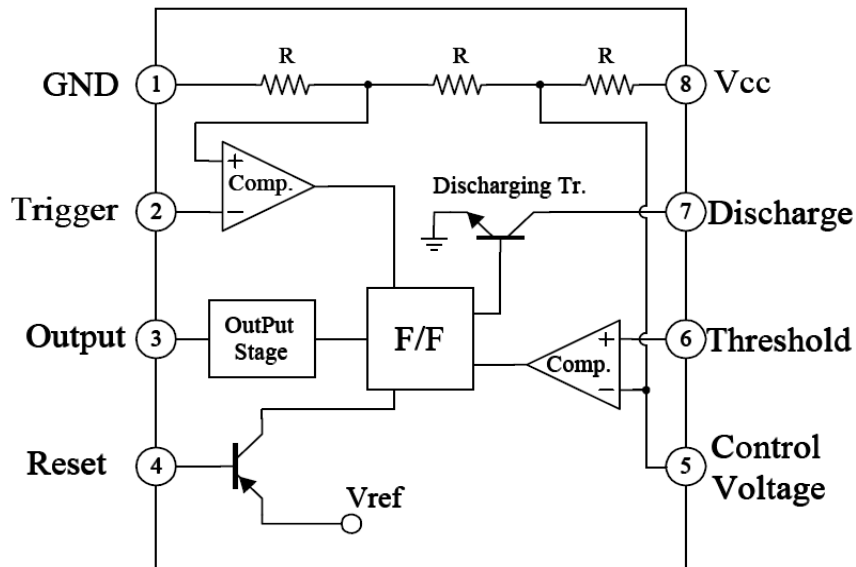


ENGR-2300
Electronic Instrumentation
Quiz 3
Spring 2015



On all questions: **SHOW ALL WORK**. BEGIN WITH FORMULAS, THEN SUBSTITUTE VALUES AND UNITS. No credit will be given for answers that appear without justification. Also, if there is a small flaw in your reasoning, we will not know and not be able to give you credit for what you have correct if you do not provide information on how you solved the problem. Read the entire quiz before answering any questions. Also it may be easier to answer parts of questions out of order.

Some Additional Background



29 April Birthdays

Jules Henri Poincaré (29 April 1854 – 17 July 1912) a French engineer, mathematician, theoretical physicist, and a philosopher of science who said in *Science and Hypothesis* (1902):

“Experiment is the sole source of truth. It alone can teach us something new; it alone can give us certainty.”



“It is often said that experiments should be made without preconceived ideas. That is impossible. Not only would it make every experiment fruitless, but even if we wished to do so, it could not be done. Every man has his own conception of the world, and this he cannot so easily lay aside. We must, example, use language, and our language is necessarily steeped in preconceived ideas. Only they are unconscious preconceived ideas, which are a thousand times the most dangerous of all.”

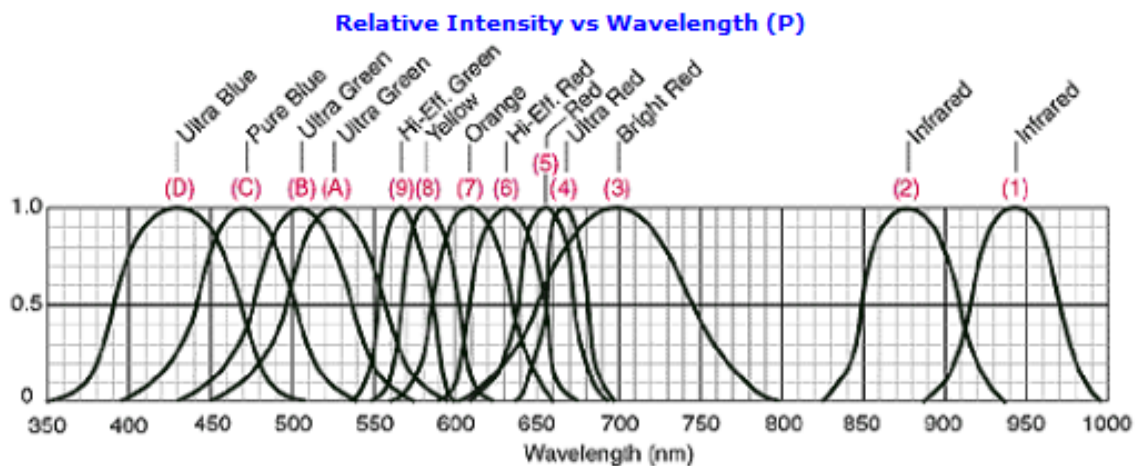


Marietta Blau “During the 1920s and 1930s, Viennese physicist Marietta Blau (29 April 1894 – 27 January 1970) pioneered the use of photographic methods for imaging high-energy nuclear particles and events. In 1937 she and Hertha Wambacher discovered disintegration stars – the tracks of massive nuclear disintegrations – in emulsions exposed to cosmic radiation. This discovery launched the field of particle physics, but Blau’s contributions were under recognized and she herself was nearly forgotten.” Ruth Lewin Sime in *Physics in Perspective* (2013).

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°	InGaAIP - Indium Gallium Aluminum Phosphide
	620	Super Orange	2.2	4500mcd @20mA	15°	InGaAIP - Indium Gallium Aluminum Phosphide
	612	Super Orange	2.2	6500mcd @20mA	15°	InGaAIP - 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°	InGaAIP - Indium Gallium Aluminum Phosphide
★	592	Super Pure Yellow	2.1	7000mcd @20mA	15°	InGaAIP - 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.

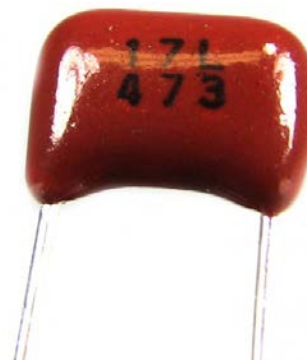
Type Number	Nominal Zener Voltage $V_Z @ I_{ZT}^{(2)}$ (Volts)	Test Current I_{ZT} (mA)	Maximum Zener Impedance $Z_{ZT} @ I_{ZT}^{(1)}$ (Ω)	Maximum Regulator Current $I_{ZM}^{(2)}$ (mA)	Maximum Reverse Leakage Current	
					$T_A = 25^\circ\text{C}$ $I_R @ V_R = 1\text{V}$ (μA)	$T_A = 150^\circ\text{C}$ $I_R @ V_R = 1\text{V}$ (μA)
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: 47000 or .047 μF

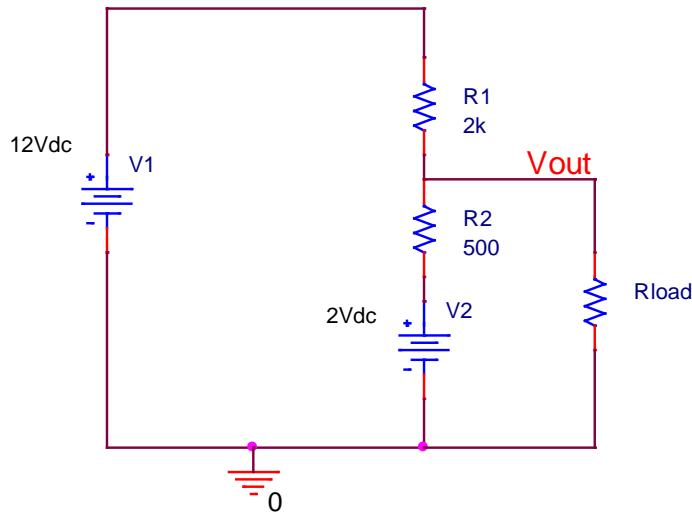
There is also often a letter after the three numbers. This indicates the tolerance of the value.



Question 1 (20 Points) A Little Thevenin & Voltage Divider Background

The following configurations behave like parts of circuits encountered in Experiments 6 and 7.

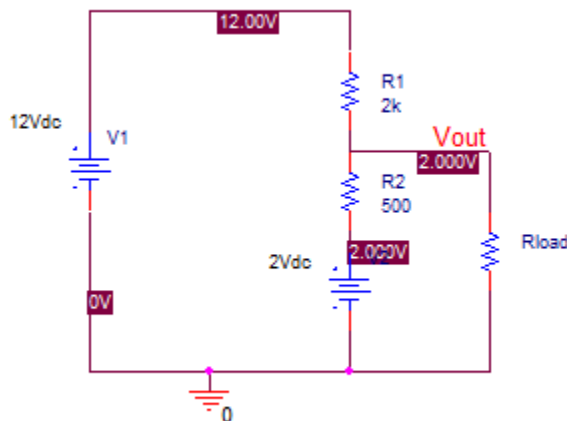
- a. Consider the very basic circuit – the voltage divider – in one of its slightly more complicated forms. Determine the Thevenin Voltage V_{TH} and Resistance R_{TH} for this configuration. (6 points)



$$V_{oc} = V_{TH} = (12-2)(500/2500) + 2 = 4V$$

$$R_{TH} = 500 || 2k = 400\Omega$$

- b. Let $R_{load} = R_{TH}$ Find V_{out} and the current through R_2 . (6 points)



$$V_{out} = 2V \text{ because that is half of } V_{TH}$$

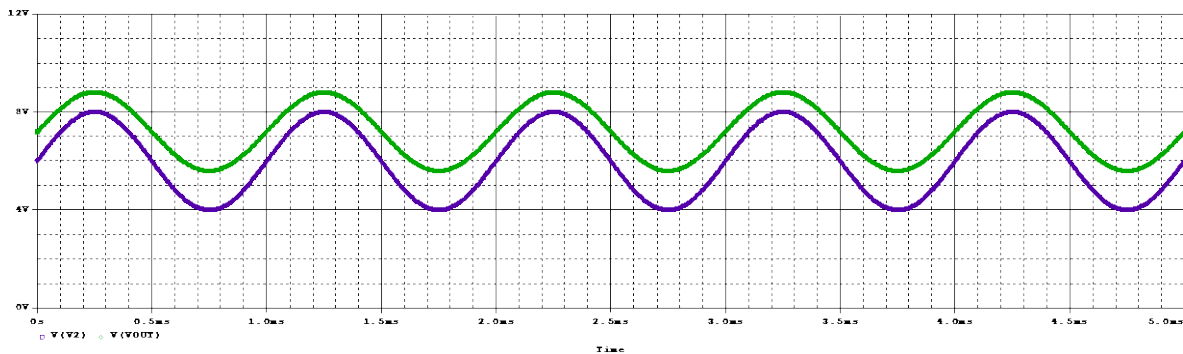
The current through R_2 is zero because the voltage is the same at both ends. This is not a general result, but only applies to this particular problem.

- c. Replace the DC voltage source V2 with a sinusoidal source (offset = 6V, freq = 1kHz, amplitude = 2V). The voltage V2(t) is plotted below. Find and plot Vout as a function of time for Rload an open circuit. The horizontal scale goes from 0ms to 5ms and the vertical scale from 0V to 12V. Sketch neatly and clearly label the maximum and minimum values of Vout. (6 points)

at a: $V = (12-6)(500/2500) + 6 = 7.2V$

at b: $V = (12-8)(.2) + 8 = 8.8V$

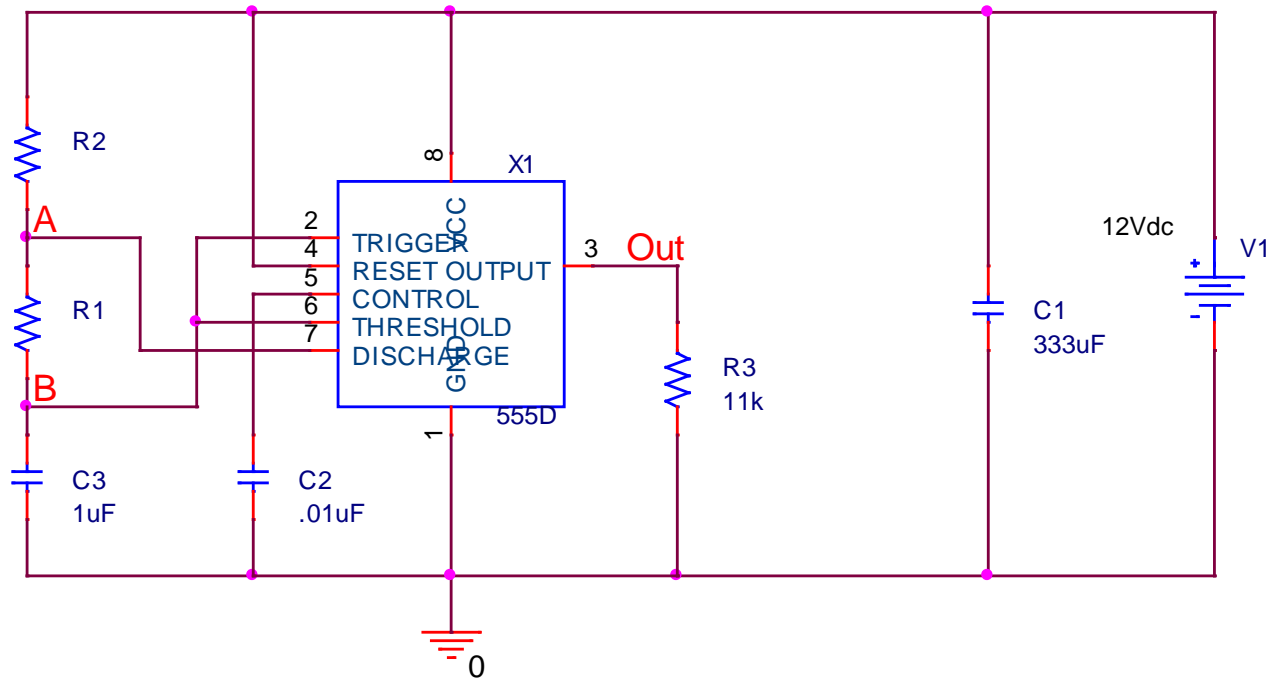
at c: $V = (12-4)(.2) + 4 = 5.6V$



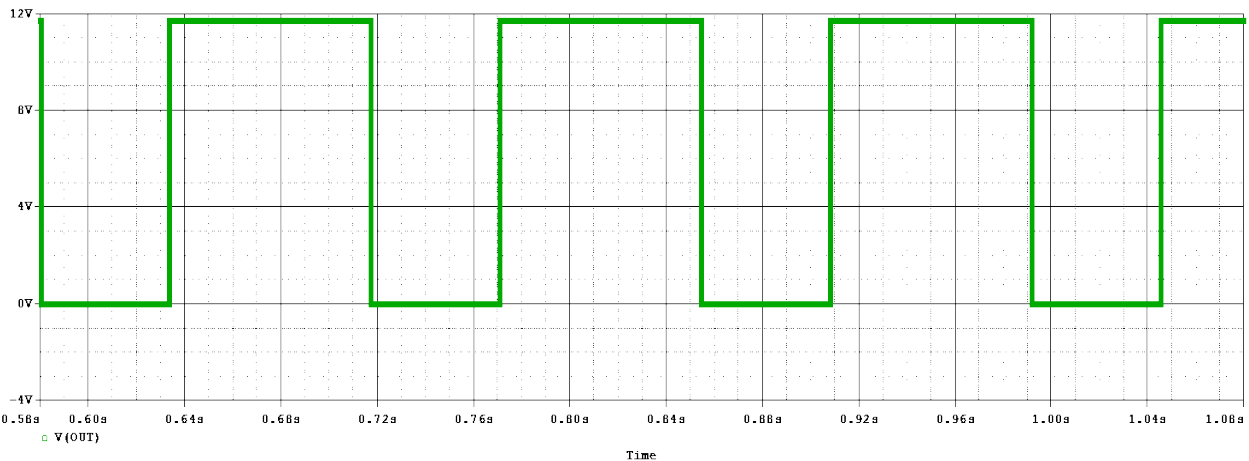
- d. What are V_{TH} and R_{TH} for the second configuration? (2 points)

R_{TH} is the same.

$$V_{TH} = 7.2 + 1.6\sin(2\pi ft) \text{ where } f = 1\text{kHz.}$$

Question 2 (20 Points) Astable Multivibrator (An Iconic 555 Timer Application)

- a. A 555 timer, astable multivibrator is built as above with $R_3 = 11\text{k}\Omega$, $R_1 = \text{unknown}$, $R_2 = \text{unknown}$, $C_1 = 333\mu\text{F}$, $C_2 = 0.01\mu\text{F}$, $C_3 = 1\mu\text{F}$, and $V_1 = 12\text{V}$. The output voltage is determined using PSpice as shown below. From the plot, determine the approximate **on time** (T_1) and the **off time** (T_2) for this circuit. *Note that you will determine these times with more accuracy below, but you only need approximate values at this point.* (4 Points)



$$T_1 \approx 0.085\text{s}$$

$$T_2 \approx 0.055\text{s}$$

by estimating.

- b. Assume that the circuit was built using resistors from a box where they were all equal to multiples of $11\text{k}\Omega$ (i.e. $11\text{k}\Omega$, $22\text{k}\Omega$, $33\text{k}\Omega$, $44\text{k}\Omega$, $55\text{k}\Omega$, $66\text{k}\Omega$, $77\text{k}\Omega$, $88\text{k}\Omega$ or $99\text{k}\Omega$). Determine the values of R_1 and R_2 (4 points)

$$R_1 = 77\text{k}\Omega$$

$$R_2 = 44\text{k}\Omega$$

Just try the values until they work. Start with R_1 because only it is involved in T_2 .

- c. Using your answers to part b, find T_1 and T_2 again, but with more accuracy this time. (4 points)

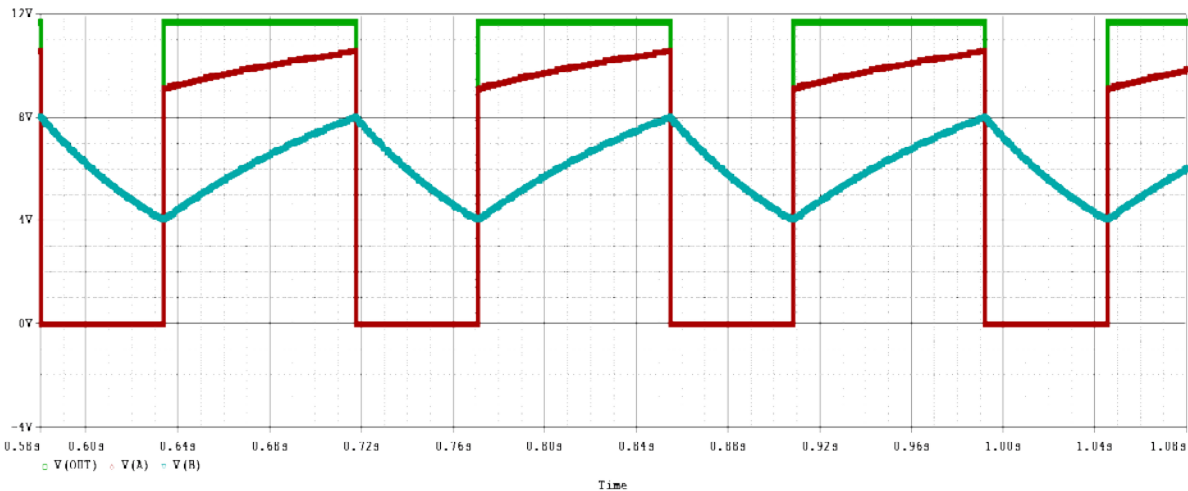
$$T_1 = 0.083\text{s}$$

$$T_2 = 0.053\text{s}$$

- d. Determine the voltages at points A and B in the circuit and then sketch them on the plot on the previous page showing the output voltage. (4 points) Label the key points on the plots. (4 points) *Show your work below.*

For points 2 & 6, the max is 8V and min is 4V

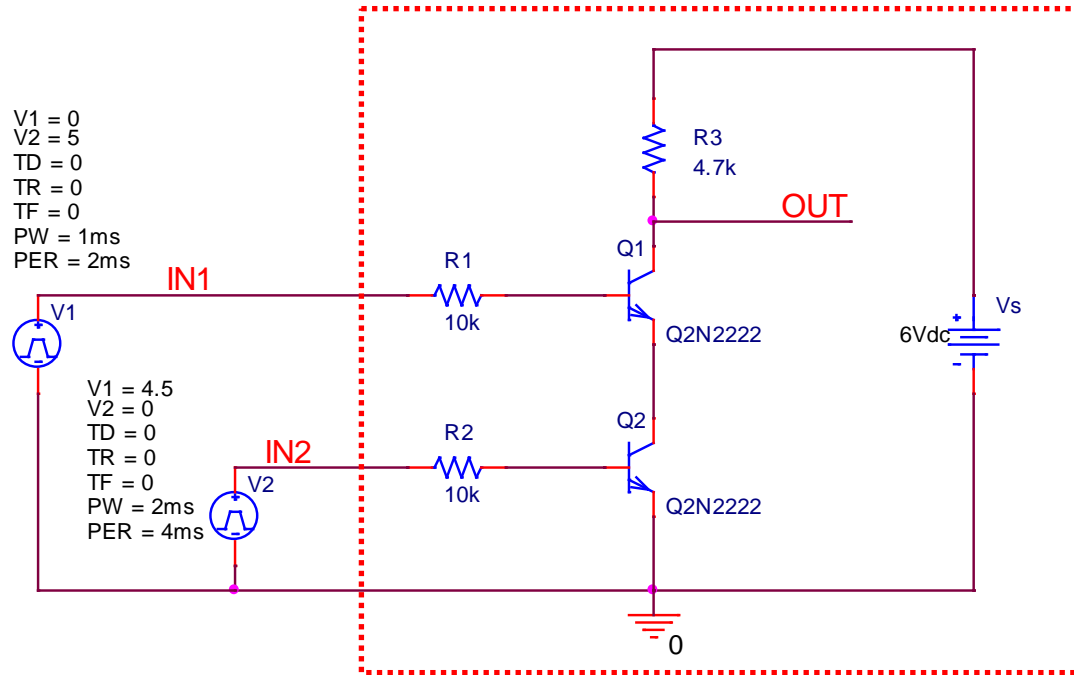
For 7, when the voltage is non-zero, the min is $4 + 8(77/121) = 9.1\text{V}$ and the max is $8 + 4(77/121) = 10.55\text{V}$



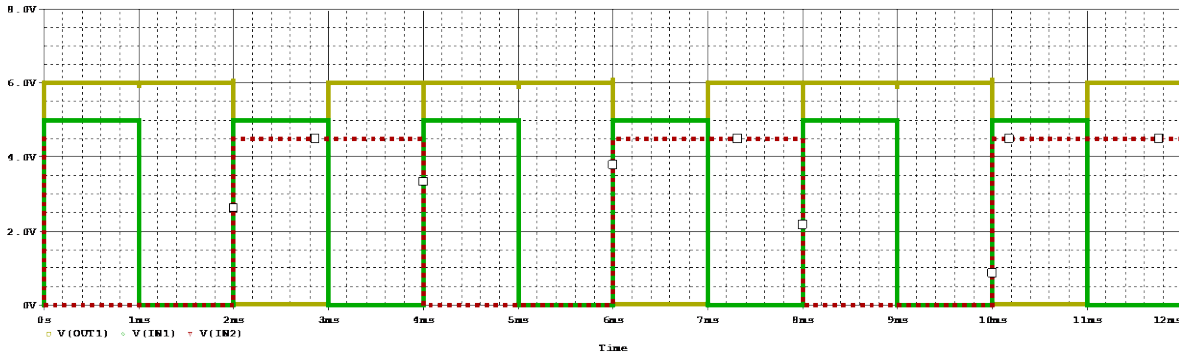
Blue is 2 & 6, Red is 7, Green is 3 (OUT) The levels match the calculations above.

Question 3 (20 Points) Combinational & Sequential Logic Circuits

- a. The circuit below shows how a simple logic gate can be built out of transistors and resistors. The circuit is inside the dashed box and has two inputs and an output.



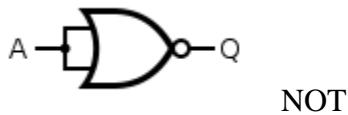
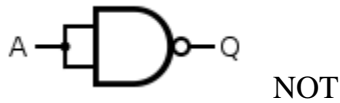
The figure below shows the input voltages for this circuit. Identify what logic gate this is and carefully sketch the output voltage. Label any significant output voltage levels. (6 points)



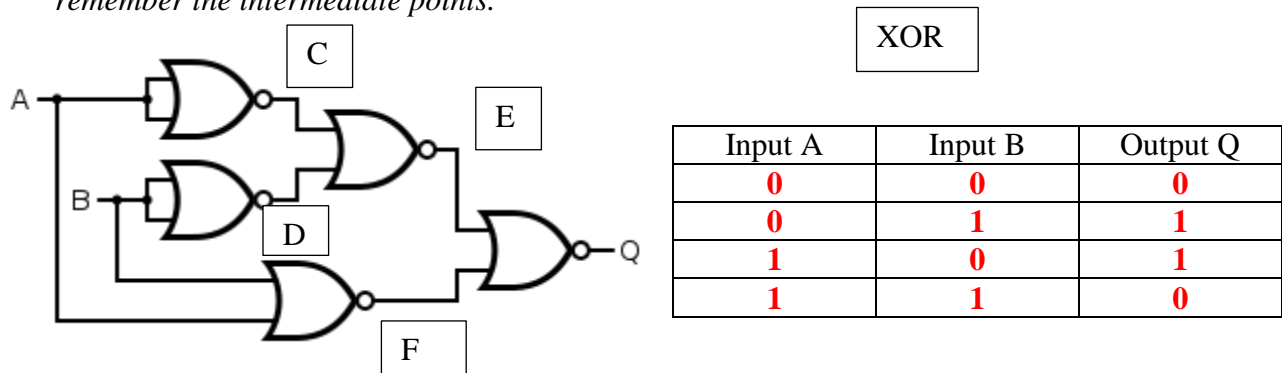
Yellow is output. Note that the output is high for all but when both inputs are high. Thus, this is a NAND gate.

It is possible to configure any standard logic gate out of either just NOR gates or NAND gates or simple combinations. *Hint: Determine the states of the other points in each circuit as you fill out the tables.*

- b. What logic gate can be realized with either the NAND or NOR configuration shown below? (2 Pts)



- c. The following circuit is configured using only NOR gates. Fill in the truth table for this circuit and identify the standard logic gate that behaves in the same manner. (6 Pts) *Again remember the intermediate points.*



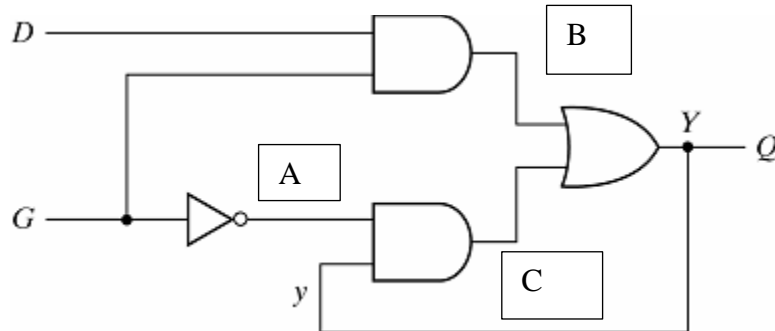
C	D	E	F
1	1	0	1
1	0	0	0
0	1	0	0
0	0	1	0

- d. A 4-bit counter is cleared and then receives a string of clock pulses. What are QA, QB, QC and QD after 18 clock pulses? Clearly indicate the state of each signal. (2pts)

QD	QC	QB	QA
0	0	1	0

Count to 15 then start over for 3 more. First is all zeros, then 0001 and then 0010

- e. Determine the truth table for the following circuit. (4 Pts) *Note that you have to do two cases, one where Q begins at 0 and one where it begins at 1.*

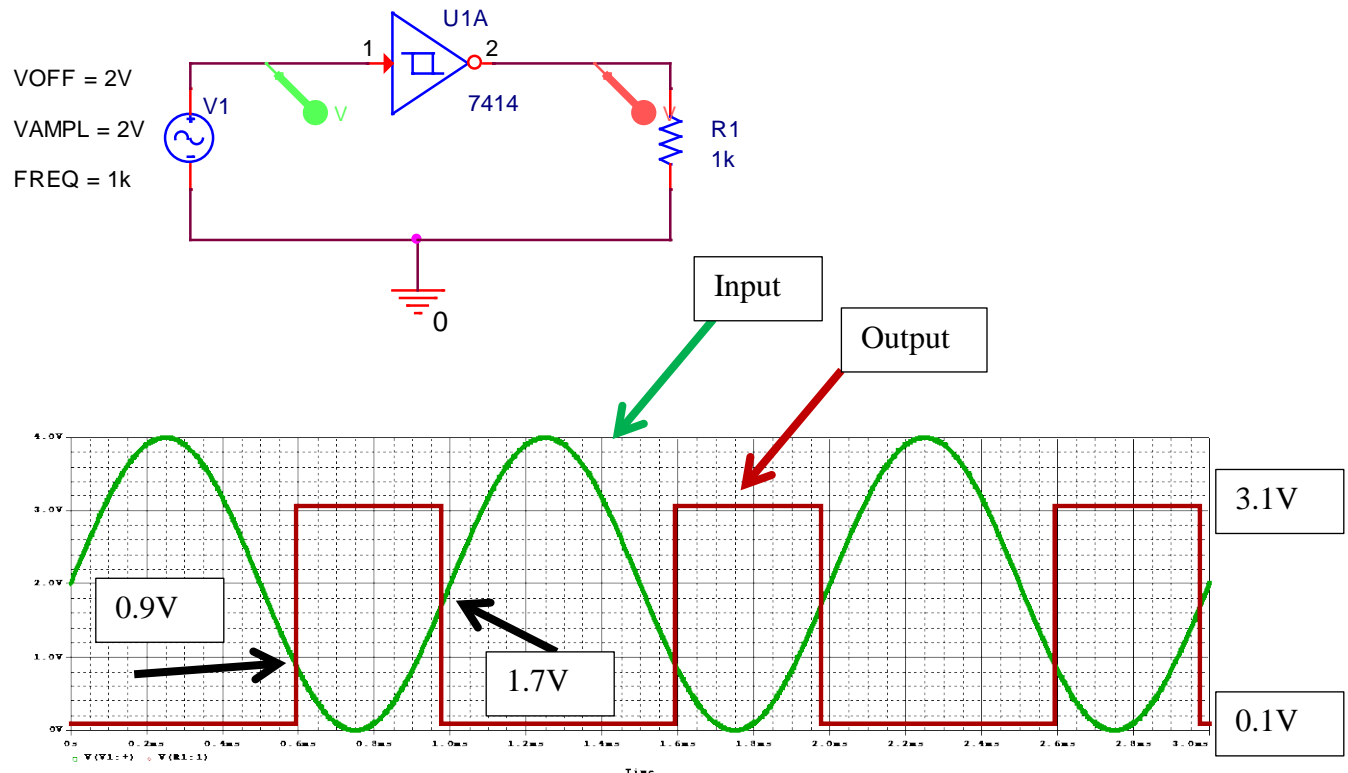


Q Before	D	G	A	B	C	Q After
0	0	0	1	0	0	0
0	0	1	0	0	0	0
0	1	0	1	0	0	0
0	1	1	0	1	0	1
1	0	0	1	0	1	1
1	0	1	0	0	0	0
1	1	0	1	0	1	1
1	1	1	0	1	0	1

Question 4 (20 Points) Schmitt Trigger

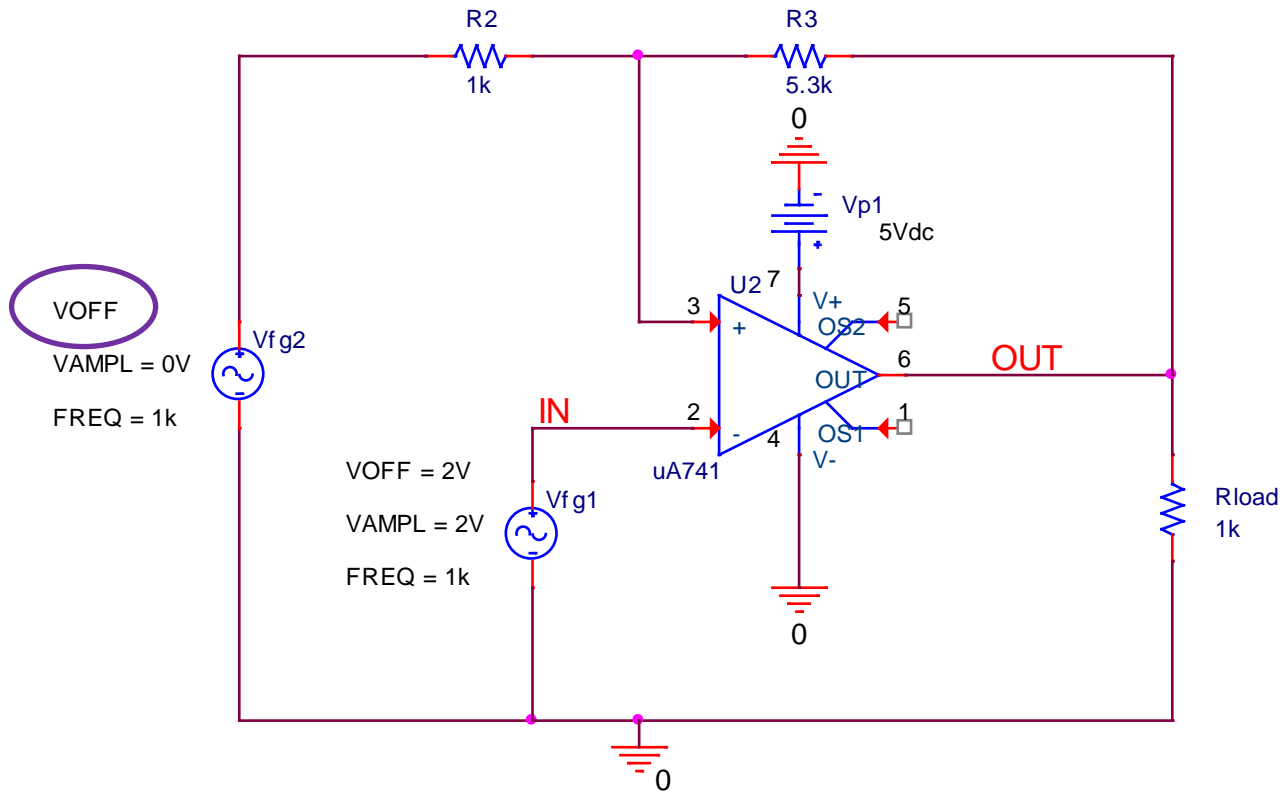
In this problem, we investigate the same properties of Schmitt Triggers we did in Experiment 6, but in a different order. First we look at how a commercial device works and then see if we can reproduce its properties using the Schmitt Trigger we can make with an op-amp.

- a. To see how a 7414 Schmitt Trigger behaves, a sine wave is selected as an input and both the input and output voltages are observed. The horizontal scale on the voltage plot is 0ms to 3ms and the vertical scale is from 0v to 4V. In the plot below, label the input and output voltages, determine and label the two reference voltages where the Schmitt Trigger switches output state. Also label the values of the two output voltage levels. (6 points)



- b. The next task is to design a homemade Schmitt Trigger that performs the same way as the 7414. You wish to test the circuit with your Analog Discovery board, so you decide to use function generator 1 (W1) for the input signal, the +5V power supply for one op-amp power connection and ground the other. For V_{ref} you use the offset voltage from the second function generator (W2) and set the amplitude to zero, so you only get a DC

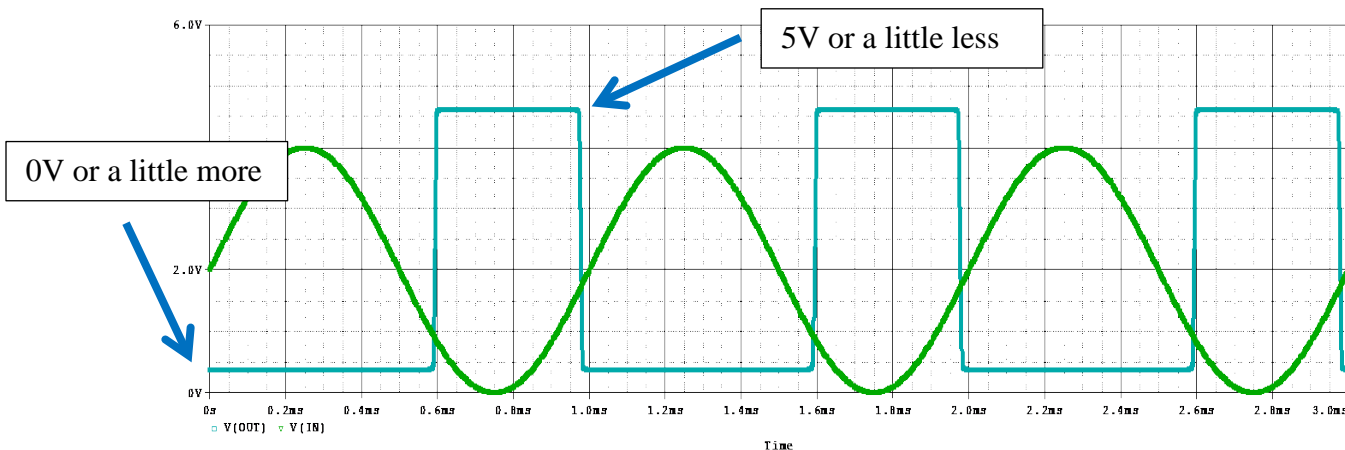
voltage. If you use $R2 = 1k\Omega$ and $R3 = 5.3k\Omega$, what value should you select for your function generator offset voltage. (6 points)



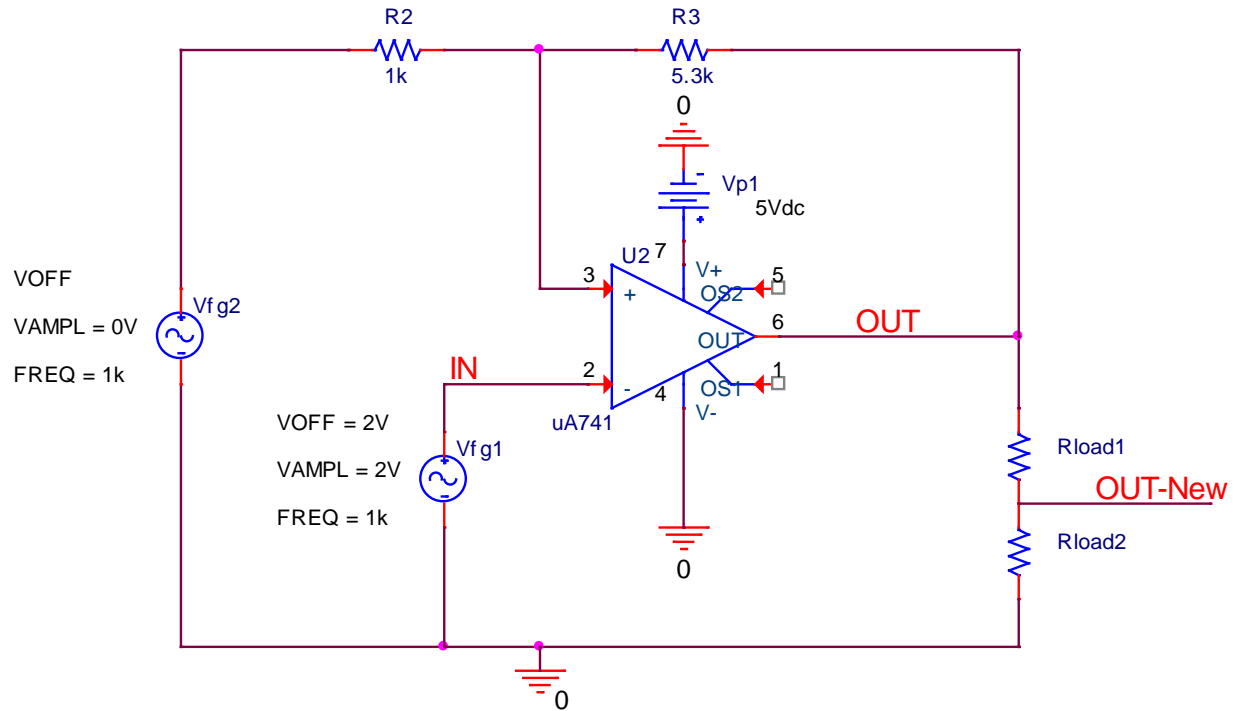
$$V_+ = \frac{R2}{R3 + R2} (V_{out} - V_{ref}) + V_{ref} \quad 0.9 = \frac{R2}{R3 + R2} (0 - V_{ref}) + V_{ref} = .84V_{ref}$$

$$V_{ref} = 1.07$$

c. Plot the output voltage for the homemade Schmitt Trigger on the figure below. The input voltage is given. (4 points) *Make any reasonable assumptions. e.g. output $V = 5V$ or $0V$*

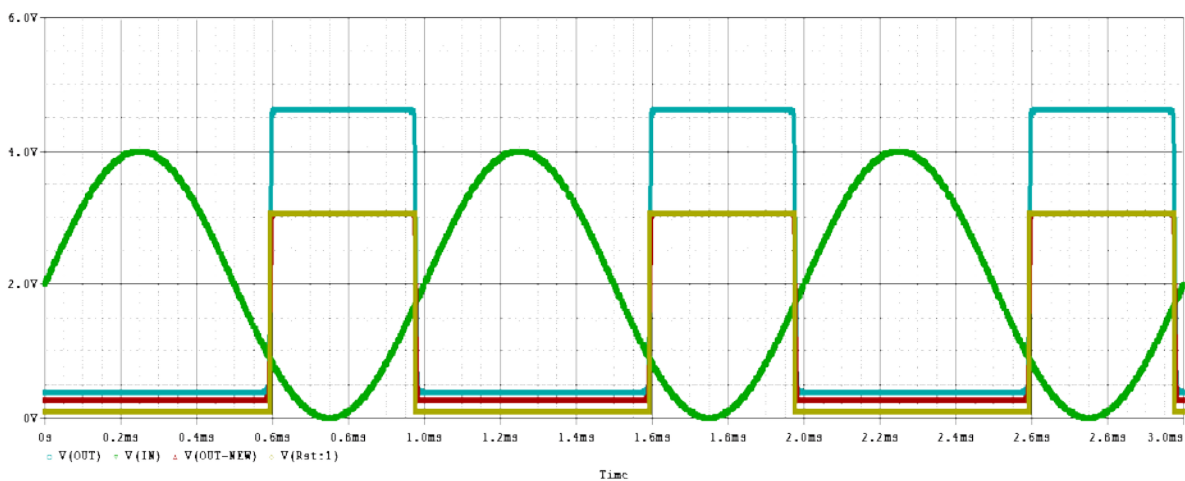


- d. Now the high output voltage should be adjusted so that it is approximately equal to the high voltage produced by the 7414. The simplest way to do this is to replace the 1kΩ resistor with two resistors that add in series to 1kΩ and divide the voltage to the level seen with the 7414. What two resistors should be used in the divider? (4 points)



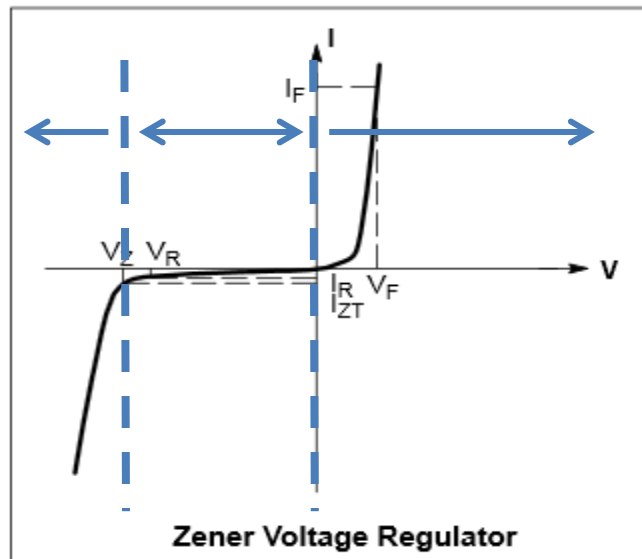
The output voltage should be about 2/3 of its previous value to be near the voltage from the 7414. Thus $R_{load2} = 600-666\Omega$ and $R_{load1} = 400-333\Omega$.

All voltages are shown below, including the 7414 output. Only the top voltage level matches. The bottom voltage level is off.

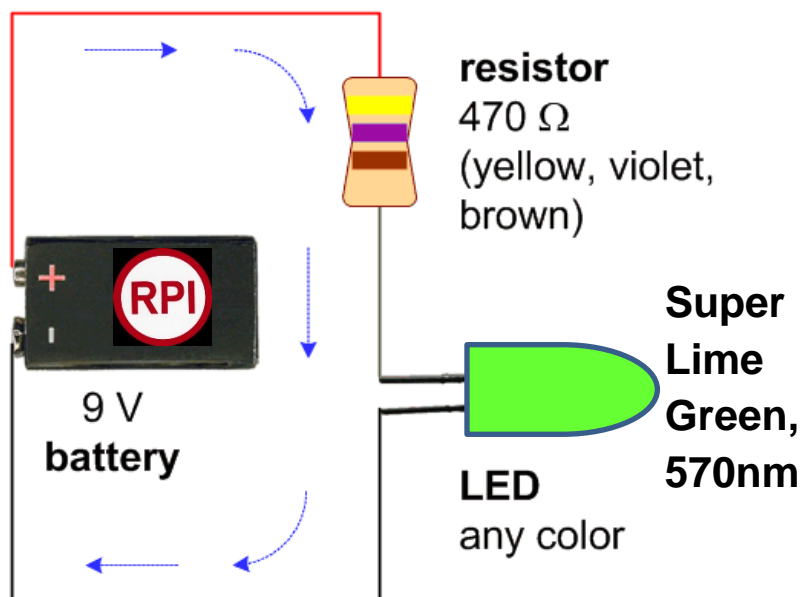


Question 5 (20 Points) Diode Circuits

- a. (3 Pts) We wish to regulate a 12V DC power supply using a Zener Diode from the table at the beginning of this quiz. Like all Zeners, this diode has three voltage ranges shown in I-V curve below: the Breakdown Region, The Forward Bias Region and the Reverse Bias Region. Assuming ideal conditions for this diode, complete the following
- The voltage across the diode is $V_D \approx 0.7V$ in the Forward Bias Region
 - The voltage across the diode is $V_D \approx 12V$ in the Breakdown Region
 - The current through the diode is $I_D \approx 0A$ in the Reverse Bias Region



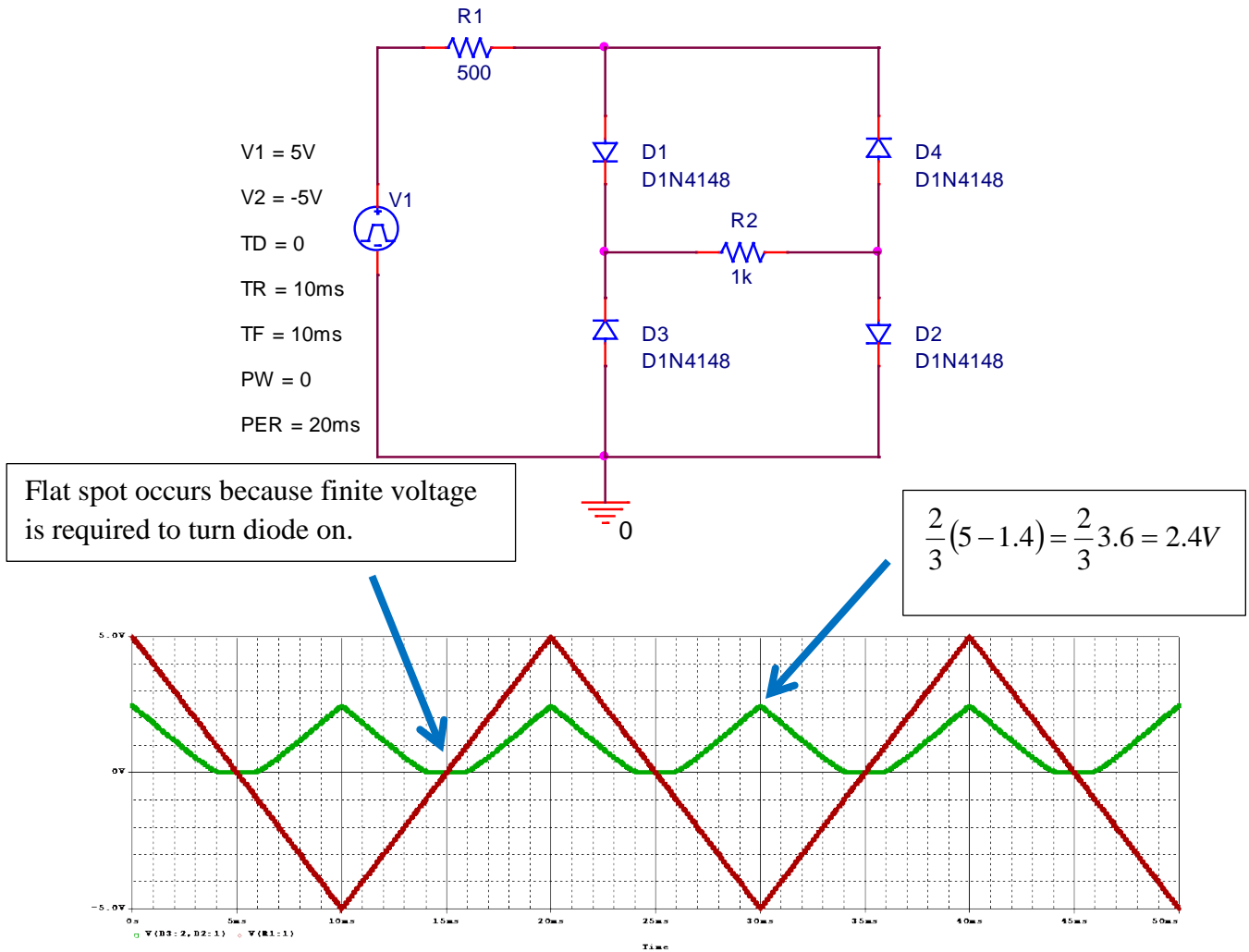
- b. (3 Pts) What is the current through the LED below, if we use the specified green LED? (Choose the closest answer.)



- 6 mA
- 9 mA
- 11 mA
- 14 mA
- 15 mA

$$(9-2)/470 = 14.9\text{mA} \approx 15\text{mA}$$

- c. (4 Pts) This problem is similar to a task from Experiment 8 with a triangular wave input voltage. The input voltage is plotted below with the vertical scale going from -5V to +5V. Plot the voltage that results across the load resistor R2 and carefully label key values. Assume the positive probe is located to the left of R2 and the negative probe to the right.



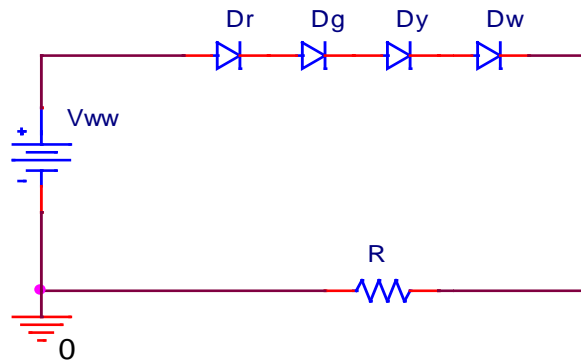
- d. (3 Pts) The voltage across each forward-biased diode in the full-wave rectifier above is
- Near the source voltage
 - Near twice the source voltage
 - Near half the source voltage
 - Near 0.6 to 0.7 volts
 - Near zero volts

- e. (4 Pts) We now want to use multiple LEDs like a short string of holiday lights. For this purpose, we will use four different color LEDs: Red, Green, Yellow and White. We will use the four 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

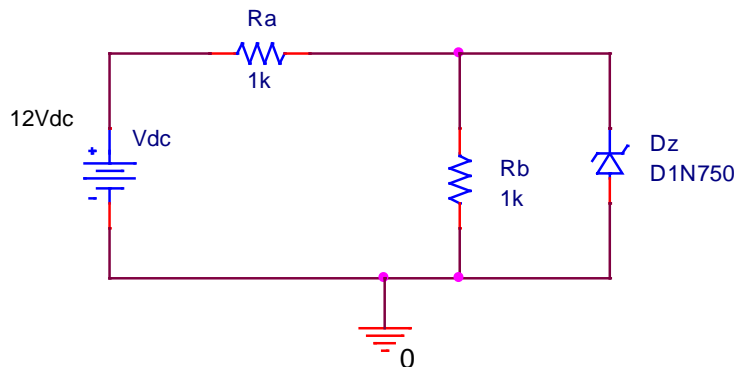
Determine the voltage V_{ww} and resistance R to achieve the desired operating conditions for the series combination of 4 LEDs shown below. Assume that the current is 25mA, since we have decided to slightly over drive our LEDs. Use the typical forward bias voltages from the table. The power supply voltage should be the minimum value that will turn on all of the LEDs.



Sum of forward voltages is $2.2 + 2.1 + 3.6 + 3.5 = 11.4$ so the 12V source is required.

$$(12 - 11.4) / (0.025) = 0.6 / 0.025 = 24\Omega$$

- f. (3 Pts) Shown below is a 1N750 Zener diode working to regulate the voltage across one resistor in a voltage divider. Determine the power dissipated by the Zener diode.



When regulating, $V_Z = 4.7V$. The current from the source is $(12 - 4.7) = 7.3mA$. The current through R_b is $4.7mA$ so the current through the Zener is $(7.3 - 4.7) = 2.6mA$ so the power dissipated by the Zener is $4.7(2.6)mW = 12.2mW$