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ELEN 115L
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<u>Lab 5: Rectifiers</u>

1: Objective:

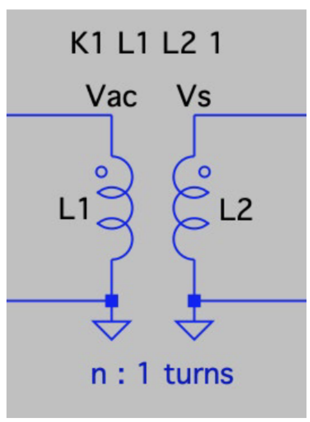
In this lab we will study rectifiers and analyze their performance. We will also calculate the average voltage obtained from each rectifier circuit. Another goal is to understand harmonic distortion and filtering requirements for various topologies.

2: Procedure:

Complete each section of the lab. For each section show:

- Show circuit schematics of each circuit you construct on LTSpice.
- Show screenshots of all plots and waveforms.
- Answer all the questions posed in the handout.

Defining a Transformer:



Question: If the coupling coefficient is 0.99 what do you think that implies?

That implies that the ratio of turns is 99 to 100.

Question: What does this ideal model state about the behavior of the diode?

Using an ideal model means that the diode will produce zero current for negative voltage and be a short for everything else. It will have a resistance of 1mohm when on, 100 megohms when off, and forward voltage of zero volts.

Part 1: Half Wave Rectifier with resistive load

In this part you will be studying the performance of the half wave rectifier

Draw the schematic shown in Figure 2.

Figure 1: Voltage Source Sine Wave in Green and Diode D1 in Blue

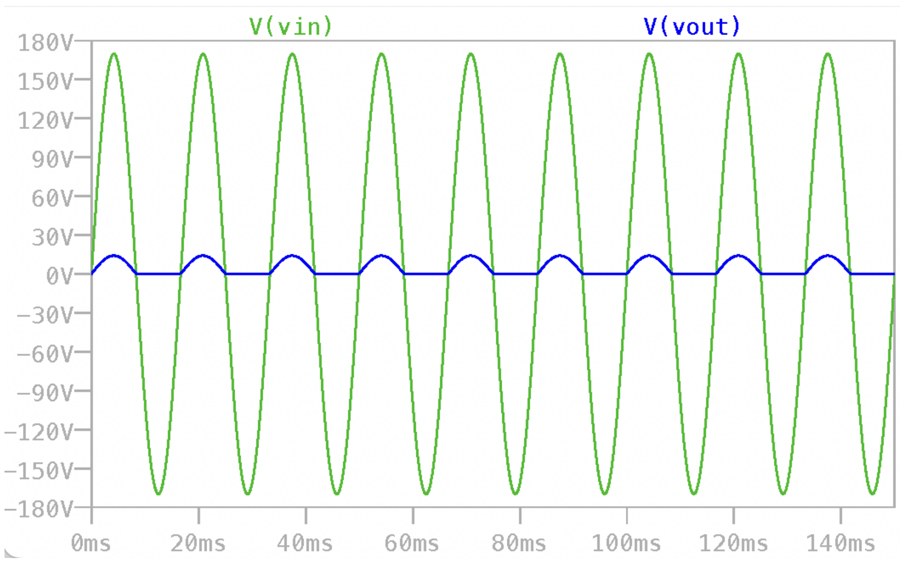
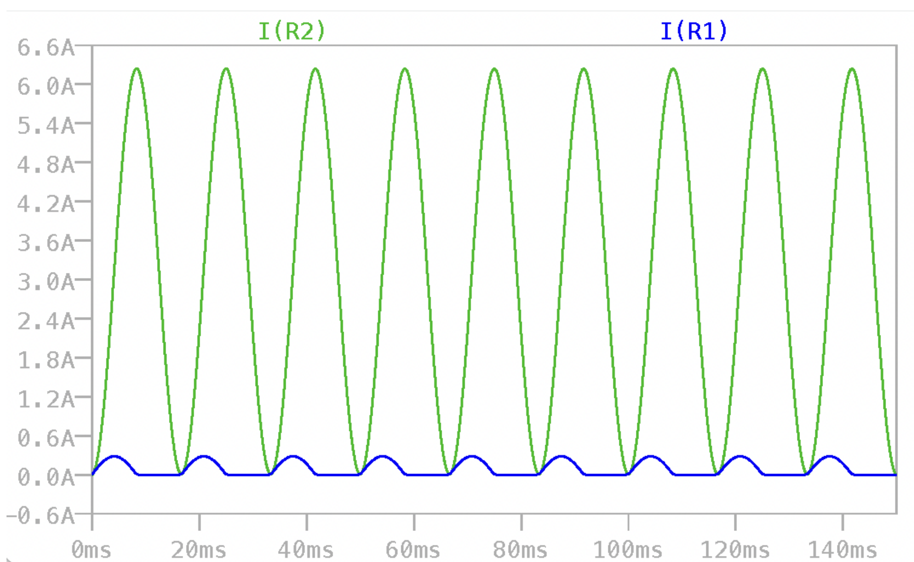


Figure 2: Curent vs Time



Question: What do the L1, L2 values provide in turns ratio?

The inductance values of L1 and L2 are proportional to the square number of turns in the coil. This gives us a turns ratio of 12:1 as the square root of 144 mH and square root of 1 mH is 1.

Figure 3: Output Voltage

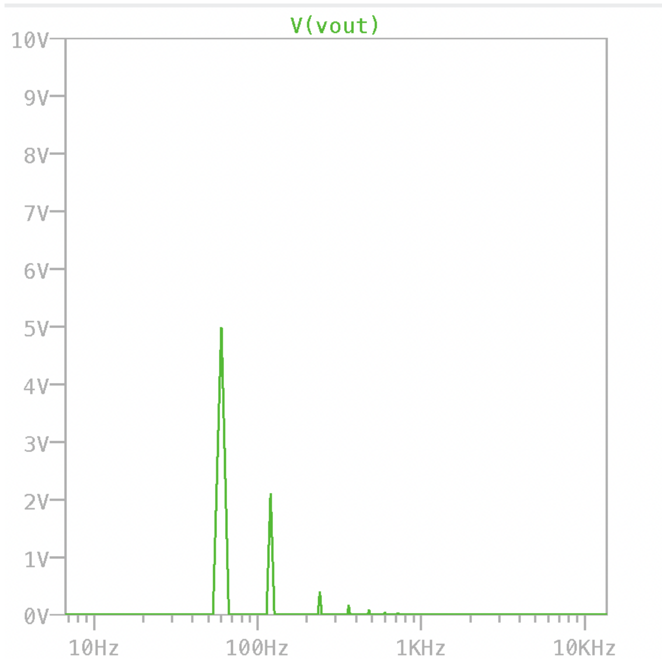


Figure 4: Output Current

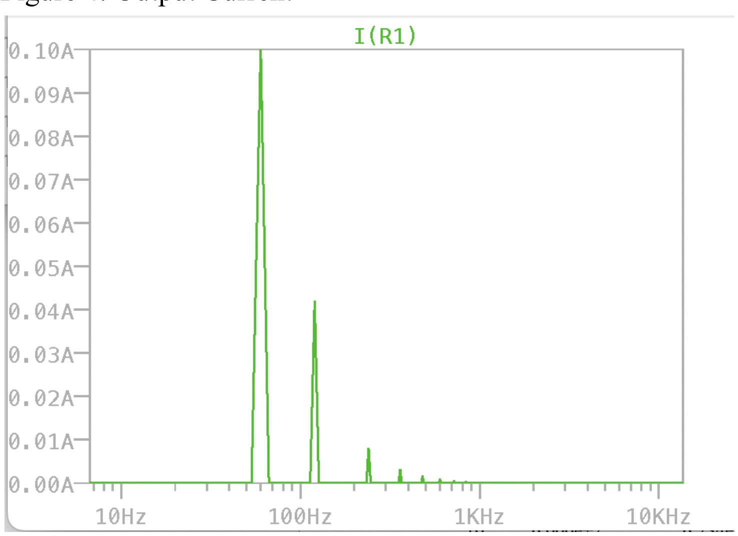


Table 1: Sample table

	Average	**RMS**	**Peak**	**FFT DC Value**	**FFT n=1**	**FFT n=2**	**FFT n=4**	**FFT n=6**	**FFT n=8**	**FFT n=10**	**FFT n=12**
Output Voltage	4.5085V	9.9791V	14.1127V	4.50472	7.055 e+0	2.966 e+0	5.718 e-1	2.305 e-1	1.177 e-1	7.884 e-3	4.117 e-2

Load Current	0.186A	0.200A	0.283A	-	-	-	-	-	-	-	-
Source Voltage	0.00V	120.1162V	169.87V	-	-	-	-	-	-	-	-

Fourier components of V(vout)

DC component:4.50472

Harmonic Number	Frequency [Hz]	Fourier Component	Normalized Component	Phase [degree]	Normalized Phase [deg]
1	6.000e+1	7.055e+0	1.000e+0	-0.05°	0.00°
2	1.200e+2	2.966e+0	4.205e-1	-89.98°	-89.93°
3	1.800e+2	6.873e-3	9.742e-4	-75.99°	-75.94°
4	2.400e+2	5.718e-1	8.105e-2	-89.84°	-89.78°
5	3.000e+2	7.110e-3	1.008e-3	-67.20°	-67.14°
6	3.600e+2	2.305e-1	3.268e-2	-89.42°	-89.36°
7	4.200e+2	7.394e-3	1.048e-3	-59.73°	-59.68°
8	4.800e+2	1.177e-1	1.668e-2	-88.52°	-88.46°
9	5.400e+2	7.669e-3	1.087e-3	-53.57°	-53.52°
10	6.000e+2	6.734e-2	9.545e-3	-86.87°	-86.82°
11	6.600e+2	7.884e-3	1.118e-3	-48.58°	-48.53°
12	7.200e+2	4.117e-2	5.835e-3	-84.10°	-84.04°

Total Harmonic Distortion: 42.994614%(43.001845%)

Questions:

<u>What do you notice with the waveforms? Describe what is happening when the AC signal is positive and when the signal is negative.</u>

The output waveform parodies the input waveform for the positive voltages, and has no output for negative. When the AC signal is positive the output is a reduced positive voltage, when the AC signal is negative the output voltage is zero.

<u>What are important parameters to consider when picking a diode?</u>

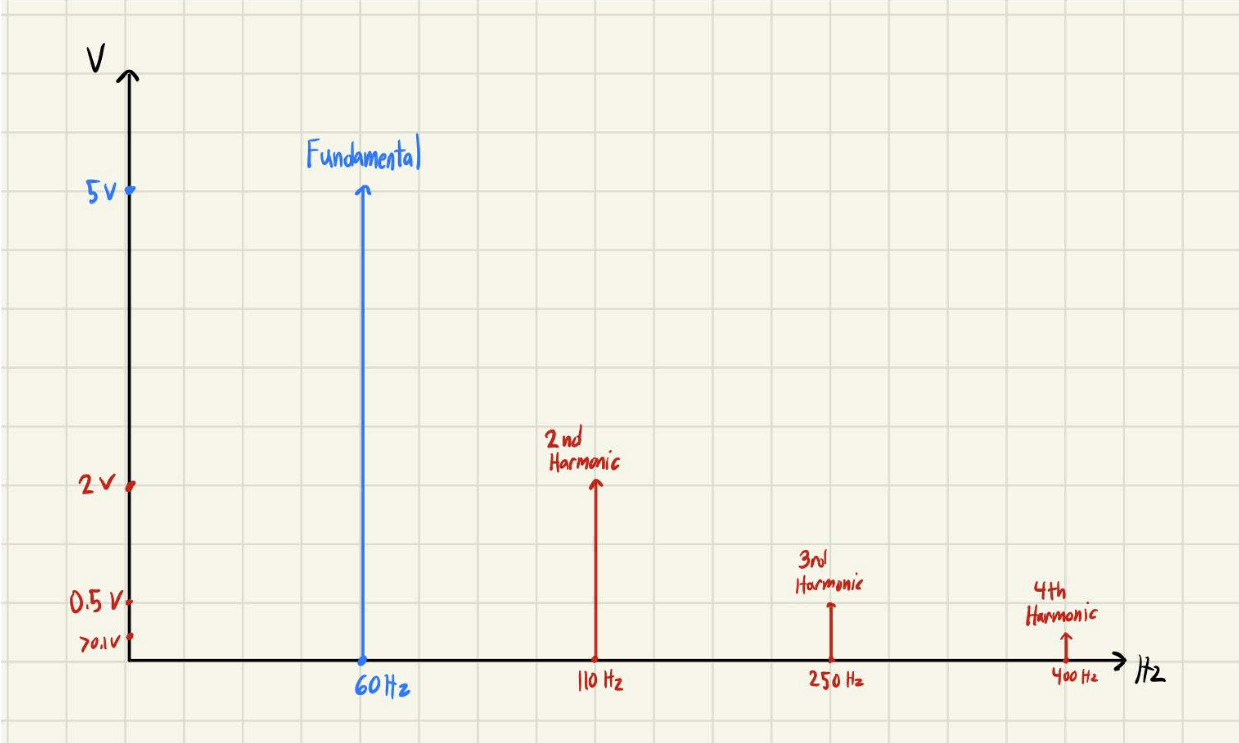
The reverse voltage rating, the forward current rating, and the forward power dissipation rating are most important when picking a diode.

<u>What is the average output voltage possible for this rectifier. What average was obtained. Are these the same. Explain why or why not?</u>

The average output voltage we obtained was 4.5085 and the possible average output voltage for a half wave rectifier is Vavg = Vo/pi = 14.1127/pi = 4.4922. These are about the same, which makes sense since we are modeling a close-to ideal version of our circuit.

<u>Draw a graph showing the frequency content of the output showing the harmonics.</u>

Figure 5: Frequency Content of Output Showing Harmonics



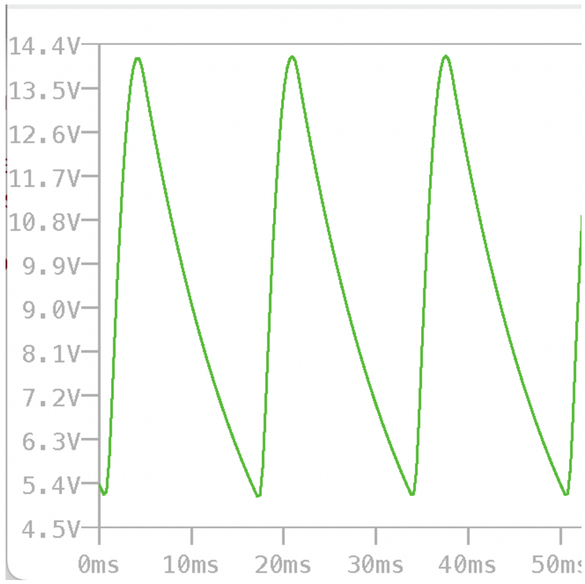
<u>Take screen shot of your circuit and all waveforms that you think are necessary to support your claims above.</u>

See above.

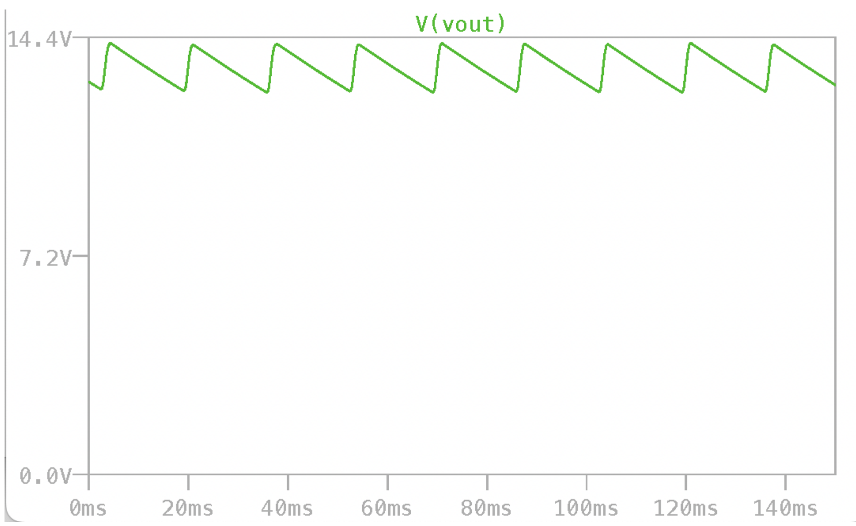
Part 2: Half Wave Rectifier with resistive-capacitive load

Modify the previous circuit from Part 1 to add a capacitor load in parallel with the resistor as shown in Figure 3. The diodes will be ideal. Set the value of C1 to be 250uF.

Using the same options as before, run a transient analysis. Zoom in on two to three cycles of the output after it has reached steady-state.



Rerun simulations for C1 to be 2.5mF.



Plot the Vs and Vout on the same plot. Plot for both capacitor values

Figure: C2 = 250uF

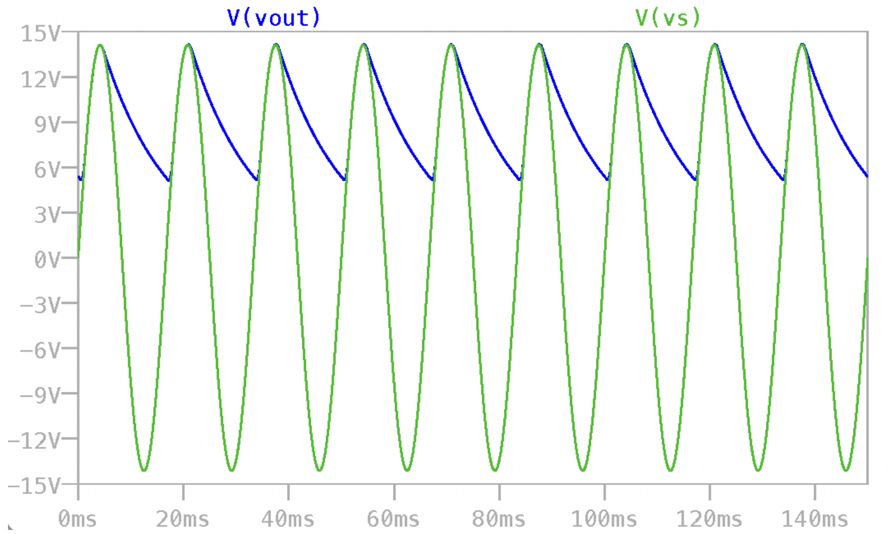


Figure: C1 = 2.5mF.

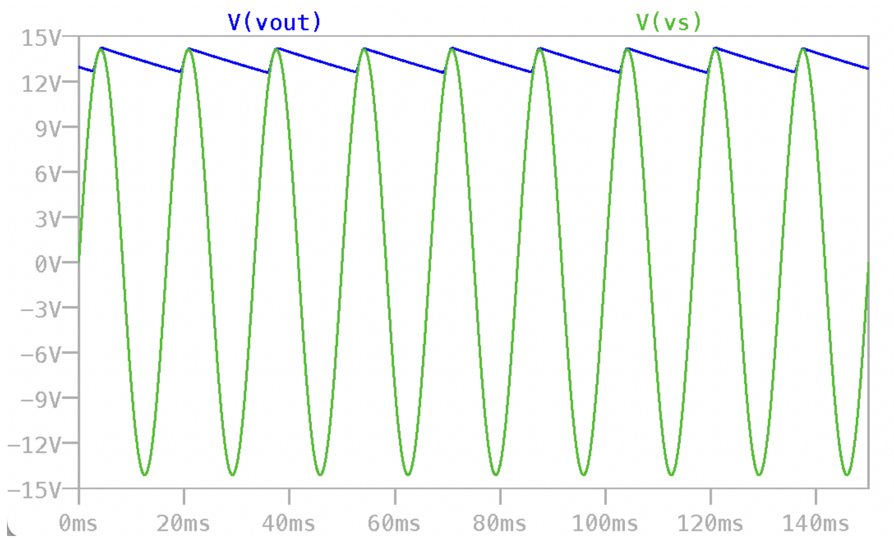


Table 2: Output Voltage for 2.5mF capacitor circuit

	Average	RMS	Peak	Voltage Ripple
Output Voltage	13.38V	13.047V	14.20V	1.6309V

Min Ripple: 12.5757
Max Riple: 14.2066

V_{rms}= $Vr_{p\text{-}p}/2\sqrt{3}$ where $Vr_{p\text{-}p}$ is the peak to peak ripple voltage. Min ripple value was then added.

What do you notice with the waveform?

The output voltage is now at the peak of the input voltage and forms a ripple pattern.

<u>Describe how the addition of the capacitor effects the output signal.</u>
The addition of the capacitor causes the output voltage to drop less abruptly, forming the ripple pattern seen above.

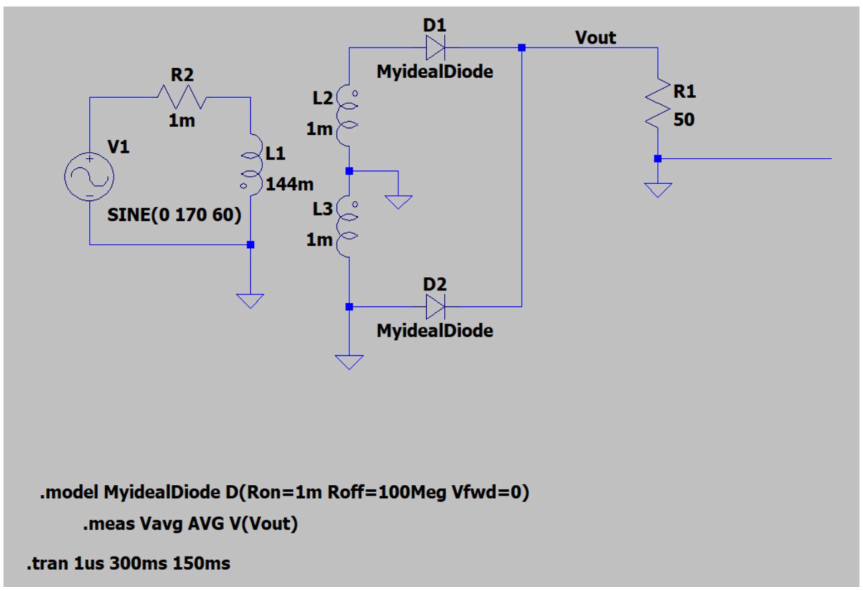
<u>What happens to the output signal if the capacitor were to increase?</u>
If we have a higher capacitance, we have less of a ripple because the capacitor discharges more slowly.

<u>What if the resistor were to decrease?</u>
Similarly, the output signal has less of a ripple because the capacitor has

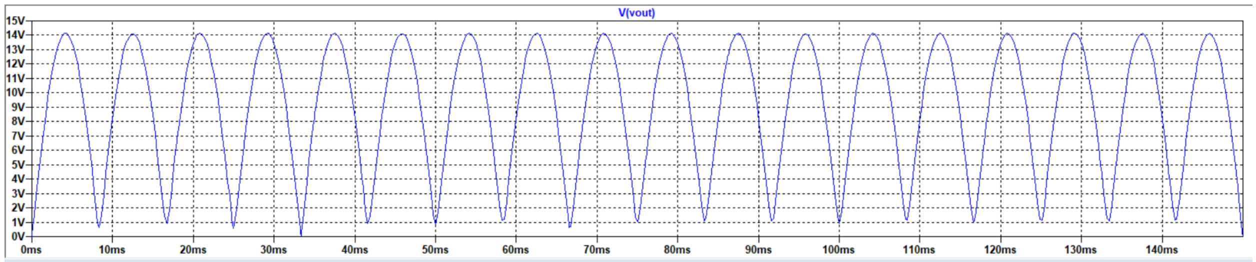
<u>What is the ripple voltage seen at the output?</u>
We saw a voltage ripple of 1.6309V between the max and minimum points on the Vout waveform.

<u>Take screen shot of your circuit and all waveforms that you think are necessary to support your claims above.</u>
See above.

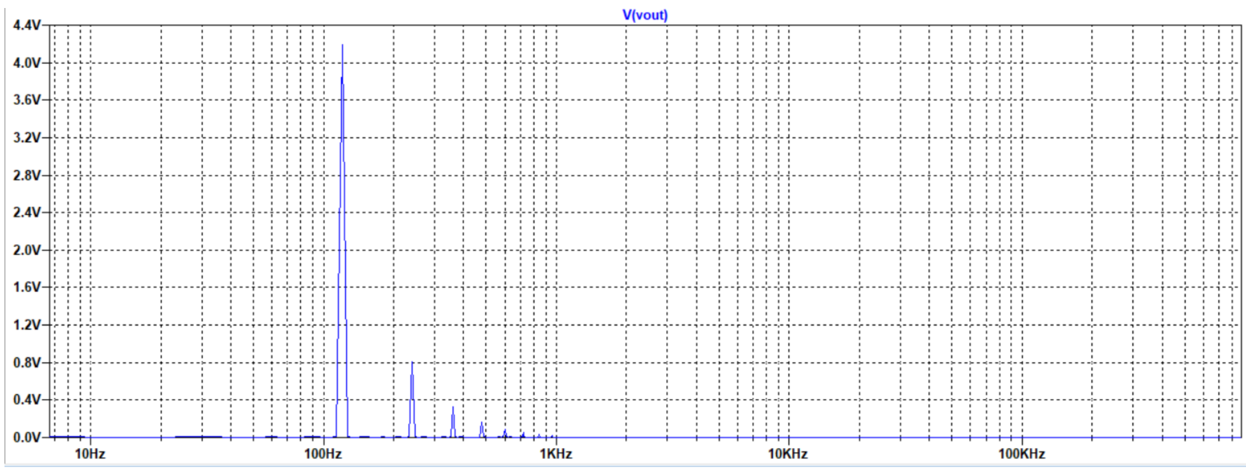
Part 3: Full-Wave Rectifier



(1) Draw the schematic for the full wave rectifier in Figure 5 using ideal diodes and resistive load R1 = 50 ohms. Label the source voltage Vs_Top and Vs_Bot so as to measure the voltages across the two secondary coils. Pick the values of L1 of the transformer to be 144mH and use 1mH for L2 and L3.



Bode Plot:



	Average	RMS	Peak	Voltage Ripple
Output Voltage	9.01663	9.98379	14.1654	14.1654

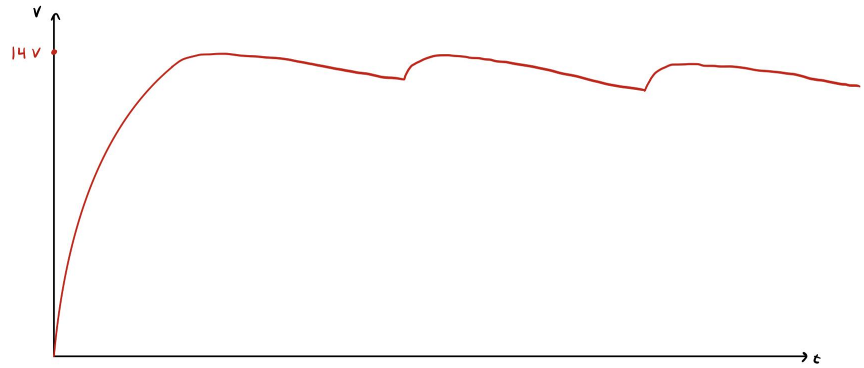
<u>How does the average output voltage compare to the half wave rectifier?</u>

The output voltage now peaks a positive voltage even for the negative half cycle.

<u>What do you observe about the harmonics?</u>

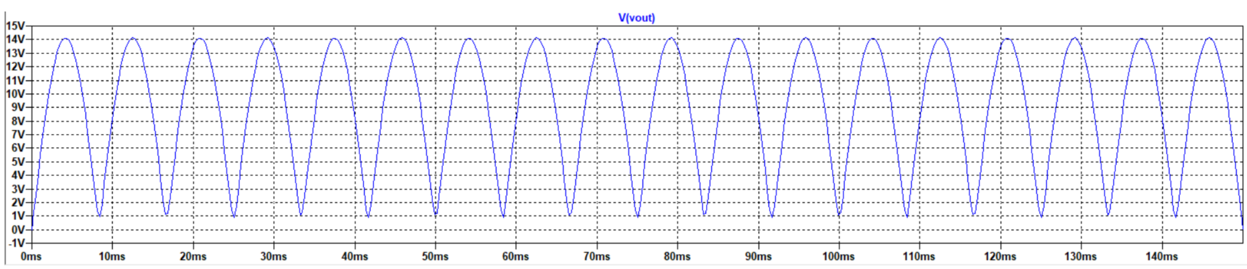
Because it is a full wave rectifier there are twice the number of pulses. The harmocins present are 2, 4, 6, and 8 from the first waveform as opposed to the 2, 3, 4, 5, 6, … according to the formula h = (n * p) +/- 1, where h is the harmonic number, n is any integer (1,2,3,..) and p is the number of pulses in the circuit.

<u>If a capacitor is added in parallel with the resistive load R1, draw the expected waveform.</u>

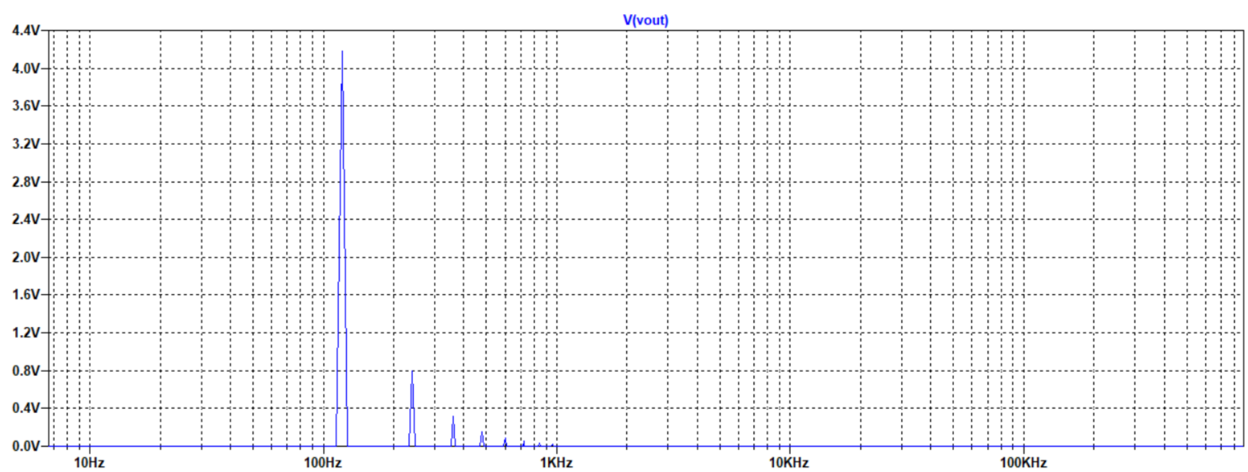


Part 4: Bridge Rectifier

Draw the schematic for the bridge rectifier in Figure 6 using ideal diodes and resistive load RL = 50 ohms. Label the source voltage Vsp and Vsn so as to measure across the secondary.



Bode Plot:



	Average	RMS	Peak	Voltage Ripple
Output Voltage	9.01729	9.97989	14.1288	14.1288

Peak current in the diodes:
0.282576 A

Maximum reverse voltage for the diodes:

Diodes	Maximum reverse voltage
D1	14.106V
D2	14.106V
D3	270.46818µV
D4	223.05651µV

How does the average output voltage compare to the half wave rectifier?
The output voltage now peaks a positive voltage even for the negative half cycle.

What do you observe about the harmonics?
Because it is a full wave rectifier there are twice the number of pulses. The harmonics present are 2, 4, 6, and 8 from the first waveform as opposed to the 2, 3, 4, 5, 6, … according to the formula h = (n * p) +/- 1, where h is the harmonic number, n is any integer (1,2,3,..) and p is the number of pulses in the circuit.

What are the advantages of this bridge rectifier perform compared to the full-wave rectifier of Part3.
The bridge rectifier tends to have a higher efficiency over the center-tapped rectifier from part 3. For each cycle, the full transformer is being utilized during the AC input, as opposed to half of the coil being used on a center tapped rectifier. Another advantage was that the bridge rectifier tended to have a smoother dc output with better filtering than the center tapped rectifier.

3: Lab Report

Which rectifier has the least stringent requirements for an output filter? Explain your answer.
The rectifier with the least stringent requirements would probably be the bridge rectifier. Out of the rectifiers we built, the bridge rectifier has the most efficiency, flexibility, and performance. We obtained the smoothest DC output from the bridge rectifier, with a setup that could be considered easier and less expensive than the center tapped rectifier.