ECE 4457A: Lab 1

Half-Wave Diode Rectifiers

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Introduction

This lab provided an opportunity for students to experiment with and familiarize themselves with the basic concepts of half-wave rectifier circuits. In the lab, the following half-wave rectifier circuits are explored:

1. Half wave rectifier with a resistive load
2. Half wave rectifier resistive and inductive (R-L) load
3. Free wheeling diode with resistive and inductive (R-L) load
4. Resistive load with a capacitive filter

Each circuit was assembled and evaluated throughout the lab and data was recorded using Labview.

Procedure

The procedure described below uses the following components:

1. A diode/rectifier box which features several traditional diodes alongside a freewheeling diode
2. An RLC load box which provides:
    a. 15Ω load resistor
    b. 50Ω load resistor
    c. Inductor
    d. Capacitor
    e. Interface to measure current and voltage
    f. Ability to connect the aforementioned components to model the 2D circuits covered in this lab
3. A 30 V_{rms} AC powersource
4. A current and voltage measurement device connected to a computer to view waveforms using Labview

Experiment A: Resistive (R) Load

1. A circuit was built using an R=15Ω resistor (See Figure 1).
2. Labview was used to analyze the waveforms of V_s and $V_{o.}$
3. The peak and average values of the aforementioned parameters were measured using Labview.

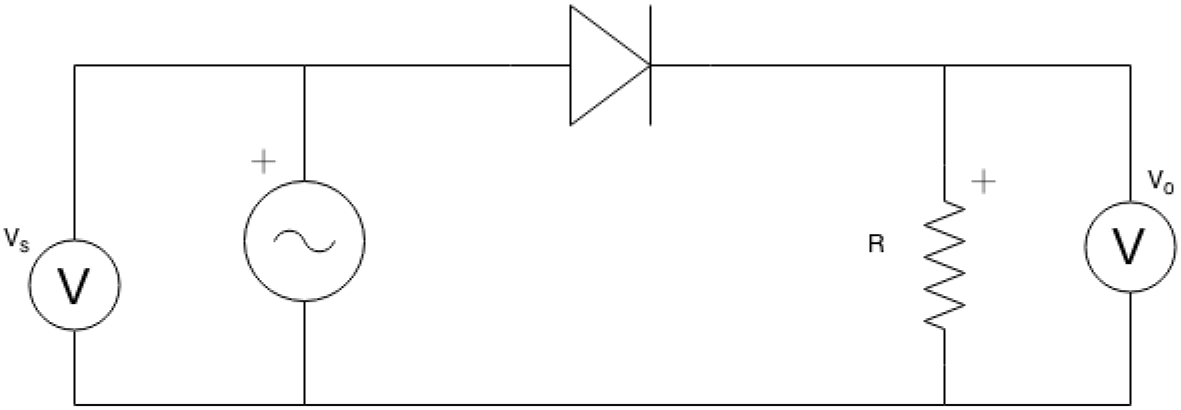


Figure 1

Experiment B: Resistive-Inductive (R-L) Load

1. A circuit was built using an R=50Ω resistor (See Figure 2).
2. Labview was used to analyze the waveforms of V_o and I_o.
3. The peak and average values of the aforementioned parameters were measured using Labview.
4. The inductor voltage V_L and the output current I_o were plotted using Labview.
5. The average inductor voltage was measured using Labview.
6. Steps 1-5 were repeated with R=15Ω.

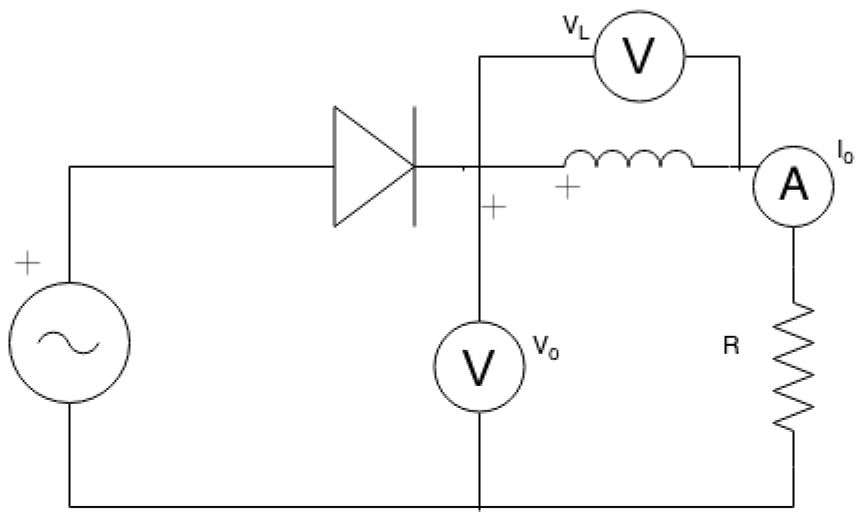


Figure 2

Experiment C: Resistive-Inductive (R-L) Load with Freewheeling Diode

1. A circuit was built using an R=15Ω resistor (See Figure 3).
2. Labview was used to plot and measure the peak and average values of the output voltage, V_o and output current I_o.

3. Labview was used to plot and analyze the peak and average values of the output voltage V_o and I_s.

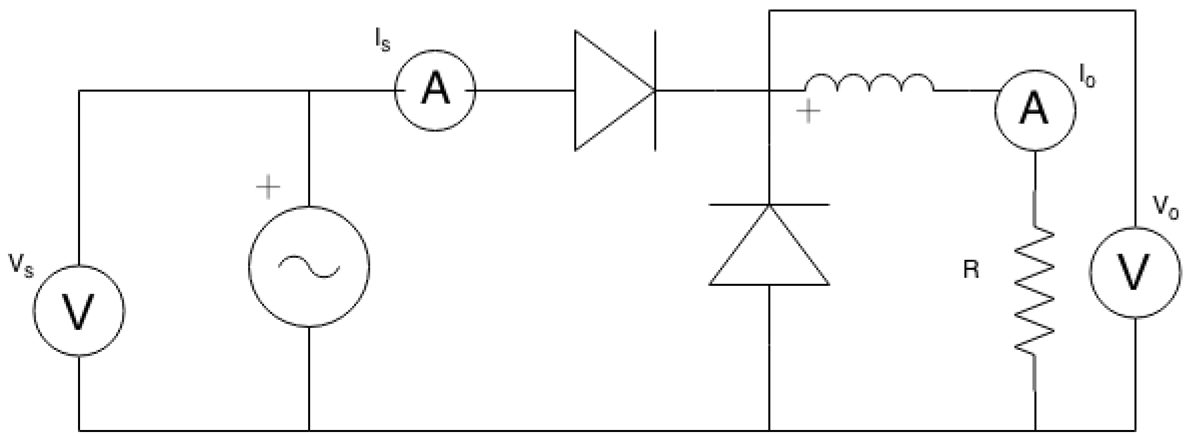


Figure 3

Experiment D: Resistive (R) Load with Capacitive (C) Filter

1. A circuit was built using an R=50Ω resistor (See Figure 4).
2. Labview was used to plot the input voltage, V_s and the output voltage, V_o. The average value of the capacitor voltage was then measured.
3. The input voltage, V_s and the current, I_c was measured and the average value of the capacitor current was calculated.
4. Steps 1-3 were repeated with R=15Ω.

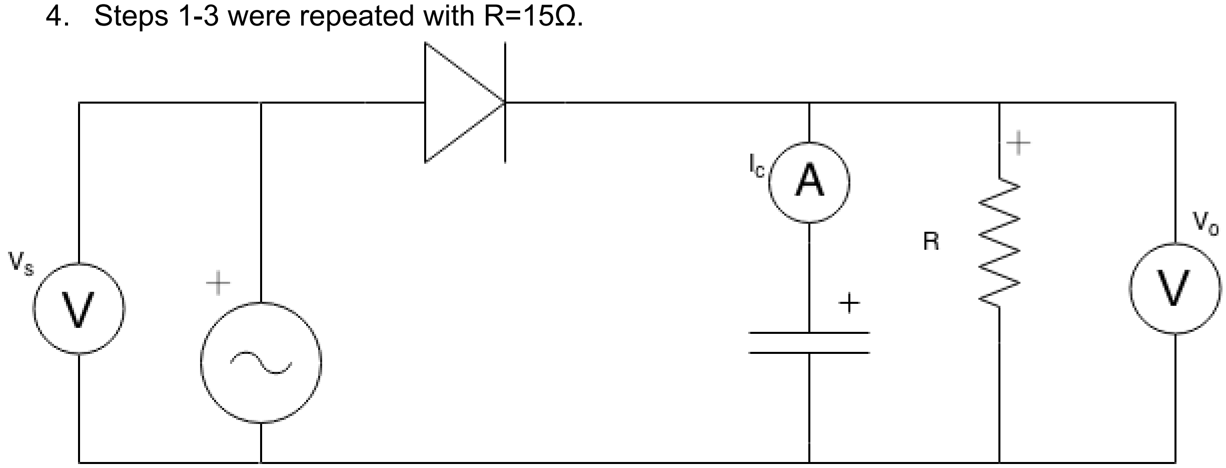


Figure 4

Experimental Results

Part A: Resistive (R) Load

- Voltage 2 (Cyan) corresponds to V_o
- Voltage 1 (White) corresponds to V_s

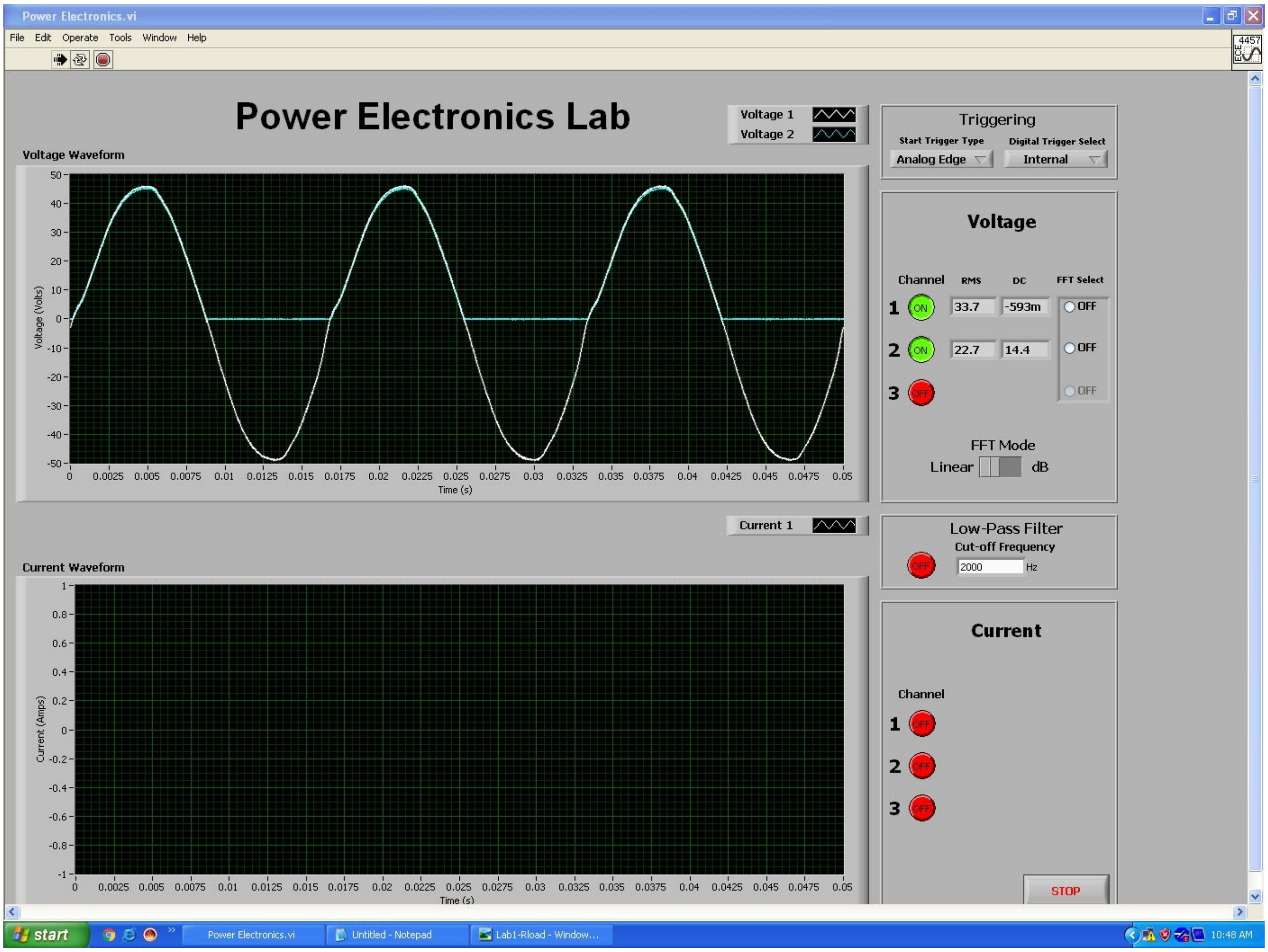


Figure 5

V_{o_avg}	14.4 V
V_{o_pk}	46 V

Table 1: Peak and Average Output Voltage for Part A

Part B: Resistive-Inductive (R-L) Load

For R = 50Ω

- Voltage 1 (White) corresponds to output voltage V_o
- Voltage 2 (Cyan) corresponds to inductor voltage V_L
- Current 1 (White) corresponds to output current I_o

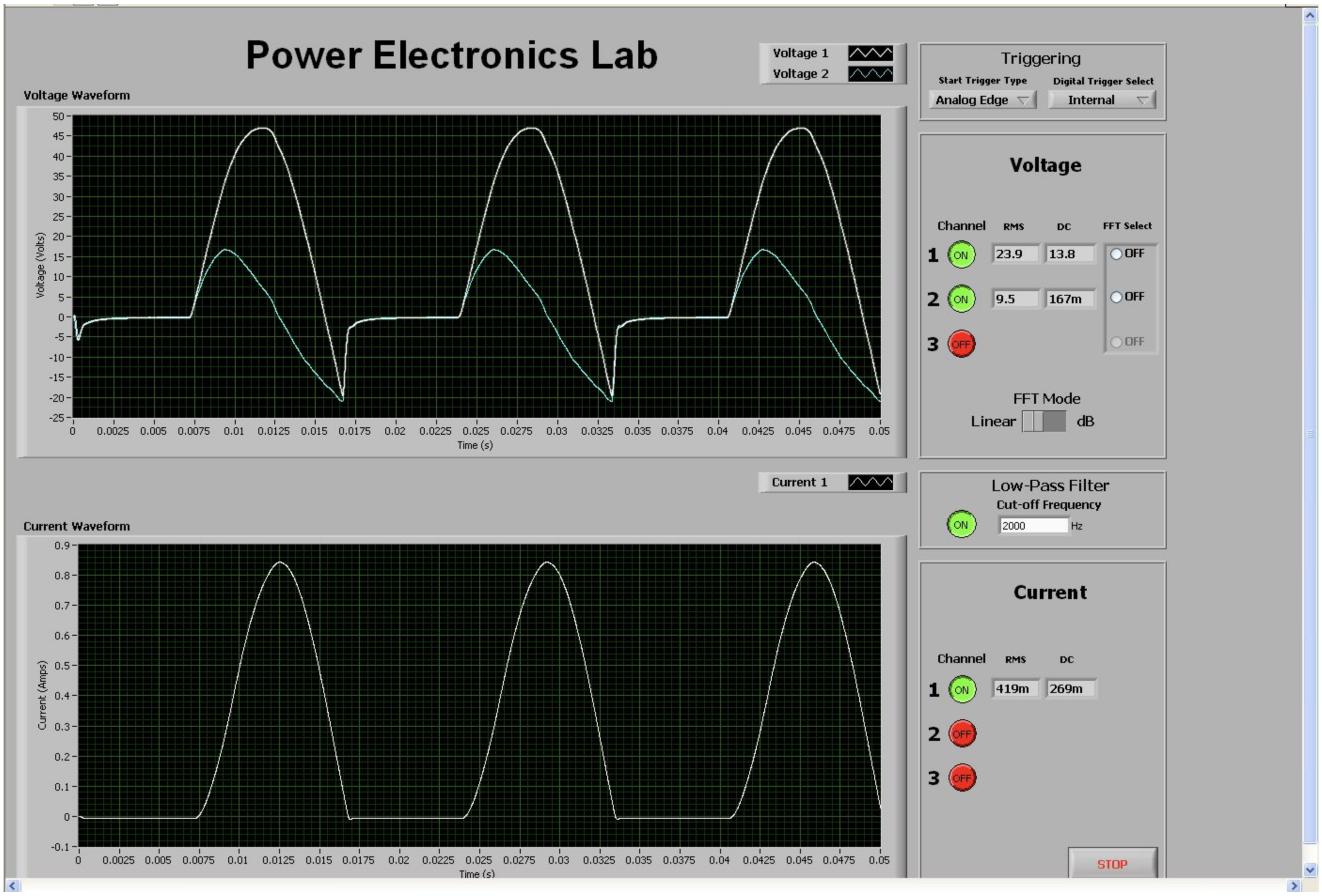


Figure 6

Parameter	Average	Peak
V_o	13.8 V	46 V
V_L	167 mV	N/A
I_o	269 mA	840 mA

Table 2: Voltage and Current Measurements for Part B R = 50Ω

For R = 15Ω

- Voltage 1 (White) corresponds to output voltage V_o
- Voltage 2 (Cyan) corresponds to inductor voltage V_L
- Current 1 (White) corresponds to output current I_o

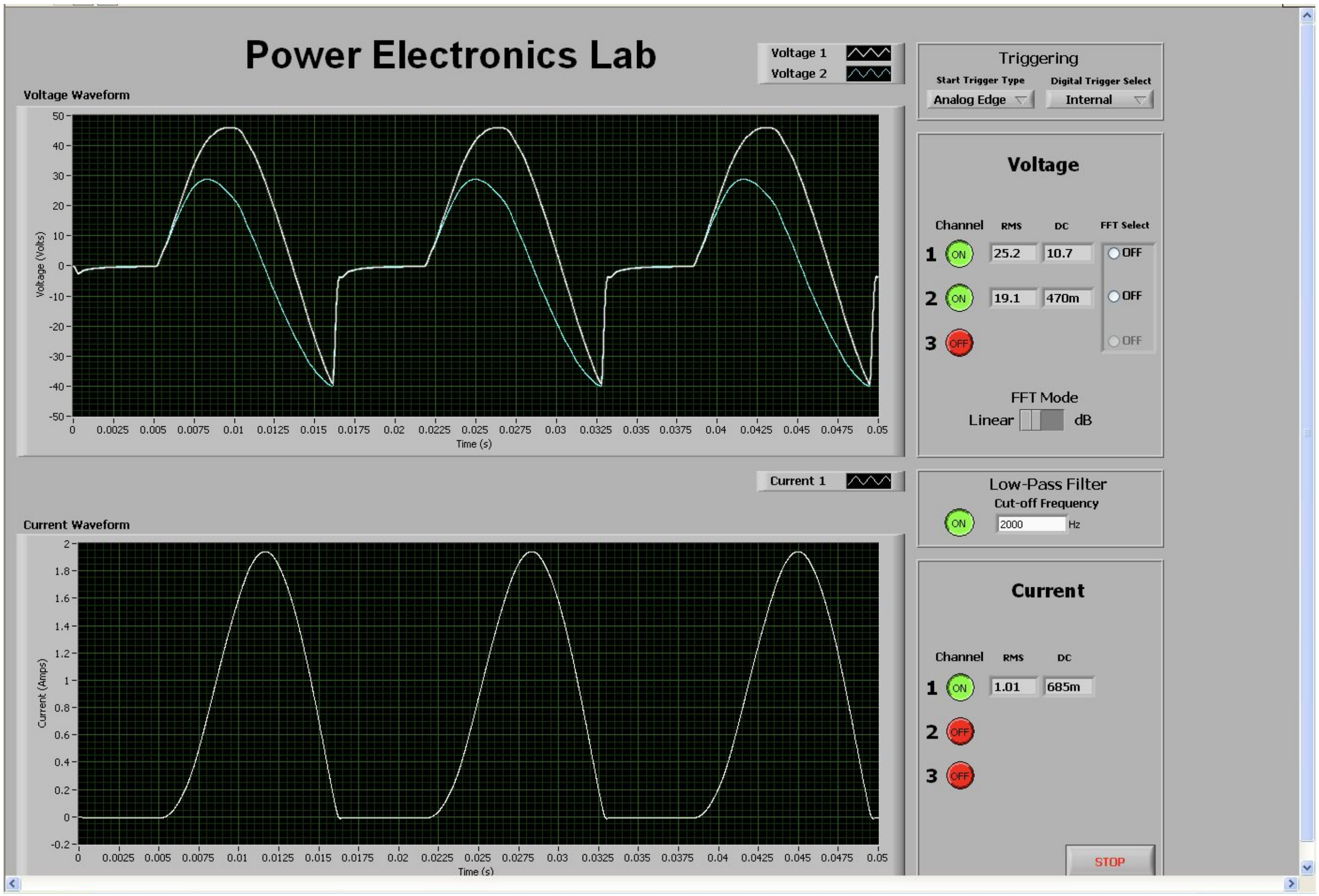


Figure 7

Parameter	Average	Peak
V_o	10.7 V	46 V
V_L	470 mV	N/A
I_o	685 mA	1.9 A

Table 3: Voltage and Current Measurements for Part B R = 15Ω

Part C: Resistive-Inductive (R-L) Load with Freewheeling Diode

- Voltage 1 (White) corresponds to input voltage, V_s
- Voltage 2 (Cyan) corresponds to output voltage, V_o
- Current 1 (White) corresponds to output current, I_o
- Current 2 (Cyan) corresponds to input/source current, I_s

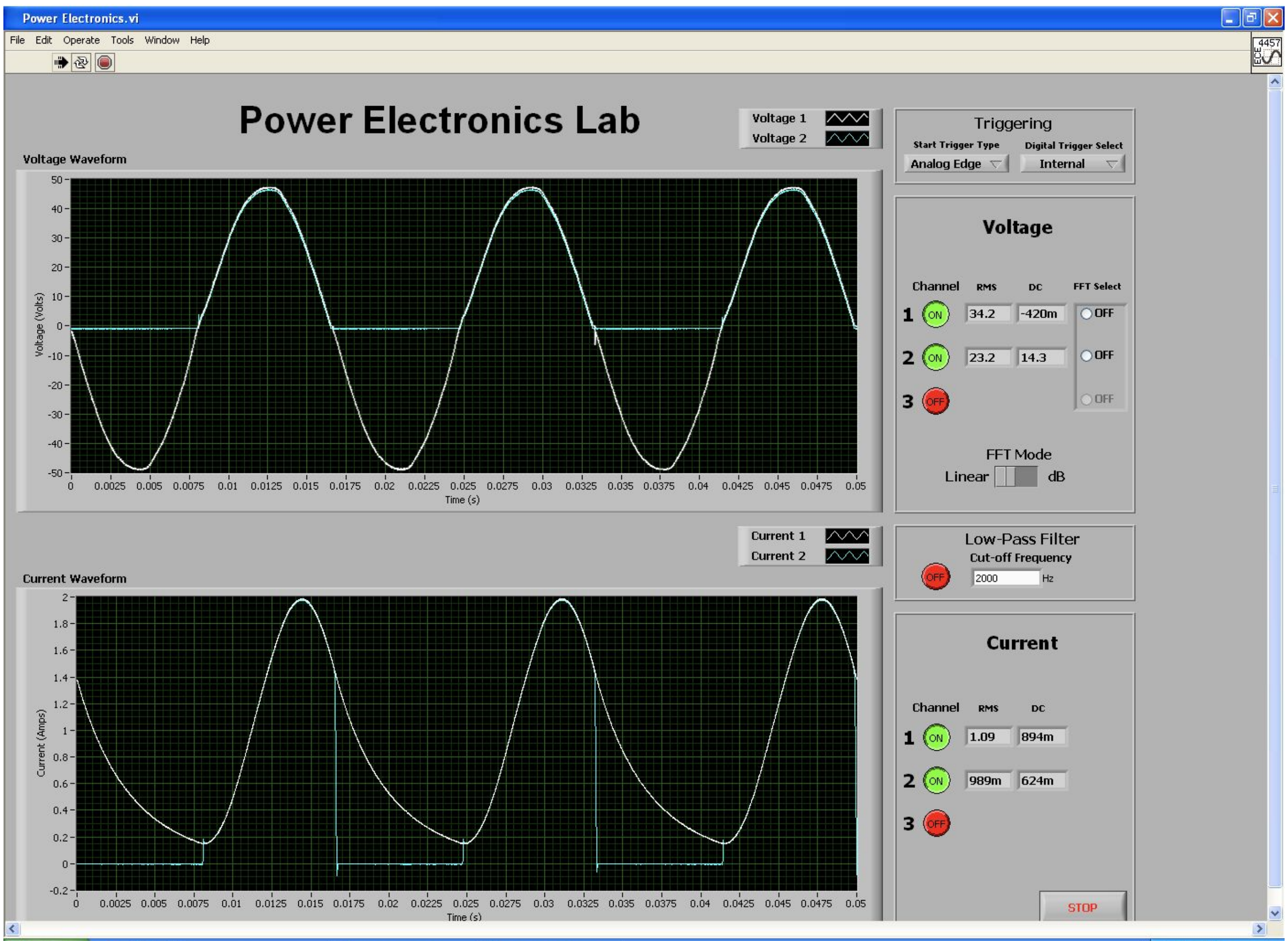


Figure 8

Parameter	Average	Peak
V_o	14.3 V	46 V
I_s	624 mA	2 A
I_o	894 mA	2 A

Table 4: Voltage and Current Measurements for Part C

Part D: Resistive (R) Load with Capacitive (C) Filter

For R = 50 Ω

*** Note that for this section, the plotted results were not what was expected. Please refer to 'Part D Discrepancy' in the Discussion section of this report.**

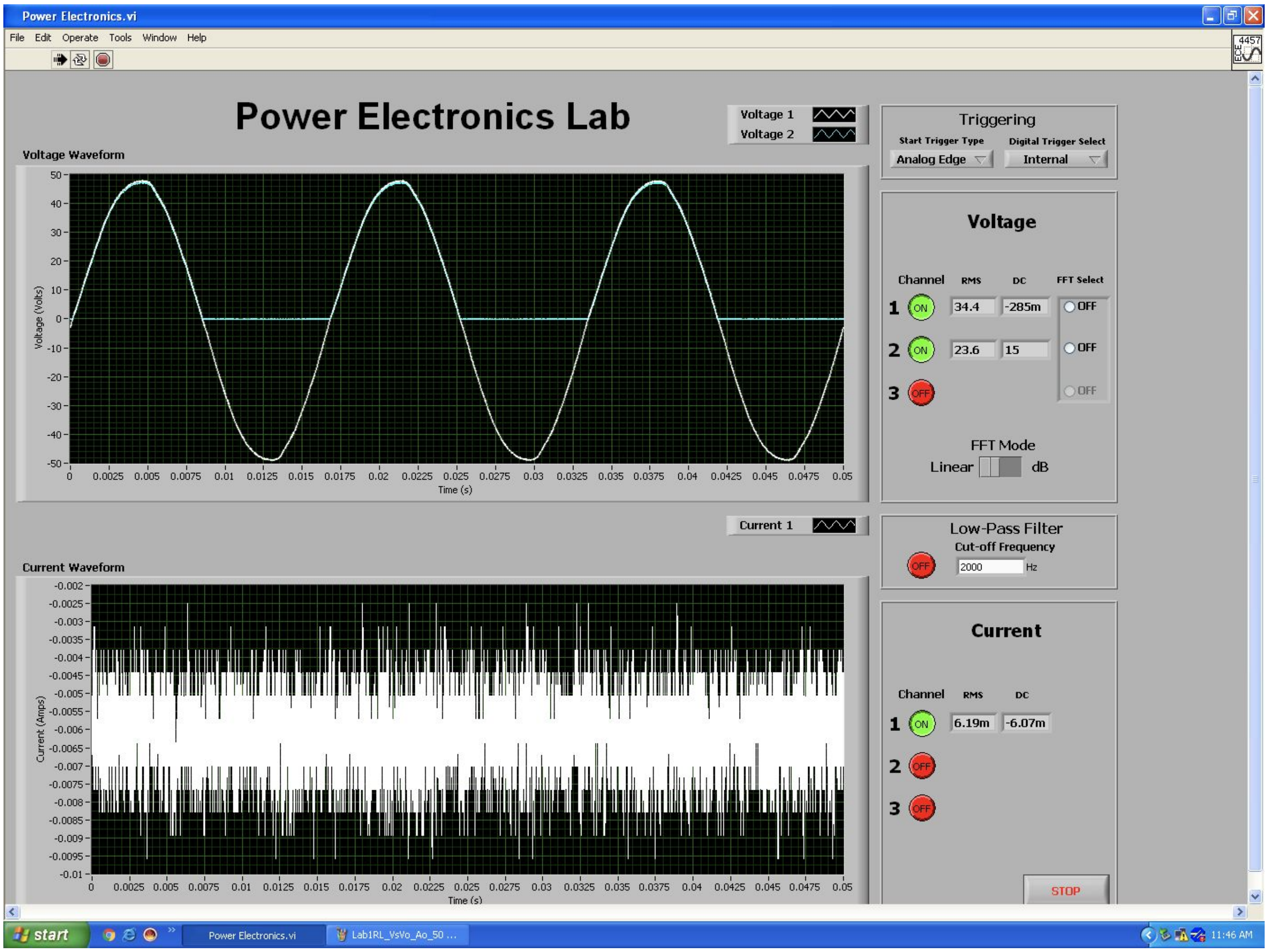


Figure 9

For R = 15Ω

*** Note that for this section, the plotted results were not what was expected. Please refer to ‘Part D Discrepancy’ in the Discussion section of this report.**

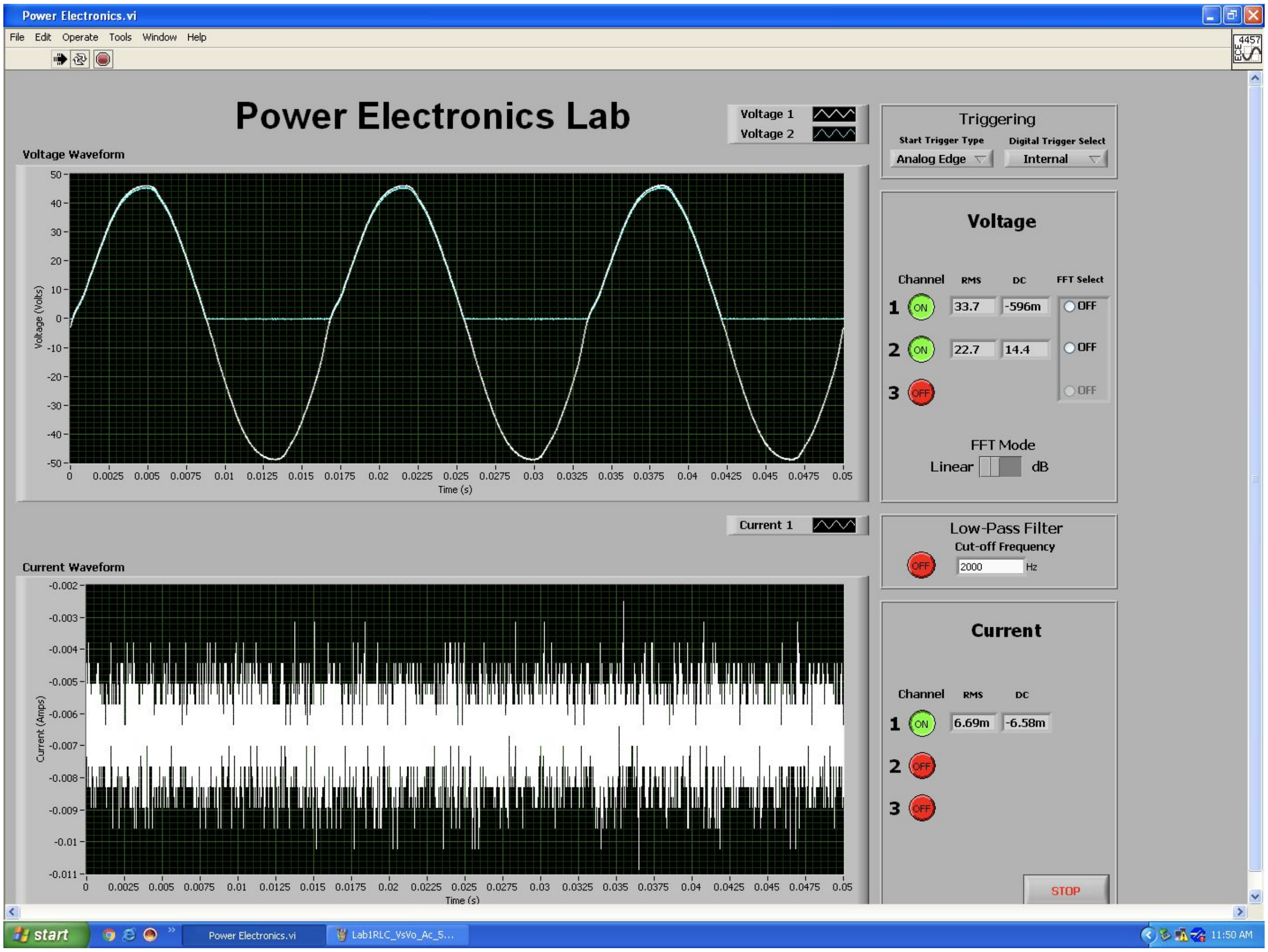


Figure 10

Discussion

Part D Discrepancy

In the results for Part D, the waveforms are very similar to that of a half-wave rectifier with a purely resistive load. (As in Part A). This is unexpected and it is suspected that there was an open circuit somewhere in the link for the capacitor in the RLC load box used in the laboratory. In order to obtain results to perform the discussion questions following this lab and to confirm that there was an issue with the equipment used, the circuit in Part D was modelled in PSim.

Below are the results from modeling the circuit in Part D in PSim.

For R = 50Ω

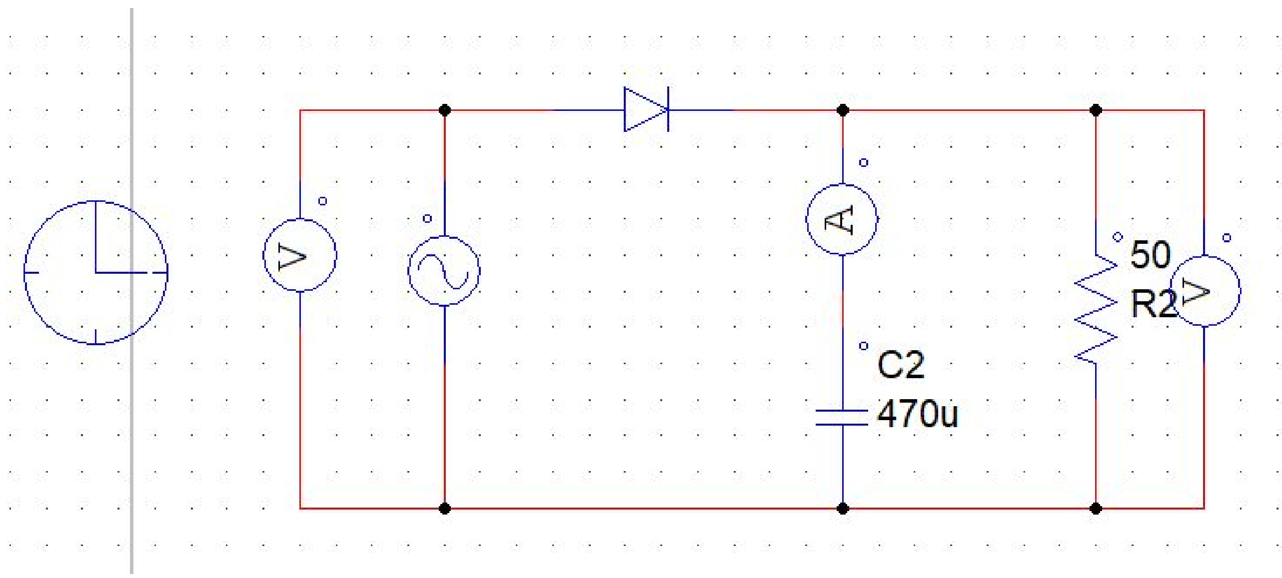


Figure 11

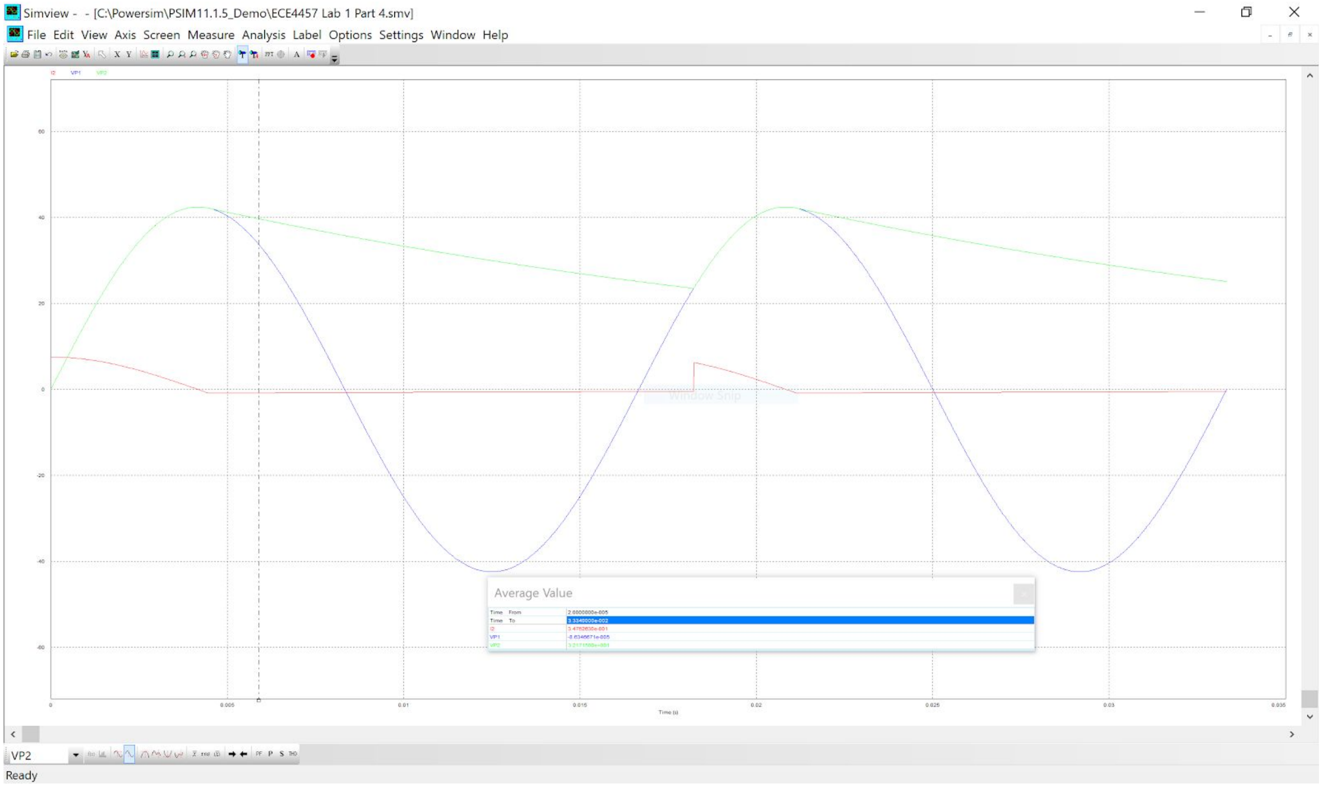


Figure 12

V_{o_avg}	32.17 V
I_{c_avg}	346 mA

Table 5: Average voltage and current readings for Part D R = 50 Ω

For R = 15Ω

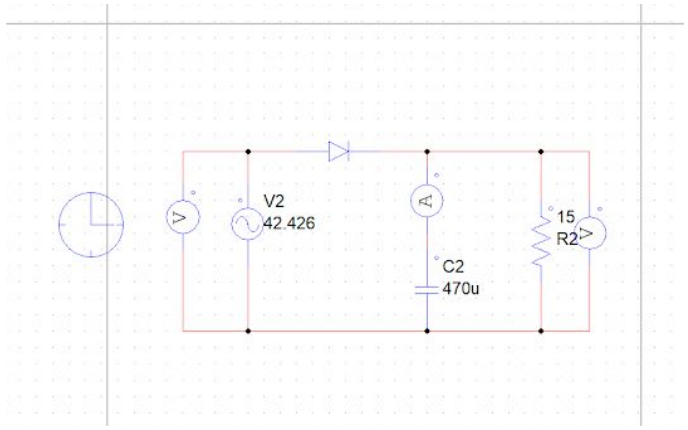


Figure 13

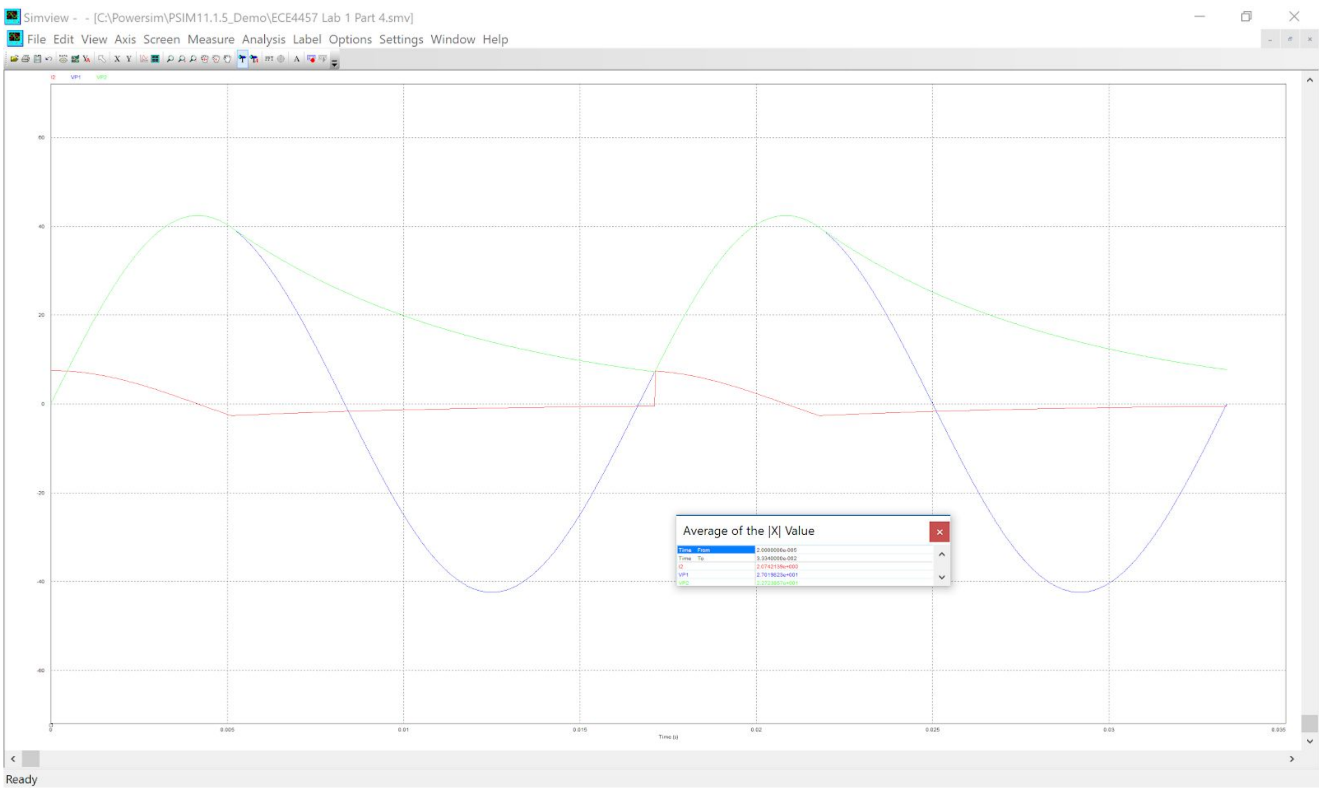


Figure 14

V_{o_avg}	22.7 V
I_{c_avg}	2.074 A

Table 6: Average voltage and current readings for Part D R = 50 Ω

Discussion Questions

1. Mathematically calculate the average value of the output voltage of the circuit in Part I.A. Compare with the value that you measured in Part I.A and comment.

   $V_m = \sqrt{2} \times 30 = 42.426\ V$
   $V_{o_{avg}} = \frac{V_m}{\pi} = \frac{42.426}{\pi} = 13.5046\ V$

   The calculated average value for the output voltage of the circuit in Part I.A is 13.5 V. From Table 1, we can see that the actual average voltage was 14.4 V. This is close to the calculated value. The discrepancy can be attributed to:
   - Error in reading the plots
   - Error in the measuring equipment
   - Error in the actual resistances due to wire lengths and resistors

2. Comment on the shape of the two output voltage waveforms obtained in Part I.B with R = 15 and 50 . Explain the difference in the two waveforms.

   For both circuits, the output voltage is positive and follows a similar shape to that of the input source during the positive values of voltage (from 0 to pi on the ωt axis). When the source voltage dips below zero, current is still flowing through the inductor since it resists change in current. During this portion, the diode is still conducting, however the output voltage is zero. When the output current drops to zero, the output voltage is then clamped to zero until the sine source becomes positive again.

   Both output voltages for R = 15 and R = 50 follow this trend, however the magnitude of the negative dip in voltages are different. For the R = 50 circuit, the negative output voltage dips to -20 V while the R = 15 circuit allows for a negative voltage of -40 V. The reason for the difference in voltage dip is because the maximum and average current through the output is higher for a higher resistance. Current is inversely proportional to resistance, therefore for lower values of resistance, the current is higher. Since the change in current through the inductor is fixed, it effectively takes longer for the current to drop to zero and at the same time, the voltage drop is greater.

3. Comment on the average value of the inductor voltage waveforms obtained in Part I.B. Explain why these values make or do not make sense.

   The average values for the inductor voltage make sense for the waveforms obtained in Part I.B. The lower higher values result in a higher average inductor voltage. Current and voltage are directly proportional therefore a higher current results in a larger average voltage across the inductor (since the impedance of the inductor does not change).

4. Compare the output voltage waveform obtained in Part I.C with that obtained for the same resistance in Part I.B and comment on any differences.

   The freewheeling diode circuit in Part I.C has only a positive voltage component for the output. From 0 to pi, the voltage is positive since the first diode is conducting. At this point, the inductor charges up. On the negative input from the sine wave, the first diode stops conducting and the freewheeling diode begins conducting. Since the output voltage is across the freewheeling diode, the output voltage is only positive. For the R-L circuit with the same voltage, the output voltage dips below 0 as the inductor discharges on the negative phase of the input source.

   The freewheeling diode circuit also has a higher average voltage than the R-L circuit which could make it more advantageous in a practical application. For example, a motor can be modelled as an inductor in series with a resistor. If you are to power a small DC motor with a half wave rectifier circuit, using a circuit with a freewheeling diode would provide more overall power for the same input voltage.

5. Using the average output voltage value obtained in Part I.C, determine an approximate value for the average output current, compare it to the measured value, and comment. Also compare the measured average output current value with that of the input value and comment

   $$I_{o_{avg}} = \frac{V_{oavg}}{R} = \frac{14.3}{15} = 0.953A$$

   The calculated average current through the output was 953 mA. Compared to the recorded observation of 894 mA, this is fairly similar. The calculated value was higher than the actual recorded observation. This is most likely due to the fact that we assumed an ideal inductor, when in reality the resistance of the inductor would contribute to a lower actual output current.

   Both the calculated and actual average current through the output is higher than the source output. This makes sense because the source output current slowly decays to 0 A on the negative phase of the input voltage, while the input current immediately clamps down to 0 A when the freewheeling diode becomes forward biased. This means that this is more area underneath the current vs. time graph for the output current, thus, a higher average current value.

6. Comment on the difference in the average value of the output voltage waveforms obtained in Part I.D with R = 15 and 50 . Which waveform has the higher average value and why?

   Please note that for this question, the circuits using PSim will be used as the integrity of the actual results retrieved in the lab are in question. The average output voltage with a resistance of 50 ohms was 32.17 V while the output voltage for the circuit with a resistance of 15 ohms was 22.7 V. The higher resistance circuit has a higher average value. This is because when the resistance is higher, the capacitor discharges slower (evident by the lower average current value for the capacitor in the 50 ohm resistor circuit), thus the rate of discharge of the capacitor is slower when the input source voltage is less than the output voltage. Looking at the shape of the waveform, you can see that the output voltage persists for longer before the input source voltage intersects with the output source voltage again. As a result, the overall average under the output voltage vs. time graph is greater under the same period, thus, a higher average output voltage.

7. Comment on the shape and average value of the capacitor current waveforms obtained in Part I.D. Explain why these waveforms make or do not sense.

   When the voltage of the sine source is positive, the capacitor in parallel charges and the output voltage at the resistor follows the same shape as the sine input. On the negative phase, however, the diode does not conduct and the circuit is simplified to just the capacitor and the resistor. With a higher resistance, the current through the load is lower. This is why the peak current of the capacitor with a higher resistor is lower than the peak current of the capacitor in the circuit with a resistance of 15 ohms.

   In addition, the shape of the capacitor current waveforms also make sense. When the diode is not conducting, the capacitor immediately discharges based on its starting voltage which is why we see the sudden jump. As the capacitor discharges, the current slowly decreases as well until the voltage of the input is greater than the voltage of the capacitor once again.

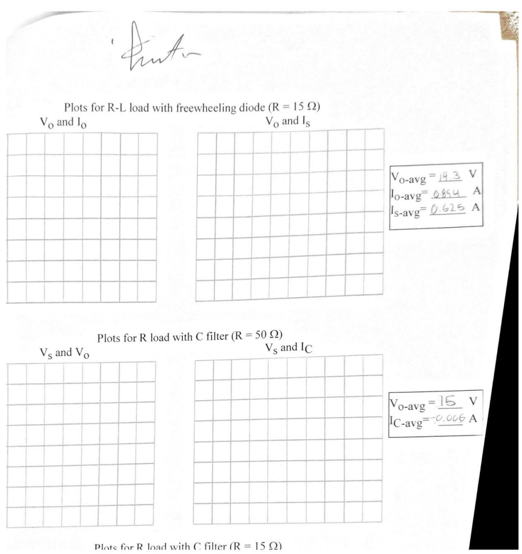
Conclusion

Overall, the uses of different half wave rectifier circuits were analyzed in this lab and the pros and cons of different circuits were determined. The benefits of the simple R load half wave rectifier circuit can be reaped in circumstances when there is an R-L load by using a freewheeling diode circuit. In instances where a low power AC-DC converter is needed, using a large capacitor in parallel with the output voltage can be a viable candidate. This lab also demonstrates the limitations of half wave rectifier circuits. While they require very few elements to build and are inherently simple, achieving a smooth DC waveform can be simple, especially for sporadic input AC waveforms.

The lab was also an excellent opportunity to evaluate the ability of PSim as a power electronics simulator that can be used to model half wave rectifier circuits. This was demonstrated in the instance where the expected results were not achieved in part 4 of the lab. PSim was easily able to model the expected results so that the discussion could be complete.

Appendix

TA Signature on measurement sheet


Plots for R-L load with freewheeling diode ($R = 15\ \Omega$)

V_o and I_o — V_o and I_s

$V_{o\text{-}avg}$ = 14.3 V
$I_{o\text{-}avg}$ = 0.854 A
$I_{s\text{-}avg}$ = 0.625 A

Plots for R load with C filter ($R = 50\ \Omega$)

V_s and V_o — V_s and I_C

$V_{o\text{-}avg}$ = 15 V
$I_{C\text{-}avg}$ = -0.006 A

Plots for R load with C filter ($R = 15\ \Omega$)