ENGR-2300

Electronic Instrumentation

Quiz 2

Spring 2014

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.

This Week in History – March 1954

Today, we indulge in a little baseball history with possibly a lesson for all of us. The story involves Bobby Thomson, who, when he was an outfielder for the NY Giants, became a celebrity for his walk-off home run off Brooklyn Dodgers pitcher Ralph Branca to win the 1951 National League pennant. The home run, nicknamed the "Shot Heard 'Round the World", was dramatic as, until 1969, league pennants were only decided by playoff when the teams involved finished the regular season in a tie. In the winter after the 1953 season, he was traded to the Milwaukee Braves. I was seven years old at the time and my family was really excited to have a major league team move so close to our home in Madison. For those of you who are from the Boston area, Braves Field was located where the BU Football team played (Nickerson Fields) until they dropped the sport in 1997. Parts of the field, such as the entry gate and right-field pavilion, remain as portions of the stadium. (The old Braves Field ticket office also remains, now used by the Boston University police department.)

13 March 1954: Braves' Bobby Thomson breaks his ankle; he is replaced by Hank Aaron.

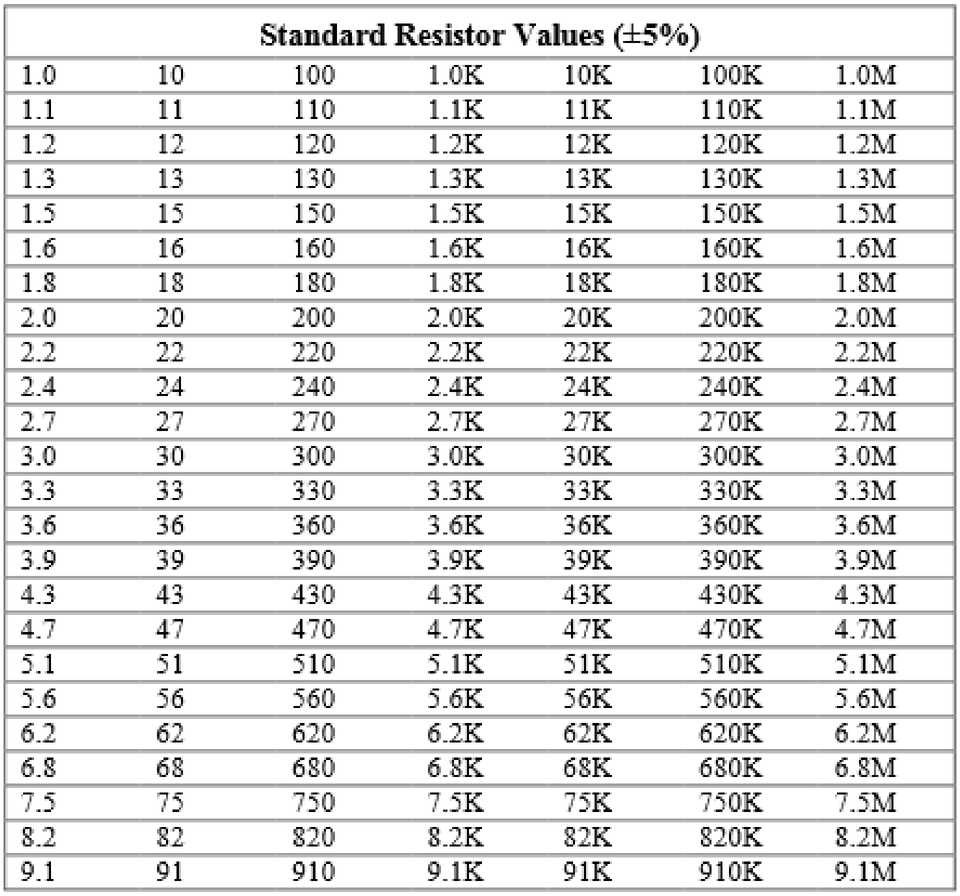
14 March 1954: Braves’ Henry Aaron homers in his 1st exhibition game. When he retired in 1976, again playing in Milwaukee, he had hit 755 home runs. Moral: don’t get hurt if a future hall of fame player is sitting on the bench. The same thing happened to Wally Pipp, when he sat out a game and let Lou Gehrig start his amazing 2130 consecutive game streak. Pipp was always criticized for not playing because he only had a headache, but he actually had a fractured skull (no helmets in those days). Maybe the moral should be to not believe the popular version of any story.

19 March 1954: 1st rocket-driven sled on rails tested in Alamogordo, NM

20 March 1954: 16th NCAA Men's Basketball Championship: La Salle beats Bradley 92-76

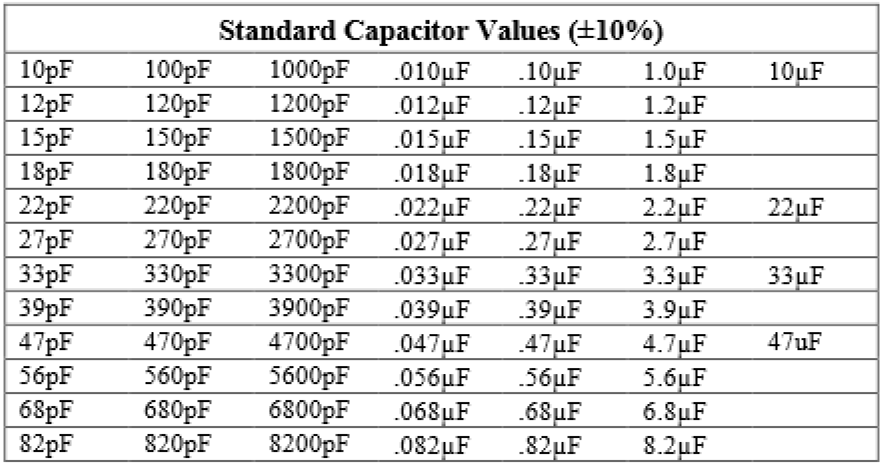
25 March 1954: RCA manufactures 1st color TV set (12½" screen at $1,000, which would have been **$8549.35** in 2013)

31 March 1954: US Air Force Academy in Colorado Springs Colo, established.



Standard Resistor Values (±5%)

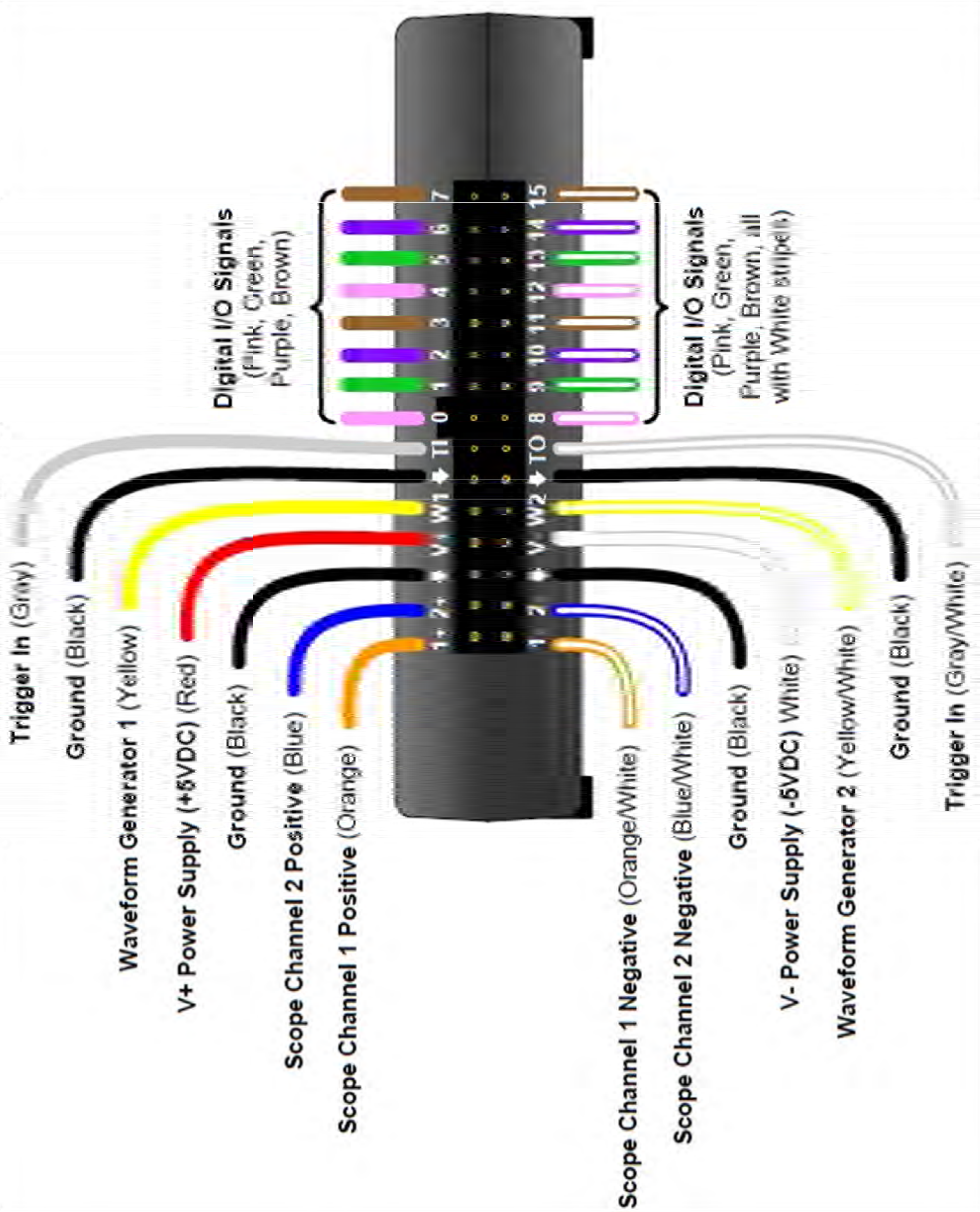
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M



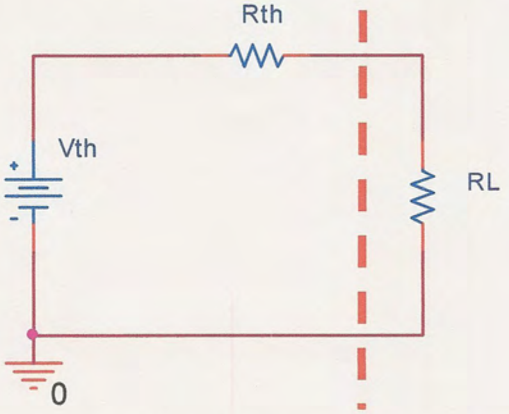
Standard Capacitor Values (±10%)

10pF	100pF	1000pF	.010µF	.10µF	1.0µF	10µF
12pF	120pF	1200pF	.012µF	.12µF	1.2µF	
15pF	150pF	1500pF	.015µF	.15µF	1.5µF	
18pF	180pF	1800pF	.018µF	.18µF	1.8µF	
22pF	220pF	2200pF	.022µF	.22µF	2.2µF	22µF
27pF	270pF	2700pF	.027µF	.27µF	2.7µF	
33pF	330pF	3300pF	.033µF	.33µF	3.3µF	33µF
39pF	390pF	3900pF	.039µF	.39µF	3.9µF	
47pF	470pF	4700pF	.047µF	.47µF	4.7µF	47uF
56pF	560pF	5600pF	.056µF	.56µF	5.6µF	
68pF	680pF	6800pF	.068µF	.68µF	6.8µF	
82pF	820pF	8200pF	.082µF	.82µF	8.2µF	

Analog Discovery Connections



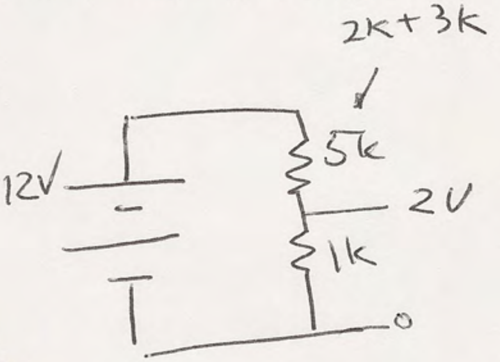
I. Thevenin Equivalent Voltage Source (25 Points)

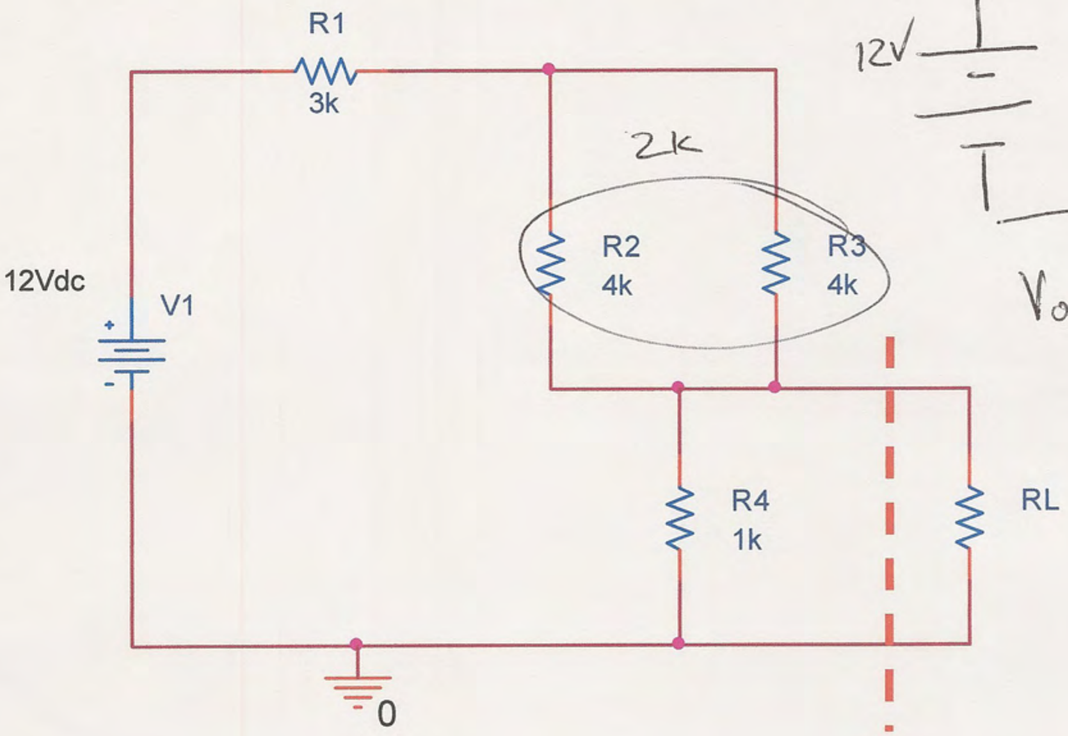


The Thevenin equivalent circuit consists of a voltage source in series with a resistor, which provides a very simple replacement for much more complex circuits. If we have this simple source, analyzing changing loads becomes quite easy.

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.

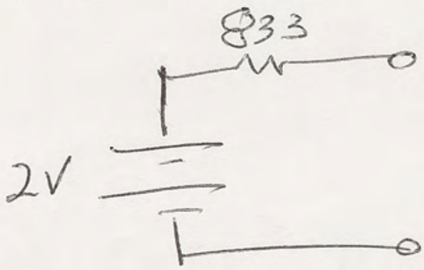
Circuit 1: (This is the simplest of the three problems.) {8 pts}



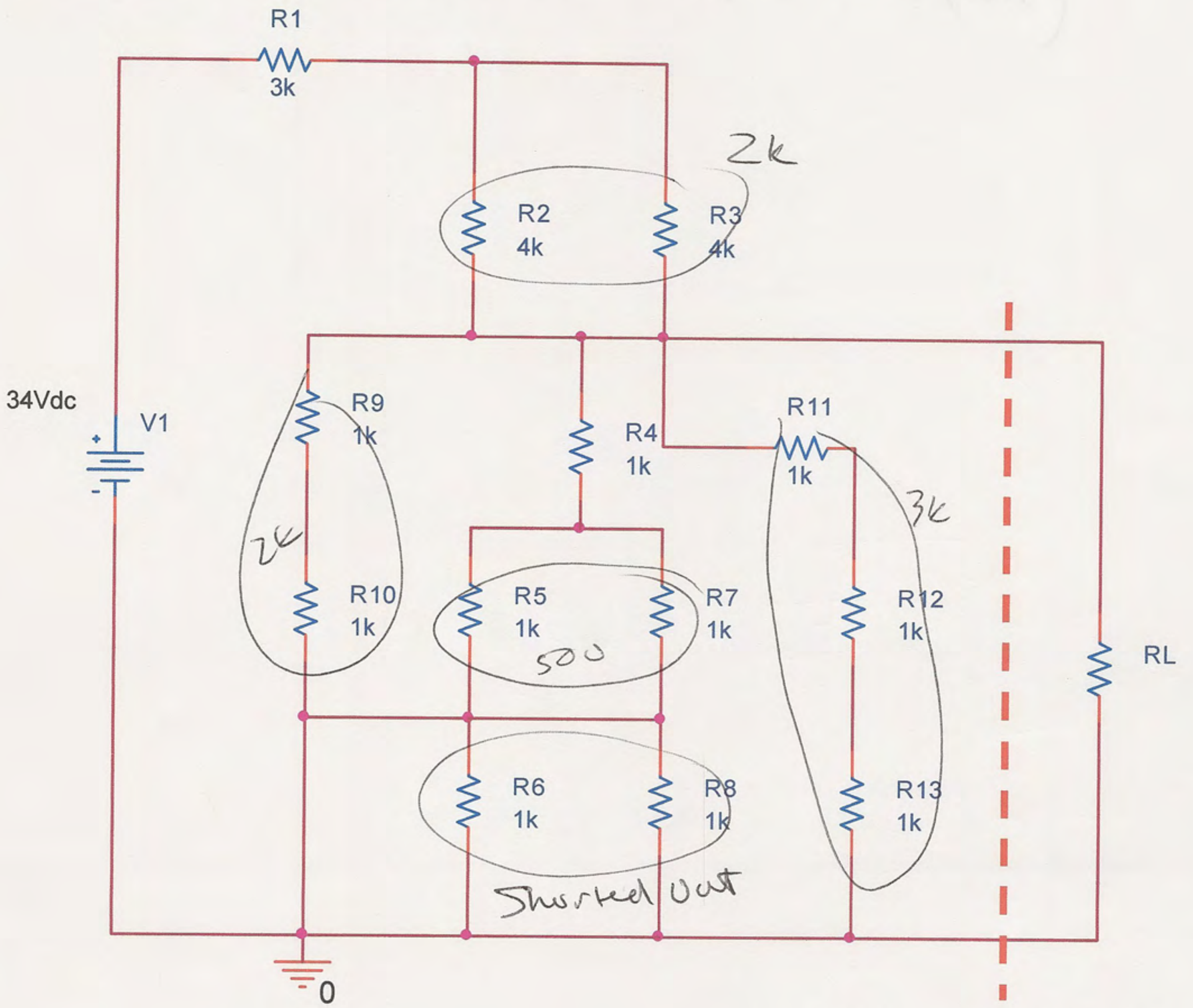


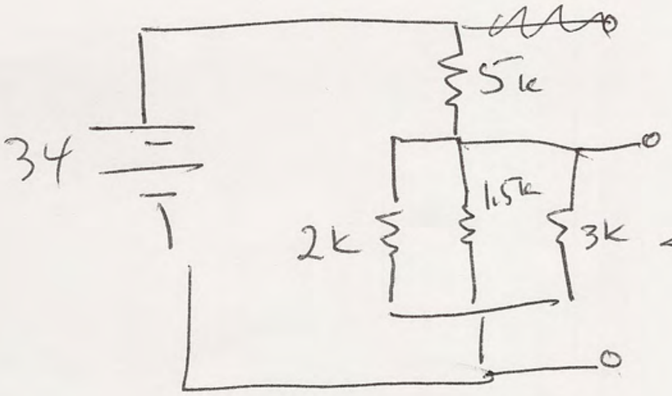
$V_{oc} = V_{th} = 2V$

5k || 1k = 833 Ω = Rth



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





← 2k || 1.5k || 3k

$= \frac{2}{3}k$

$34\,\frac{2/3}{5\,2/3} = 34\,\frac{2}{17} = 4V.$

$= V_{oc} = V_{th}$

$R_{th} = 5k \| 2k \| 1.5k \| 3k$

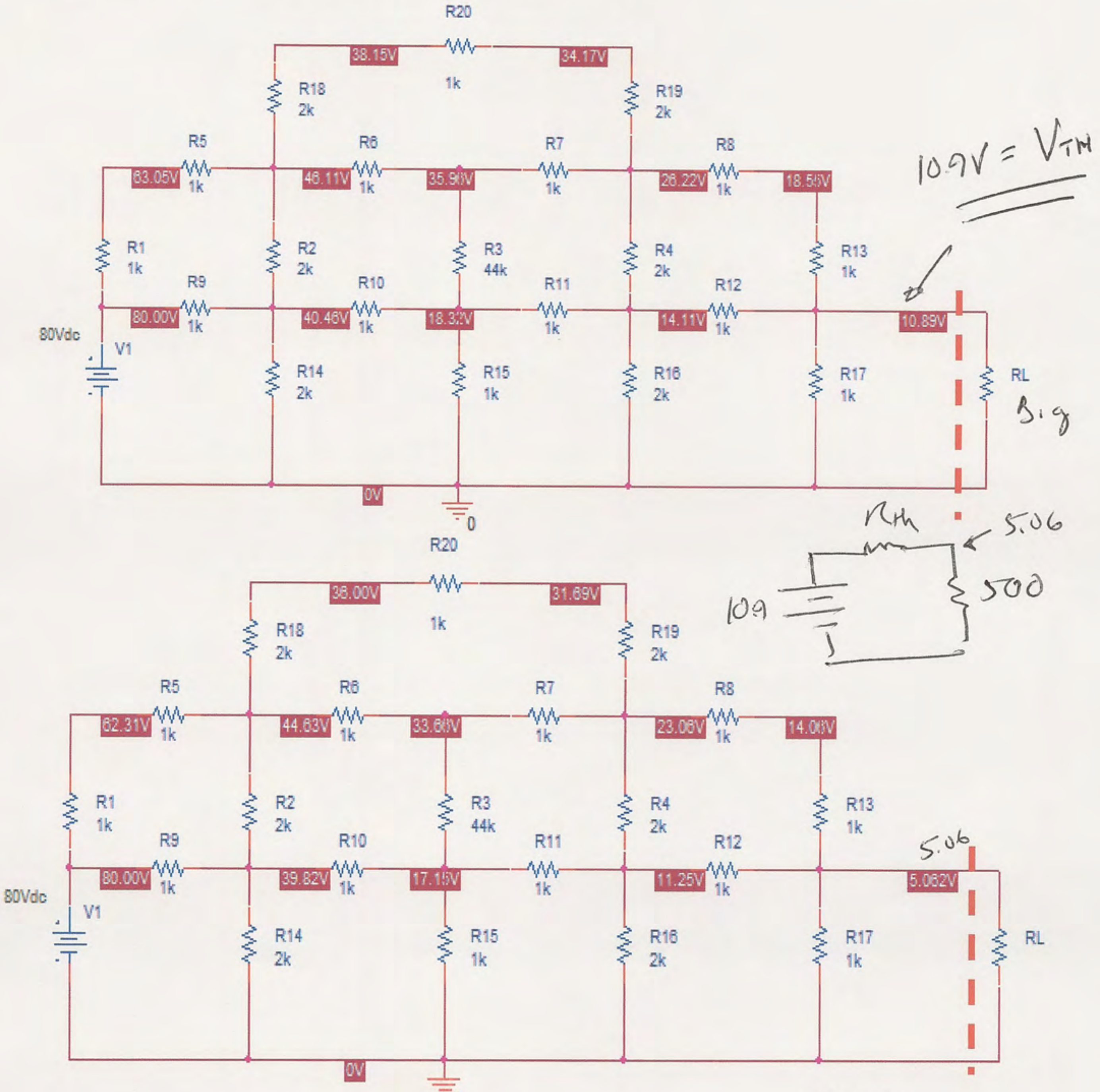
$= .59k = \underline{\underline{590}}$

$R_{th} = 5k \| 2k \| 1.\underset{6}{5}k \| 3k$
$= 588\ \Omega$

588 actually

Circuit 3:

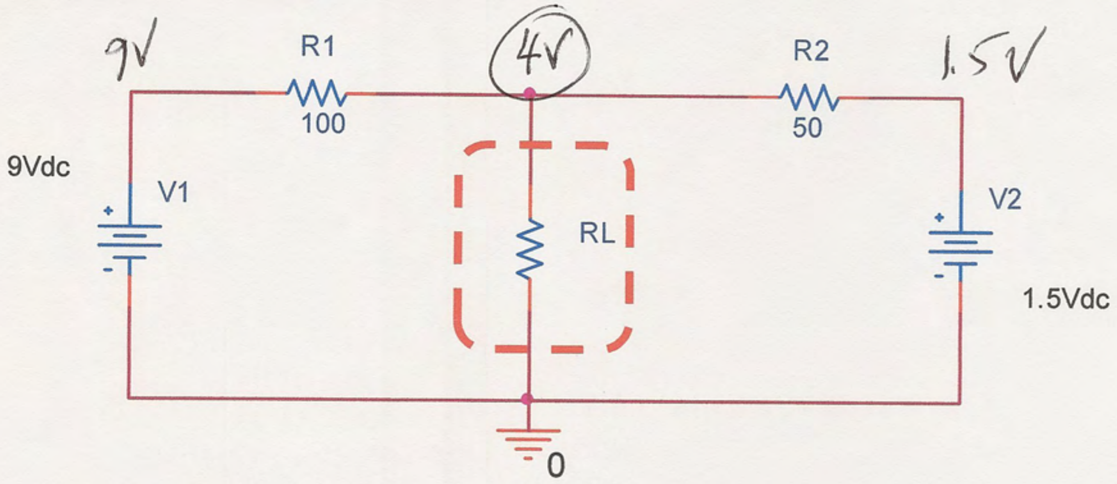
The 3rd circuit is significantly more complicated than the other two. Rather than analyze it from first principles, we will use the results from a PSpice simulation. In the first plot, the load resistor is very large (100MOhms) while in the second the load resistor is much smaller (500Ohms). Using the given voltages at each of the nodes for an open circuit load (RL is the load) and for a 500Ω load, determine Vth and Rth. {8 pts}



$$5.06 = 10.9 \frac{500}{500+R_{th}} \Rightarrow R_{th} = 577$$

Circuit 4:

Now we want to try something a little different and connect two sources to the same load and then find the Thevenin Equivalent. {4 pts}



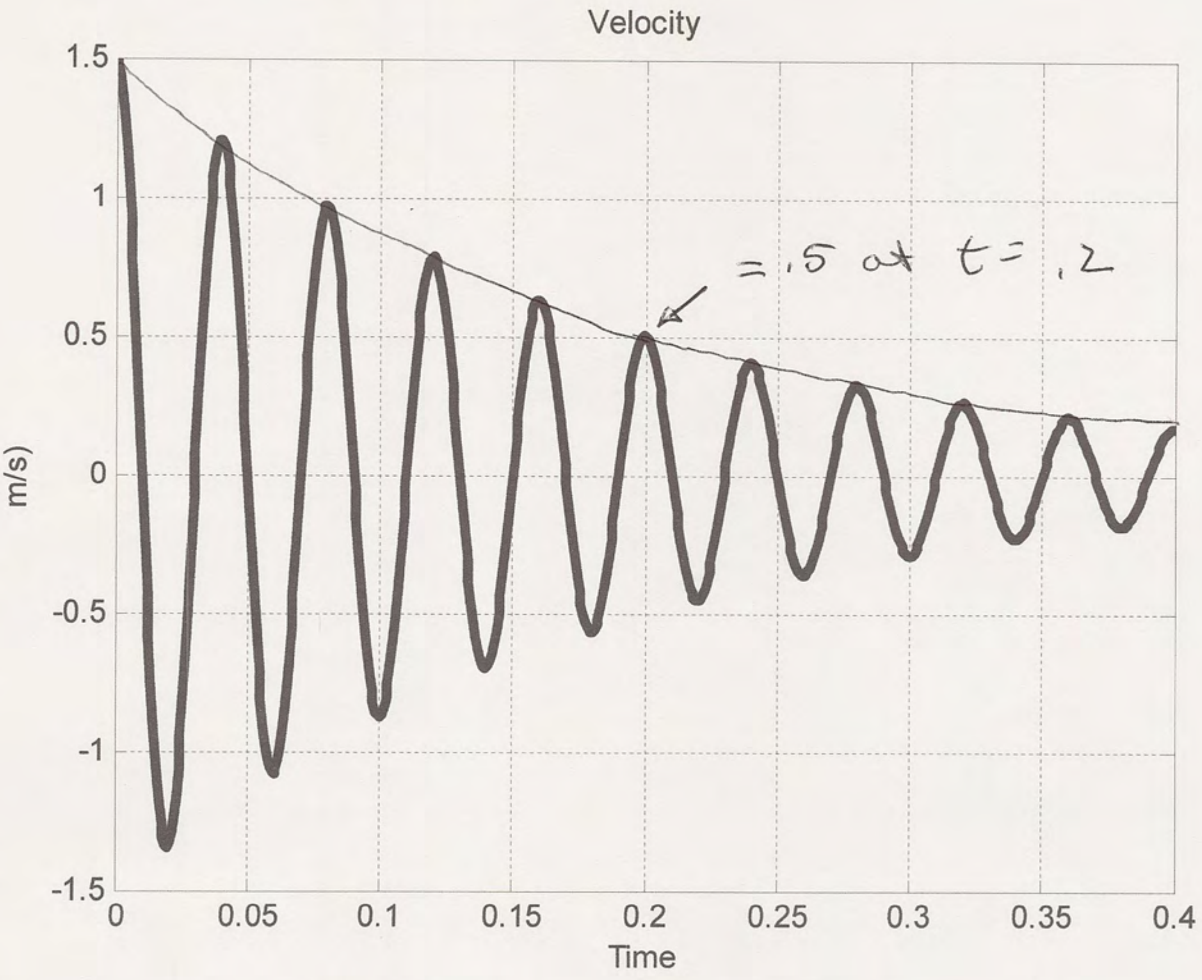
$9 - 1.5 = 7.5V.$

$\frac{50}{150} 7.5 + 1.5 = 4V. = V_{OC} = V_{TH}$

$R_{TH} = 50 \parallel 100 = 33.3 \Omega$

II. Harmonic Oscillators (25 Points)

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



where the horizontal scale is time (0.05 sec per division) and the vertical scale is velocity (0.05m/s per division).

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

10 cycles in .4 sec $= \frac{10}{.4} = 25$ Hz

$1.5e^{-\alpha(.2)} = .5$

$-\alpha(.2) = -1.1$

$\alpha = \frac{1.1}{.2} = 5.5$ (values between 5 & 6 OK)

$\boxed{\text{Actually } 5.43}$

b. Write the mathematical expression for the velocity in the form $v(t) = Ae^{-\alpha t}\cos\omega t$ in m/s. Use real values for the constants and provide units where appropriate. {6 pts}

$$V(t) = 1.5\, e^{-5.5t} \cos(50\pi t)$$

$$\omega = 2\pi f = 50\pi$$

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.* {4 pts}

$$a = \frac{dV}{dt} = \cancel{(1.5)(-5.5)e^{-5.5t}\cos 50\pi t}$$

Neglect the small term

$$-(1.5)(50\pi)e^{-5.5t}\sin 50\pi t$$

$$\approx -75\pi e^{-5.5t}\sin 50\pi t$$

d. A guess is made for the amplitude of the beam position *x(t)*. The consensus of the team partners is that the displacement is about 1cm or 0.01m. Write the mathematical expression for the position in the form $x(t) = Be^{-\alpha t}\sin\omega t$ in meters, find the approximate velocity *v(t)* and compare the result with your answer to part b. Was the guess high, low or about right? {4 pts}

$$x = (0.01)e^{-5.5t}\sin 50\pi t$$

$$V = \frac{dx}{dt} = \cancel{(0.01)(-5.5)e^{-5.5t}\sin 50\pi t}$$

neglect

$$+(0.01)(50\pi)e^{-5.5t}\cos 50\pi t$$

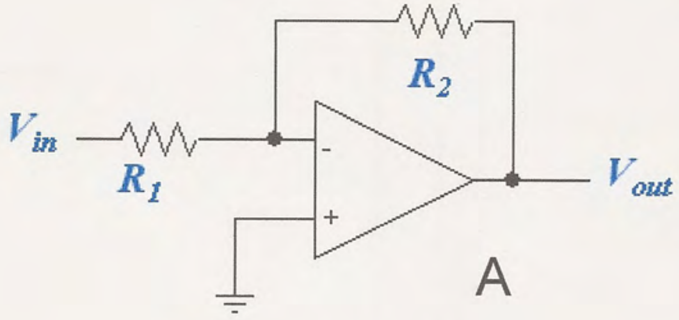
$$\approx \frac{\pi}{2}e^{-5.5t}\cos 50\pi t$$

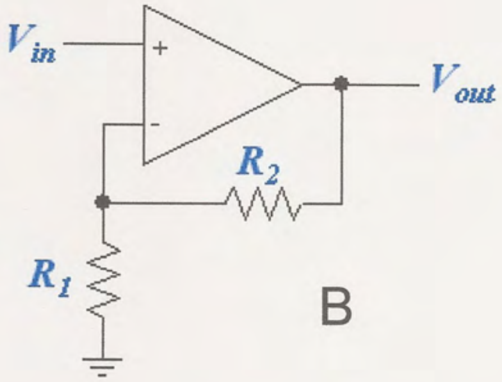
Note that $\frac{\pi}{2} \approx 1.5$ so a good guess

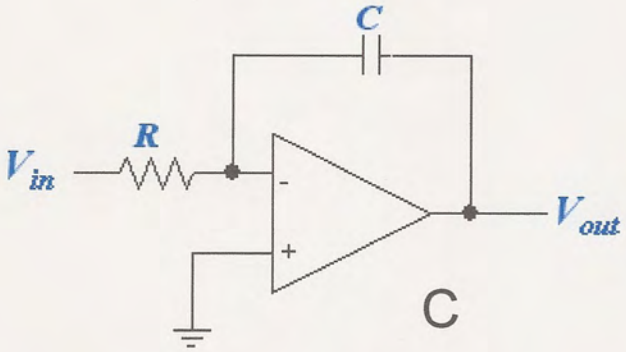
e. Assume that you would like to build an LC oscillator circuit that operates at the same frequency and the beam above. You have an 8F capacitor (they do exist) and need to make an inductor. What value of inductance is necessary to achieve this frequency? {5 pts}

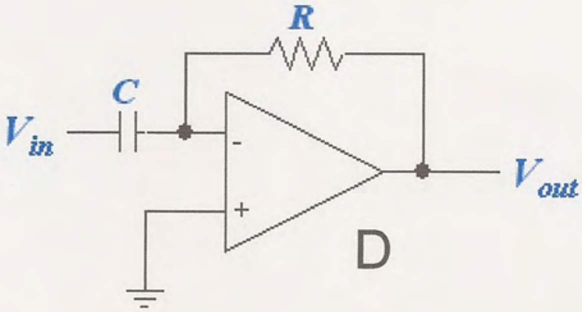
$$\omega = \frac{1}{\sqrt{LC}} \Rightarrow L = \frac{1}{\omega^2 C} = \frac{1}{(50\pi)^2 8} \cong 5\mu H$$

III. Operational Amplifiers (25 Points)



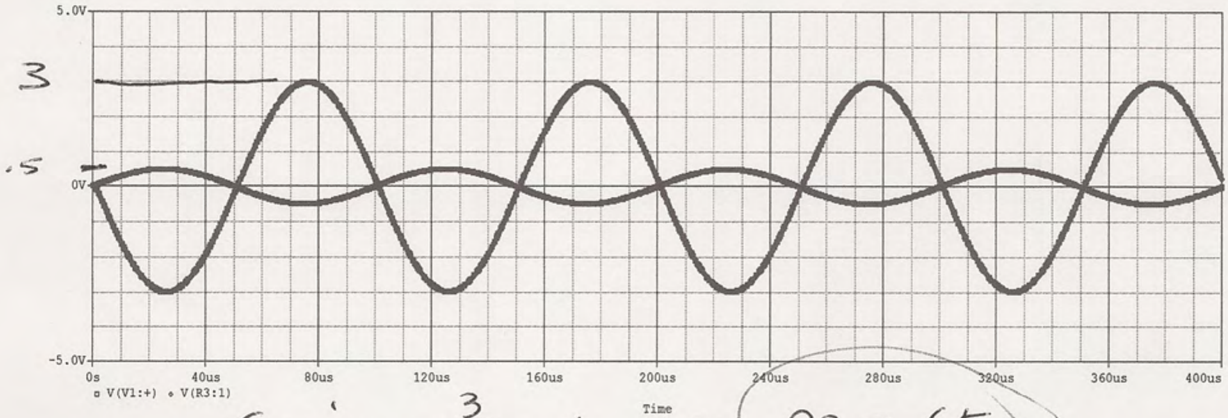






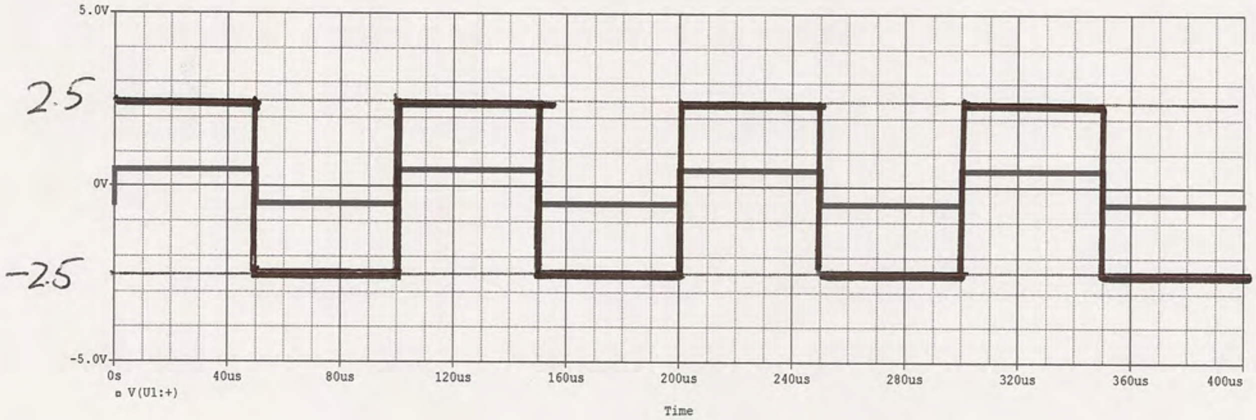
a. {2 pts} What type of amplifier is each circuit?
  - a. A INVERTING
  - b. B NON INVERTING
  - c. C INTEGRATOR
  - d. D DIFFERENTIATOR

b. {4 pts} The input voltage for circuit A is shown below. If R1=1kΩ, solve for the value of R2. The vertical scale -5V to +5V and the horizontal scale is from 0 to 400μs.

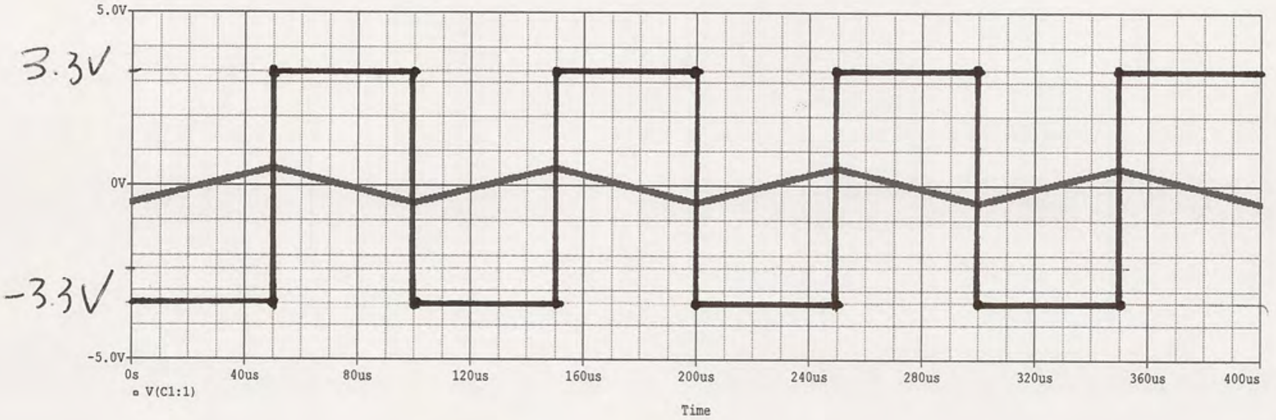


$\text{Gain} = \frac{3}{.5} = 6 \Rightarrow \boxed{R2 = 6K}$

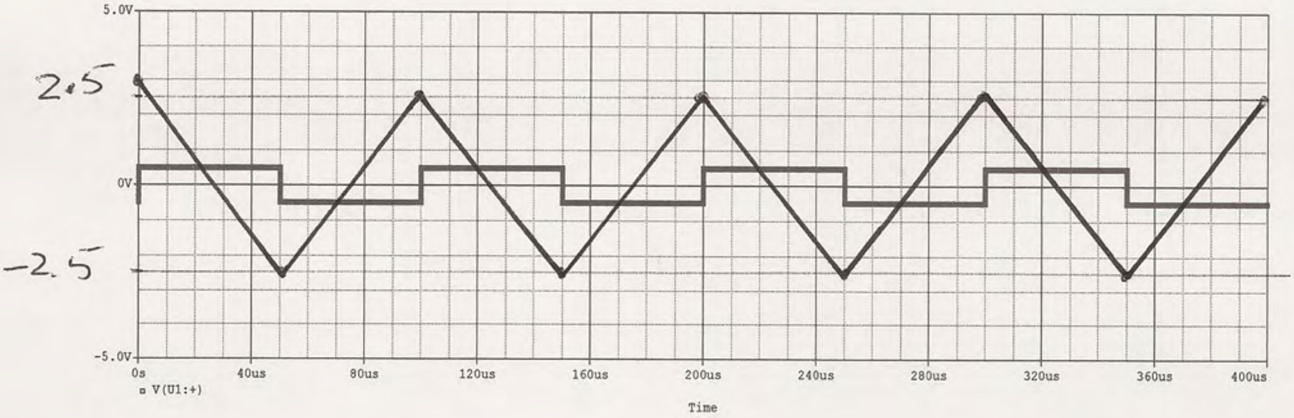
c. {4 pts} The input voltage for circuit B is shown below. Solve for and sketch the output voltage with R_1=2kΩ and R_2=8kΩ. Same scales as in part b.



d. {4 pts} The input voltage is shown below. Solve for and sketch the output voltage for circuit D with C=.033μF and R=5kΩ. Same scales as in part b.



e. {4 pts} The input voltage is shown below. Solve for and sketch the output voltage for circuit C with R=100Ω and C=0.047μF. Same scales as in part b.



Workspace for parts b-e:

c. $\text{Gain} = \frac{R_2}{R_1} + 1 = 4 + 1 = 5$

d. $RC = (5000)(.033)(10^{-6})$

slope of triangular wave $= \frac{0.5 + 0.5}{50\,\mu s} = \frac{10^6}{50} = 2 \times 10^4$

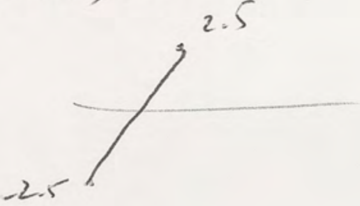
$(RC) \times (\text{slope}) = (5000)(.033)10^{-6}(2 \times 10^4) = 3.3$

Differentiator $RC\frac{d}{dt}$

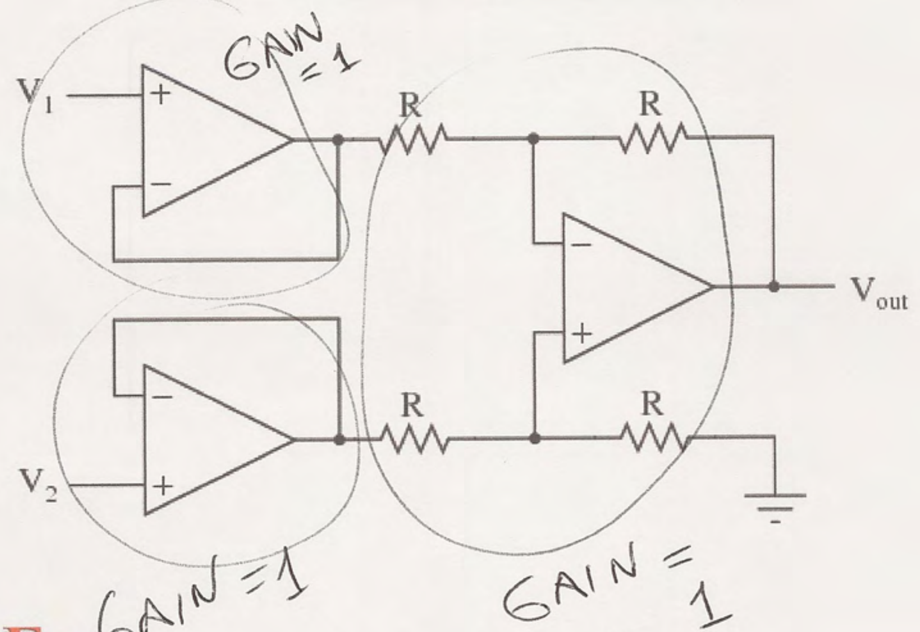
e. const from square wave

$\frac{1}{RC}\int .5\,dt = \frac{.5t}{(100)(.047)10^{-6}} = 1.06 \times 10^5 \simeq 10^5$

$(10^5)(\underbrace{50\,\mu s}_{\text{half periods}}) = 5$

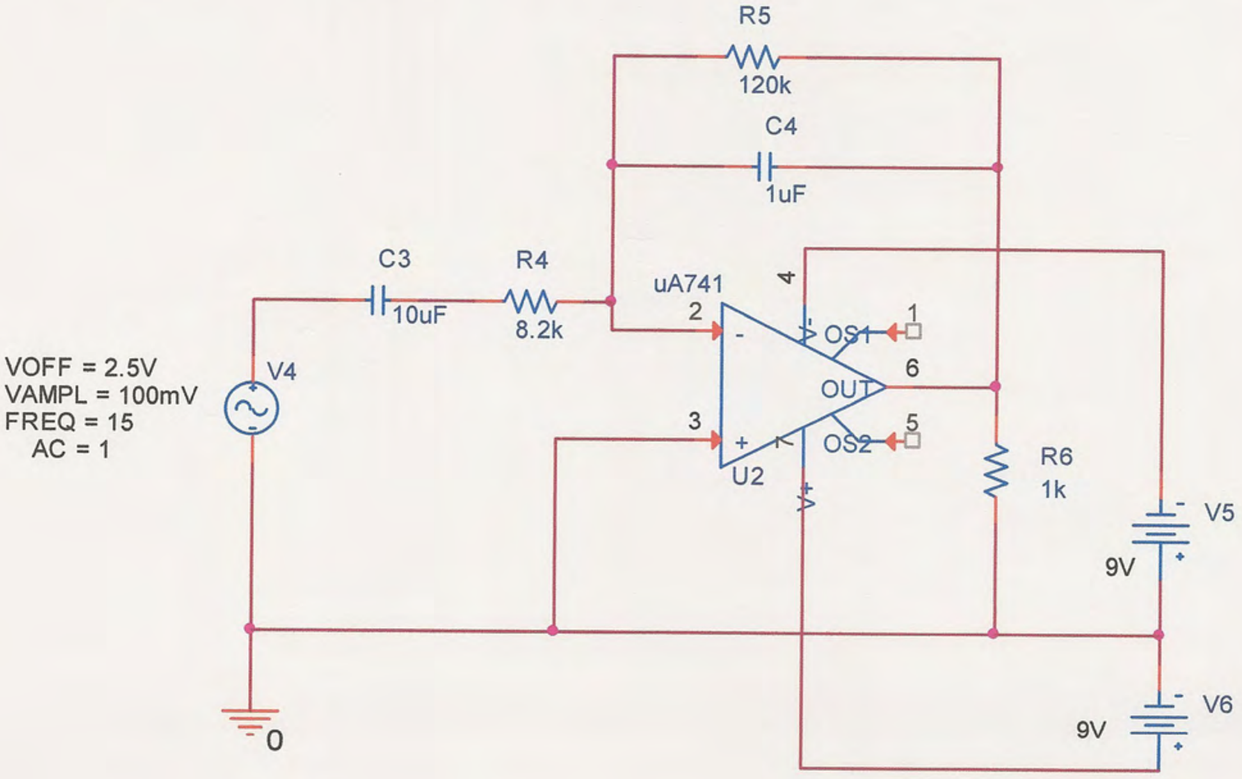


f. {2pts} Determine the output V_{out} of the circuit below in terms of V_1 and V_2.



$V_{out} = V_2 - V_1$

g. {5 pts} You should recognize the circuit below as a slight modification of the integrator circuit from Project 2. The only change in the circuit is that a capacitor C3 has been added between the signal source V4 (which represents the output from the accelerometer) and the input resistor R4. C3 is added to block the DC offset but, if chosen correctly, will still permit the circuit to function as an integrator for frequencies of interest. Estimate the range of frequencies for which this circuit will work as an integrator. Specify the criterion you are applying to obtain your answer.



C3 & R4 are in series so $Z_{C_3} << R_4$ to ignore it.

$Z_{C_3} < \frac{R_4}{10}$ Any reasonable criterion is OK

$\frac{1}{\omega C_3} < \frac{R_4}{10}$

or $\omega > \frac{10}{R_4 C_3} = \frac{10}{(8.2k)(10^{-5})} \simeq 100$ (actually 122)

or $f \gtrsim 19$ Hz

IV. Concepts, Troubleshooting and Data Analysis (25 Points)

a. {6 pts} Today's date is 3-19-2014. 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. 3 Black - Orange - Black

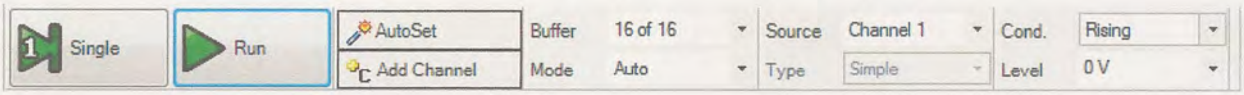
  b. 19 Brown - White - Black

  c. ~~2014~~ Cannot do 4 numbers

b. {3 pts} Classroom Knowledge: Where are the four multi-meters found in the classroom?

2 on center table, one each under the side cabinets

c. {6 pts} Triggering: The Analog Discovery oscilloscope, like all oscilloscopes, must be told when to start displaying the signal. To set up triggering you must select the channel you will use to trigger the plot, the trigger level (indicated by a small triangle on the screen), whether you will trigger the plot when the signal crosses the specified level while it is increasing (rising) or decreasing (falling), and where on the screen (in time) you will start the plot (this is also indicated with a small triangle). All but the last of these specifications are done using drop-down menus at the top of the oscilloscope screen. In the four cases shown below, Auto triggering is chosen for simplicity.



Buffer 16 of 16
Mode Auto
Source Channel 1
Type Simple
Cond. Rising
Level 0 V

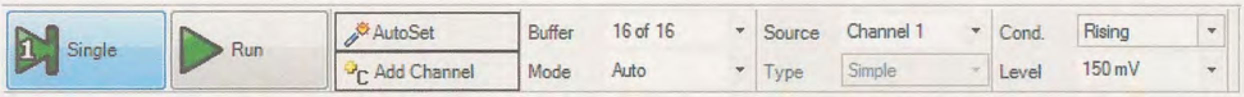
A

Buffer 16 of 16
Mode Auto
Source Channel 1
Type Simple
Cond. Falling
Level 0 V

B

Buffer 16 of 16
Mode Auto
Source Channel 1
Type Simple
Cond. Falling
Level 150 mV

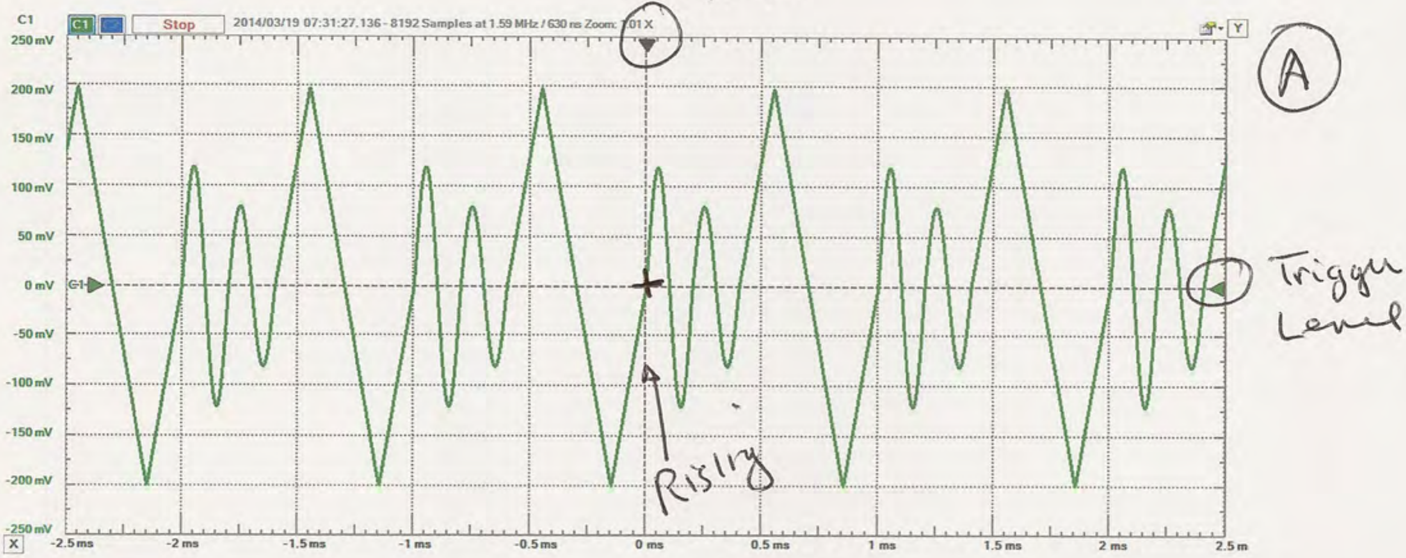
C

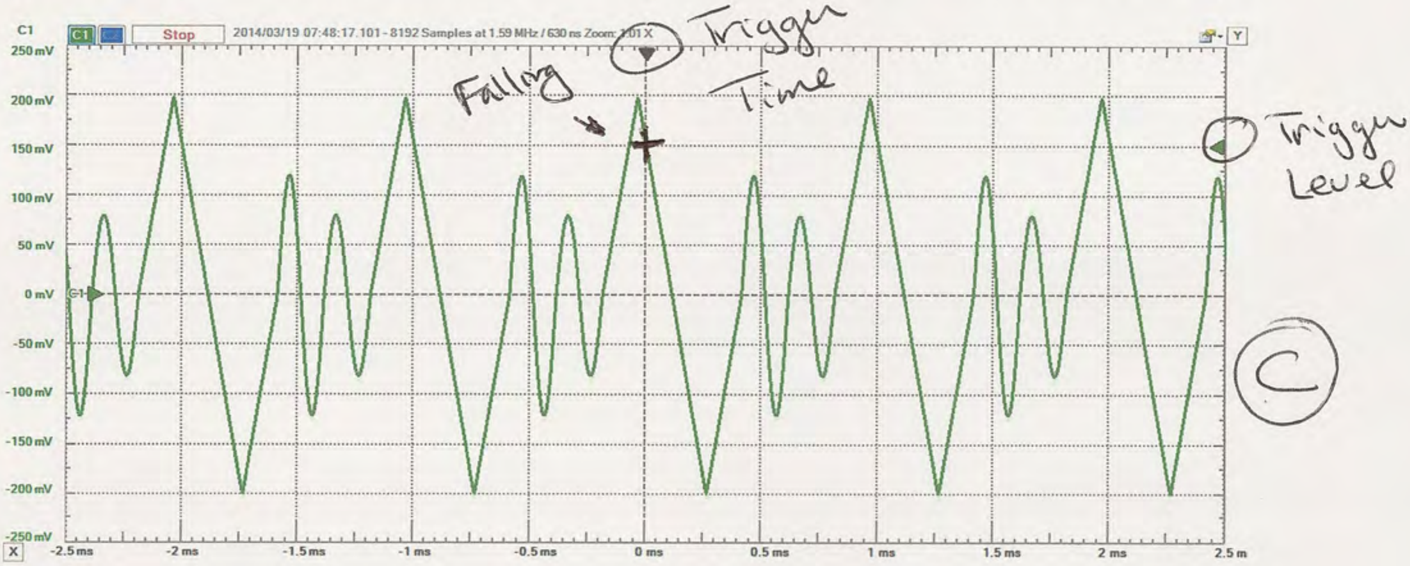


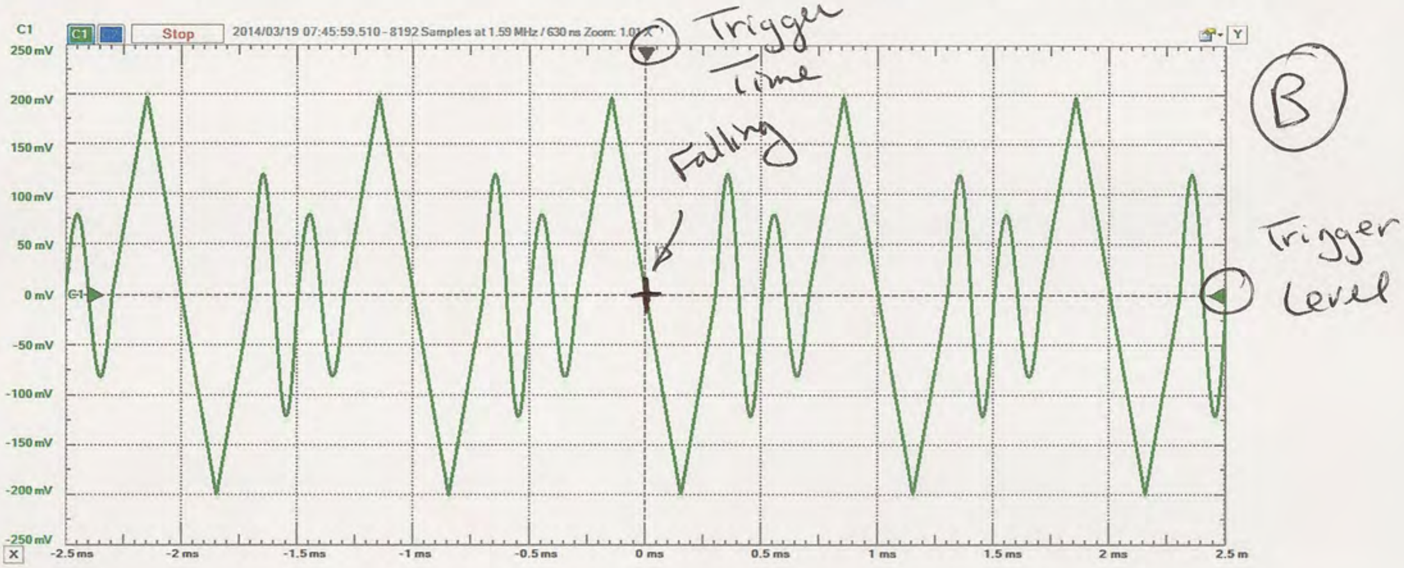
Buffer 16 of 16
Mode Auto
Source Channel 1
Type Simple
Cond. Rising
Level 150 mV

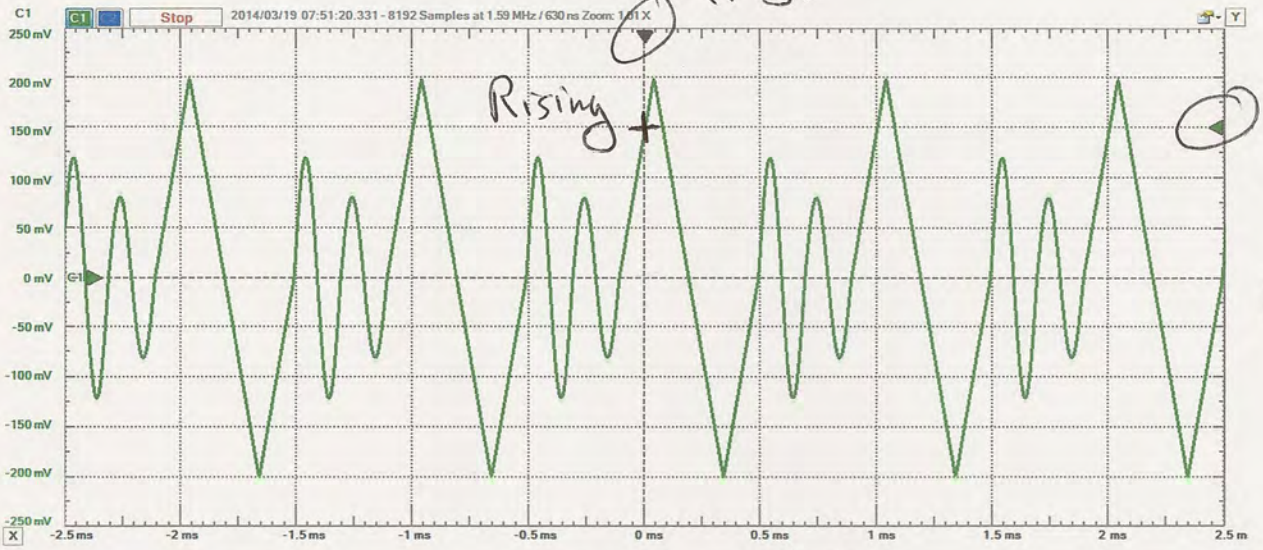
D

For each of the six plots below, circle and label the small triangle that shows the triggering level and the small triangle that shows where in time that the signal crosses the trigger level. Also indicate which of the four triggering specifications was used to generate the plot using the letters A-D.

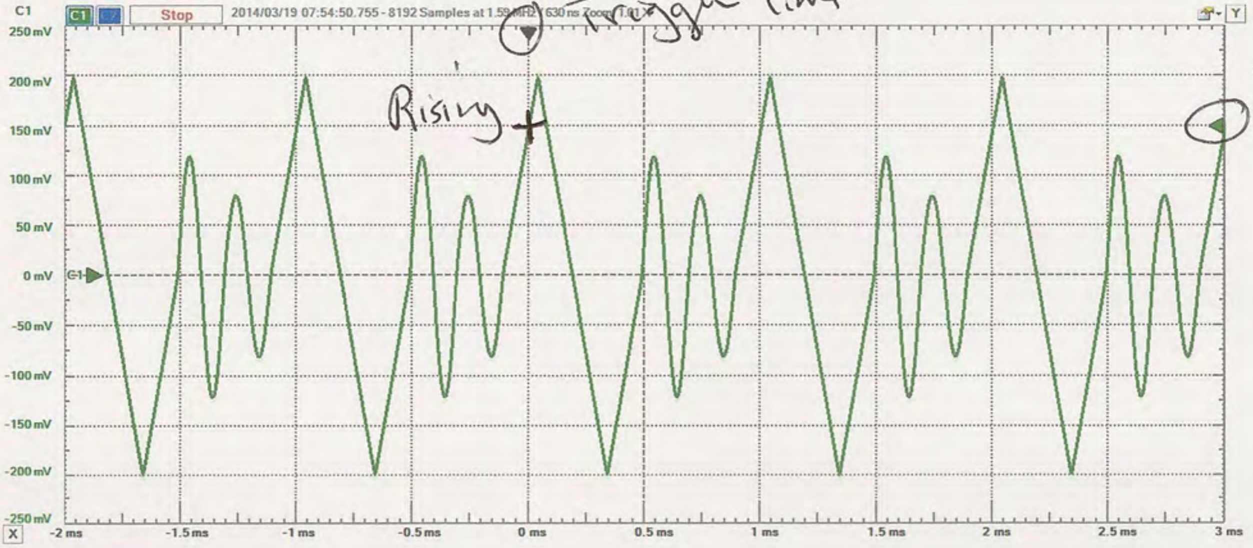

Trigger Time
A
C1
Stop
2014/03/19 07:31:27.136 - 8192 Samples at 1.59 MHz / 630 ns Zoom: 1.01 X
250 mV
200 mV
150 mV
100 mV
50 mV
0 mV
-50 mV
-100 mV
-150 mV
-200 mV
-250 mV
-2.5 ms
-2 ms
-1.5 ms
-1 ms
-0.5 ms
0 ms
0.5 ms
1 ms
1.5 ms
2 ms
2.5 m
Trigger Level
Rising


C1
Stop
2014/03/19 07:48:17.101 - 8192 Samples at 1.59 MHz / 630 ns Zoom: 1.01 X
Trigger Time
Falling
Trigger Level
C
250 mV
200 mV
150 mV
100 mV
50 mV
0 mV
-50 mV
-100 mV
-150 mV
-200 mV
-250 mV
-2.5 ms
-2 ms
-1.5 ms
-1 ms
-0.5 ms
0 ms
0.5 ms
1 ms
1.5 ms
2 ms
2.5 m

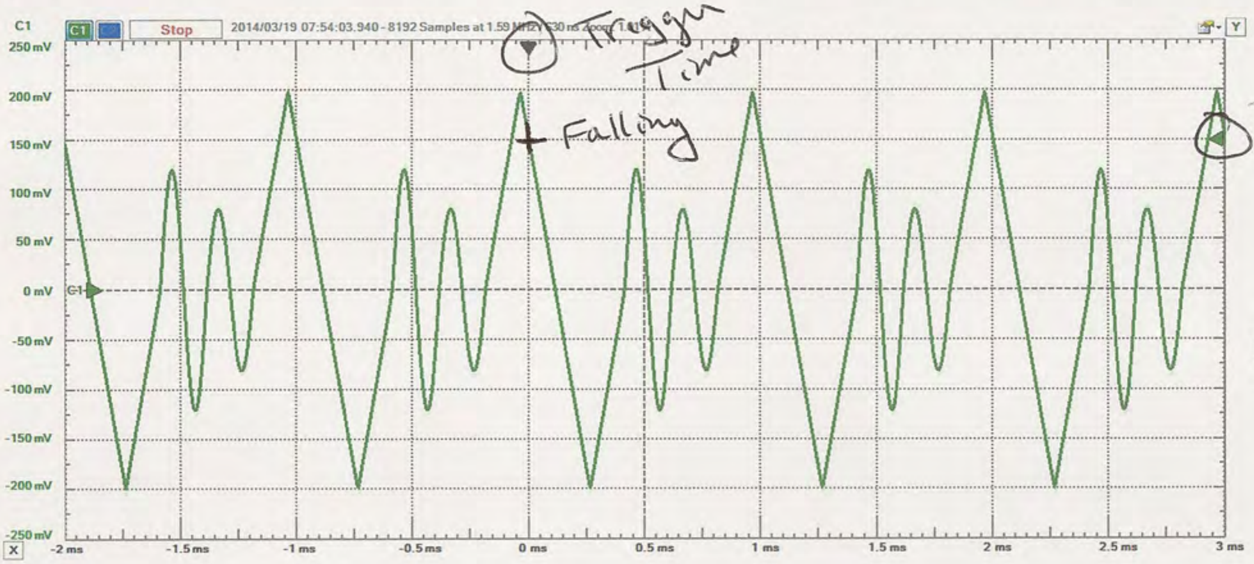

C1
Stop
2014/03/19 07:45:59.510 - 8192 Samples at 1.59 MHz / 630 ns Zoom: 1.01 X
Trigger Time
B
Falling
Trigger Level
250 mV
200 mV
150 mV
100 mV
50 mV
0 mV
-50 mV
-100 mV
-150 mV
-200 mV
-250 mV
-2.5 ms
-2 ms
-1.5 ms
-1 ms
-0.5 ms
0 ms
0.5 ms
1 ms
1.5 ms
2 ms
2.5 m


C1
Stop
2014/03/19 07:51:20.331 - 8192 Samples at 1.59 MHz / 630 ns Zoom: 1.01 X
250 mV
200 mV
150 mV
100 mV
50 mV
0 mV
-50 mV
-100 mV
-150 mV
-200 mV
-250 mV
-2.5 ms
-2 ms
-1.5 ms
-1 ms
-0.5 ms
0 ms
0.5 ms
1 ms
1.5 ms
2 ms
2.5 ms
Trigger Time
Rising
Trigger Level

D

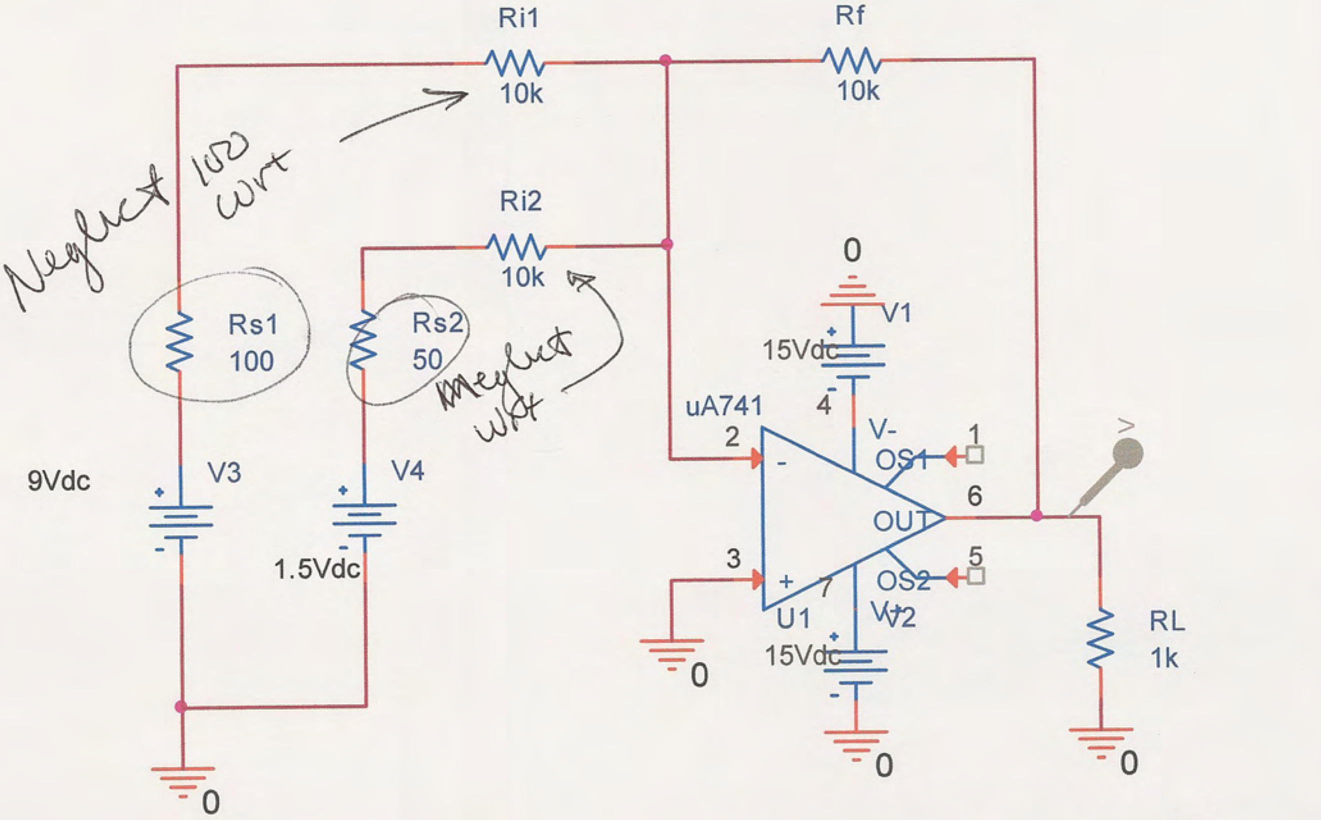

C1
Stop
2014/03/19 07:54:50.755 - 8192 Samples at 1.59 MHz / 630 ns Zoom: 1.01 X
250 mV
200 mV
150 mV
100 mV
50 mV
0 mV
-50 mV
-100 mV
-150 mV
-200 mV
-250 mV
-2 ms
-1.5 ms
-1 ms
-0.5 ms
0 ms
0.5 ms
1 ms
1.5 ms
2 ms
2.5 ms
3 ms
Trigger Time
Rising
Trigger Level

D


C1
Stop
2014/03/19 07:54:03.940 - 8192 Samples at 1.59 MHz / 630 ns Zoom: 1.01 X
250 mV
200 mV
150 mV
100 mV
50 mV
0 mV
-50 mV
-100 mV
-150 mV
-200 mV
-250 mV
-2 ms
-1.5 ms
-1 ms
-0.5 ms
0 ms
0.5 ms
1 ms
1.5 ms
2 ms
2.5 ms
3 ms
Trigger Time
Falling
Trigger Level

C

d. {5 pts} Reworking a Previous Problem: In Problem 1, **Circuit 4**, two voltage sources where connected to the same load and you were asked to find the Thevenin equivalent of the combination. Here we consider the same two sources connected to the op-amp as shown below. Identify the type of op-amp circuit this is and determine the voltage across the load resistor RL.



Neglect 100Ω wrt

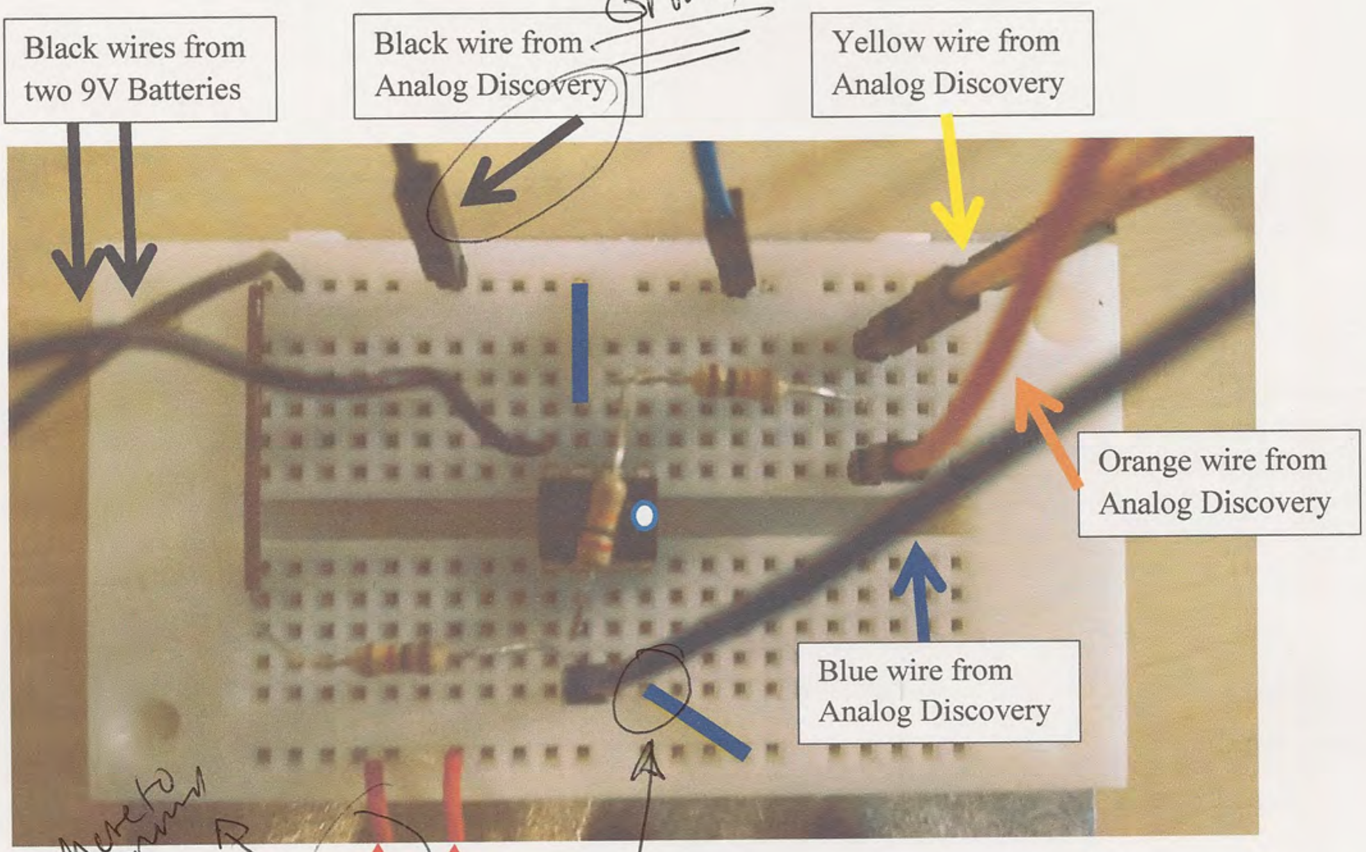
Neglect wrt

Adder Ckt

$$V_{out} = \frac{10k}{10k} 9 + \frac{10k}{10K} 1.5$$

$$= 10.5 V$$

e. {5 pts} Circuit-Building Errors: The circuit shown below and on the next page has two errors in its construction. First identify the type of circuit this is and then circle and explain the two construction errors. Also draw a circuit diagram, which will help identify the problems. The battery wires and the main wires from Analog Discovery are labeled. The blue and orange wires with stripes are not labeled to avoid clutter in the figure. Two jumper wires have been made darker to make them easier to see. They are a lighter color in the second photo. A bright white dot has been added to the chip because the little dimple was hard to see in the first figure.



Black wires from two 9V Batteries

Black wire from Analog Discovery

Ground

Yellow wire from Analog Discovery

Orange wire from Analog Discovery

Blue wire from Analog Discovery

Move to ground

Red wires from two 9V Batteries

The red wire for the DC Power connected to Pin 4 should be grounded

+Vcc Connected to Pin 8

Inverting op-amp