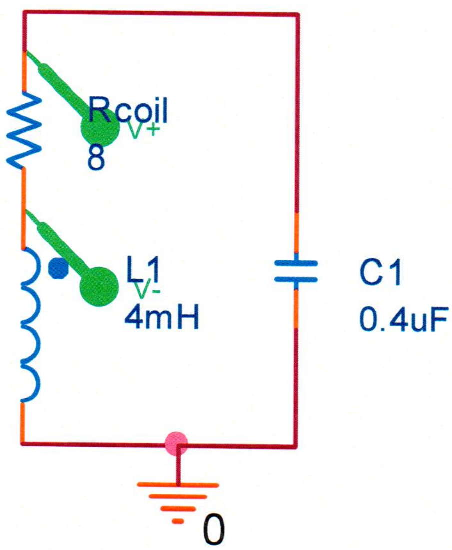
$V_{out} = 4.5 - 4.523 = -23\,mV$

iii. {4p} For the strain gauge on the instrumented beam, R1 and R2 are fixed. Why are they included? In other words: Why are they useful? There is more than one correct answer, just provide one. If stuck consider what would happen to Vright if Vin is provided by a 9V battery and the battery voltage changed by 5% during a lab session. 25 words or less.

1) By taking $V_{left} - V_{right}$, if balanced $V_{out} = 0$, easy to see an 11 mV change from 0 V than 11 mV change from 4.5 V

OR 2) If the battery voltage dropped by 5%, then Vright would also drop by 5% on 22 mV, this could be confused with beam motion, But small effect on Vout

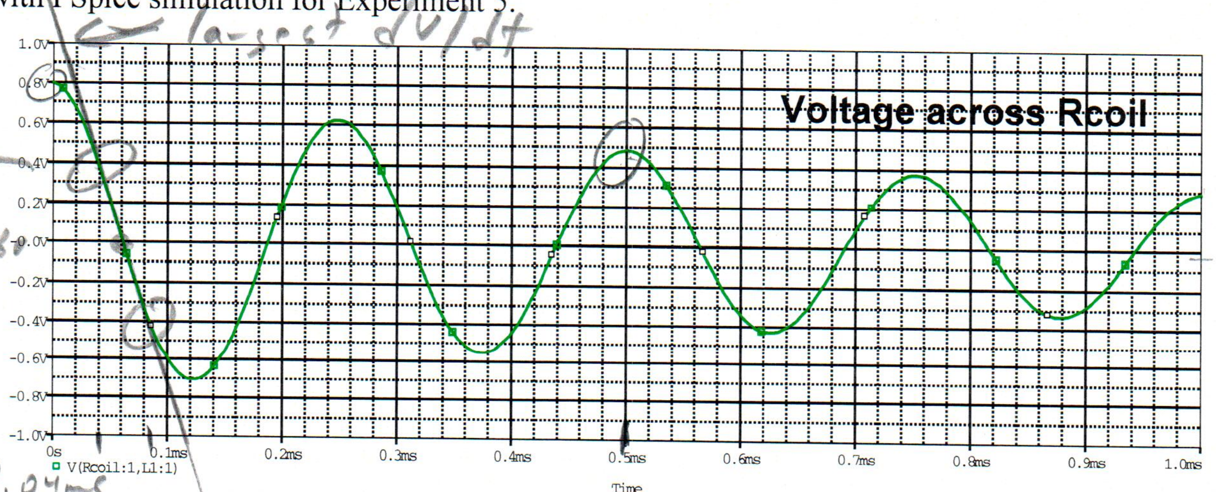
2. Harmonic Oscillators and Math



For the circuit shown, Rcoil and L1 are the effective resistance and inductance of a real (not ideal) coil. At low frequencies the capacitor acts close to ideal. The models for both the inductor and the capacitor become more complicated at high frequencies, high voltage or high currents.

In the real circuit, Rcoil and L1 are distributed along the length of the inductor and the voltage across Rcoil doesn't exist. However it is often useful to use a lumped parameter model – all of the R is included into one effective (ideal) resistor and all of the L is included in one effective (ideal) coil. One cannot measure the voltage on Rcoil in a real circuit but it can be simulated in PSpice to gain understanding. The trace shown below is from such a model. It is the simulation value of the voltage across R_{coil}.

The circuit being modeled is simply an inductor in parallel with a capacitor. At t=0 there is stored energy in the magnetic field of the inductor as was done in both as physical experiment as with PSpice simulation for Experiment 5.



The horizontal scale is time (1ms full scale) and the vertical scale is Voltage (-1V to +1V).

a. Estimate the greatest |dV/dt| on this plot, give the value and mark the time point on the graph. This is for part f. later in the problem. {1pt} $\Delta V \sim 0.8V$, $\Delta t \sim 0.04ms$

$$\left|\frac{dV}{dt}\right| \simeq \frac{0.8}{0.04 \times 10^{-3}} \cong 20{,}000\ V/s = 20\ V/ms$$

b. Find the decay constant α and the angular frequency ω for this data. Mark the points used on the plot. {6 pts} More space is available on the next page.

$t=0$, $0.8V$

$t=0.5ms$, $0.5V$

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

$$\ln\frac{0.5}{0.8} = (-\alpha)(5\times10^{-4})$$

$\alpha \simeq 9.4\ sec^{-1}$

$\alpha \simeq 9.4$

Soln

Space to continue part b. 2 cycles in 0.5 mS

$$w = \frac{(2\pi)(2)}{0.5\times10^{-3}} = 25.1\times10^{3}\ \text{rad/sec}$$

$f = 4\,\text{kHz}$

$w = 2\pi f$

$w = 25\times10^{3}\ \text{rad/sec}$

c. Write the mathematical expression for the voltage across Rcoil, V_{coil} 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}

starts at peak

$$V(t) = 0.8\,e^{-9.4t}\cos(25\times10^{3}t) = V_{Rcoil}(t)$$

$v(t=0)$ α w

R coil

d. Using your expression for the voltage across R1, write an equation for the current through L1 as a function of time. {1pt}

$$I_R = I_{L1} \quad I_R = \frac{V_{Rcoil}}{R} = \frac{0.8\,e^{-9.4t}\cos(2.5\times10^{4}t)}{8}$$

$$I_{L1} = 0.1\,e^{-9.4t}\cos(2.5\times10^{4}t)$$

e. Using the result of part d., determine the voltage across the simulated inductor, L1, as a function of time. Keep only the dominant term. Crib sheet for Quiz 1 may help for this and part f below {4 pts}

$$V_L = L\frac{di_L}{dt}$$

small

$$\frac{di_L}{dt} = \cancel{(0.1)(-9.4)e^{-9.4t}\cos(2.5\times10^{4}t)} + (0.1)(e^{-9.4t})(-2.5\times10^{4}\sin 2.5\times10^{4}t)$$

$$V_L = (4\times10^{-3})(0.1)(-2.5\times10^{4})e^{-9.4t}\sin 2.5\times10^{-4}t$$

$$V_L = -10\,e^{-9.4t}\sin(2.5\times10^{-4}t)$$

f. Use your result from part a. of this problem to estimate the largest magnitude voltage across L1. Does it appear to fit with the answer to part e. {2pts}

$|V_L|_{max} \sim 10$

From part a)

$$\frac{di}{dt}(max) = \frac{1}{R_{coil}}\frac{dV_{Rcoil}}{dt}$$

$$\frac{2\times10^{4}}{8}$$

$$V_L = L\frac{di_L}{dt} = 4\times10^{-3}\cdot\frac{10^{4}}{4} \simeq 10\,V$$

Yes

g. The energy stored in the magnetic field of an inductor is $W = \frac{1}{2}LI^2$ Determine the initial energy stored in the inductor. Include units. {2 pts}

$t=0$ $V_{Rcoil} = 0.8V$, $I_{\Omega} = \frac{0.8V}{8\Omega} = 0.1$ amps

$I_L = I_{Rcoil} = 0.1$ amps

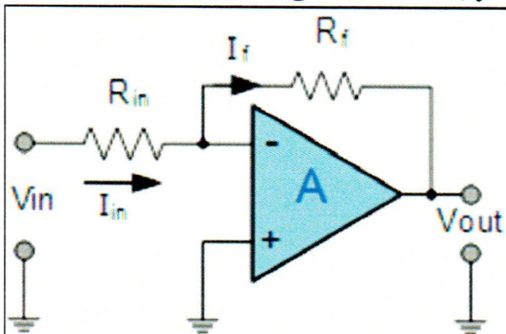
$W = \frac{1}{2}LI^2 = (0.5)(2\times10^{-3})(0.1)^2$

$= (10^{-3})(10^{-2}) = 10\mu$ Joules

OR 10^{-5} Joules

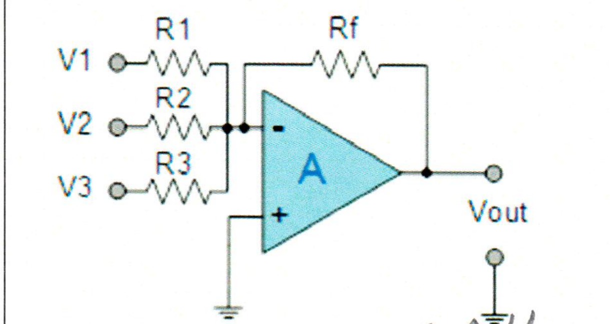
3. Operational Amplifier Applications

a. **For each diagram list what type of amplifier shown and the equation for Vout as a function of the input signals and the component values. If there is more than one formula for a given circuit, you only need to present one. {6pts}**



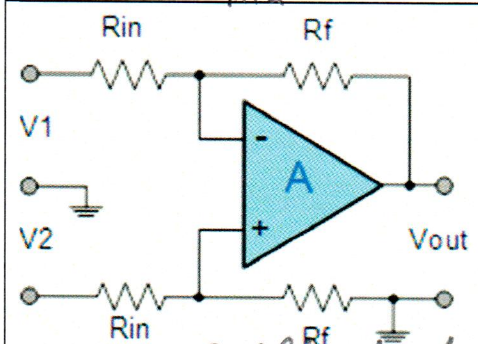
i. Type is: Inverting

Vout= $-\frac{R_f}{R_{in}} \cdot V_{in}$



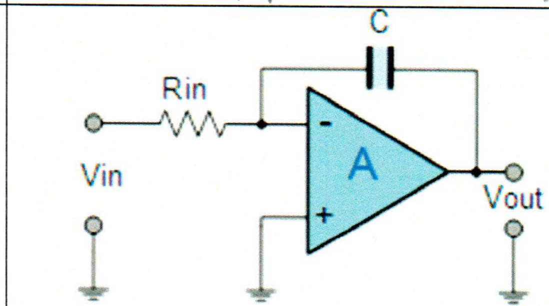
ii. Type is: Summer OR Adder

Vout= $-V_1 \cdot \frac{R_f}{R_1} - V_2 \frac{R_f}{R_2} - V_3 \frac{R_f}{R_3}$



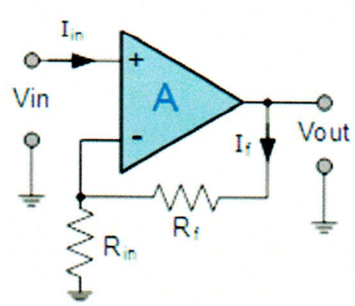
iii. Type is: Differential

Vout= $\frac{R_f}{R_{in}} (V_2 - V_1)$



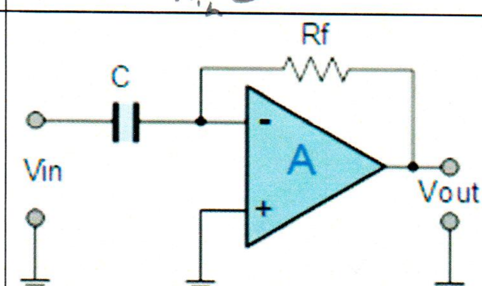
iv. Type is: Integrator

Vout= $-\frac{1}{R_{in} C} \int V_{in}(t) dt$



v. Type is: Non-Inverting Amp.

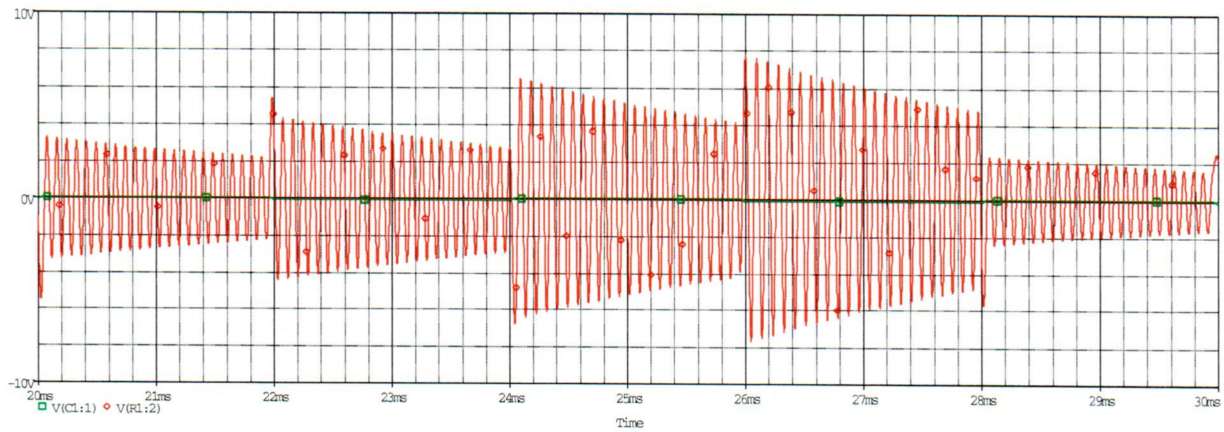
Vout= $V_{in}\left(1 + \frac{R_f}{R_{in}}\right) = V_{in}\left(\frac{R_{in} + R_f}{R_{in}}\right)$



vi. Type is: Differentiator

Vout= $-R_f C \frac{d V_{in}(t)}{dt}$

d. When you built and tested this type of circuit in class, you should have observed that your practical version had a problem not encountered in the ideal version of the circuit above. Shown below is a PSpice simulation of the same circuit used in Experiment 4 with an approximately square wave input voltage. What you observed is unlikely to be exactly the same, but you should have seen something similar. What is different about this plot than what you would expect to observe if the circuit was ideal? What did you do to fix the problem?{6 pts}



e. For the PSpice analysis in part d, 15V DC supplies were used to power the 741 op-amp. How would the results be different if the 5V DC supplies from Analog Discovery were used instead? Be specific. {2 pts}

The op-amp output is limited to the voltage of the power supplies, actual to about 1V short of the supplies.
The output would be clipped at ~+4 max and −4V min, OR use +5 & −5, OR use +3.5 & −3.5.

Soln.

4) Concepts, Troubleshooting and Data Analysis

a. **Classroom Knowledge and Tasks** {4pts} 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

ii. There is no reasonable need to ever calibrate the Analog Discovery board.

False

iii. 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

iv. 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

b. Which of the following op-amp configurations works best to amplify the signal from a stain gauge bridge circuit? Circle one. {2 pts}

Voltage Follower Inverting Non-Inverting Differential

Adder Integrator Differentiator

c. Which of the following op-amp configurations works best to connect to the output of an accelerometer if it is desired to find the velocity of accelerometer? Circle one. {2 pts}

Voltage Follower Inverting Non-Inverting Differential

Adder Integrator Differentiator

Sol'n

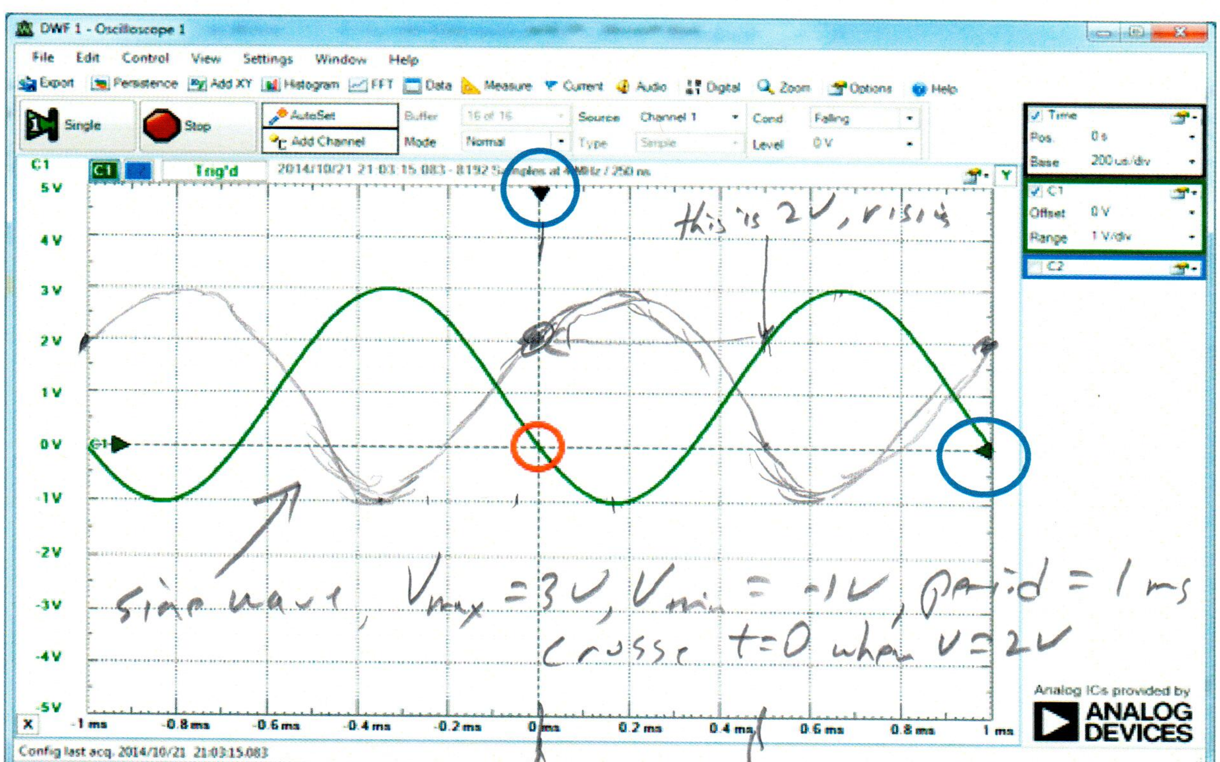
d. Energy is lost as a function of time in the harmonic oscillators we studied. For the RLC oscillators what component causes the energy loss? Will the loss be the greatest at the time of the peak voltage on the inductor or at the time of the peak rate of change of the voltage on the inductor? Circle correct answers. {2pts}

Component causing the loss: Resistor Inductor Capacitor

Time of peak loss: At peak inductor voltage At peak dV/dt of the voltage on the inductor

Peak loss when peak current in Rcoil ⇒ peak I_L
peak I_L when dV/dt is max.

e. **Triggering** 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 2V and rising**. Please draw neatly and explain your answer. {4pts}



shift ~ 2.5 divisions

Soln

f. Explain in 25 words or less: Why does the Miller Integrator (practical integrator) have a resistor across the capacitor while the ideal integrator doesn't have one? {2pts}

A real circuit will have dc offset, Integrating even a small dc will eventually saturate the op-amp output

g. What is the likely capacitance of a capacitor with a label of 104 on the side? {2pts}

$104 \Rightarrow 10 \times 10^4 = 10^5$ the caps we see are in the range of 1000pF to 100,000,000pF

So most like $C = (10^5)pF = 0.1\mu F$

will allow $C = 10^5 nF = 100\mu F$

h. Name the professor and a TA who is typically in your section of EI. First names count. {2pts}

	Section 1	Section 2
	Ken Connor	Paul Schoch Prof.
TA	Waleed Mansha	Zach Amodeo
	Mitchell Phillips	Yao Zhao
	Garrison Johnston	Assile Batainch