ENGR-2300

Electronic Instrumentation

Quiz 2

Fall 2013

Name Solution

Section ___

Question I (25 points) ___________

Question II (25 points) ___________

Question III (25 points) ___________

Question IV (25 points) ___________

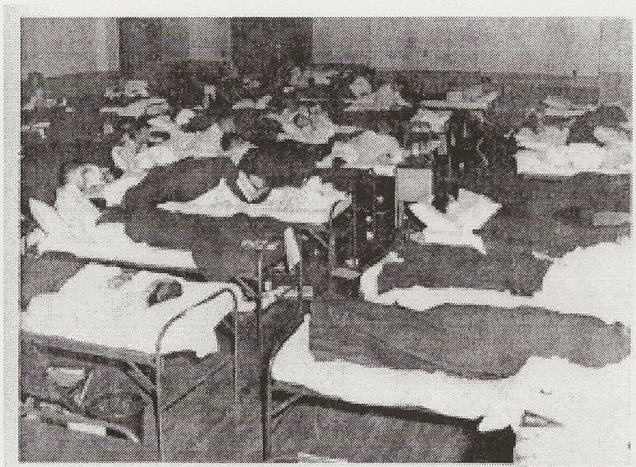
Total (100 points) ______________

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.

October in RPI History (From RPI Archives) **Flu pandemic retrospect**

It is not surprising to find that flu pandemics have impacted the RPI community in the past. In 1918, the Spanish flu hit campus at a most inopportune time. It was ***October*** and 650 students conscripted into the Student Army Training Corp were about to move into temporary barracks on campus. The flu ripped through the SATC and by the end of October, six men had died of pneumonia. Nearly 200,000 people in the U.S. died of flu complications during that month. A quarantine of the troops at RPI was lifted in November as the number of cases declined. The soldiers were then able to move into barracks set up in the 87 Gym, Student Clubhouse and the new dormitories. The flu epidemic was followed by an outbreak of diphtheria; at least thirty-five cases were reported. A total of fourteen students died as a result of these diseases. Students were quickly immunized with diphtheria antitoxin if they tested negative to immunity.

During the month of ***October*** in 1957, nearly 20% of the student population was suffering from the Asiatic flu. Many of the affected students were freshmen. The Infirmary was filled to capacity and additional beds were set up in the 15th St. Lounge (now the Playhouse) to house the sick. The IFC Ball and the RPI-Union football game were canceled, but both events were eventually rescheduled and RPI's hopes of defeating Union were realized.



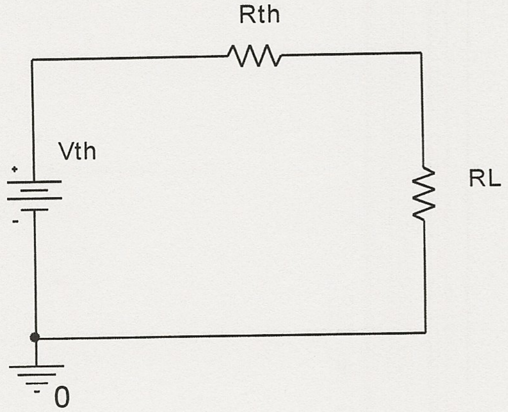
From Wikipedia: The **1918 flu pandemic**
(January 1918 – December 1920) was an unusually deadly influenza pandemic, the first of the two pandemics involving H1N1 influenza virus (the second being the 2009 flu pandemic). It infected 500 million people across the world, including remote Pacific islands and the Arctic, and killed 50 to 100 million of them—3 to 5 percent of the world's population at the time—making it one of the deadliest natural disasters in human history. The 1957 and 1968 pandemic flu strains were caused by reassortment between an avian virus and a human virus, whereas the H1N1 virus responsible for the 2009 swine flu outbreak has an unusual mix of swine, avian and human influenza genetic sequences.

KC: My grandparents, Stephen and Gertrude Connor, died during the 1918 pandemic in January, 1919, on their farm in Armour, SD, leaving my father and his brother and sister orphans.

Think-Pair-Share Topics: (For Info Only)

1. None
2. (Exp 1) Hand-drawn circuit diagram … one of the key tasks for every experiment and simulation you do involving a circuit is to draw the circuit diagram by hand before you begin building it or setting up the simulation. Give two reasons why this will be helpful for you and your team.
3. (Exp 1) What is a resistor … what is an inductor … what is a capacitor? Describe at least two of the three devices in some useful manner. Give a practical example of something that is not a typical circuit component, but electrically is one of these devices. (e.g. A person can be any of the three. In the winter, we are capacitors when we charge up walking across a carpeted floor and then give shocks to the people we touch.)
4. (Exp 2) What is meant by a low frequency or a high frequency when dealing with RC, RL or RLC circuits?
5. (Exp 2) In ideal circuit models, resistors are resistors, inductors are inductors and capacitors are capacitors. Is this also true for real devices? What examples can you think of that are at least two or maybe all three of these devices at the same time?
6. (Exp 3) What is the purpose of an ideal model for an inductor if the analytical formula we can derive from it does not provide a particularly accurate prediction of inductance? How can you make practical use of such models?
7. (Exp 3) We investigate two different ways of measuring inductance in Experiment 3. What other techniques can you think of? Can you think of an application of an inductance measurement as a sensor of some kind?
8. (Exp 3/Proj 1) When is a transformer a transformer? What is it when it is not a transformer? Is this a really strange question? Note that this is an electrical question and has nothing to do with the toys or animated characters.
9. (Proj 1) Pick a moving object of interest to you and suggest two or three different techniques for determining its velocity.
10. (Exp 4) Describe 2 or 3 techniques for troubleshooting a circuit. Apply your ideas to one of the more complex circuits from this course.
11. (Exp 4) How and why do practical op-amp differentiators and integrators differ from their ideal counterparts? How do we verify that they are indeed integrating or differentiating?
12. (Exp 5) What is a damped harmonic oscillator? What real-world examples of such harmonic oscillators can you identify?
13. (Exp 5) What is the Thevenin equivalent circuit and why is it useful? What is the Thevenin equivalent circuit for a standard 9V battery?

I. Thevenin Equivalent Voltage Source

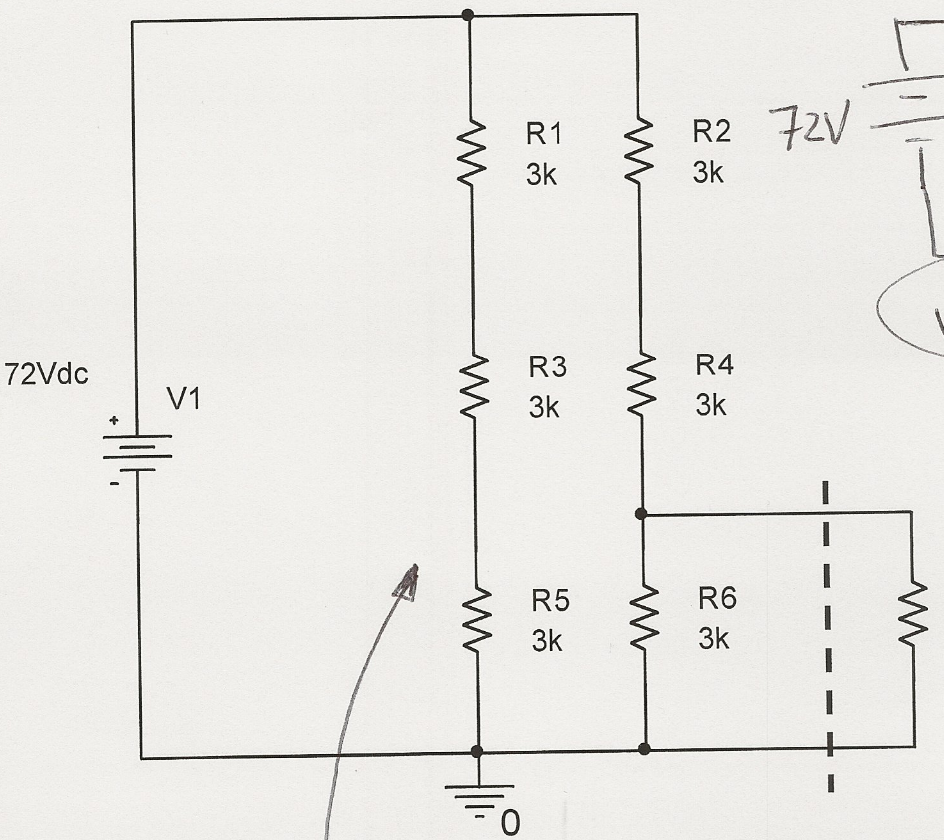


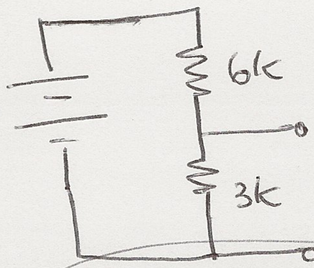
The Thevenin equivalent circuit consists of a voltage source in series with a resistor, which provides a very simple replacement for much more complex circuits. If we have this simple source, analyzing changing loads becomes quite easy.

In this problem, you are to find the Thevenin voltage and resistance for three circuits. The load is to the right of the dashed line in the first two circuits.

Circuit 1: (This is the simplest of the three problems.) {8 pts}

Simplify:

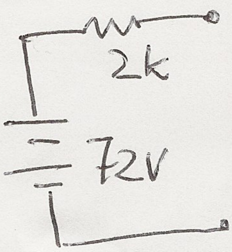




$V_{th} = \frac{3}{9} 72 = 24V.$

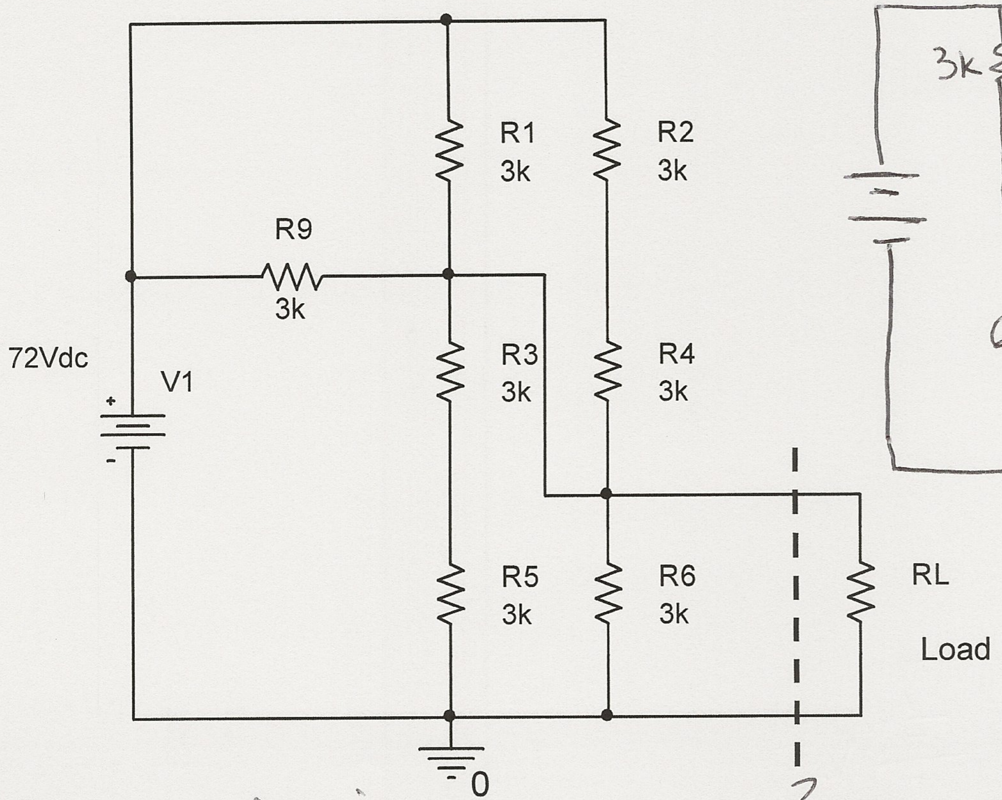
$R_{th} = 6k || 3k$

$= 2k\Omega$

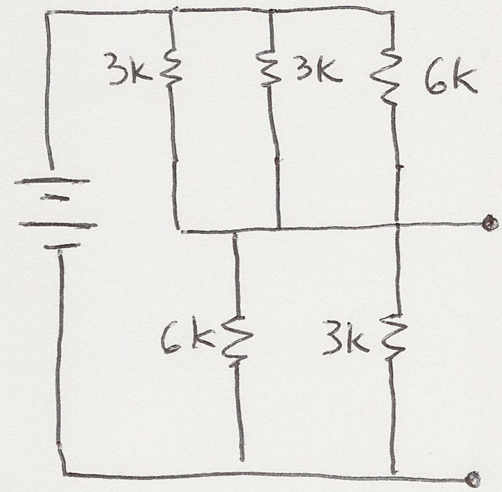


R_1, R_3, R_5 can be ignored

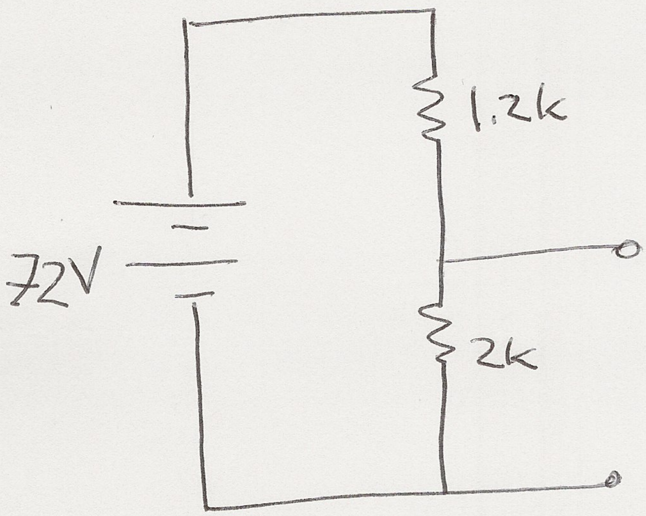
Circuit 2: (This is slightly more complex.) {5 pts}



Redraw

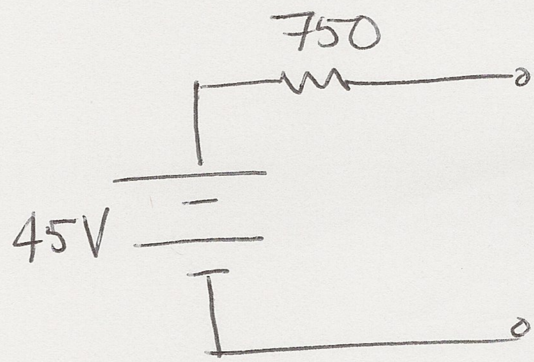


Redraw Again



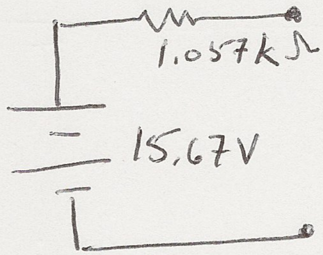
$$V_{th} = \frac{2}{3.2} 72 = 45V$$

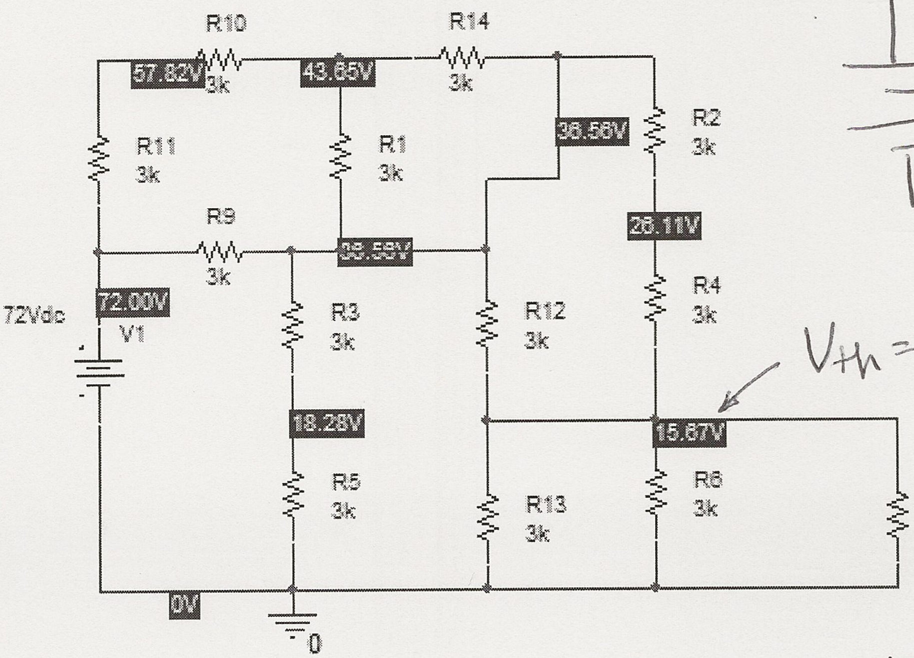
$$R_{th} = (1.2k) \| 2k = 750$$



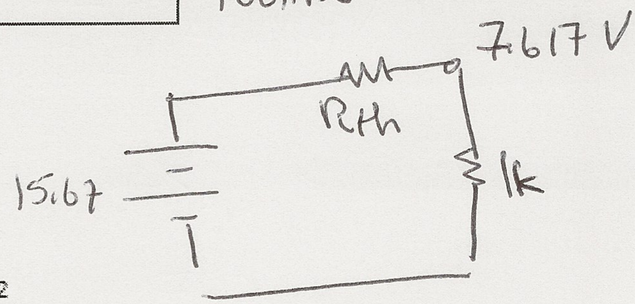
Circuit 3:

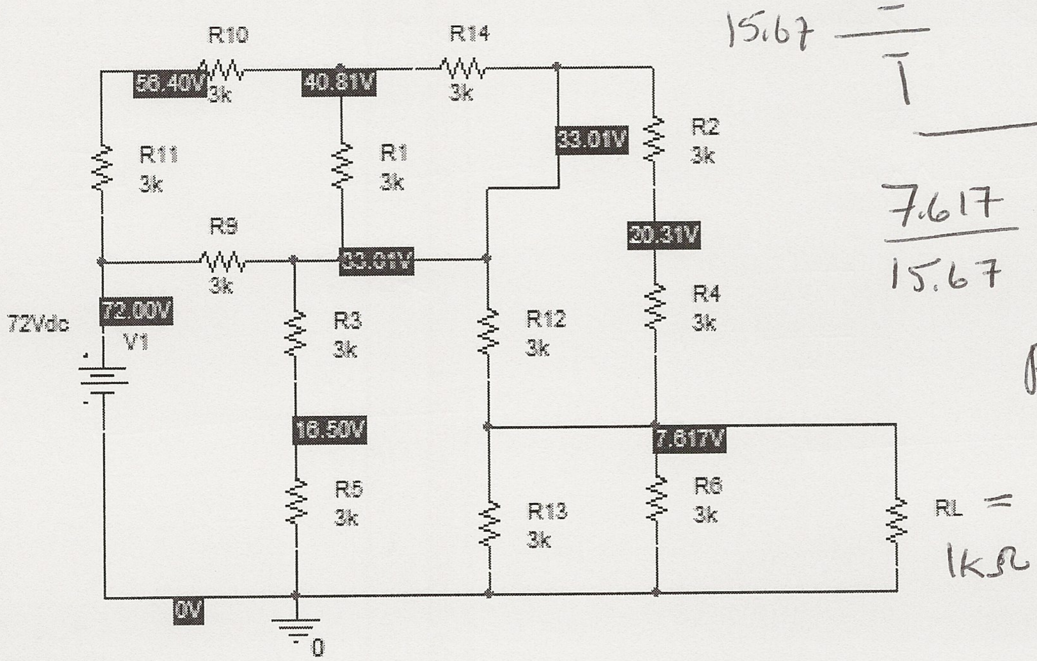
The 3rd circuit is significantly more complicated than the other two. Rather than analyze it from first principles, we will use the results from a PSpice simulation. In the first plot, the load resistor is very large (100MOhms) while in the second the load resistor is much smaller (1kOhm). Using the given voltages at each of the nodes for an open circuit load (RL1 is the load) and for a 1kΩ load, determine Vth and Rth. {8 pts}





$V_{th} = V_{oc} = 15.67V$





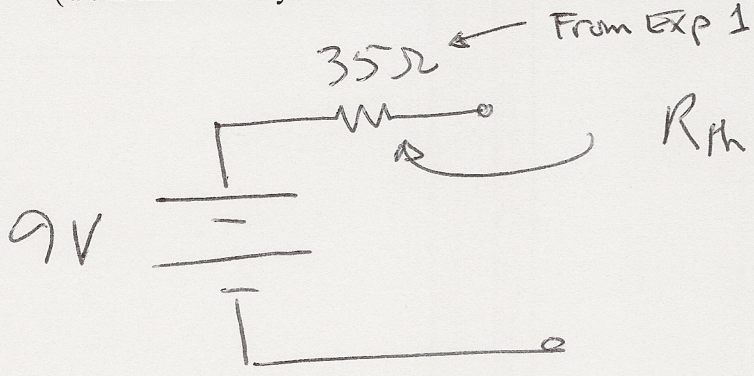
$$\frac{7.617}{15.67} = \frac{1k}{1k + R_{th}} = .486$$

$$R_{th} = \frac{1 - .486}{.486} k$$

$$= 1.057k$$

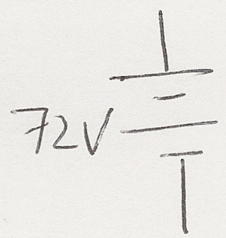
Circuit 4:

What is the Thevenin Equivalent circuit for one of the cheap green 9V batteries we use for our experiments? Provide a typical value for its Thevenin resistance. Draw the circuit diagram. (Your answer only needs to be reasonable. There is no exact answer to this question.) {2 pts}

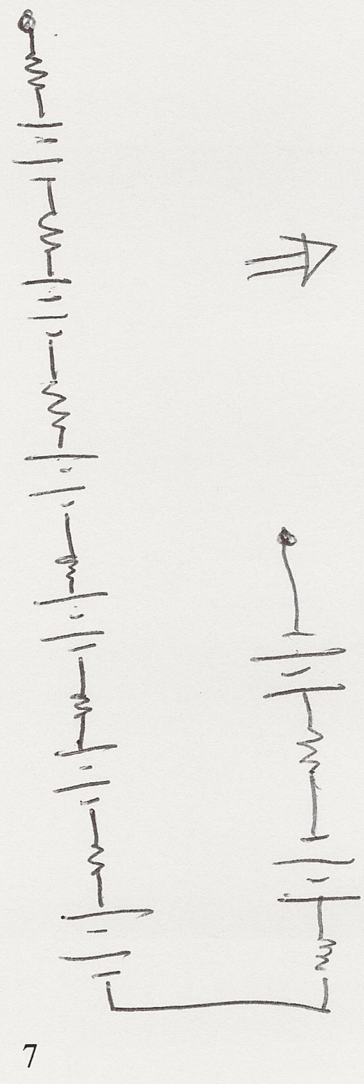


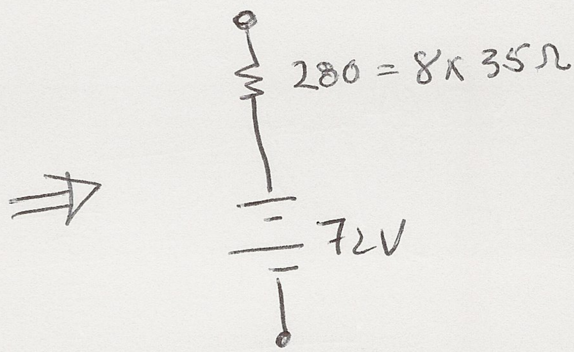
R_{th} for such batteries can be 10 - 40Ω but any value from 1 - 50Ω is OK

Redraw Circuit 1 using as many 9V batteries as necessary to produce 72V. Use your Thevenin model for each of the batteries. {2 pts}



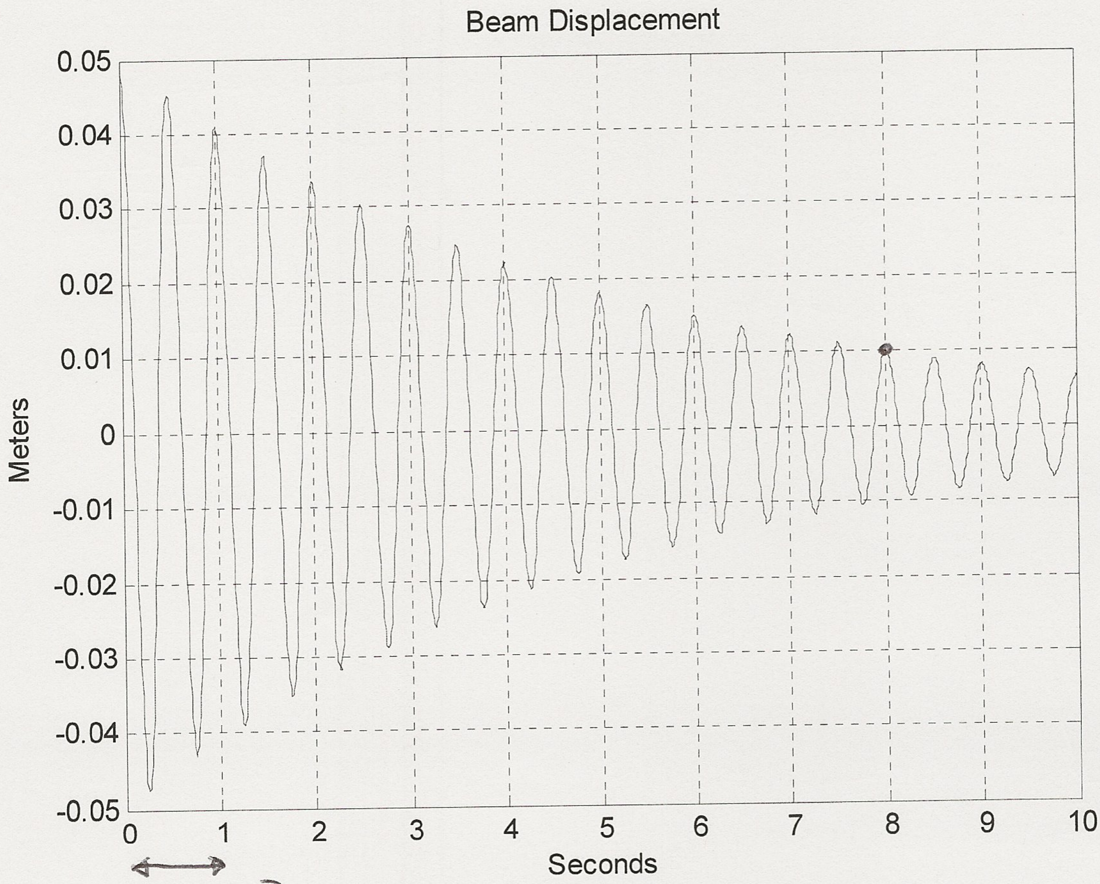
Replace with





II. Harmonic Oscillators

The position measured for an oscillating cantilever beam is shown in graphical form as:



$2T = \frac{2}{f}$

where the horizontal scale is time (1 sec per division) and the vertical scale is distance (0.01m per division).

a. Find the decay constant α and the angular frequency ω for this function. {6 pts}

$x = 0.05 \exp(-\alpha t) = 0.05 \exp(-\alpha 8) = 0.01$

$-\alpha 8 = \ln \frac{.01}{.05} \Rightarrow \alpha = .2$

$f = 2\,Hz \qquad \omega = 2\pi f = 4\pi$

b. Write the mathematical expression for the position in the form $x(t) = Ae^{-\alpha t}\cos\omega t$. Use real values for the constants and provide units where appropriate. {4 pts}

$$X(t) = 0.05 \cdot \exp(-t/5) \cdot \cos(4\pi t)$$

c. Find the approximate acceleration *a(t)* of the beam from your answer to part b. Again, use real values for the constants and provide units where appropriate. *Hint: Keep only the largest terms in your expressions.* {6 pts}

$$\frac{dx}{dt} = \left(-\frac{1}{5}\right) 0.05 \exp(-t/5) \cos 4\pi t$$

$$- 0.05\ 4\pi \exp(-t/5) \sin 4\pi t$$

$$\simeq (-0.05)\, 4\pi \exp(-t/5) \sin 4\pi t$$

$$\frac{d^2x}{dt^2} \approx -(4\pi)^2 x$$ dropping the smaller term.

d. Assume that you would like to build an LC oscillator circuit that operates at the same frequency and the beam above. You have a 470μF capacitor and need to make an inductor. What value of inductance is necessary to achieve this frequency? {4 pts}

$$4\pi = \frac{1}{\sqrt{LC}} \qquad L = \frac{1}{(4\pi)^2 C} \simeq 13.5\,H$$

Very Big!

e. Give three real-world examples of damped harmonic oscillators. Full credit will only be given for answers that are significantly different. *Be creative.* {5 pts}

Guitar String

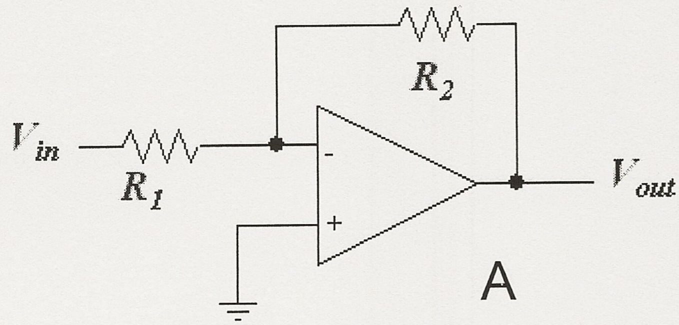
Popcycle Stick

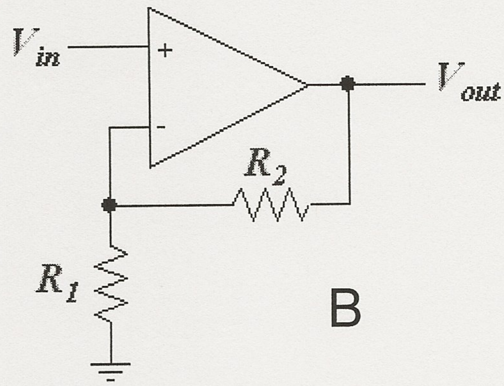
Skyscraper

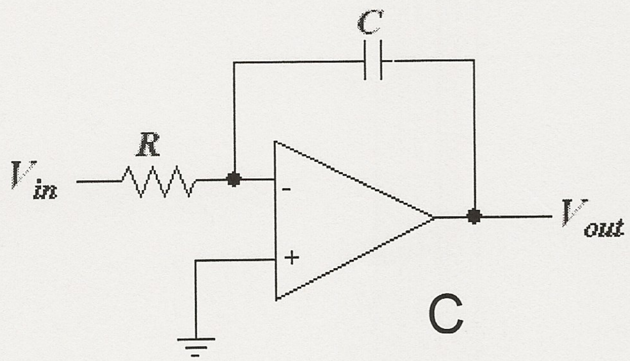
Arrow stuck in target

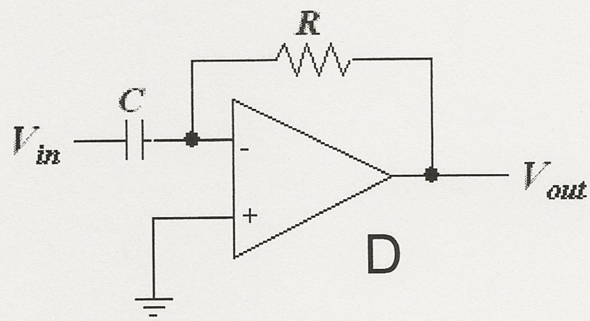
etc.

III. Operational Amplifiers









a. {2 pts} What type of amplifier is each circuit?

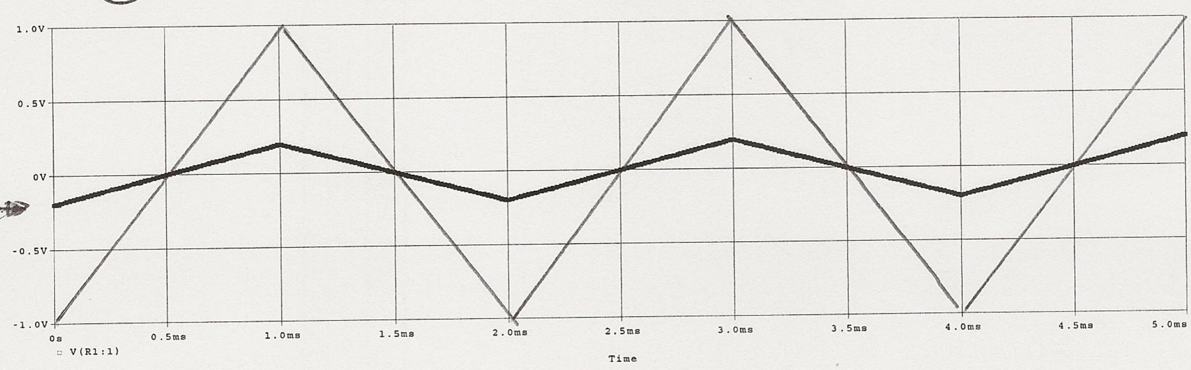
  a. A
  b. B
  c. C
  d. D

b. {3 pts} The input voltage is shown below. Solve for and sketch the output voltage for circuit B with R_1=1kΩ and R_2=4kΩ.

Gain = 1+4=5

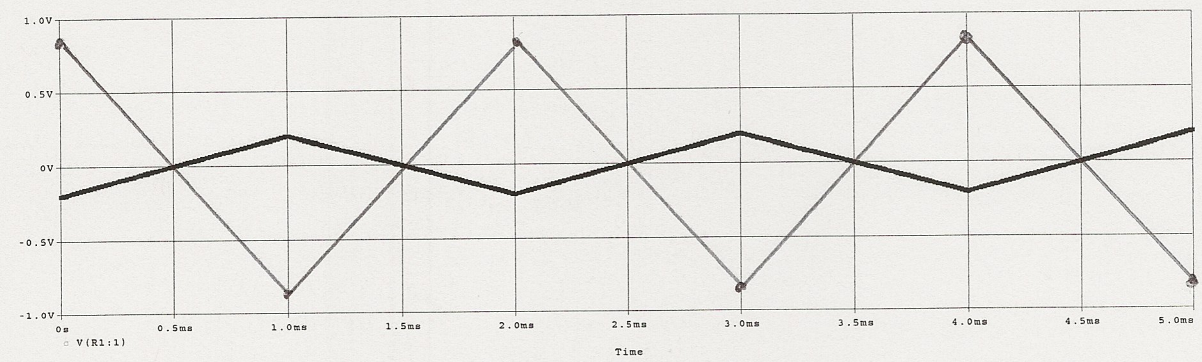
-.2

Reasonable values are OK



The vertical scale is -1V to +1V and the horizontal scale is from 0 to 5ms.

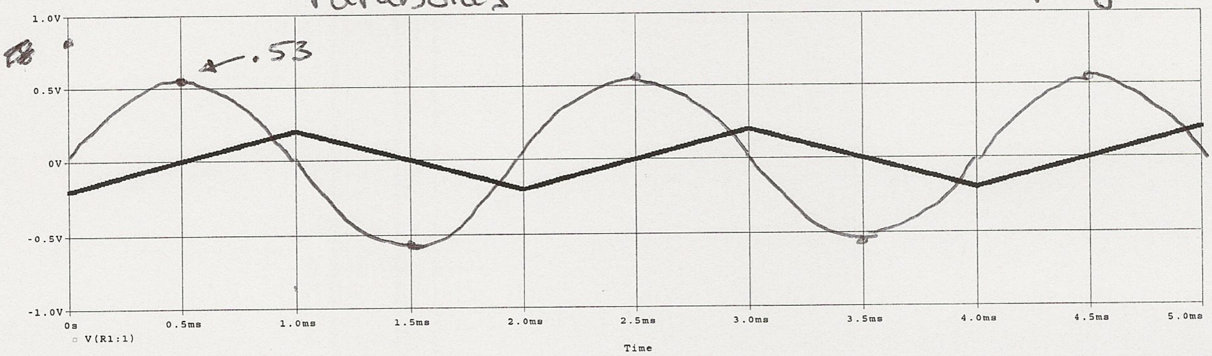
c. {3 pts} The input voltage is shown below. Solve for and sketch the output voltage for circuit A with R_1=1kΩ and R_2=4kΩ. Gain = −4



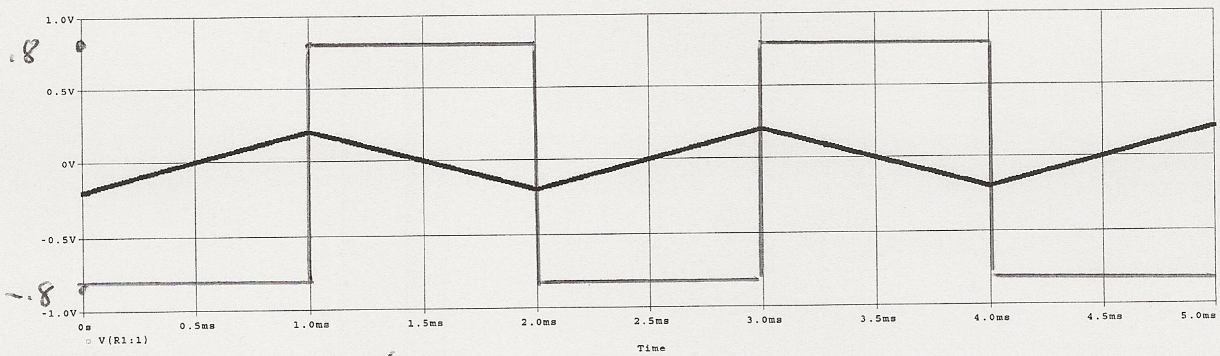
d. {3 pts} The input voltage is shown below. Solve for and sketch the output voltage for circuit C with R=2kΩ and C=0.047μF. RC ⇒ see next page

Parabolas

Hardest One



e. {3 pts} The input voltage is shown below. Solve for and sketch the output voltage for circuit D with C=.33μF and R=6kΩ.



Slope $= \frac{.4}{1ms} = .4 \times 10^3$

RC = (6000)(.33×10⁻⁶) = .002

} product = .8

Space for the analysis of the circuits above:

Integrator

$V(t) = (.4 \times 10^3)\, t$

$RC = (2000)(.047 \times 10^{-6})$

$\frac{1}{RC} = 10638$

$\int_0^{.5ms} (.4 \times 10^3) \frac{t^2}{2} \Big|_0^{.5}$

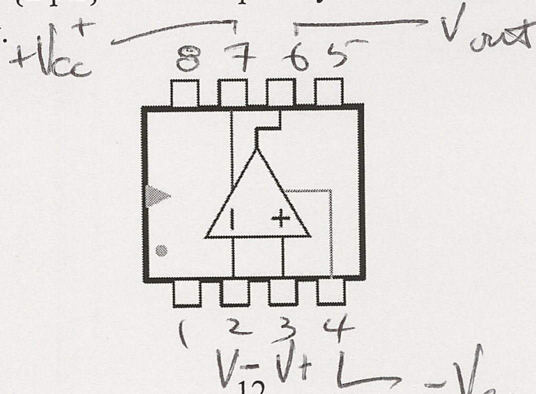
$\frac{1}{RC} a \frac{t^2}{2} = (10638)(.05 \times 10^{-3})$

$= .53$

$= (.4 \times 10^3)\ .125 \times 10^{-6}$

$= .05 \times 10^{-3}$

f. **Practical Knowledge** {2 pts} Label the pins by number and function on the 741 op-amp package shown below.



g. {9 pts} The response of the circuit below has been simulated using PSpice.

Differentiator

$RC = (.68\mu F)(1.867k)$

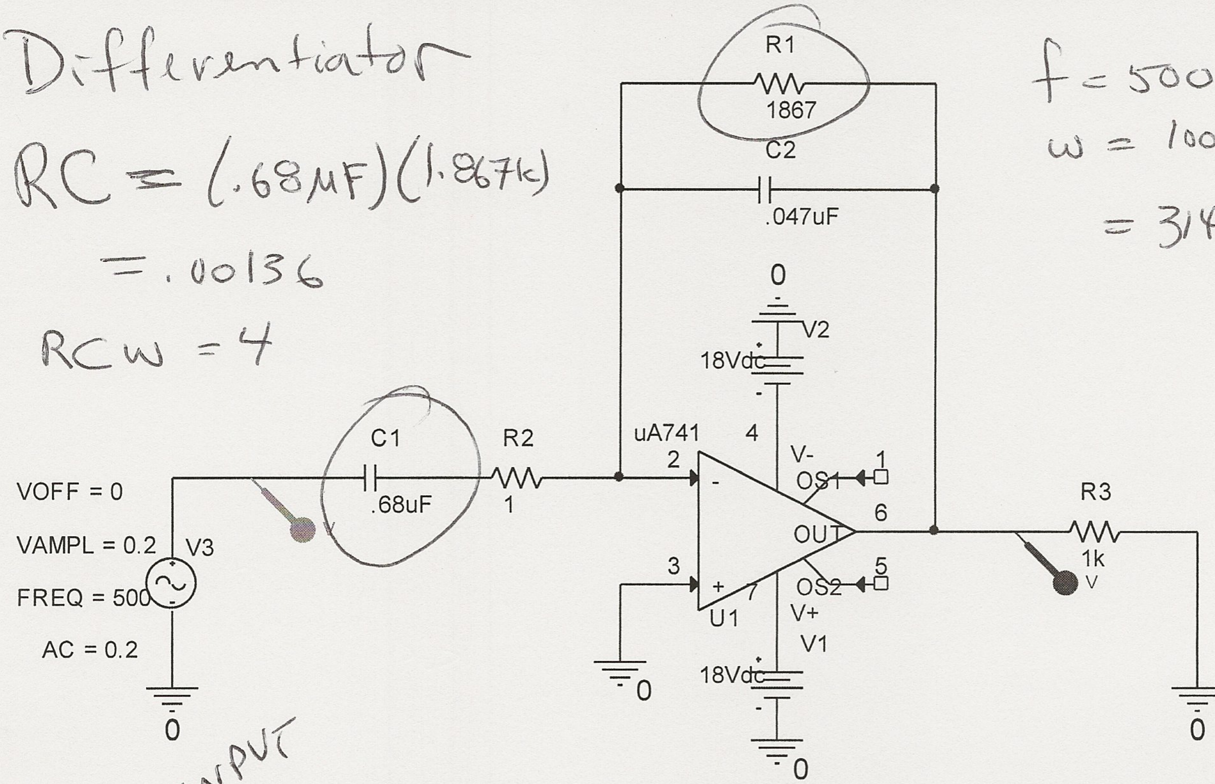
$= .00136$

$RC\omega = 4$

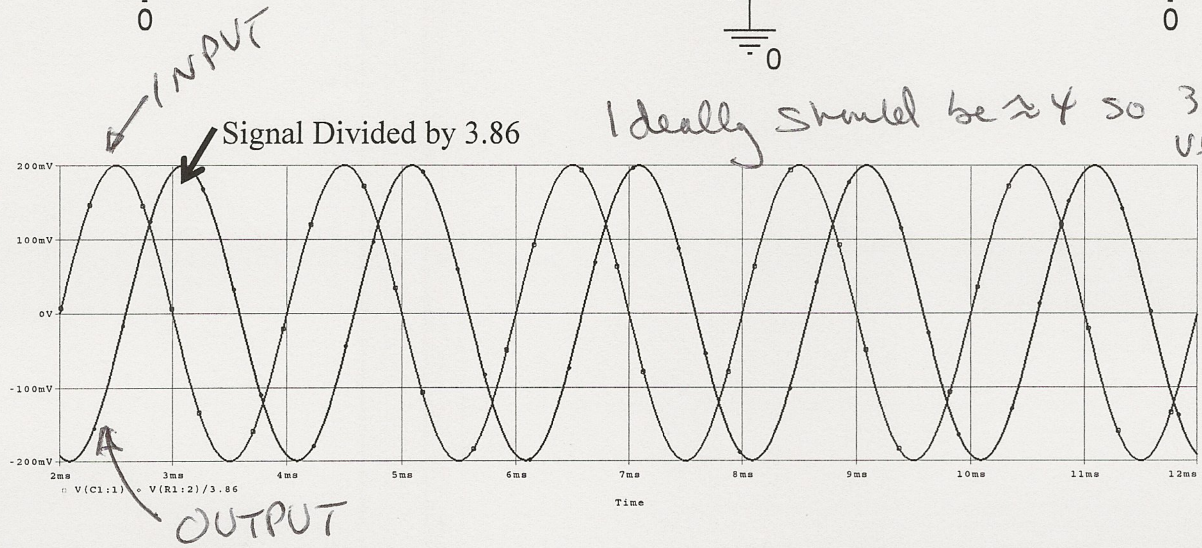
$f = 500$

$\omega = 1000\pi$

$= 3141.59$



Ideally should be ≈ 4 so 3.86 is very close



Label the input voltage and the output voltage on the plot showing the signals. Note that one of the signals has been divided by 3.86 so that it is about the same size as the other one. {2 pts} The circuit configuration does not look exactly like any of the ideal op-amp circuits. However, it largely provides the functionality of one of the ideal circuits. From the input and output voltages, identify what kind of circuit this is {3 pts}, indicate the circuit components that you can neglect in your analysis and why, and verify mathematically that it is working at least approximately the way it should. {4 pts}

IV. Concepts, Troubleshooting and Data Analysis

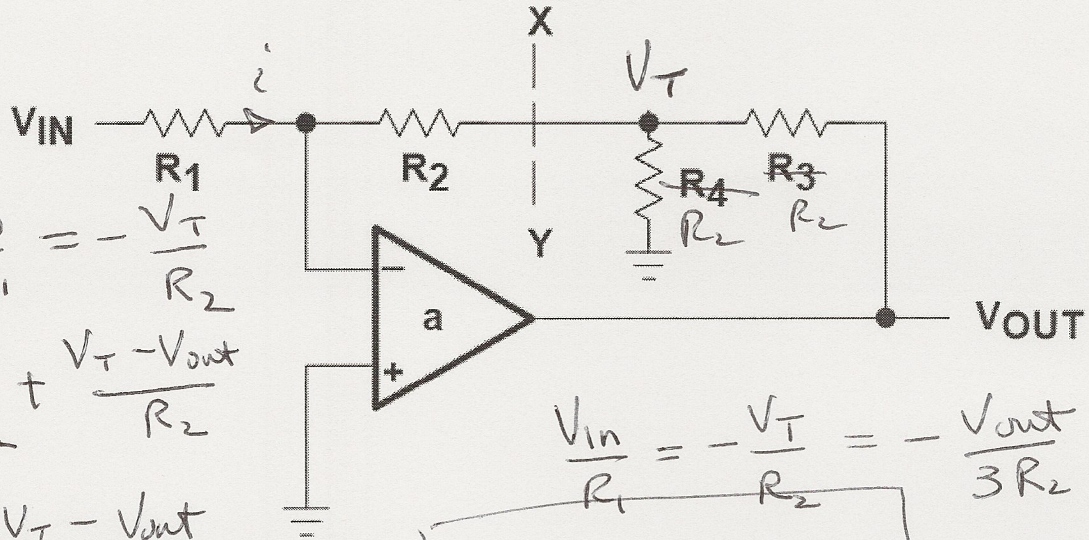
a. {6 pts} Today's date is 8-23-2013. Because the date consists of three numbers, how would you represent each number with the resistor color code, if indeed it can be done? If it can be, give the color code. If it cannot be, cross out the number.

a. 8 Black Gray Black

b. 23 Red Orange Black

c. ~~2013~~ Cannot do 4 #'s with one R
Can do it with two resistors though

b. {4 pts} An ideal op-amp circuit is configured with what is called a T configuration of resistors in the feedback loop rather than just one resistor. Derive the expression for V_{OUT} in terms of V_{IN} starting from the golden rules of op-amps. For simplicity, assume that $R_2 = R_3 = R_4$.



$$i = \frac{V_{IN}}{R_1} = -\frac{V_T}{R_2}$$

$$= \frac{V_T}{R_2} + \frac{V_T - V_{out}}{R_2}$$

$$\Rightarrow -V_T = 2V_T - V_{out}$$

$$\text{or } V_{out} = 3V_T$$

$$\frac{V_{in}}{R_1} = -\frac{V_T}{R_2} = -\frac{V_{out}}{3R_2}$$

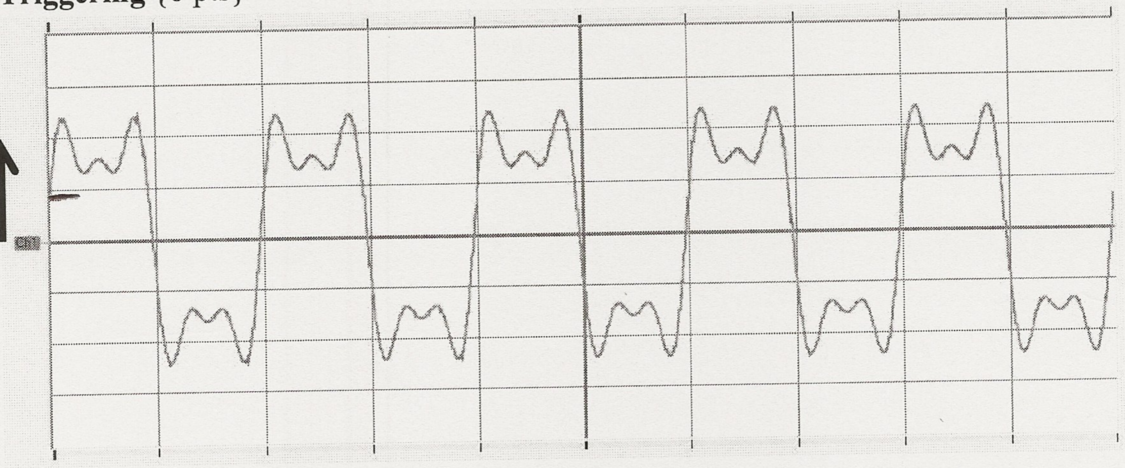
$$\boxed{\frac{V_{out}}{V_{in}} = -3\frac{R_2}{R_1}}$$

c. **Classroom Knowledge** {3pts} Where is the electrical tape found in our classroom?

Next to the wire reels by the doors

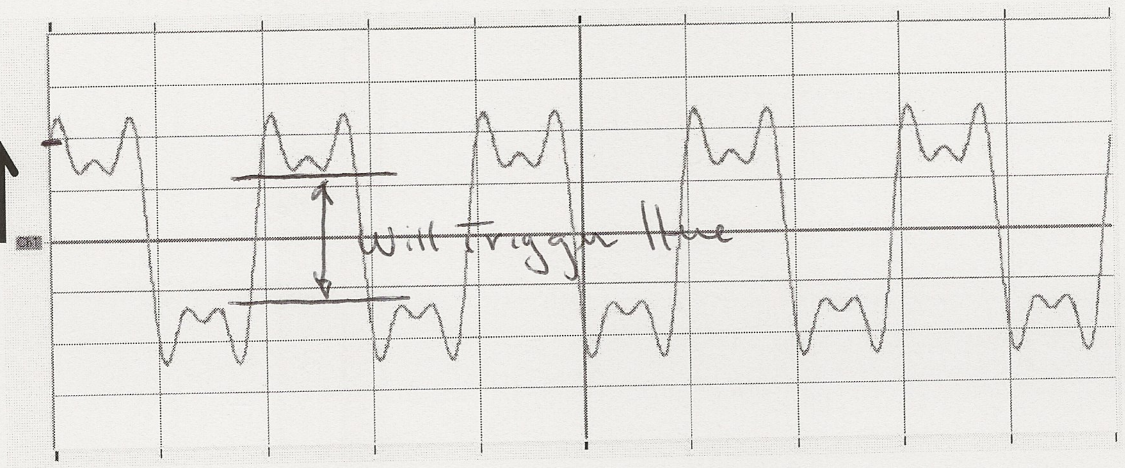
d. **Triggering** {6 pts}

1V



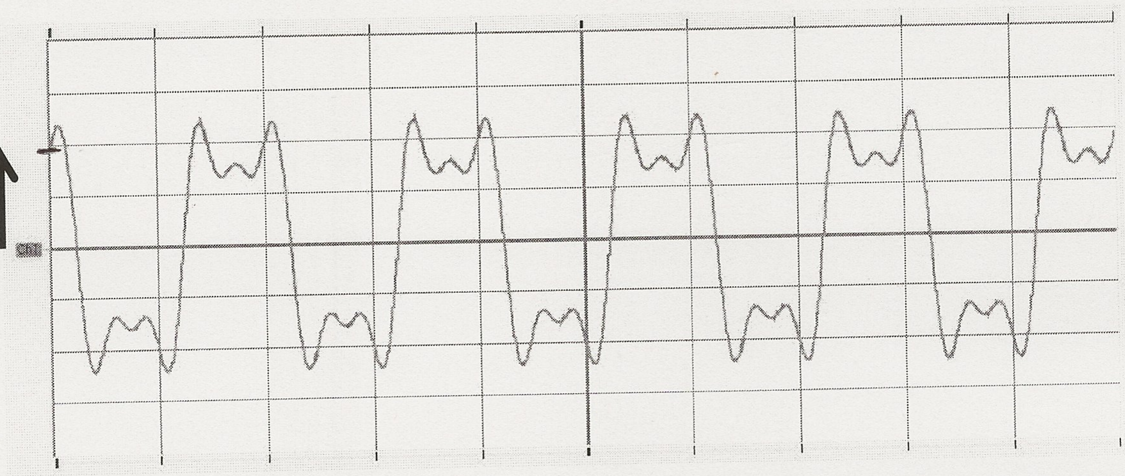
Horizontal: 500 µs/Div Trigger: 0.400V
Channel 1: Vertical: 500 mV/Div
Coupling: DC
Input: AWG1

1V



Horizontal: 500 µs/Div Trigger: 0.960V
Channel 1: Vertical: 500 mV/Div
Coupling: DC
Input: AWG1

1V



Horizontal: 500 µs/Div Trigger: 0.960V
Channel 1: Vertical: 500 mV/Div
Coupling: DC
Input: AWG1

On the previous page is shown the same signal with two different triggering conditions. For one case the trigger level is set at 0.4V and for the other it is set at 0.96V. For the latter setting, the signal displayed on the screen will switch back and forth between the two cases and never remain stationary. This cannot be shown here because all images on paper are static. However, you should be able to imagine how this jittery signal appears. Explain why the trigger level in the first case produces a stable plot while the second case does not.

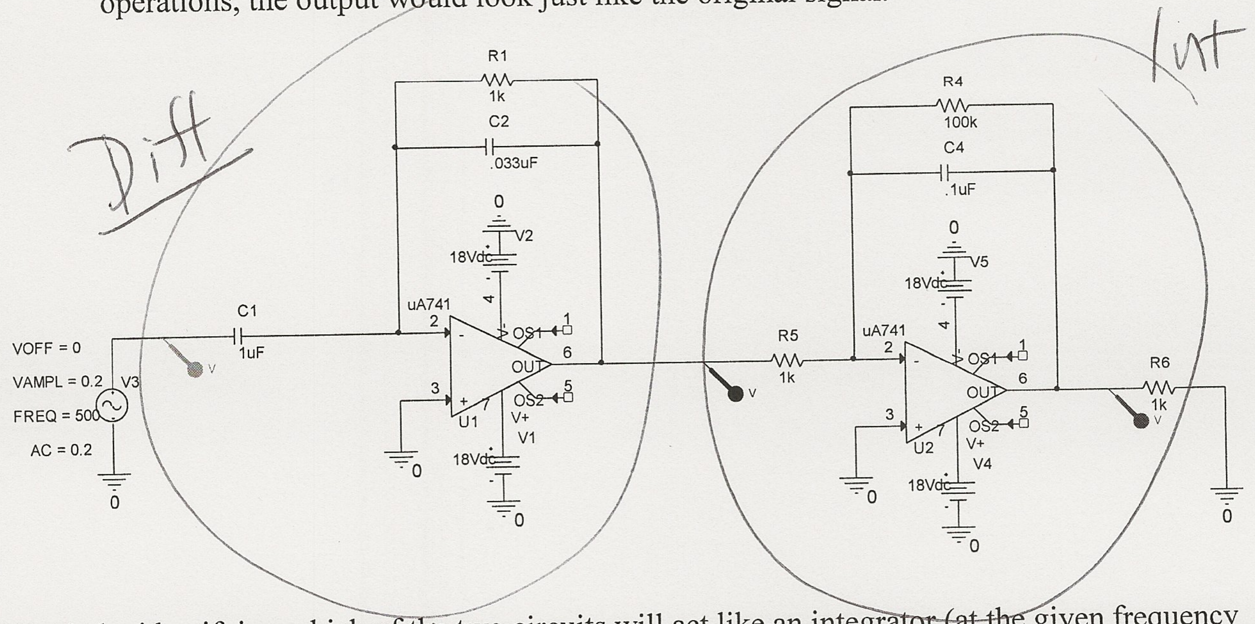
(1) There is only one time per cycle where the signal passes the trigger level

(2) There are two times per cycle where the signal passes the trigger level. It will jump between them.

Approximately for what range of trigger values will the displayed signal be stable?

About ± .6V (See Figure)

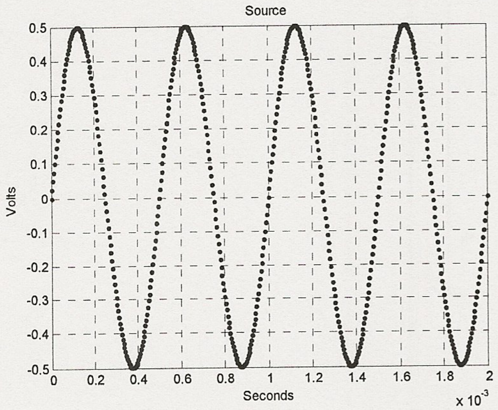
e. **Combining Functions** {6 pts} As an exercise in understanding how op-amp circuits work, the configuration below was modeled using PSpice. The circuit was designed by a student to integrate and differentiate a signal in a known manner so that, after both operations, the output would look just like the original signal.

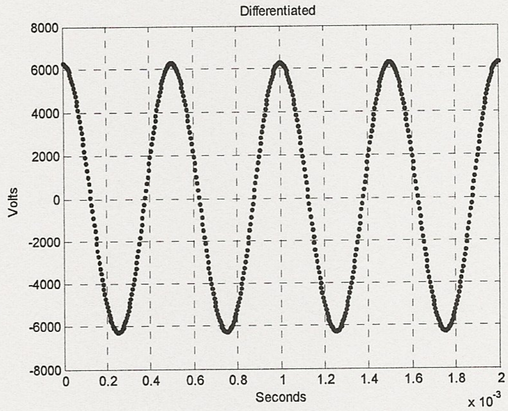


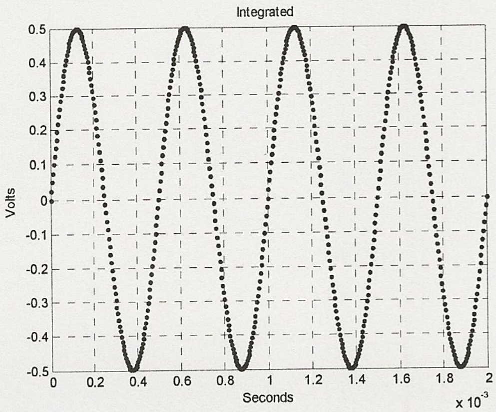
Begin by identifying which of the two circuits will act like an integrator (at the given frequency of 500Hz) and which will act like a differentiator. Note that each of the two circuits will work at this frequency.

$RC = 10^{-3}$ $RC = 10^{-4}$

The student who designed this, set up a Matlab simulation to test out the idea. Plots of the voltages at the three points (from Matlab, not from PSpice or a Mobile Studio experiment):







These results from Matlab (displayed in order with the first signal the source and the third signal the final output) were supposed to provide some guidance for running the actual experiment. It turns out that the student had too simplistic a view of how these circuits worked. The prediction is correct in form, but the vertical scales are wrong. Find the correct vertical scales for the second and third plots so that the signals are displayed correctly for the circuit from the PSpice diagram.

Mult by $-RC$ for Differentiator
Mult by $\frac{-1}{RC}$ for Integrator
} Together $(-RC)(-\frac{1}{RC}) = 10$

Also need to correct for different amplitude - but this is not necessary for this problem

What one change in the second circuit would make the output from the integrator circuit agree with the Matlab prediction?

Make the R's & C's the same so

C4 should be 1μF