ENGR-2300

Electronic Instrumentation

Quiz 1

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 Day in History – 19 February

I enjoy history very much, especially history that has something to do with engineering and electronics. There are so many things that happened on this day that I will not limit things to just technology. However, you should know that something in this short summary of the events of 19 February will show up in a question on this quiz. Engineers, scientists, Americans, world citizens … can feel proud about some of the things that happened on this date. There are also some events that should make us less than proud.

1847 – The first group of rescuers reaches the Donner Party. The Donner Party was a group of American pioneers who set out for California in a wagon train. Delayed by a series of mishaps, they spent the winter of 1846–47 snowbound in the Sierra Nevada. Some of the emigrants resorted to cannibalism to survive, eating those who had succumbed to starvation and sickness. Of the 87 members of the party, 48 survived to reach California. Historians have described the episode as one of the most spectacular tragedies in Californian history and in the record of western migration.

Topographic map of Tunnel 6's location (note also tunnels 7 and 8 to the east). This comes from the Manual for Railroad Engineers, 1883 and was drawn by Samuel Montague and Lewis M. Clement CPRR Chief and Ass't Chief engineers responsible for building Tunnel 6 and the CPRR line. "Summit Lakes" is now just Lake Mary which turned the two lakes into one with a railroad built dam to store water for steam powered locomotives.

In the 1860s, the first American transcontinental railroad crossed Donner Pass at an elevation of 7,000 feet, through an area that gets an average of 34 feet of snow a year. The route follows the plan laid out by Theodore Judah for whom Donner Summit's Mt. Judah is named. At 1659ft, the tunnel at Donner Pass is the longest of the 15 tunnels necessary to take the Central Pacific RR through the Sierras. Today much of the original route is still in use. The Summit Tunnel has been replaced by a 10,322-foot tunnel known as The Big Hole, which passes beneath Mt. Judah about a mile south of Donner Pass. Theodore Judah is a member of the Rensselaer Alumni Hall of Fame. His picture is etched in the window glass near the south entrance of the DCC.

1878 – Thomas Edison patents the phonograph.

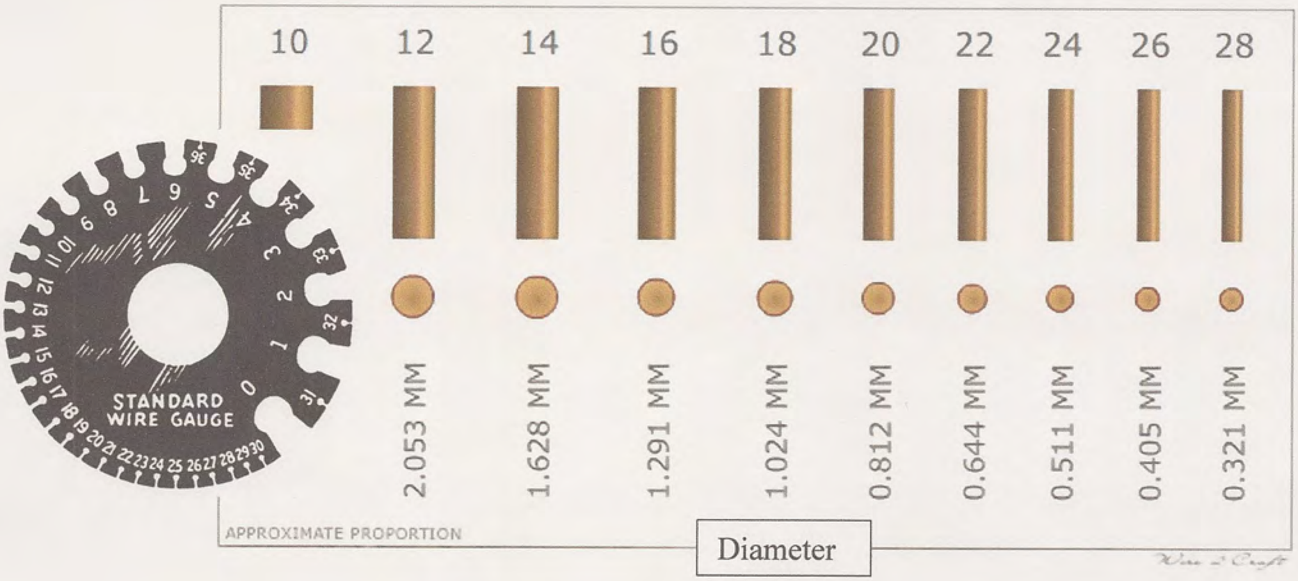
1942 – President Franklin D. Roosevelt signs the executive order 9066, allowing the United States military to relocate Japanese-Americans to internment camps.

1943 – Homer Hickam, American author and engineer, is born. His autobiographical novel *Rocket Boys: A Memoir*, was a No. 1 New York Times Best Seller, is studied in many American and international school systems, and was the basis for the film *October Sky*.

1976 – Executive Order 9066 is rescinded by President Gerald R. Ford's Proclamation 4417.

2002 – NASA's Mars Odyssey space probe begins to map the surface of Mars using its thermal emission imaging system.

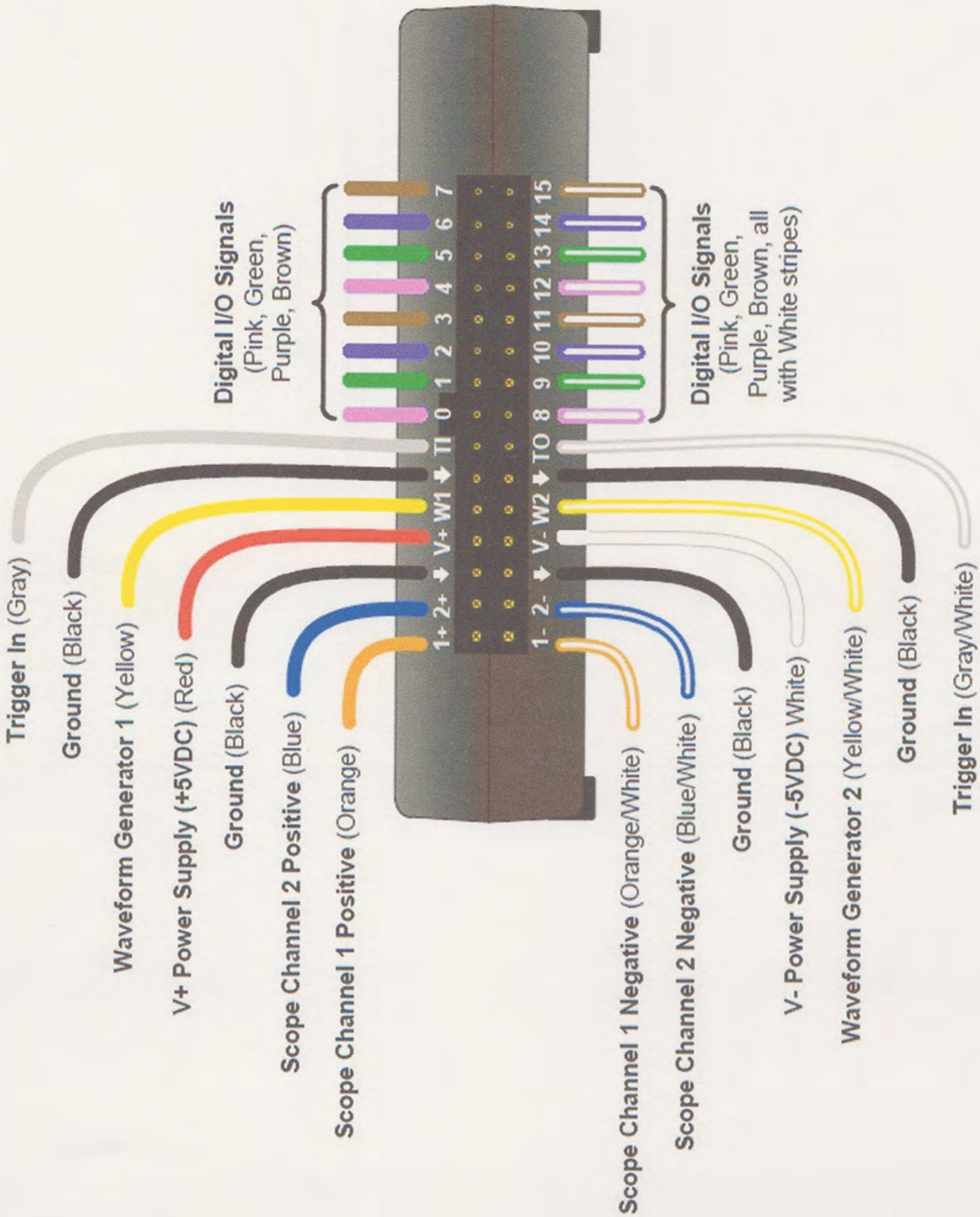
Additional Reference Info



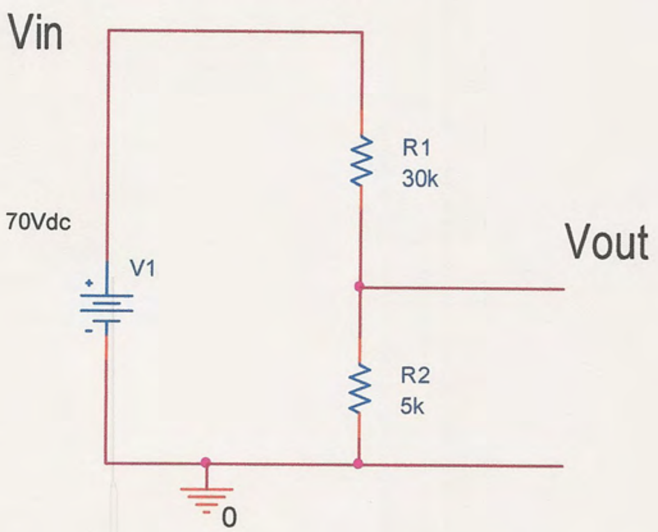
Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	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. Resistive circuits (25 points)



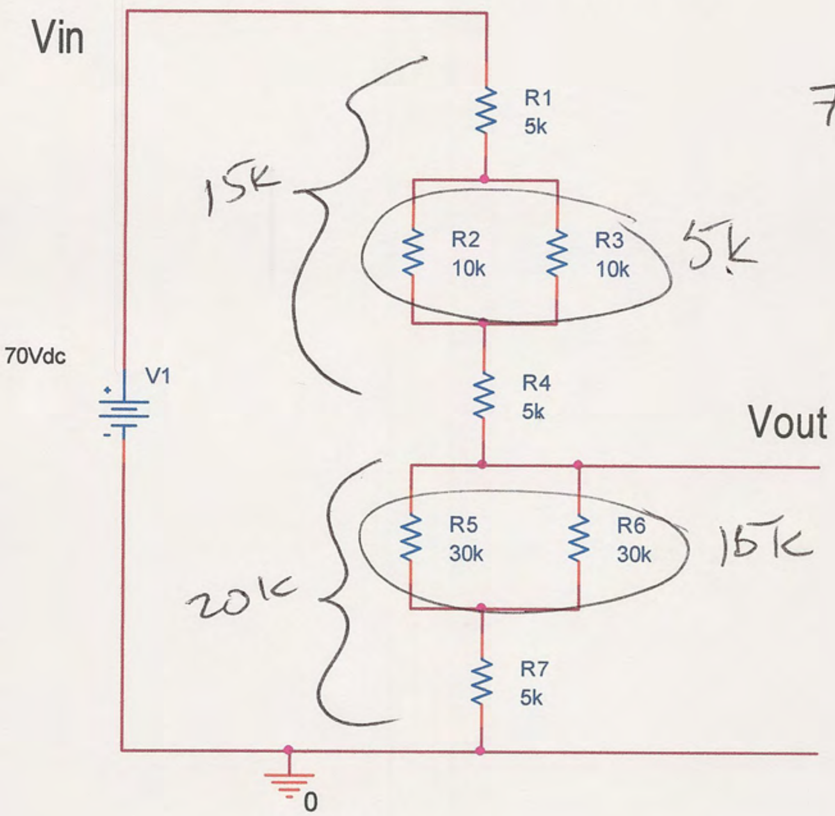
Voltage Divider

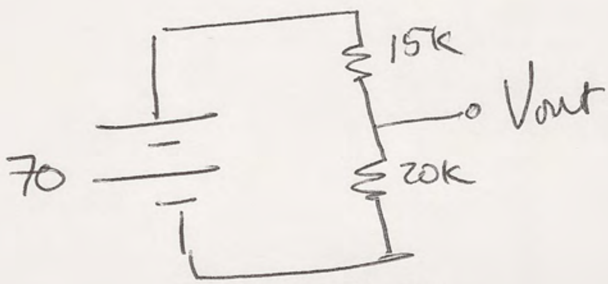
$$V_{out} = V_{in} \frac{R2}{R1+R_2}$$

$$= 70 \frac{5}{35}$$

$$= 10V$$

a) Find the voltage Vout in the circuit above. (4 pts)



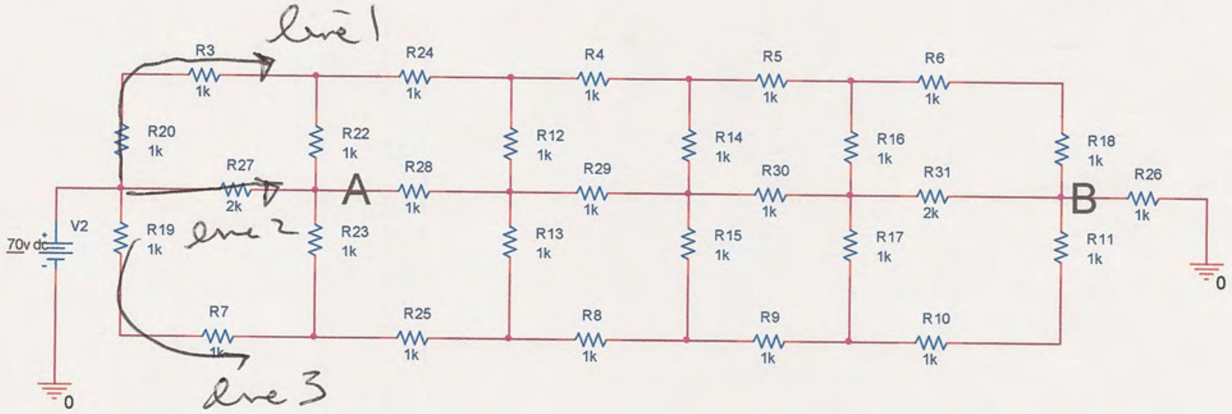


$$V_{out} = V_{in} \frac{20}{20+15}$$

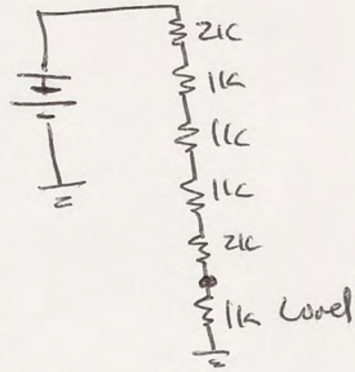
$$= 70 \frac{20}{35}$$

$$= 40V$$

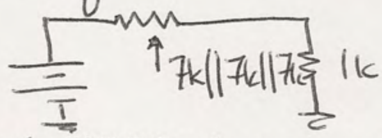
b) Reduce the circuit above to the form of the circuit in part a. That is, redraw it as a circuit consisting of a voltage source and two resistors. Also label the two resistors with their values. Then find the voltage Vout. (6 pts)



c) Find the voltages of the points A & B, in the circuit above. (6 pts) There are three identical lines of resistors. 2k + 1k + 1k + 1k + 2k from the source to the load. Each looks like



& each carries an equal current. Thus The ckt looks like 3 7k resistors in parallel + load.



d) Find the current drawn from the 70V DC voltage source. (2 pts)

Several ways to do this but the result is

$$\frac{V_B}{1k} = \frac{21}{1k} = 21mA$$

e) Assume that the resistance R26 is replaced by a short circuit. Find the voltages at points A and B and the total current from the source. (5 pts)

If $R26 = 0$ then $V_B = 0$

$$V_A = \frac{5}{7} 70 = 50 V.$$

Part C continued

$$V_B = \frac{1k}{\frac{7k}{3} + 1k} 70 V.$$

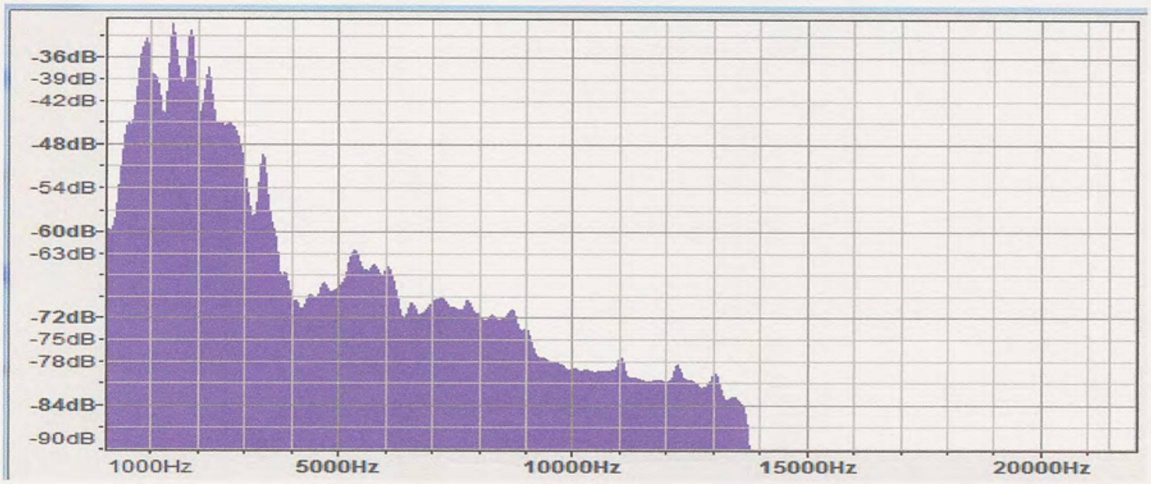
$$= \frac{3}{7+3} 70 = 3 \times 7 = 21V$$

$$V_A = 21 + (70-21)\frac{5}{7} \simeq 56 V$$

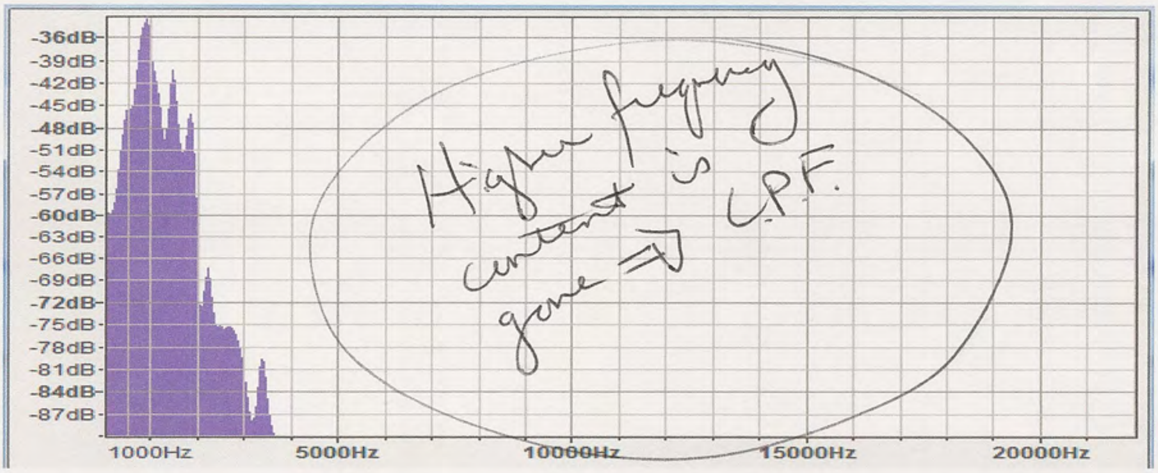
voltage divider

$$7k || 7k || 7k = \frac{7}{3} k$$

f) A recording from one of Edison's phonograph cylinders (Silent Night, made about 1915) has the frequency spectrum shown below. His phonograph was entirely mechanical and thus had a lot of hiss and scratchy sounds from the heavy needle moving around the cylinder. (2 pts)



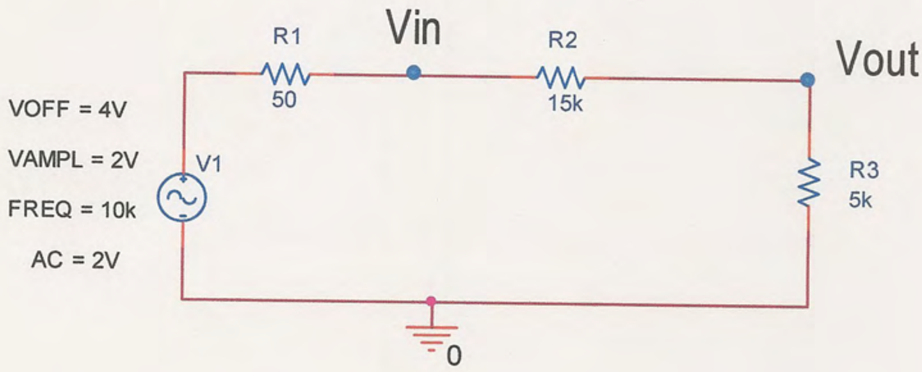
The recording was filtered to remove some of the extraneous noise, with the resulting spectrum shown below.



What kind of filter was applied to the sound? Circle the correct answer. Explain

High Pass, Low Pass, Band Pass or Band Reject

II. Filters & Transfer Functions (25 points)



a) Find the transfer function $Vout/Vin$ for the resistive circuit shown above in terms of *R1, R2,* and/or *R3*. Note that output is measured across *R3*. (2 pts) *Hint: You may not need to include all components in the transfer function.* Do not need R1

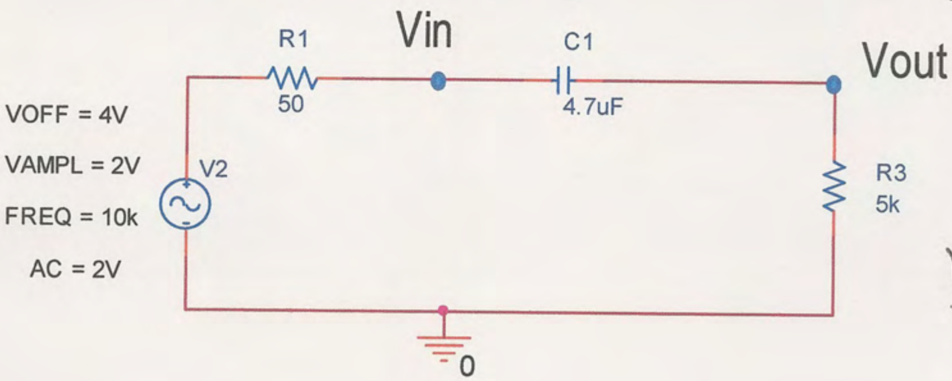
$$\frac{V_{out}}{V_{in}} = \frac{R3}{R2+R3} = \frac{5k}{15k+5k} = \frac{1}{4}$$

b) Write the input voltage *Vin* and the output voltage *Vout* as sinusoidal functions with offsets for the given operating conditions. That is write the voltages in the form $Vin = A + B\sin\omega t$ and $Vout = C + D\sin\omega t$ Write your answer with 2 significant digits. (2 pts)

$V_{in} = 4 + 2\sin\omega t$ $\omega = 20\pi k = 62832$ radians

$V_{out} = 1 + 0.5\sin\omega t$

The previous circuit is modified by replacing the second resistor with a capacitor.



$$\frac{V_{out}}{V_{in}} = \frac{R3}{R3 + \frac{1}{j\omega C1}}$$

c) Find the transfer function V_{out}/V_{in} for the new circuit. Write it first in general form $H(j\omega)$ in terms of ω, *R1*, *R3*, and C*1* and then plug in the given numerical values. (4 pts) *Same hint.*

$$\frac{V_{out}}{V_{in}} = \frac{j\omega C1R3}{1+j\omega C1R3} = \frac{j1480}{1+j1480}$$

d) Simplify the transfer function for low frequencies and for high frequencies. (4 pts)

$H_{low}(j\omega) = ?$ $= j\omega C1R1$

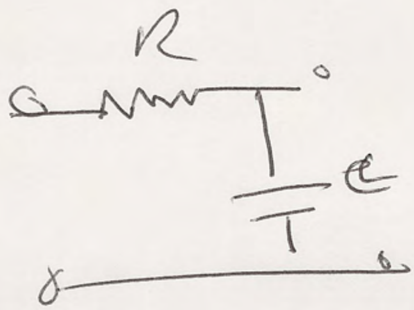
$H_{high}(j\omega) = ?$ $= 1$

e) What kind of filter response would best represent this circuit? (Please circle one.) (2 pts)

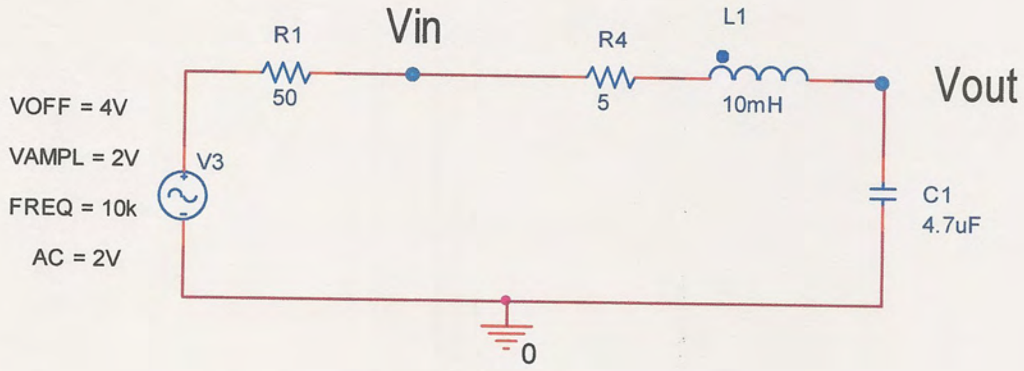
i) Low Pass ii) Band Pass **(iii) High Pass** iv) Band Reject

f) What kind of filter response would best represent this circuit if the positions of the ~~inductor~~ capacitor and resistor R3 are reversed? (Please circle one.) (2 pts) *Hint: Sketch the new circuit diagram.*

(i) Low Pass ii) Band Pass iii) High Pass iv) Band Reject



The capacitor is now moved to replace the resistor R3 and its place is taken by a realistic inductor L1 (which includes some resistance R4).



g) Find the transfer function $Vout/Vin$ for the new circuit. Write it first in general form $H(j\omega)$ in terms of ω, $R1$, R4, $L1$, and $C1$ and then plug in the given numerical values. (4 pts) *Same hint.*

$$\frac{V_{out}}{V_{in}} = \frac{\frac{1}{j\omega C1}}{R4 + j\omega L1 + \frac{1}{j\omega C1}} = \frac{1}{1 + j\omega C1 R4 - \omega^2 L1 C1}$$

$$= \frac{1}{1 + j1.48 - 186} = \frac{1}{-185 + j1.48}$$

h) Determine the corner frequency f_c for the circuit with the capacitor and resonant frequency f_r for the circuit with the inductor and capacitor. Find the numerical values, not just the general expression. (2 pts)

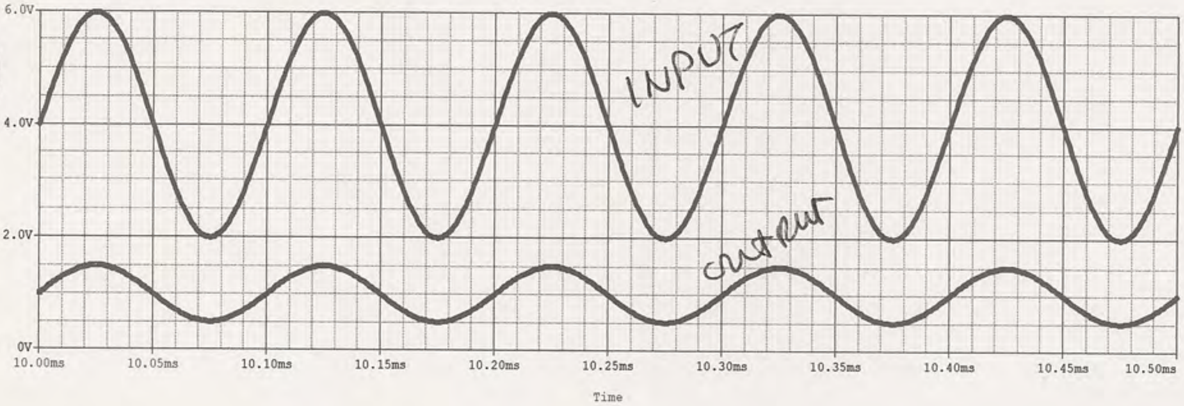
Inductor f_c: $\frac{1}{2\pi RC} = \frac{1}{2\pi(4.7\mu F)(5k)} = 6.8\ Hz$

Inductor/Capacitor f_r: $\frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{10mH\ 4.7\mu F}} = 734\ Hz$

h) On this page are the input and output voltages for the three circuit configurations considered in this problem (3R, 2R+C, 2R+L+C). Label which plot goes with which circuit and explain your answer. (3 pts)

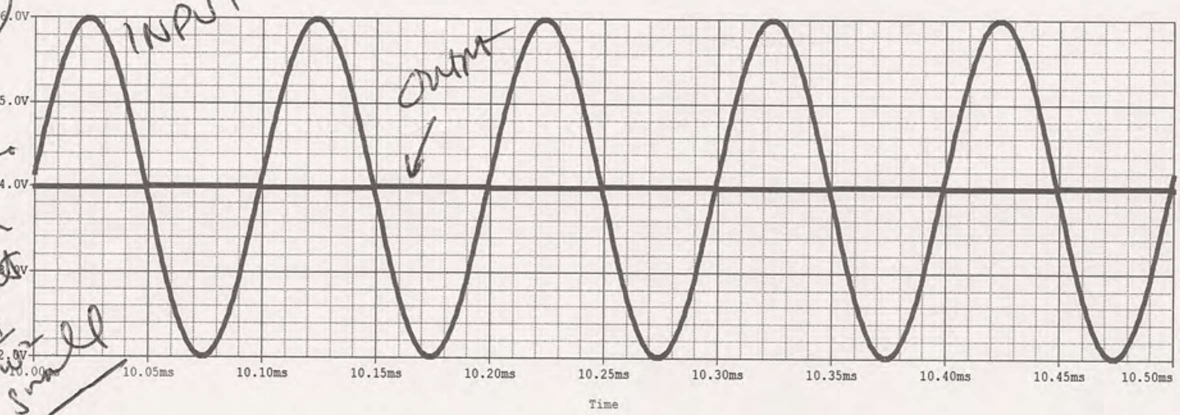
Both the offset & sinusoid are smaller by 1/4

3R

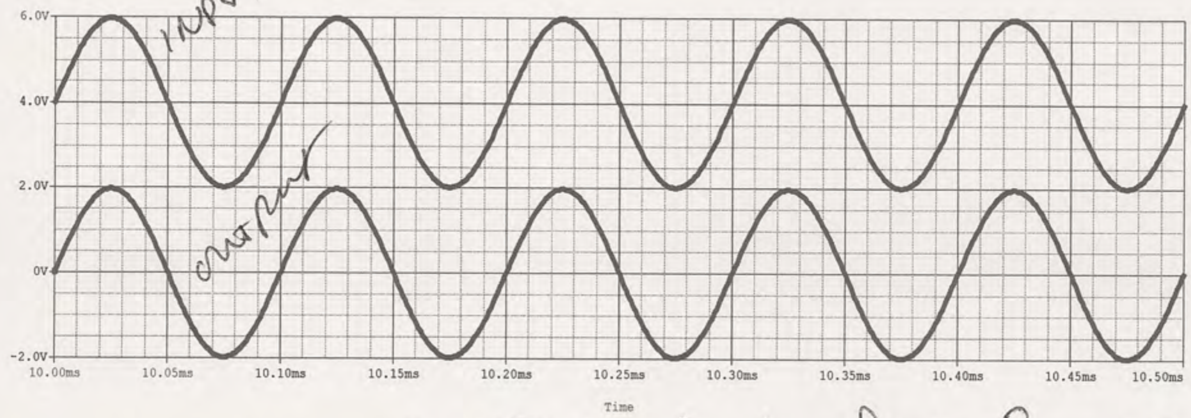


2R+L+C

By process of elimination at high f the output must ~ 1/ω so very small

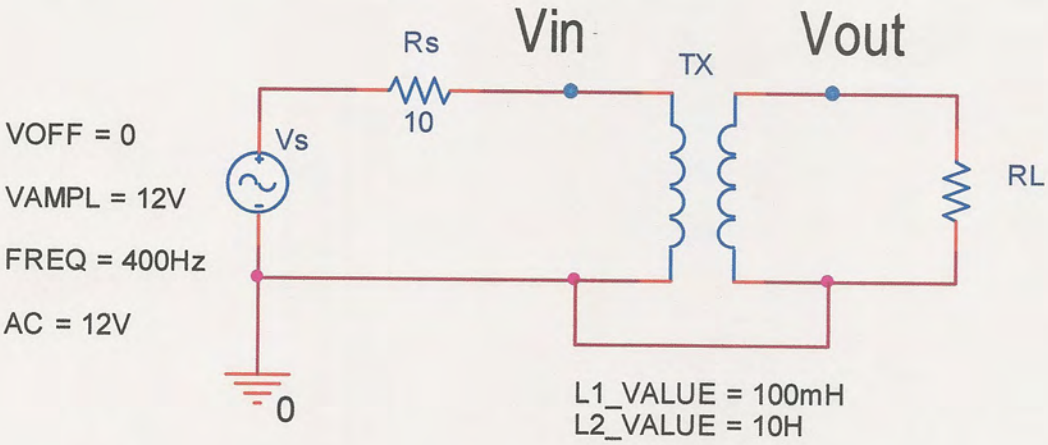


2R+C



C blocks the DC but f >> fc so The AC (sinusoid) signal completely passes.

III – Signals, Transformers and Inductors (25 points)



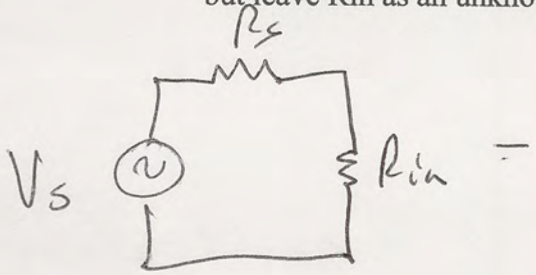
Given the circuit above, assume an ideal transformer with full coupling. Rs = 10Ω, L1=100mH, L2=10H and RL is unknown. The goal of this problem is to determine the value of RL that will produce a Vout of 80V.

a) For the given information, write out the expressions for the ratios Vout/Vin, Iout/Iin and the transformer input impedance Rin. Obviously, for the last expression, you will have to leave your answer in terms of RL because it does not have a specific value at this point. (9 pts)

$$a = \sqrt{\frac{L_2}{L_1}} = \sqrt{100} = 10$$

$$\frac{V_2}{V_1} = a = 10 \qquad \frac{I_1}{I_2} = a = 10 \qquad R_{in} = \frac{R_L}{a^2} = \frac{R_L}{100}$$

b) Find the expression for Vin in terms of Rs, Rin and Vs. Plug in real values for Rs and Vs, but leave Rin as an unknown parameter. (4 pts)



$$V_{in} = \frac{R_{in}}{R_{in} + R_s} V_s = \frac{R_{in}}{R_{in} + 10} 12$$

c) Now, assume Vout = 80V. Use the expressions you have written above to find the value of RL. Check to be sure that your answer is a standard resistance value using the chart on page 4. (4 pts)

$80 = V_{out} = 10\,V_{in} = 10 \frac{R_{in}}{R_{in}+10} 12 = \frac{\frac{R_L}{100}}{\frac{R_L}{100}+10} 120$

$\frac{2}{3} = \frac{R_{in}}{R_{in}+10}$ or $2R_{in}+20 = 3R_{in}$, $R_{in} = 20$

$R_L = 100 R_{in} = 2000 = 2k$ which is a standard R.

d) Up to this point, you have assumed that the transformer equations are all valid. To justify your solution, show that the magnitude of the inductive impedances at the given frequency are much larger than the resistances. That is, the inductive impedance of the primary is much larger than Rs and the inductive impedance of the secondary is much larger than RL. (4 pts)

$\omega L_1 >> R_S$ or $251 >> 10$ ✓

$\omega L_2 >> R_L$ or $25132 >> 2000$ ✓

e) You decide to build this transformer by winding 12 gauge wire, in a single layer, on a long cylinder with a 50cm radius. This wire has a diameter of 2.053mm. Using the ideal long solenoid inductance formula, determine how many turns you will need for both the primary and secondary. $\mu_o = 4\pi \times 10^{-7}$ S/m. How many turns will be required and approximately how long must the solenoid be? Are you surprised at your answer? (4 pts)

$L = \frac{\mu_o N^2 \pi r_c^2}{l}$ length $= Nd$ (↑ diameter of wire)

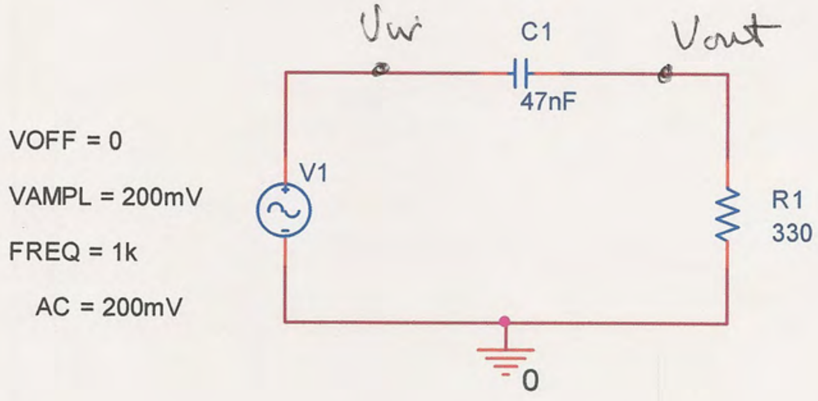
$= \mu_o \frac{N^{\not 2} \pi r_c^2}{\not N d}$

$N = \frac{dL}{\mu_o \pi r_c^2} = \begin{cases} 20822 & \text{Secondary} \\ 208 & \text{Primary} \end{cases}$

length of secondary = 42.8m → ~ 65km of wire! } Really Big. Need

IV – Instrumentation, PSpice, Components, Troubleshooting & Concepts (25 points)

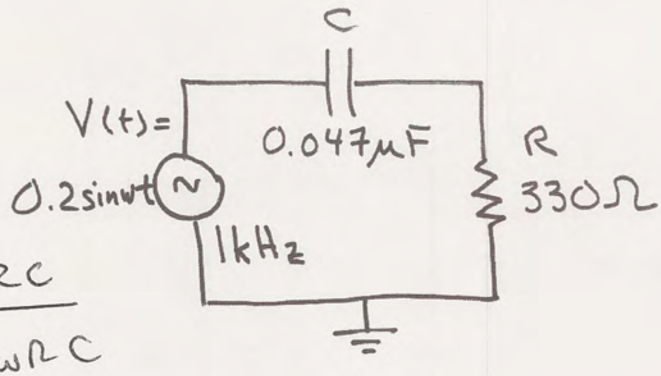
You are given the PSpice generated circuit diagram at the right to address the three ways we do just about everything in this course: paper and pencil analysis using simplified formulas, simulation with PSpice and experiment with Mobile Studio.



a) Label the location of V_{IN} and V_{OUT} on the plot above. (2 pts)

There are many ways to hand-draw this circuit. One common approach is shown below. This diagram is to be used for all three approaches to characterizing this circuit.

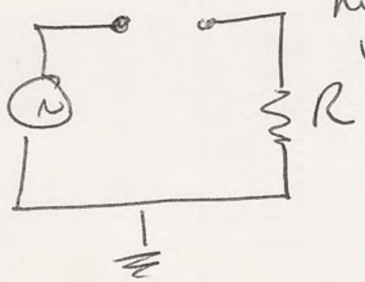
b) Find the transfer function for this circuit, simplify it for both high and low frequencies, and redraw the diagram for high frequencies and low frequencies (2 diagrams). (6 pts)



$$\frac{V_{out}}{V_{in}} = \frac{R}{R + \frac{1}{j\omega RC}} = \frac{j\omega RC}{1 + j\omega RC}$$

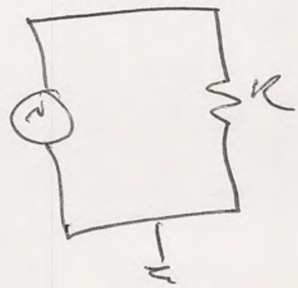
low f $\frac{V_{out}}{V_{in}} = j\omega RC$ high f $\frac{V_{out}}{V_{in}} = 1$

low f

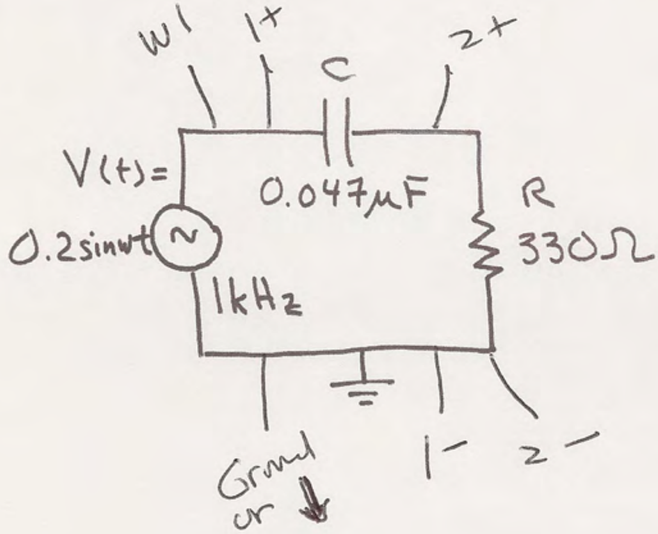


– No current so no load voltage

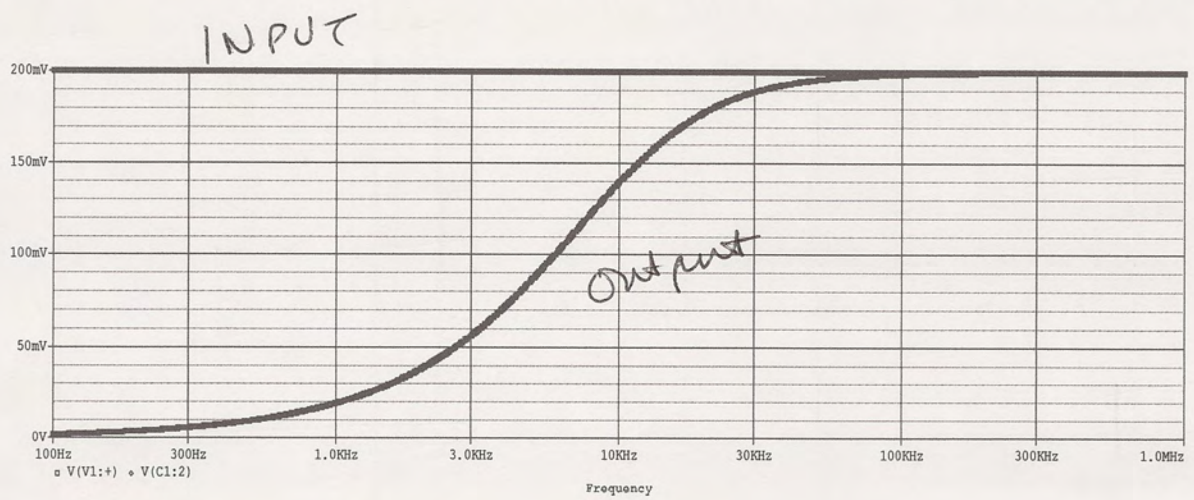
high f



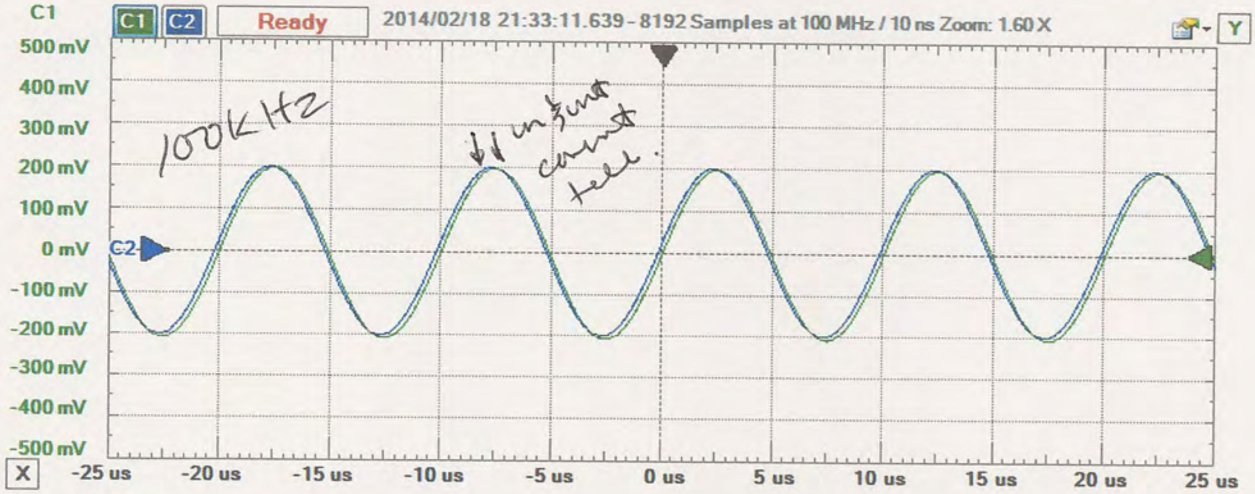
c) On the hand-drawn circuit diagram (repeated here), label where connections are to be made with the Analog Discovery board to experimentally study the circuit. That is, use the labels from the board (e.g. 1+). *Hint: Be sure to show all necessary connections. The connection diagram is on page 5.* (4 pts)

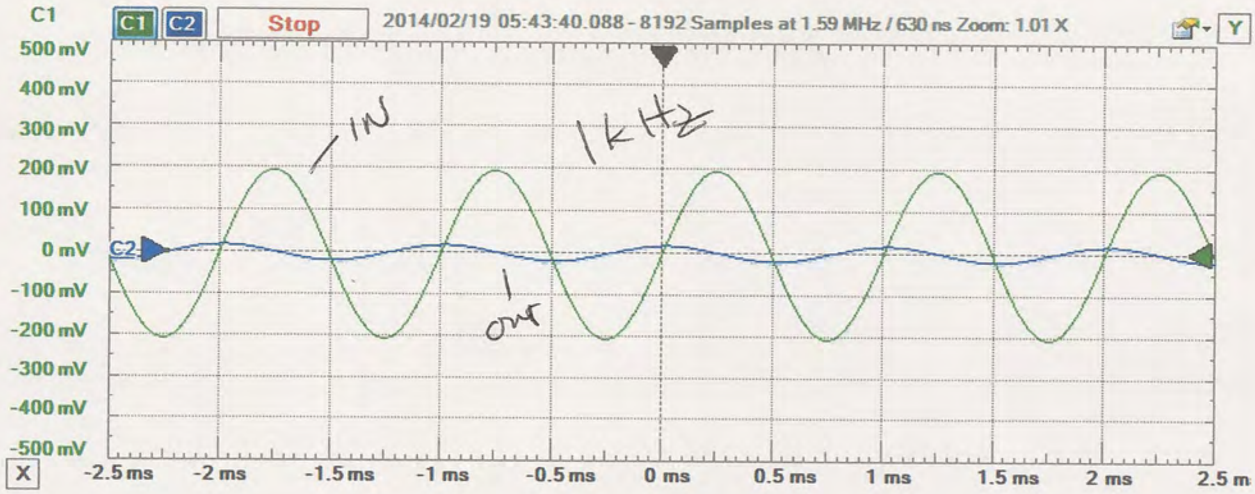


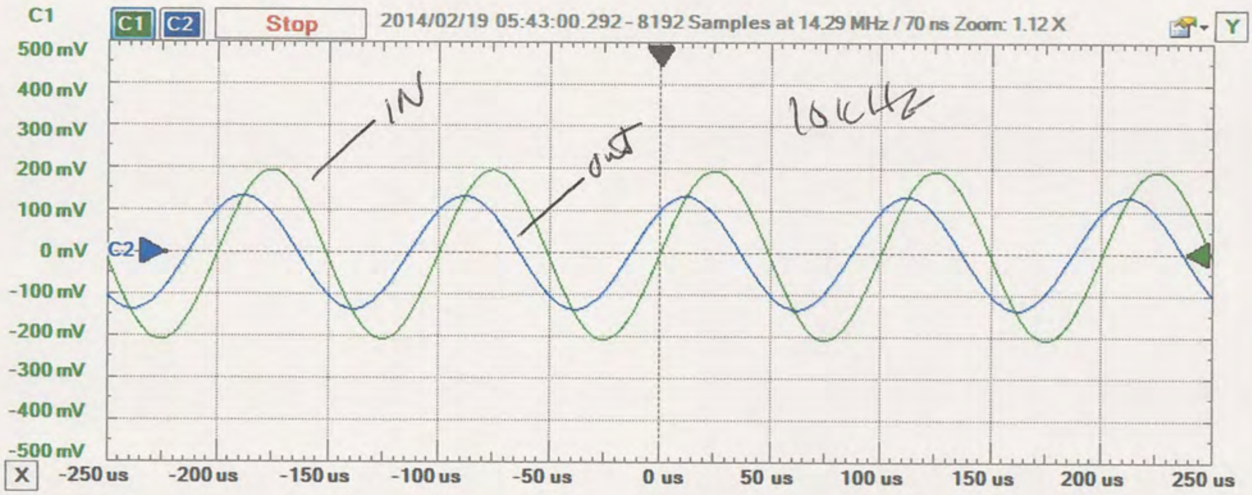
d) Shown below is the PSpice output for the circuit. Label the input and output voltages. (2 pts)



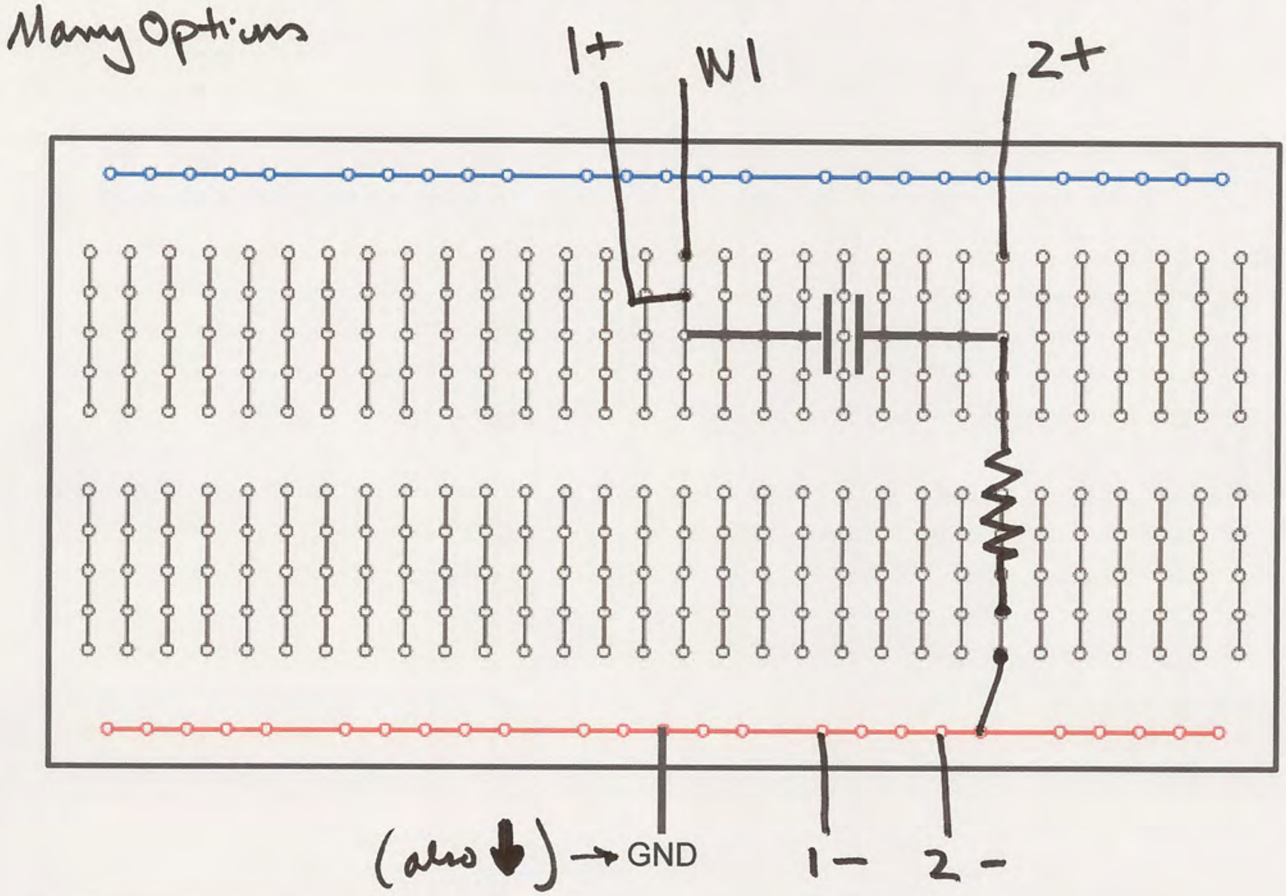
e) Measurements are made of the input and output voltages at three different frequencies (1kHz, 10kHz, 100kHz). The results are shown below. Label the input and output voltages, the peak-to-peak amplitudes of the input and output voltages and the frequency for each case. (6 pts)

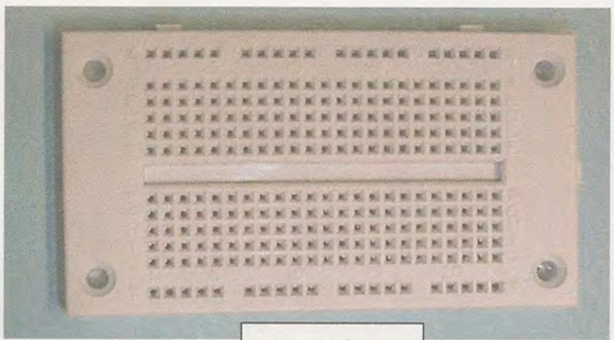




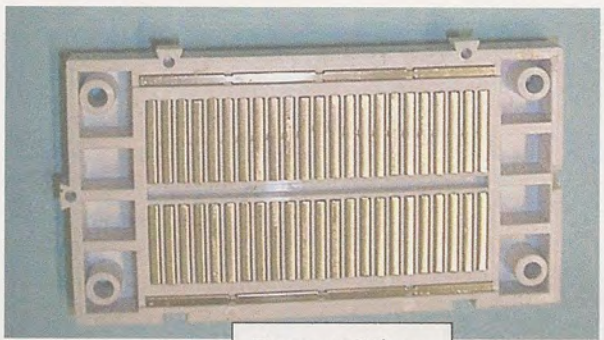


f) Configure the circuit on the protoboard below. For clarity, the capacitor has been drawn showing where it is connected, as has the connection to the ~~Mobile Studio~~ Analog Disc ground. Add the resistors and all other connections to the ~~Mobile Studio~~ Analog Disc board so that, through measurements, it is possible to demonstrate that your circuit is working. Note that your protoboard diagram must be neat and easy to read. Your connections to the ~~Mobile Studio~~ Analog Disc should be drawn like the ground, with a short, straight line terminated in the label of the connection. Also, photos of the top and bottom view of a protoboard are shown at the bottom of this page. (5 pts)





Top View



Bottom View