

## ENGR-2300

## Electronic Instrumentation

## Quiz 4

Fall 2013

***Solution***

Question I (25 points) \_\_\_\_\_

Question II (25 points) \_\_\_\_\_

Question III (25 points) \_\_\_\_\_

Question IV (25 points) \_\_\_\_\_

Total (100 points) \_\_\_\_\_



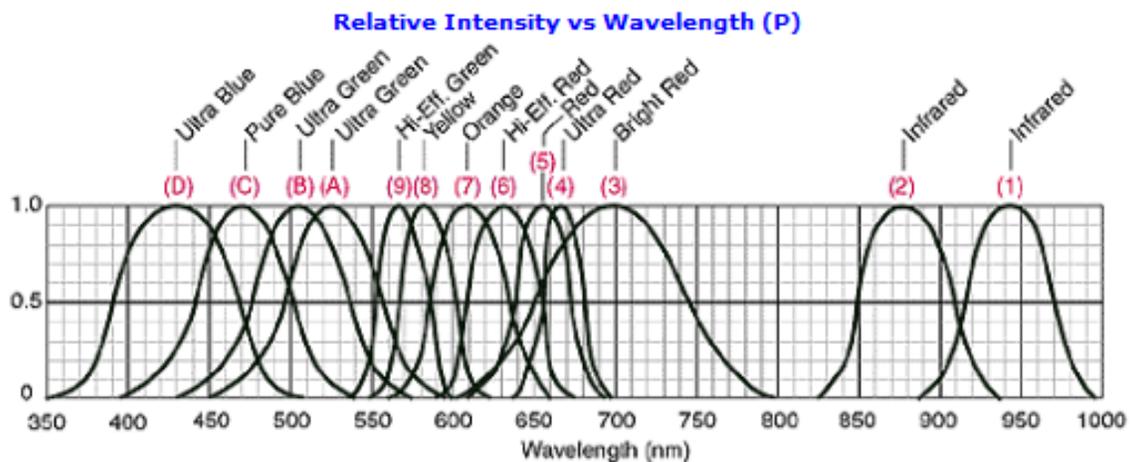
On all questions: **SHOW ALL WORK. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS.** No credit will be given for numbers that appear without justification. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order.

### Some Additional Background

Some Typical LED Operating Info:

	Wavelength (nm)	Color Name	Fwd Voltage (Vf @ 20ma)	Intensity 5mm LEDs	Viewing Angle	LED Dye Material
	940	Infrared	1.5	16mW @50mA	15°	GaAIAs/GaAs -- Gallium Aluminum Arsenide/Gallium Arsenide
	880	Infrared	1.7	18mW @50mA	15°	GaAIAs/GaAs -- Gallium Aluminum Arsenide/Gallium Arsenide
	850	Infrared	1.7	26mW @50mA	15°	GaAIAs/GaAs -- Gallium Aluminum Arsenide/Gallium Aluminum Arsenide
	660	Ultra Red	1.8	2000mcd @50mA	15°	GaAIAs/GaAs -- Gallium Aluminum Arsenide/Gallium Aluminum Arsenide
	635	High Eff. Red	2.0	200mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
	633	Super Red	2.2	3500mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
	620	Super Orange	2.2	4500mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
	612	Super Orange	2.2	6500mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
	605	Orange	2.1	160mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
	595	Super Yellow	2.2	5500mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
	592	Super Pure Yellow	2.1	7000mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
	585	Yellow	2.1	100mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
	4500K	"Incandescent" White	3.6	2000mcd @20mA	20°	SiC/GaN -- Silicon Carbide/Gallium Nitride

	6500K	Pale White	3.6	4000mcd @20mA	20°	SiC/GaN -- Silicon Carbide/Gallium Nitride
★	8000K	Cool White	3.6	6000mcd @20mA	20°	SiC/GaN - Silicon Carbide / Gallium Nitride
	574	Super Lime Yellow	2.4	1000mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
★	570	Super Lime Green	2.0	1000mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
	565	High Efficiency Green	2.1	200mcd @20mA	15°	GaP/GaP - Gallium Phosphide/Gallium Phosphide
	560	Super Pure Green	2.1	350mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
	555	Pure Green	2.1	80mcd @20mA	15°	GaP/GaP - Gallium Phosphide/ Gallium Phosphide
	525	Aqua Green	3.5	10,000mcd @20mA	15°	SiC/GaN - Silicon Carbide / Gallium Nitride
	505	Blue Green	3.5	2000mcd @20mA	45°	SiC/GaN - Silicon Carbide / Gallium Nitride
	470	Super Blue	3.6	3000mcd @20mA	15°	SiC/GaN - Silicon Carbide / Gallium Nitride
★	430	Ultra Blue	3.8	100mcd @20mA	15°	SiC/GaN - Silicon Carbide / Gallium Nitride



From Wikipedia: A **Zener diode** is a diode which allows current to flow in the forward direction in the same manner as an ideal diode, but also permits it to flow in the reverse direction when the voltage is above a certain value known as the breakdown voltage, "zener knee voltage", "zener voltage", "avalanche point", or "peak inverse voltage".

The device was named after Clarence Zener, who discovered this electrical property. Many diodes described as "zener" diodes rely instead on avalanche breakdown as the mechanism. Both types are used. Common applications include providing a reference voltage for voltage regulators, or to protect other semiconductor devices from momentary voltage pulses.

Type Number	Nominal Zener Voltage $V_Z @ I_{ZT}^{(2)}$ (Volts)	Test Current $I_{ZT}$ (mA)	Maximum Zener Impedance $Z_{ZT} @ I_{ZT}^{(1)}$ ( $\Omega$ )	Maximum Regulator Current $I_{ZM}^{(2)}$ (mA)	Maximum Reverse Leakage Current	
					$T_A = 25^\circ\text{C}$ $I_R @ V_R = 1\text{V}$ ( $\mu\text{A}$ )	$T_A = 150^\circ\text{C}$ $I_R @ V_R = 1\text{V}$ ( $\mu\text{A}$ )
1N746A	3.3	20	28	110	10	30
1N747A	3.6	20	24	100	10	30
1N748A	3.9	20	23	95	10	30
1N749A	4.3	20	22	85	2	30
1N750A	4.7	20	19	75	2	30
1N751A	5.1	20	17	70	1	20
1N752A	5.6	20	11	65	1	20
1N753A	6.2	20	7	60	0.1	20
1N754A	6.8	20	5	55	0.1	20
1N755A	7.5	20	6	50	0.1	20
1N756A	8.2	20	8	45	0.1	20
1N757A	9.1	20	10	40	0.1	20
1N758A	10	20	17	35	0.1	20
1N759A	12	20	30	30	0.1	20

## Capacitor Codes

Physically larger capacitors, like electrolytics, usually have the capacitance value written simply on them. For smaller capacitors, like ceramics, there are three numbers written to indicate the value. The first two digits of the code represent part of the value; the third digit corresponds to the number of zeros to be added to the first two digits. This is the value in pF.

For Example: CODE: 4 7 3   
 VALUE: 47 000 or .047  $\mu\text{F}$

There is also often a letter after the three numbers. This indicates the tolerance of the value.



## 4 Dec – Cultural News for Today

# Frank Benford

Physicist

Frank Albert Benford, Jr., was an American electrical engineer and physicist best known for rediscovering and generalizing Benford's Law, a statistical statement about the occurrence of digits in lists of data.

Wikipedia

**Born:** May 29, 1883, Johnstown, PA

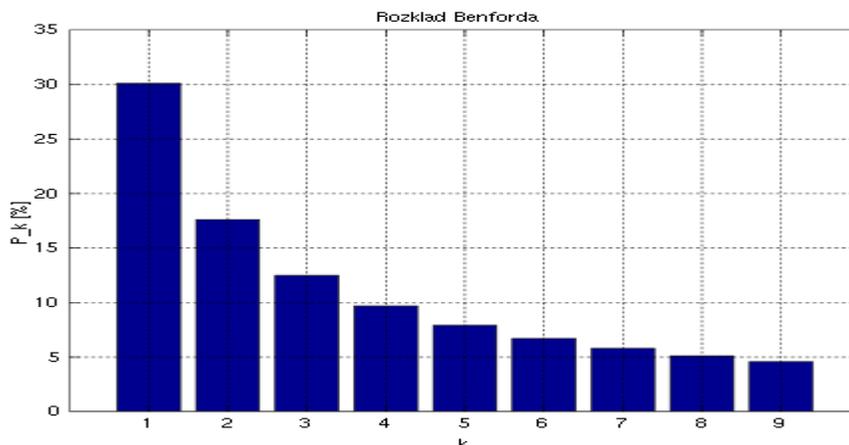
**Died:** December 4, 1948, Schenectady, NY

**Education:** University of Michigan



**Benford's Law** is not intuitive, but almost anyone who tries it out experimentally finds it to be true. Select any data set that covers several orders of magnitude and you will see that it works. In addition to discovering this interesting law, Benford also developed an instrument for determining the refractive index of glass.

From Wikipedia: **Benford's Law**, also called the **First-Digit Law**, refers to the frequency distribution of digits in many (but not all) real-life sources of data. In this distribution, the number 1 occurs as the leading digit about 30% of the time, while larger numbers occur in that position less frequently: 9 as the first digit less than 5% of the time. This result has been found to apply to a wide variety of data sets, including electricity bills, street addresses, stock prices, population numbers, death rates, lengths of rivers, physical and mathematical constants, and processes described by power laws (which are very common in nature). It tends to be most accurate when values are distributed across multiple orders of magnitude. The graph below shows Benford's Law for base 10. It is named after Frank Benford, who stated it in 1938, although it had been previously stated by Simon Newcomb in 1881. Benford spent most of his career at GE working in the Illuminating Engineering Laboratory.



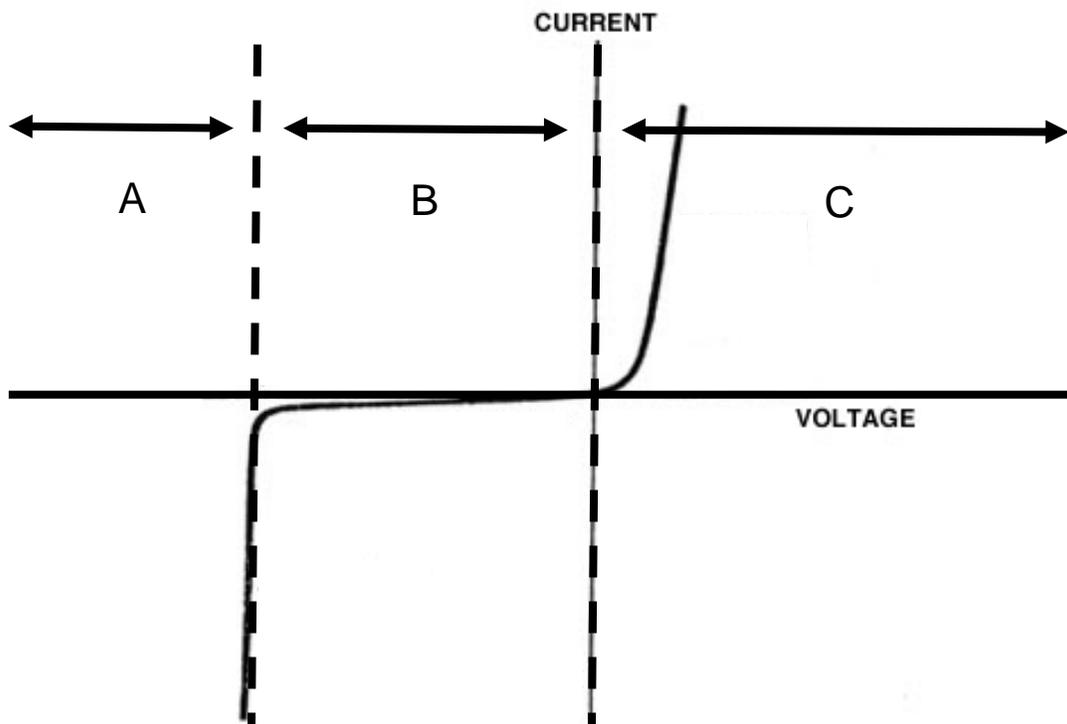
**Benford's Law** is used to identify fraudulent data sets by looking for significant deviations from this distribution of digits. Made up data tends to be much more uniform.

### Question I Multiple Choice & Short Answer Questions (25 points)

For these multiple choice questions, circle the correct answer or, for the first question, fill in the blanks. All questions are 3pts, except h, which is worth 4pts. Be sure to explain your answer.

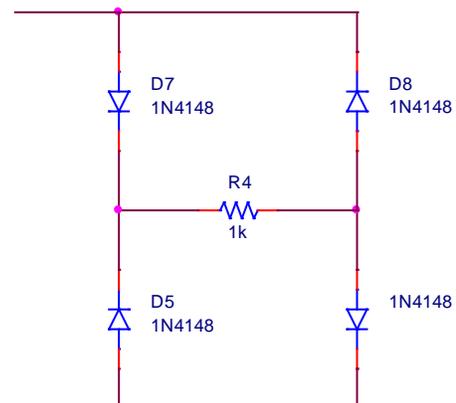
*Hint: if there is no figure with the question, it is a good idea to draw one.*

- a. There are three voltage ranges shown in the diode I-V curve below. Write the letter from the figure in the blank next to the name for the range.
- Breakdown Region **A**
  - Forward Bias Region **C**
  - Reverse Bias Region **B**



- b. The voltage across each reverse-biased diode in a typical full wave bridge rectifier is
- Hint: Draw the circuit*

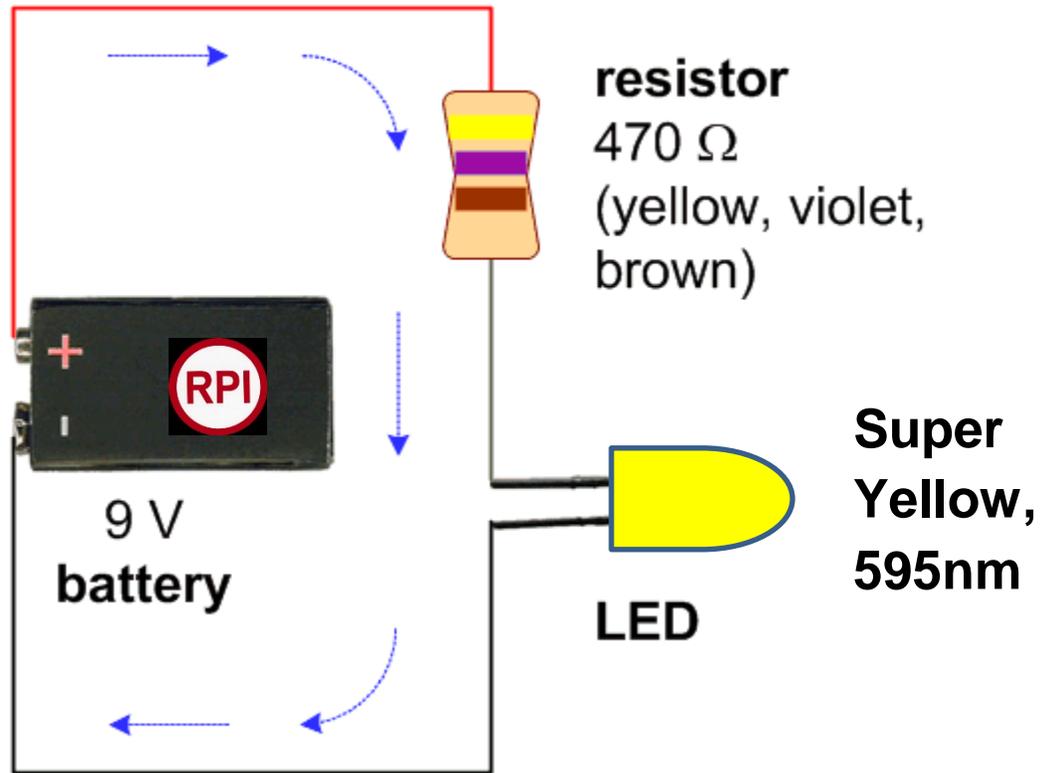
- Near the source voltage
- Near twice the source voltage
- Near half the source voltage
- Near zero volts



Forward biased diodes are near zero volts so nearly all of the source voltage must appear across the reverse biased diodes.

**Question I Multiple Choice & Short Answer Questions (continued)**

- c. What is the current through the LED, if we use the specified yellow LED? (Choose the closest answer.)



- a. 5 mA  
 b. 9 mA  
 c. 12 mA  
 d. 14 mA  
 e. 19 mA
- The forward bias for this LED is 2.2V. Thus the voltage across the resistor is 6.8V and the current is  $6.8/470 = 14.5\text{mA}$ . The closest value is 14mA.
- d. A full-wave bridge rectifier is built using four red LEDs rather than conventional diodes (like the 1N4148). For a given AC input voltage, will the rectified voltage across the load be
- a. Smaller  
 b. Larger  
 c. The same  
 d. None of the above
- The forward bias for this LED is larger than the forward bias for the 4148. Thus, more voltage must drop across the LEDs so there is less for the output.

than it was with four 1N4148 diodes?

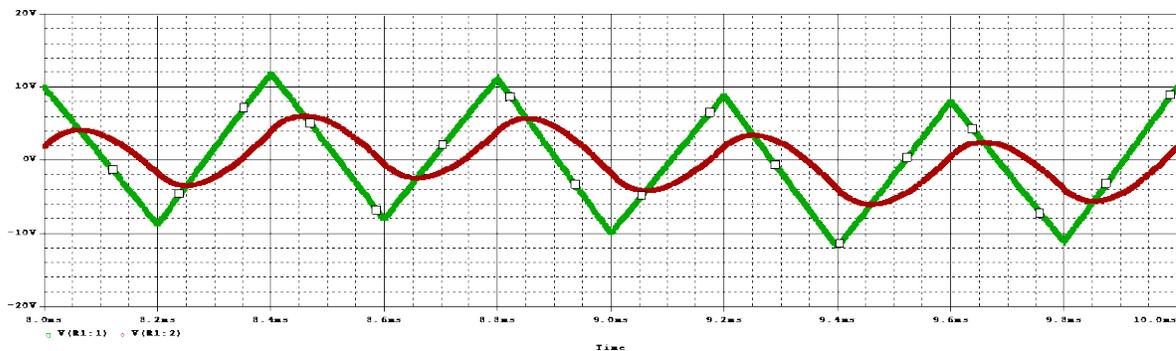
### Question I Multiple Choice & Short Answer Questions (continued)

e. If the frequency of a sinusoidal voltage is lowered, will the ripple for a filtered half-wave rectifier voltage (for the same load resistance and capacitor values):

- a. Become smaller.
- b. Become larger.
- c. Stay the same.
- d. None of the above.

At a lower frequency, there is more time to droop, so the ripple will be larger.

f. The input voltage to a passive integrator circuit is the combination of a 500Hz sine wave and a 2.5kHz triangular wave. The figure below shows both the input and the voltage measured at the output of the integrator. If the frequency of the triangular wave is raised



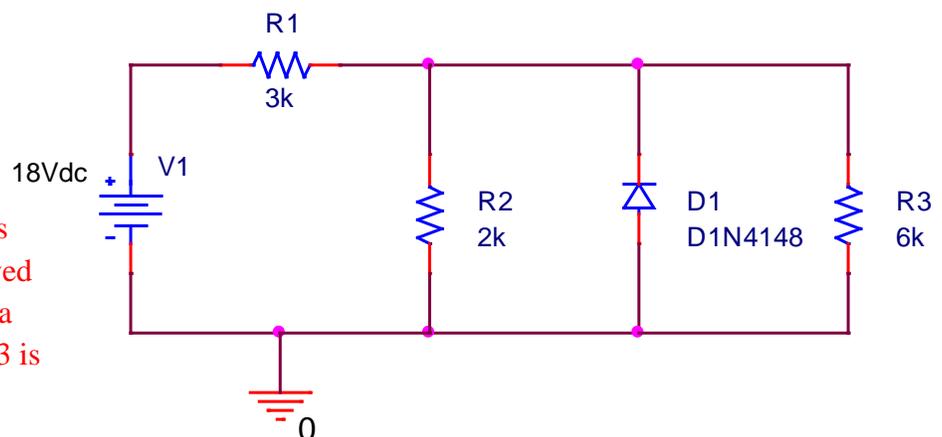
to 25kHz, which of the following will be true about the ratio of the triangular wave amplitude to the sine wave amplitude?

- a. It will remain about the same as it was for  $f = 2.5kHz$
- b. It will increase noticeably from its value at  $f = 2.5kHz$
- c. It will decrease noticeably from its value at  $f = 2.5kHz$
- d. There is not enough information provided to select any of the given answers.

Integrators are low pass filters, so higher frequencies are more attenuated.

g. What is the approximate current magnitude through the resistor R3 in the circuit below?

- a. 0 mA
- b. 0.5 mA
- c. 1 mA
- d. 1.5 mA



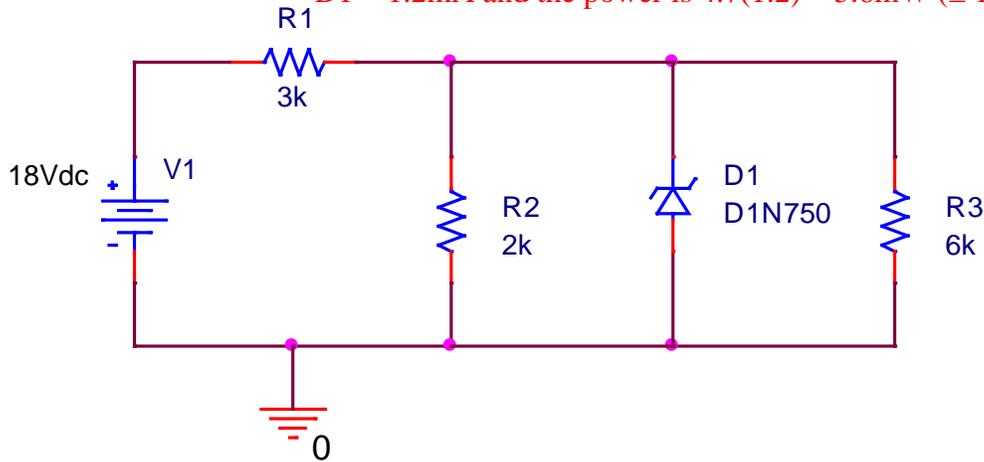
The diode is reverse biased so it is off (open circuit). It can be removed from the circuit. We are left with a voltage divider. Voltage across R3 is 6V so the current is 1mA

**Question I Multiple Choice & Short Answer Questions (continued)**

h. What is the approximate power dissipated by the Zener diode? (4pts)

- a. 0 mW
- b. 3 mW
- c. 6 mW
- d. 10 mW
- e. 13 mW

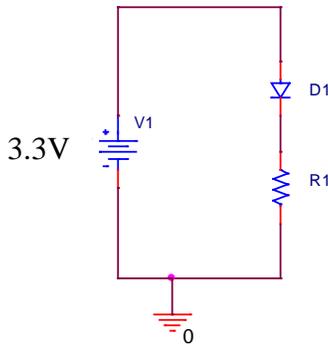
From the previous problem, the voltage across R3 is 6V with no Zener. If we add the Zener, this will be limited to 4.7V (see table for value). Current in R1 is  $(18-4.7)/3k = 4.4\text{mA}$ . The current through R2 is  $4.7/2k = 2.4\text{mA}$  & through R3 is .8mA. Thus, the current through D1 = 1.2mA and the power is  $4.7(1.2) = 5.6\text{mW}$  ( $\pm 15\%$ )



**Question II - LEDs Circuits (25 points)**

A 850nm infrared LED (like the ones used in a TV remote control) is driven by a standard DC source. The source we have is a 3.3V coin battery. From the chart provided at the beginning of the quiz, we need a forward bias voltage of 1.7V and a current of 50 mA.

- a) (8pts) Using the coin battery, **determine the resistance R1** necessary to achieve the desired operating conditions for the diode. Also determine the total power dissipated in the circuit.



The voltage across the resistor is  $3.3 - 1.7 = 1.6\text{V}$ . The resistance must be  $R1 = 1.6 / (.05) = 32\Omega$ .

The power in the circuit is trivially found from the product of the current and the battery voltage  $= 3.3(.05) = 165\text{mW}$

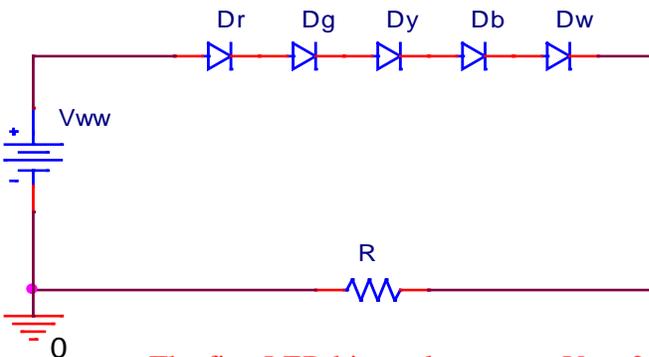
We now want to use multiple LEDs like a short string of holiday lights. For this purpose, we will use five different color LEDs: Red, Green, Yellow, Blue and White. We will use the five LEDs marked with a ★ in the table above. For the power supply, we will use one of two universal AC adapters available online that can output one of the following voltages (switch selectable):

Universal AC Adapter 15V 16V 18V 18.5V 19V 19.5V 20V 22V 24V 70W

Universal AC Adapter 3V 4.5V 6V 7.5V 9V 12V 10W

For the next two questions, select the minimum voltage from one of the power supplies.

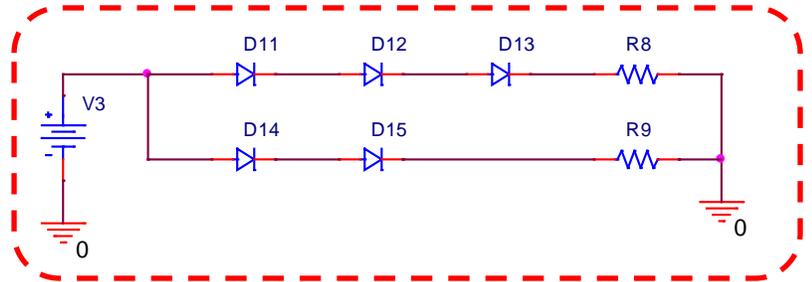
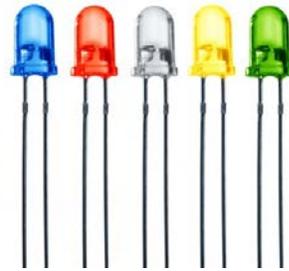
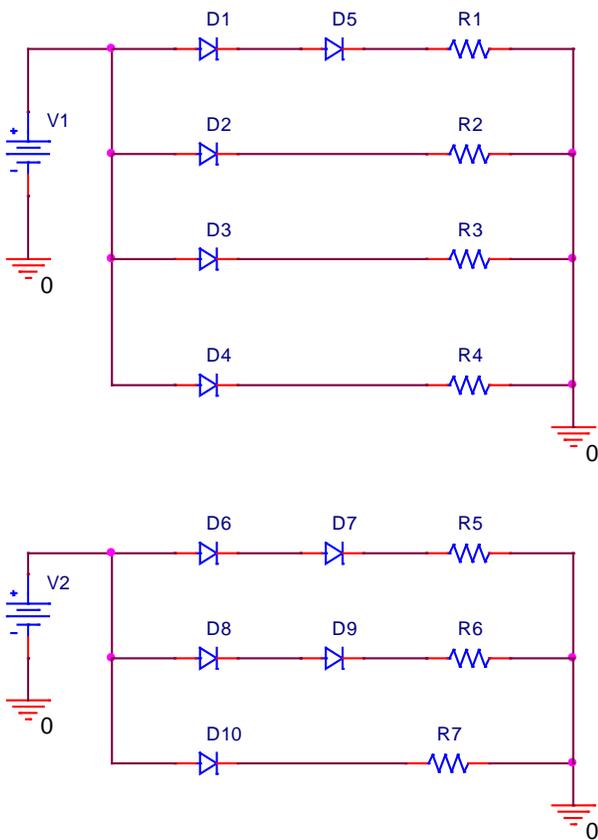
- b) (8 pt) **Determine the voltage V<sub>ww</sub> and resistance R** to achieve the desired operating conditions for the series combination of 5 LEDs shown below. Assume that the current is 20mA, since we have to be limited to the smallest maximum current for any of our five LEDs. Use the typical forward bias voltages from the table. The power supply voltage should be the minimum value that will turn on all of the LEDs.



The five LED bias voltages are:  $V_r = 2$ ,  $V_y = 2.1$ ,  $V_w = 3.6$ ,  $V_g = 2$ ,  $V_b = 3.8$  which total to 13.5V. The smallest voltage level that is larger than this is  $15\text{V} = V_{ww}$ . The resistor  $R = (15 - 13.5) / .02 = 75\Omega$

## Question II - LEDs Circuits (Cont)

- c) (9 pt) Determine the configuration and resistances to achieve the desired operating conditions for the series/parallel combination of 5 LEDs if we are limited to only the 9V source and you are to use the minimum number of components required to light up all five LEDs. Assume that the current in each of the LEDs is 20mA, since we have to be limited to the smallest maximum current for any of our LEDs. Use the typical forward bias voltages from the table. Note, two options have been eliminated (all in series and each diode in its own parallel leg), so you only have to consider 3 possibilities.



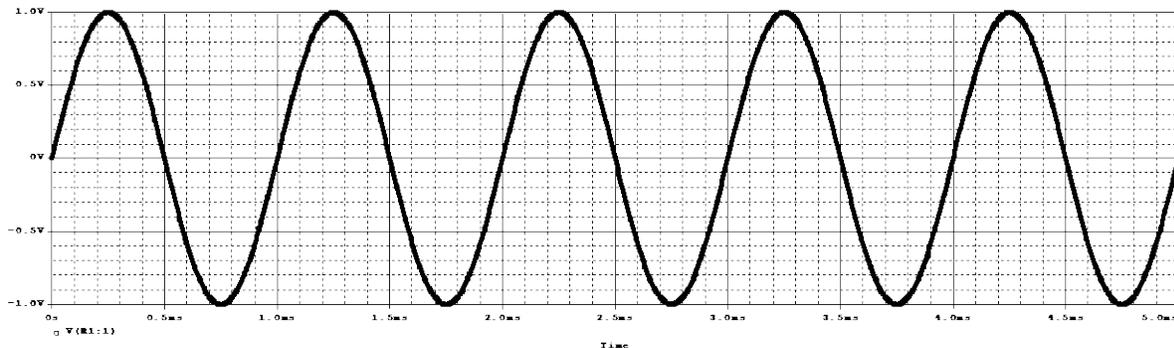
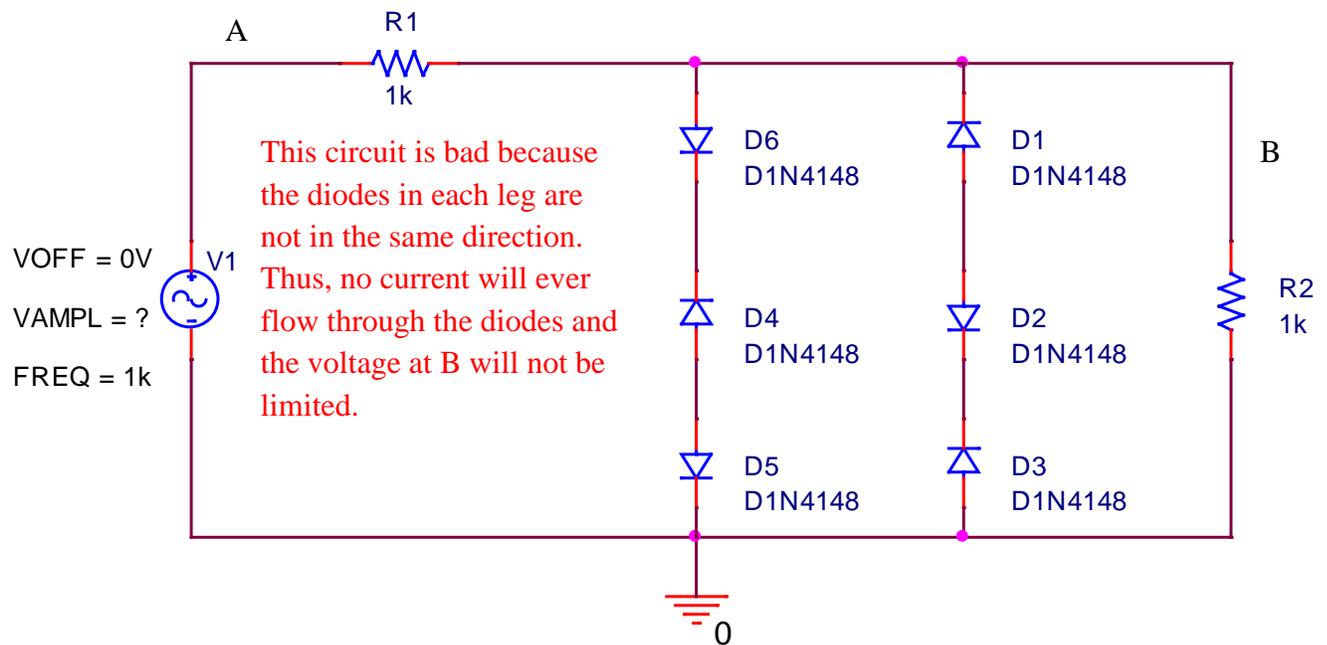
Start with the design with the least number of components (above).  $2 + 2 + 2.1 = 6.1 < 9V$  and  $3.6 + 3.8 = 7.4 < 9V$  so we can use the one above. The two resistors are  $R8 = (9-6.1)/.02 = 145\Omega$  and  $R9 = (9-7.4)/.02 = 80\Omega$

**Question III – Diode Circuits (25 Points)**

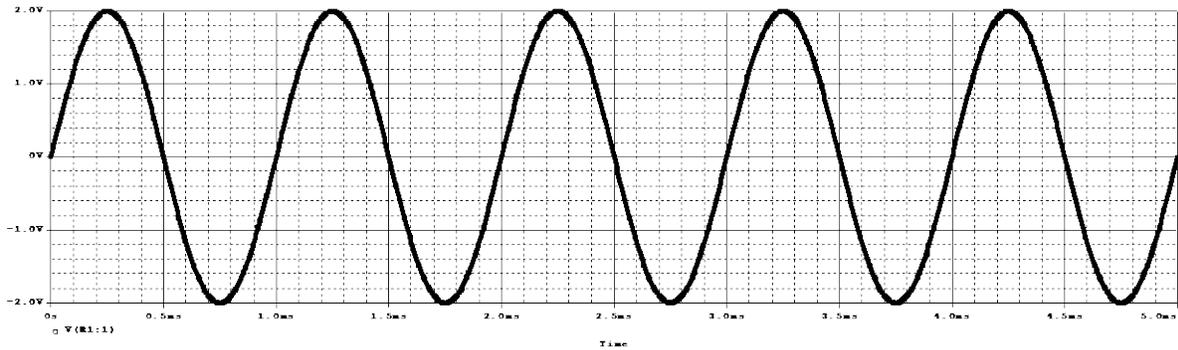
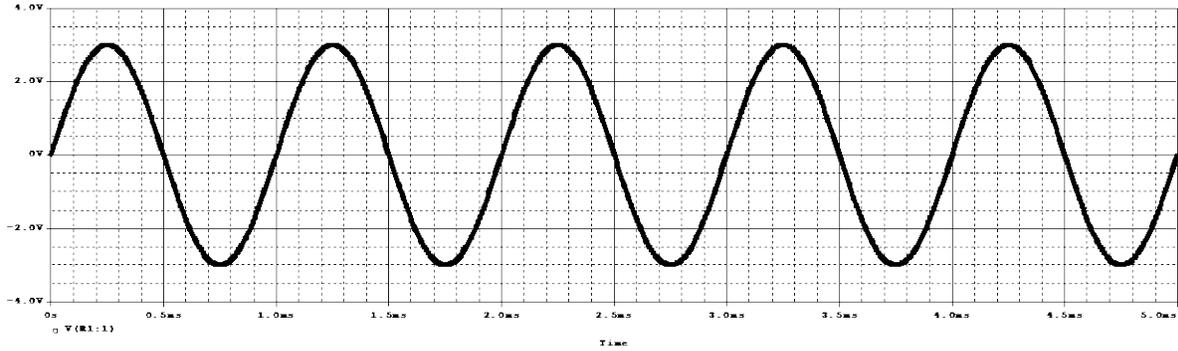


*Note – There are three parts to this question, each involving an application of diodes. One circuit does not work. You should first identify which is the bad circuit and explain thoroughly why it does not work. You do not have to answer any questions for the bad circuit. Just explain why it is bad. Then address the other two parts. The bad circuit is worth 9pts.*

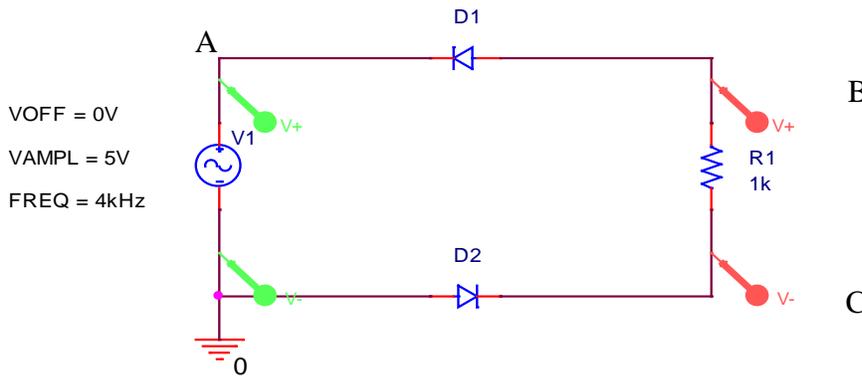
- a. Limiter Circuit (8 or 9pts) – 1N4148 diodes are used to limit the voltage at a resistive load. (Protection like this keeps the Mobile Studio board working even when you build your circuit incorrectly.) In the circuit below, a total of 6 diodes are used to limit the input voltage. Shown below are the voltage observed at point A for three different input signals. Sketch and label the output voltage at B for each case.



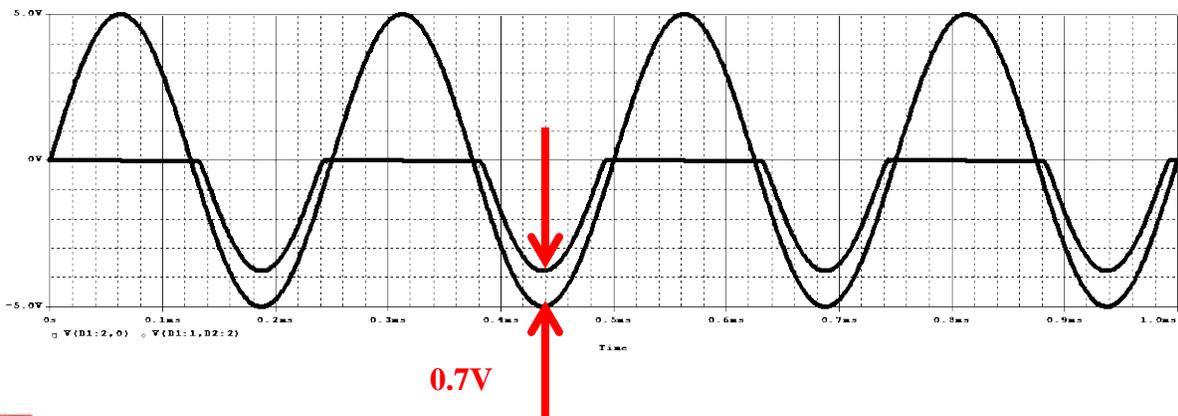
Question III – Diode Circuits (Cont)



b. Rectifier Circuit (8 or 9pts) – Two 1N4148 diodes are used to rectify an AC signal. The input signal at A is shown. Sketch the output signal between points B & C.

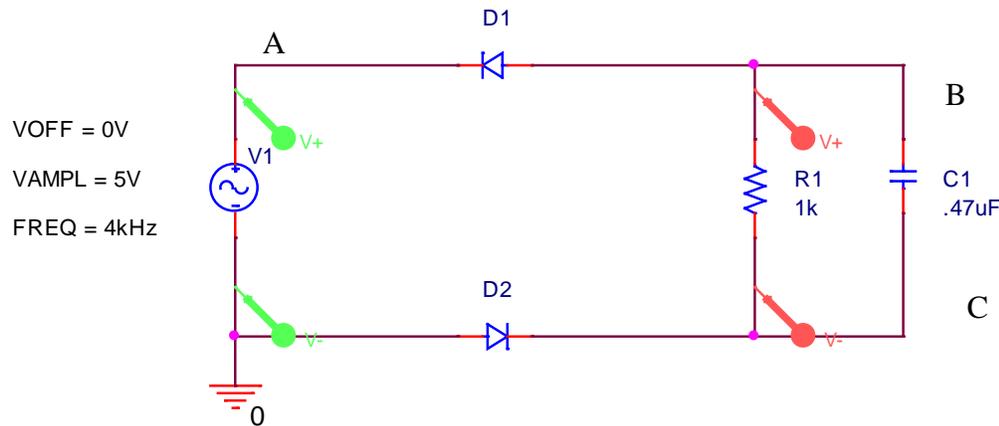


This is just a half wave rectifier with the diodes backwards. Thus, the voltages across R1 are negative and equal  $V_{in} - 0.7V$  in magnitude.  $0.6V$  is also OK.

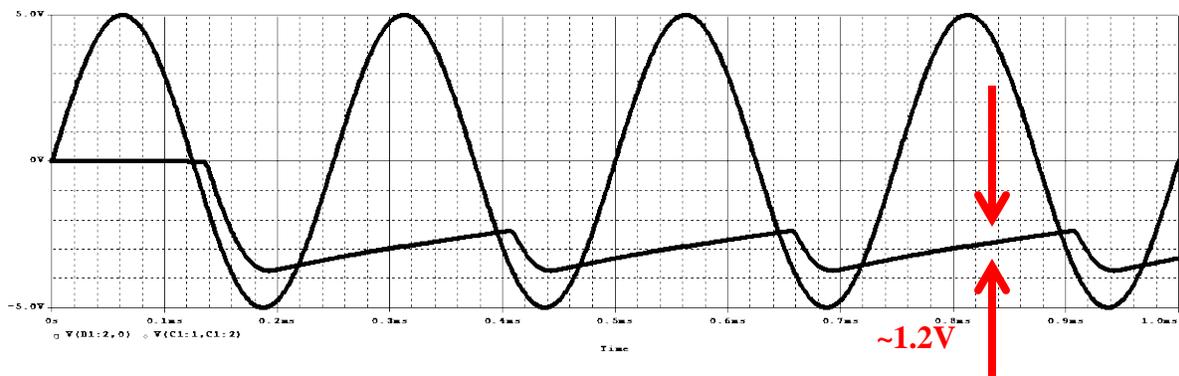


**Question III – Diode Circuits (Cont)**

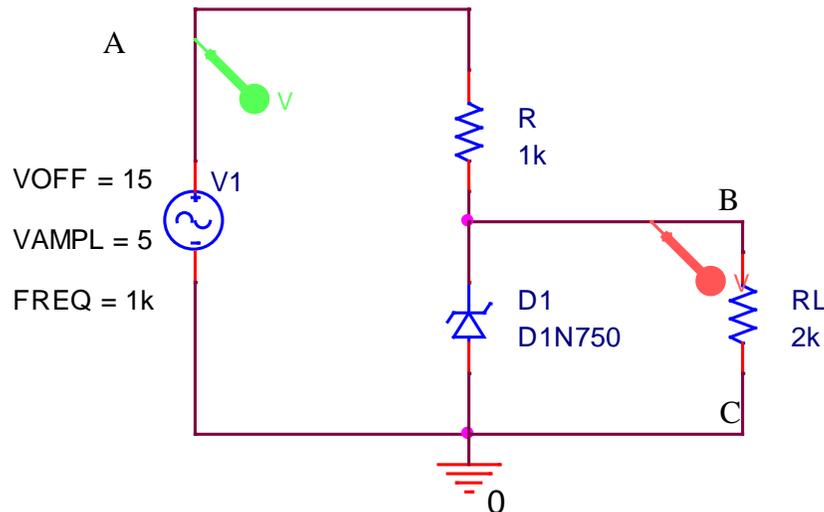
A smoothing capacitor is added to the circuit, as shown below. Calculate the droop (the capacitor voltage decay between charging cycles) and sketch the output voltage with the capacitor in place.



The time between peaks (period =  $T$ ) is about 0.25ms. The time constant  $\tau = RC = .47\text{ms}$ . Thus,  $T$  is about half  $\tau$  and the droop will be  $(5-1.4)(.5) = 1.8$ . The droop time is actually about  $2/3$  of  $T$  so 1.2V, which agrees with the PSpice result.



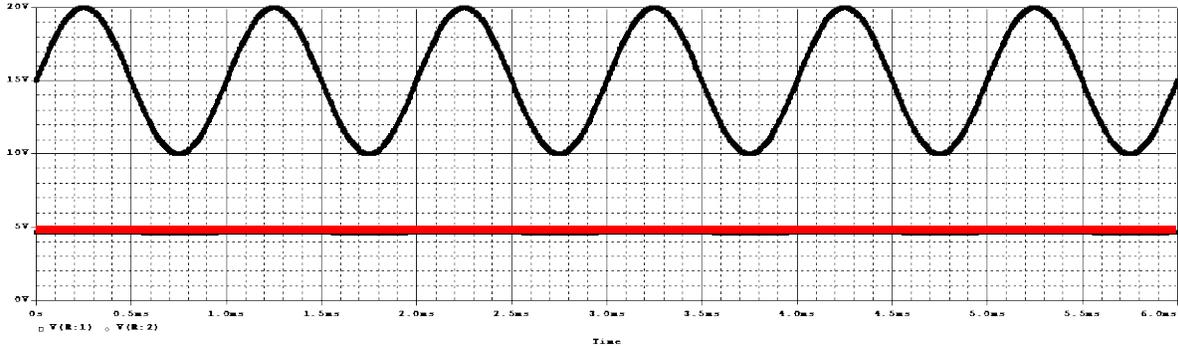
c. Zener Circuit (8 or 9pts) – A 1N750 Zener diode is used with the goal of producing a nearly constant DC signal from an AC input.



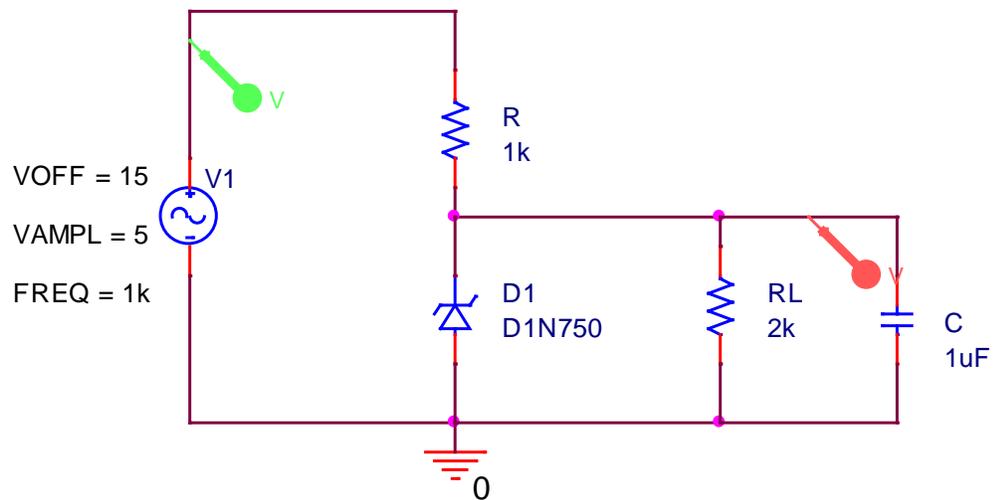
The shape of the input voltage does not matter as long as the voltage delivered to the Zener is greater than 4.7V, which it is. Thus the output will just be flat at 4.7V.

**Question III – Diode Circuits (Cont)**

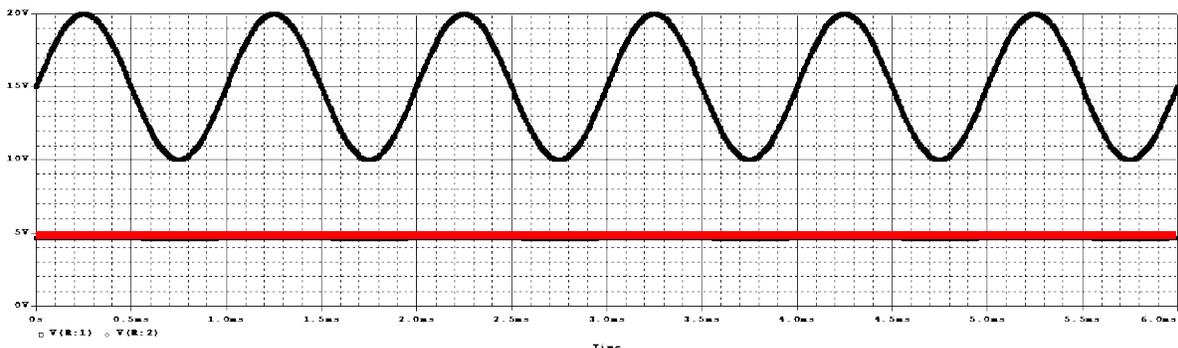
The input signal at A is shown. Sketch the output signal between B and C.



A smoothing capacitor is added to the circuit, as shown below. Sketch the output voltage between B and C with the capacitor in place.

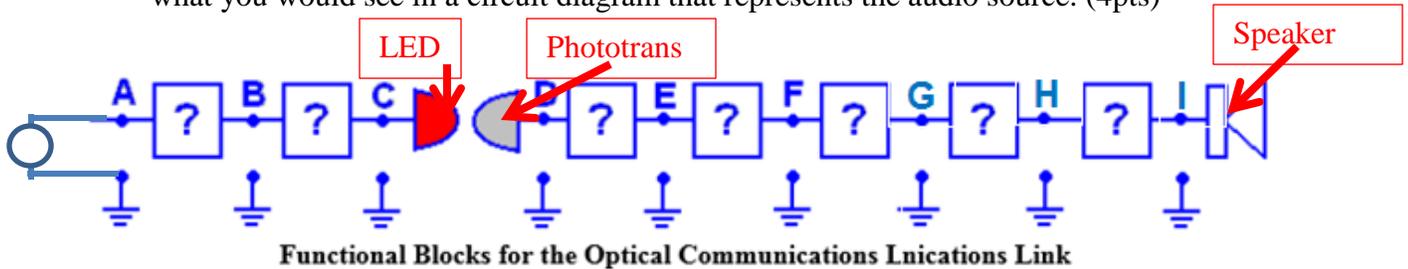


Note that there is a very small wiggle in the output voltage because there is not quite enough current to get fully past the knee. Also, because the output is already flat (DC), adding C makes no difference.



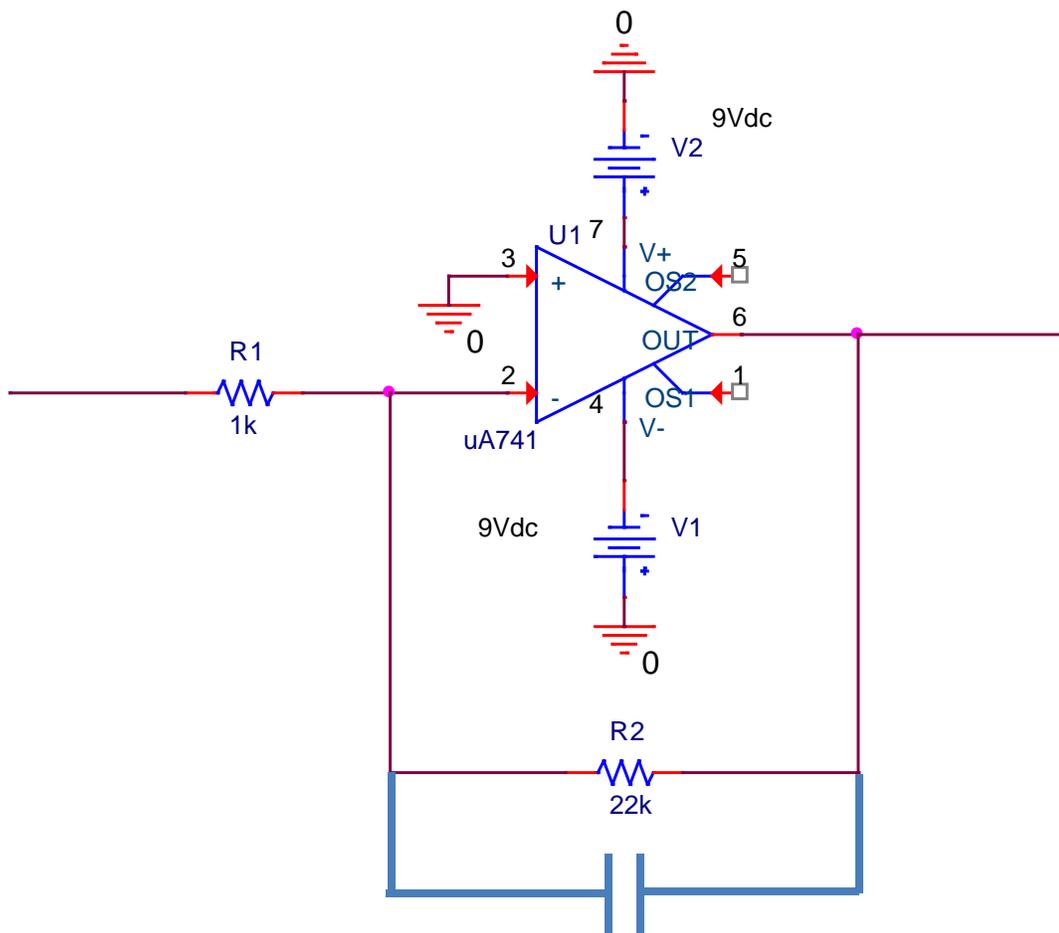
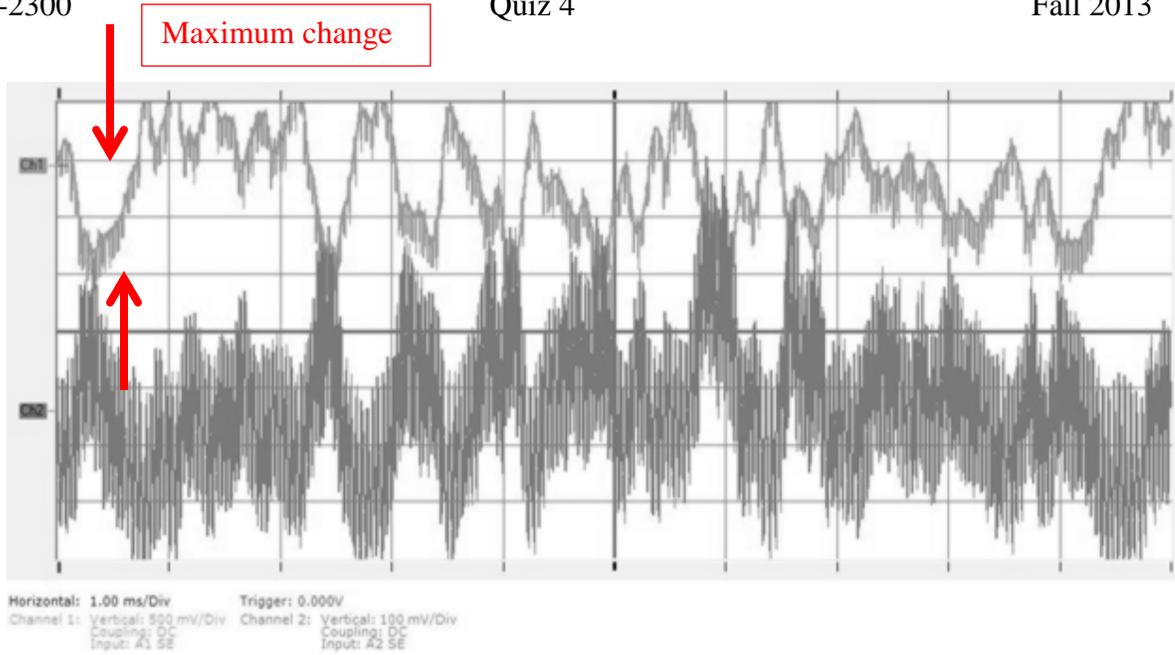
**Question IV – Complex Circuits (25 Points)**

- a. Optical Transmitter-Receiver Project – Shown below is the general diagram of the functional blocks for Project 4. Label the speaker, the LED and the phototransistor. Then add in the audio source using the appropriate circuit element or elements. That is, draw in what you would see in a circuit diagram that represents the audio source. (4pts)



- b. Next, identify each block below by indicating the node letters on either side. Then, explain the function of the block. For clarity, one of the elements has already been identified and its function described. There are only 6 blocks (6pts)
- 1) Audio Amplifier **G-H amplifies signal from pre-amp and is designed to drive speakers through matching networks.**
  - 2) DC Blocking Capacitor **A-B capacitor blocks DC to protect the audio source (e.g. phone) from DC voltages on pin 5 of 555.**
  - 3) Pre-amplifier **E-F amplifies the low level AC signal from the phototransistor to levels that the audio amplifier can work with.**
  - 4) Astable Multivibrator **B-C produces a PPM/PWM signal whose average carries the value of the input audio, sample time is the full pulse cycle time.**
  - 5) Matching Network **H-I matches the impedance of the speaker to optimize the transfer of power from the audio amp to the speaker. (Missing from diagram)**
  - 6) Volume Control **F-G a potentiometer that can reduce the output voltage from the pre-amp if it is too large.**
  - 7) Bias Resistor & DC Blocking Capacitor **D – E Provides the DC bias voltage and current for the phototransistor and allows only the AC voltage to reach the pre-amplifier.**
- c. In the project, you notice that the signal driving the speaker looks similar to the original audio input voltage, but contains artifacts from the transmitter modulation in the form of large spikes. An example plot obtained with Mobile Studio is shown below. Assume that you decide to modify the pre-amplifier so that it acts like an integrator. The pre-amp circuit is shown below. What is the gain of this amplifier before any modifications are made? (4pts)

The gain is the ratio of the feedback resistor to the input resistor and negative. Thus, gain = -22.



You decide to make the simplest possible change to this circuit by adding a capacitor so that it functions as an integrator. Add the capacitor to the circuit diagram above. (4pts)

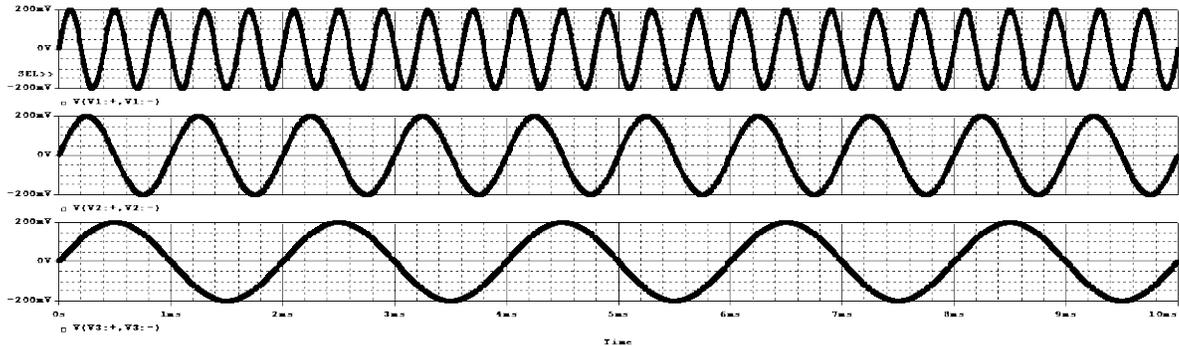
### Question IV – Complex Circuits (Cont)

In the example input audio signal shown above, the frequency is seen to vary with time but stays largely in the range of 500Hz to 2500Hz. The spikey noise on the output is around 25kHz. For reference, plots of three frequencies in the 0.5kHz to 2.5kHz range are shown below for times from 0 to 10ms. Label the frequency of each plot. (3pts)

25 peaks in  
10ms is  $f =$   
2.5kHz

10 peaks in  
10ms is  $f =$   
1kHz

5 peaks in  
10ms is  $f =$   
500Hz



Using the common trial-and-error method applied often in class, you reach into your parts bag and pull out the first relatively small capacitor you find. A picture of the capacitor is shown at the right. You connect it to your circuit and *eureka!* you find that the signal at the speaker looks a lot more like the original input signal. (Sometimes, you just get lucky.) To receive full credit on your project report, you realize that you have to explain why it works. First, what is the actual value of this capacitor? (2pts)



103 is 10000pF or 0.01μF

Next, determine the **approximate amplitude** of the output at the three frequencies above and at 25kHz. Assume the input amplitude shown in the figure above (0.4V peak-to-peak) and make any reasonable assumptions. Express your answer as a peak-to-peak voltage. (4pts) **Answers within 33% OK.**

At frequency 1:  $V_{OUT} = .4(13) = 5.2V$

At frequency 2:  $V_{OUT} = .4(9) = 3.6V$

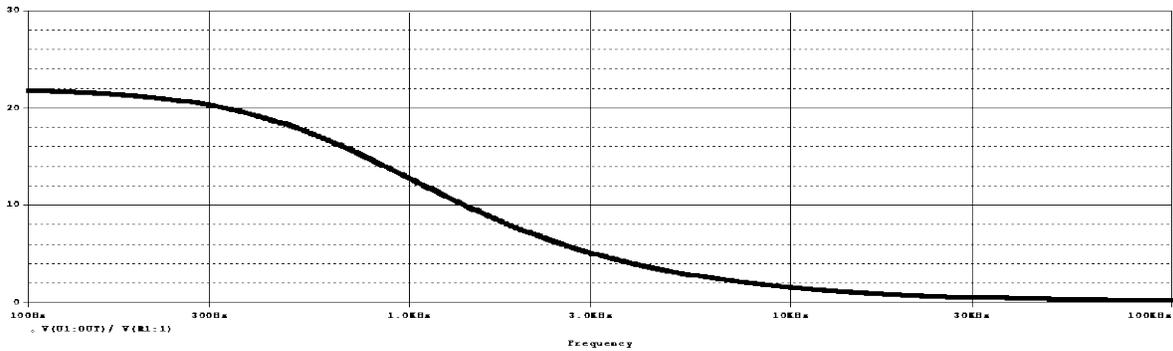
At frequency 3:  $V_{OUT} = .4(5) = 2V$

At frequency = 25kHz:  $V_{OUT} = .4(.6) = .24V$

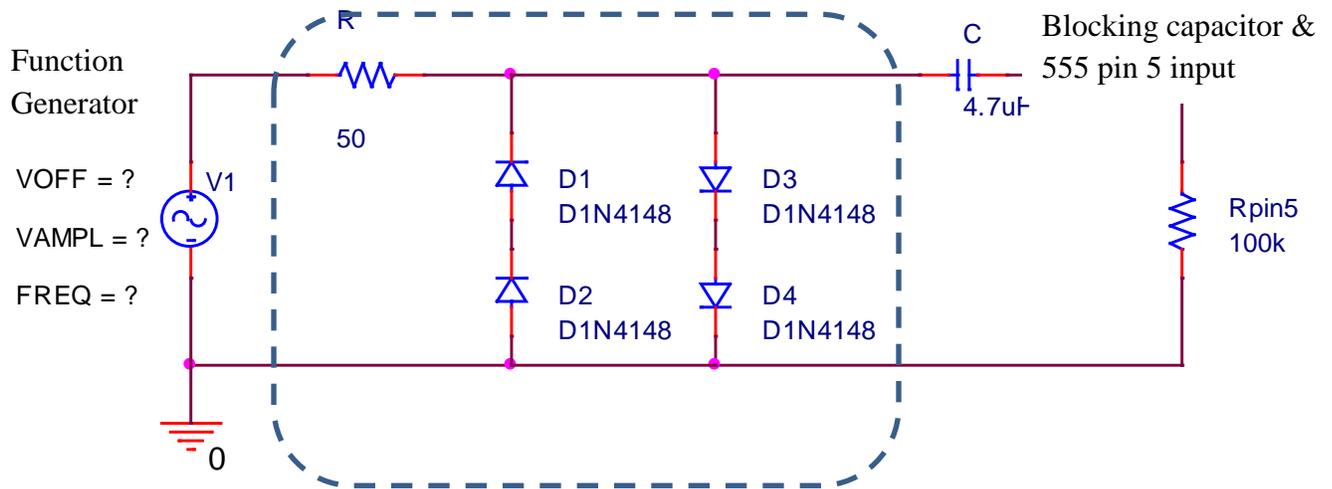
Check the Capacitor impedance relative to 22k to see if the configuration amplifies or integrates. At 25kHz,  $(1/\omega C) \approx .6k$  (integrates); at 2.5k,  $(1/\omega C) \approx 6k$  (integrates, mostly); at 1k,  $(1/\omega C) \approx 16k$  (amplifies, mostly); at 500,  $(1/\omega C) \approx 32k$  (amplifies). In all cases, the out will be at least a little less than without the capacitor.

$V_{OUT} = V_{IN}(\text{Gain})$  where the gain is approximately the parallel combo of 22k &  $1/\omega C$  divided by 1k. For the four cases, Gain is 13, 9, 5 & .6 in decreasing order. This gain calc is approximate because we just use the magnitudes. Gain from PSpice on the next page.

The gain from PSpice is a bit larger, but similar. PSpice uses complex arithmetic to get the exact result. The exact result is  $Gain = \frac{R2}{R1\sqrt{1 + \omega^2 R2^2 C^2}}$  which agrees with PSpice. The question here only asks for an approximate result.



d. A student team decides to add the circuit below to protect the input to their transmitter.



Will this circuit allow the example audio input signal shown above to pass through unchanged to the pin 5 input of the 555 chip? The voltage scale for the input signal is 500mV/div. Explain your answer. (2pts)

The limiting voltage for the two diodes is  $2 \times .7$  or 1.4V. The maximum amplitude in the audio signal is about 1V, which easily fits in 1.4V so the signal will pass through unchanged. The arrows in the figure show the max change.