Electronics
Lab Report 1
Diode

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Date of experiment: 26 October 2021
Date of submission: October 2021

Contents

1 Introduction

In this experiment, several applications of different diodes such as rectifiers, voltage regulators, clampers, and clippers were studied. The main purpose of this experiment is to become familiar with semiconductor diodes and their applications.
A diode is a semiconductor device that essentially acts as a one-way switch for current. It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction. When a diode allows current flow, it is forward-biased. Otherwise, it is reverse-biased. However, unlike a resistor, a diode does not work linearly, it has an exponential I-V relationship. It means that it can not be described by a simple equations such as Ohm's law. Also, diodes are considered as passive elements.

2 Prelab Diodes

2.1 Problem 1: Current/voltage characteristic of a diode

1. Figure 1 shows the circuit built in LTSpice and the plot of the forward diode current versus the diode voltage

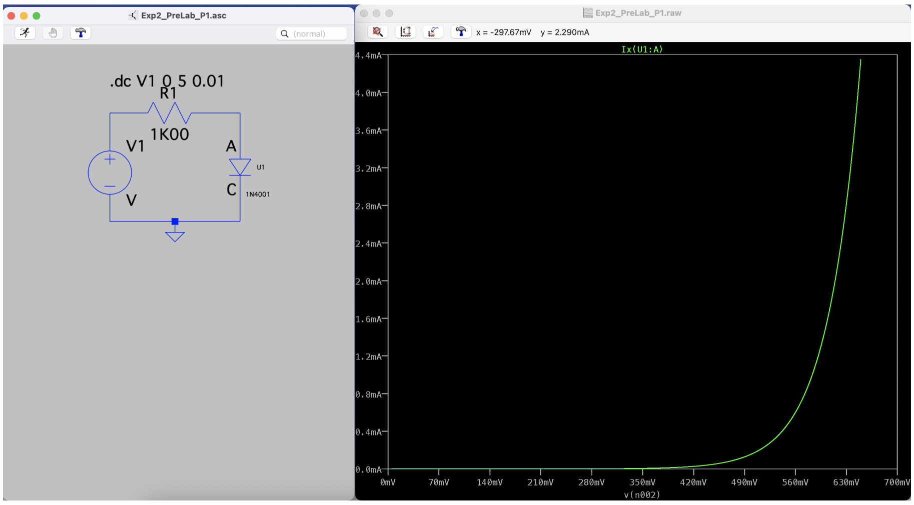


Figure 1: The current versus the voltage of the diode with a linear scale

2. Figure 2 shows the circuit built in LTSpice and the plot of the forward diode current versus the diode voltage using the semi ln plot.

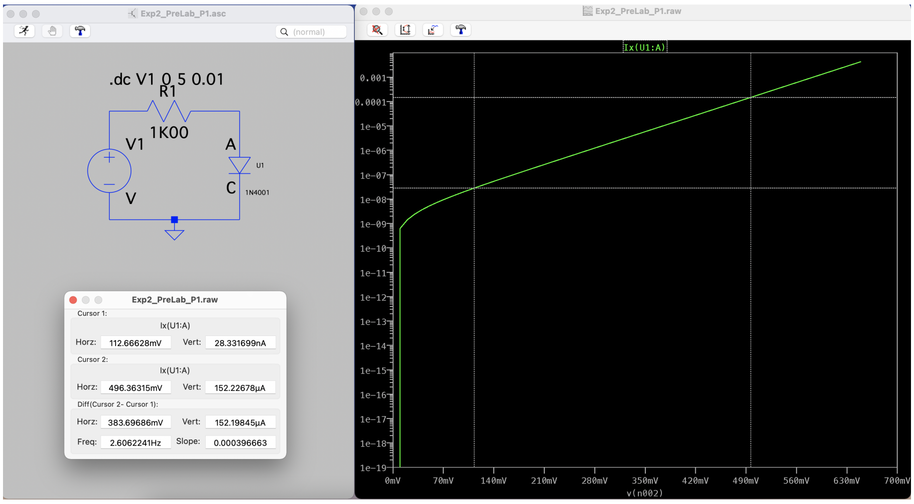


Figure 2: The current versus the voltage of the diode with a semi ln plot

3. If I_1 and I_2 can be expressed as

$$I_1 = I_s exp\left(\frac{V_1}{nV_T}\right) \qquad I_2 = I_s exp\left(\frac{V_2}{nV_T}\right)$$

Dividing them gives:

$$\frac{I_1}{I_2} = exp\left(\frac{V_1 - V_2}{nV_T}\right) \quad \Rightarrow \quad ln\left(\frac{I_1}{I_2}\right) = \frac{V_1 - V_2}{nV_T} \quad \Rightarrow \quad n = \frac{V_1 - V_2}{ln(I_1) - ln(I_2)} \frac{1}{V_T}$$

From Figure 2, two points from the plot are known. Substituting them gives the following diode factor:

$$n = \frac{496.36315 \cdot 10^{-3} - 112.66628 \cdot 10^{-3}}{ln(152.22678 \cdot 10^{-6}) - ln(28.331699 \cdot 10^{-9})} \frac{1}{26 \cdot 10^{-3}} = 1.72$$

The saturation current can be found as following:

$$I_s = \frac{I}{exp(V/(nV_T))} = \frac{28.331699 \cdot 10^{-9}}{exp(112.66628 \cdot 10^{-3}/(1.72 \cdot 26 \cdot 10^{-3}))} = 2.27nA$$

2.2 Problem 2: Halfwave rectifier

1. Figure 3 shows the circuit without C_1 built in LTSpice and the plot of U_L, V_{in}, and I_D.

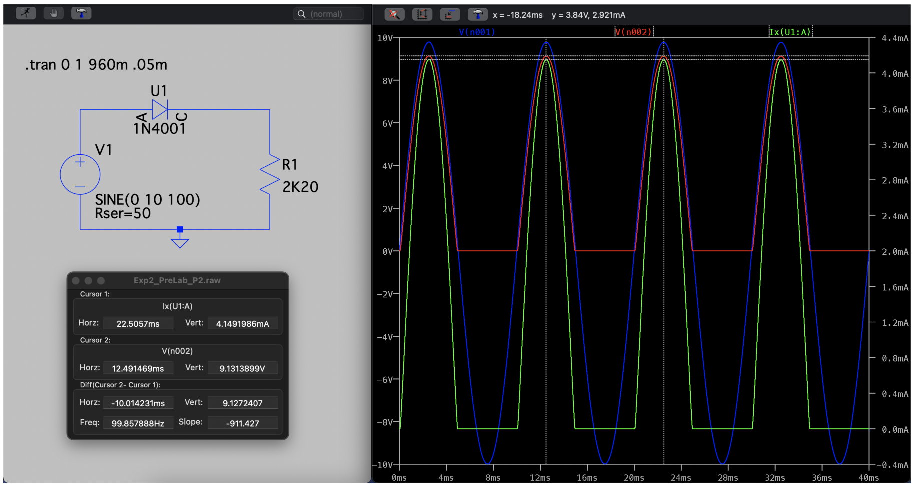


Figure 3: U_L, V_{in}, and I_D

2. From Figure 3, peak voltage at R_L and the peak current I_D can be obtained.

$$V_{peak} = 9.13V \qquad I_{peak} = 4.15mA$$

3. Figure 4 shows the circuit with C_1 built in LTSpice and the plot of U_L, V_{in}, and I_D.

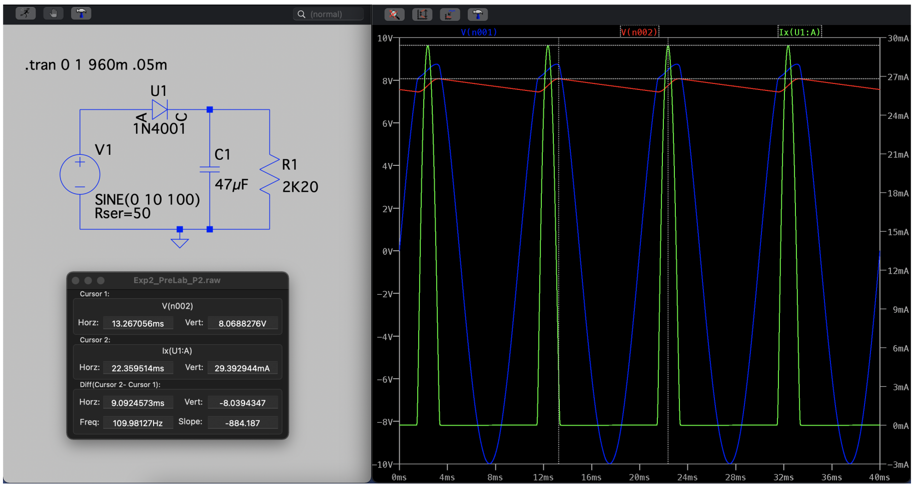


Figure 4: U_L, V_{in}, and I_D

4. From Figure 4, peak voltage at R_L and the peak current I_D can be obtained.

$$V_{peak} = 8.07V \qquad I_{peak} = 29.39mA$$

5. Figure 5 shows the ripple of the voltage at the load resistor. It is clearly seen that the ripple of the voltage is $614.57mV$. Using the formulas gives the following:

$$V_r = \frac{V_p}{fCR_L}\left(1 - \sqrt[4]{\frac{R_i}{R_L}}\right) = \frac{10}{100 \cdot 47 \cdot 10^{-6} \cdot 2200}\left(1 - \sqrt[4]{\frac{50}{2200}}\right) = 591.61mV$$

The theoretical and experimental values are very close.

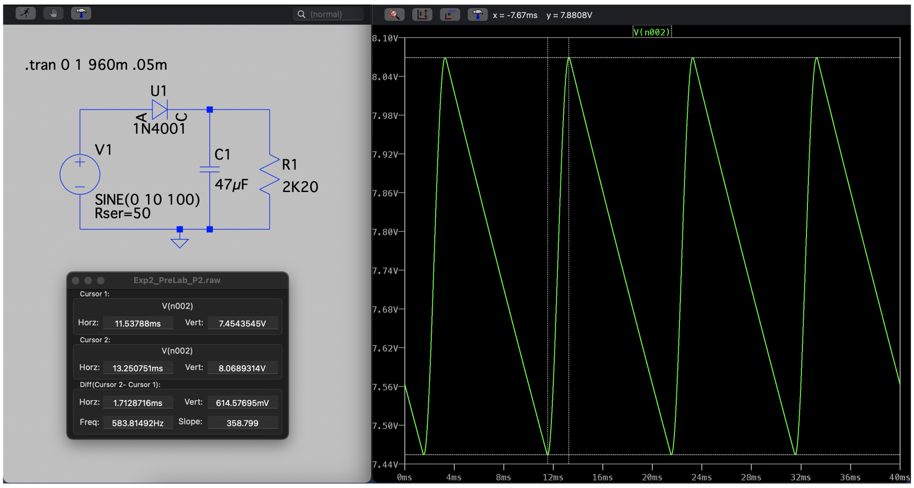


Figure 5: Ripple of the voltage

2.3 Problem 3: Fullwave rectifier

1. Figure 6 shows the circuit without C_1 built in LTSpice and the plot of U_L, V_{in}, and I_D.

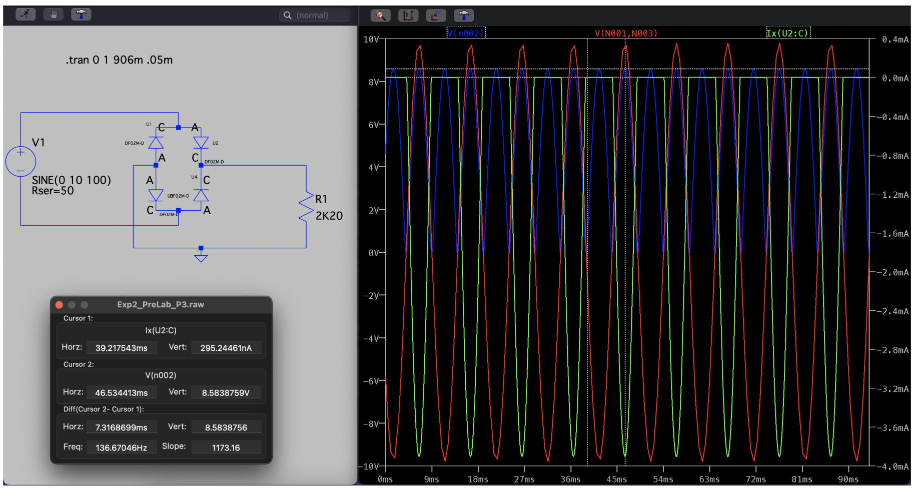


Figure 6: U_L, V_{in}, and I_D

2. From Figure 6, peak voltage at R_L and the peak current I_D can be obtained.

$$V_{peak} = 8.58V \qquad I_{peak} = 295.24nA$$

3. Figure 7 shows the circuit with C_1 built in LTSpice and the plot of U_L, V_{in}, and I_D.

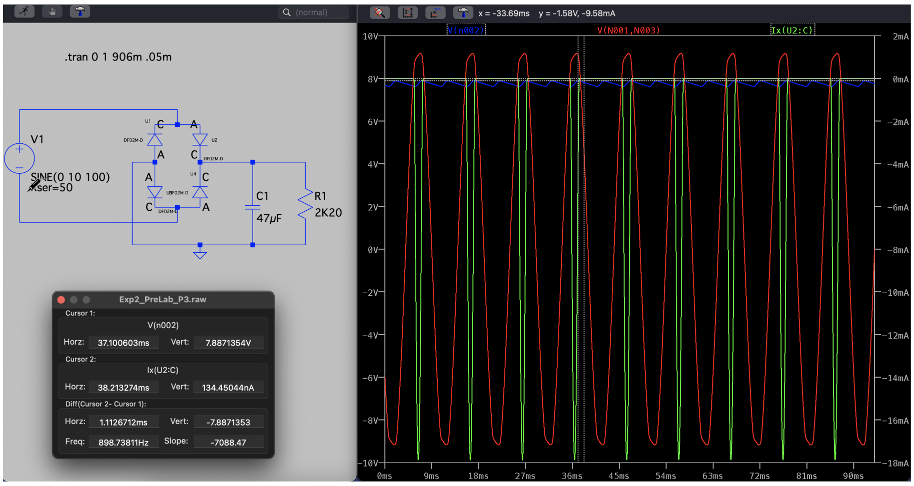


Figure 7: U_L, V_{in}, and I_D

4. From Figure 7, peak voltage at R_L and the peak current I_D can be obtained.

$$V_{peak} = 7.89V \qquad I_{peak} = 143.45n.A$$

5. Figure 5 shows the ripple of the voltage at the load resistor. It is clearly seen that the ripple of the voltage is $263.60mV$. Using the formulas gives the following:

$$V_r = \frac{V_p}{2fCR_L}\left(1 - \sqrt[4]{\frac{R_i}{R_L}}\right) = \frac{10}{2 \cdot 100 \cdot 47 \cdot 10^{-6} \cdot 2200}\left(1 - \sqrt[4]{\frac{50}{2200}}\right) = 295.81mV$$

The theoretical and experimental values are very close.

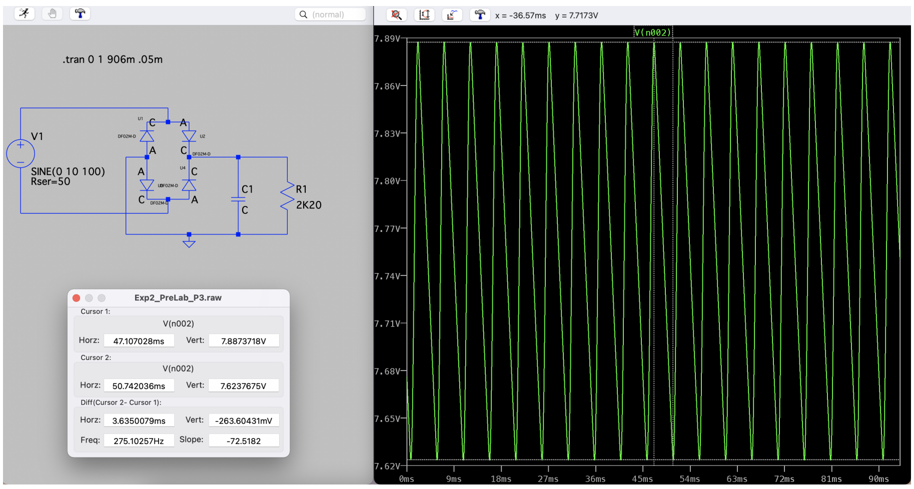


Figure 8: Ripple of the voltage

2.4 Problem 4: Rectifier

1. A rectifier is used to convert AC current into a single direction DC current. Having some oscillation after passing the signal means that there is still some unwanted AC component. This can be avoided by adding a capacitor in parallel to the load resistor. Since the capacitor allows AC signals and blocks DC, all DC components will flow through the load resistor.
   The half-wave rectifier contains a single diode. It means that only negative half-cycle of the input signal is blocked. Thus, the capacitor is not charged for almost the half period, resulting in a large ripple. On the other side, the full-wave rectifier passes negative signal by inverting it. It results of having two times more peak-to-peak ripple voltage. Figure 5 and Figure 8 gives that peak-to-peak voltage of the half-wave rectifier and full-wave rectifier are $614.59mV$ and $263.60mV$ respectively. Note that for half-wave it is almost two times more, as expected.

2. Having the capacitor in a circuit results a bigger current amplitude. In two previous problems, the current amplitude of the circuit with the capacitor is bigger than of the circuit without the capacitor. Thus, the current through the diode changes because of two factors: type of rectifier and whether a capacitor is part of the circuit or not. Also, the current amplitude of the half-wave rectifier circuit is two times smaller than of the full-wave rectifier circuit with the capacitor. It is expected because the ripple voltage is two times smaller.

3. From obtained hard-copies, it can be concluded that a big $R \times C$ value results a small ripple voltage. It means that DC output would be smother.

2.5 Problem 5: Zener Diode

1. Figure 9 shows the circuit built in LTSpice and the plot of the input voltage and the output voltage across the load resistor. Also, Figure 10 shows the input voltage and output voltage separately, which gives more detailed look.

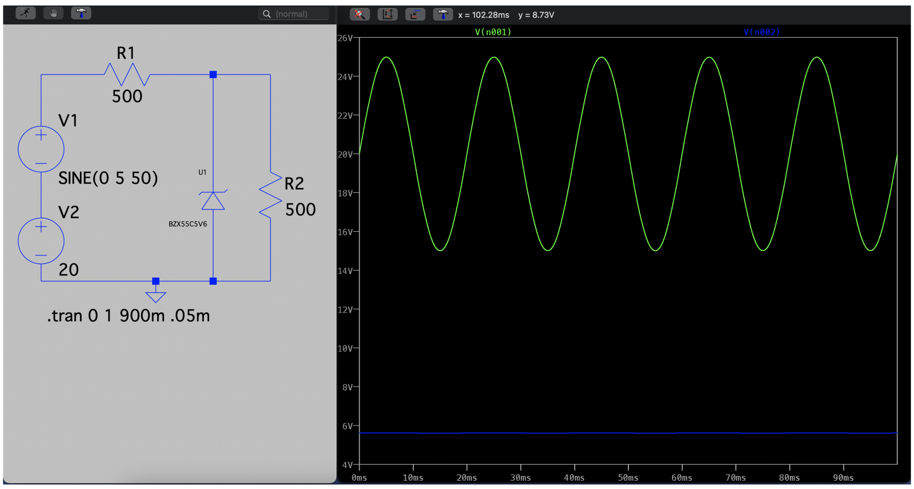
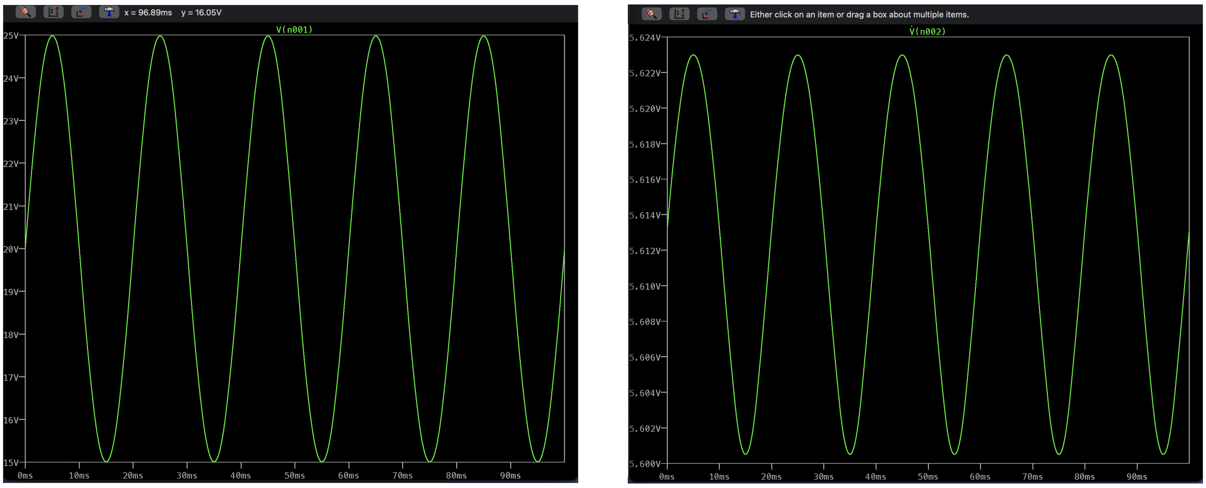


Figure 9: Input and output voltage



(a) Input voltage (b) Output voltage

Figure 10: Voltage plot

2. A Zener diode is a special type of diode designed to reliably allow current to flow "backwards" when a certain set reverse voltage, known as the Zener voltage, is reached. In this case, if the voltage at the zener exceeds $5.6V$, it opens in reverse. As the voltage is higher than $5.6V$, the current starts flowing through the diode. It means that if the voltage across the load rises or falls, the current through the Zener diode changes respectively.

3 Execution Diodes

3.1 Problem 1: Diode Switching Characteristic

The circuit shown in Figure 12 was constructed on the breadboard.

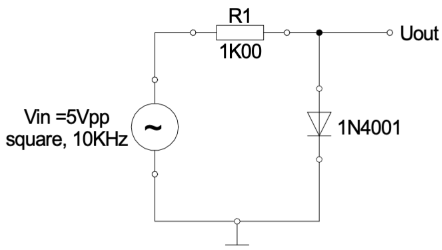
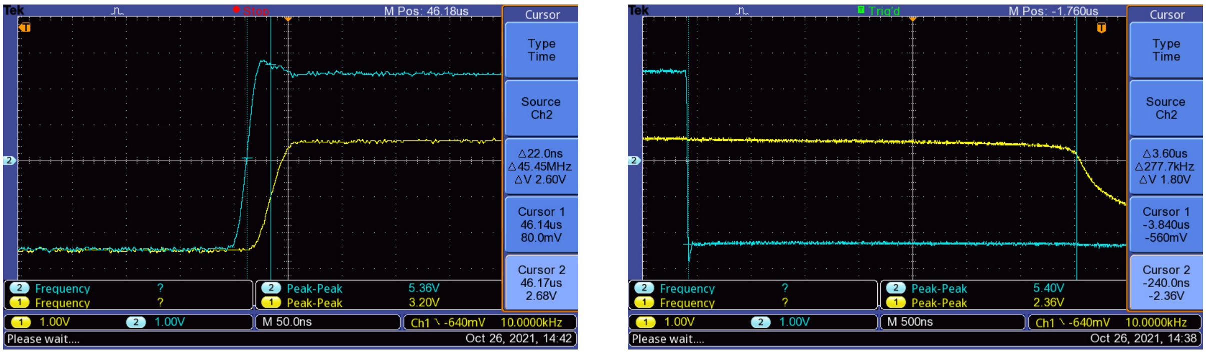


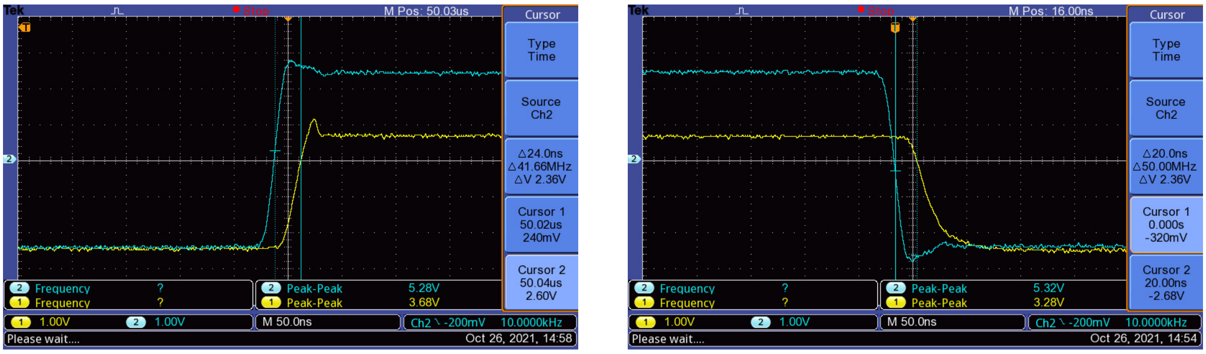
Figure 11: Circuit

The delay time during reverse/forward transition and the storage time after forward/reverse transition were measured. They are shown in Figure 12. After measuring everything, the 1N4001 rectifier diode was replaced with the 1N4148 signal diode. All previous measurements were repeated. They can be observed in Figure 13.



(a) Delay time (b) Storage time

Figure 12: With the rectifier diode



(a) Delay time (b) Storage time

Figure 13: With the signal diode

3.2 Problem 2: Rectifier

3.2.1 Half-wave rectifier

The circuit from Figure 14 was built.

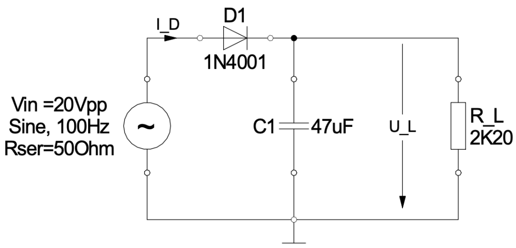
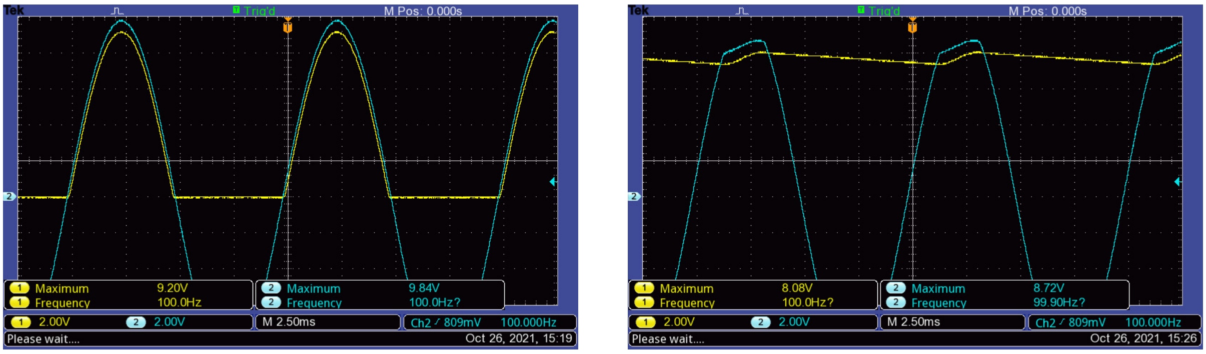


Figure 14: Circuit

First, the capacitor was removed and the output voltage across R_L was recorded. The result is shown in Figure 15a. Then, with the connected capacitor, the same voltage was measured and can be seen from Figure 15b. Finally, the ripple voltage was expended to see it more clearly. Figure 16 shows the obtained hard-copy.



(a) With the capacitor

(b) Without the capacitor

Figure 15: Voltage across R_L

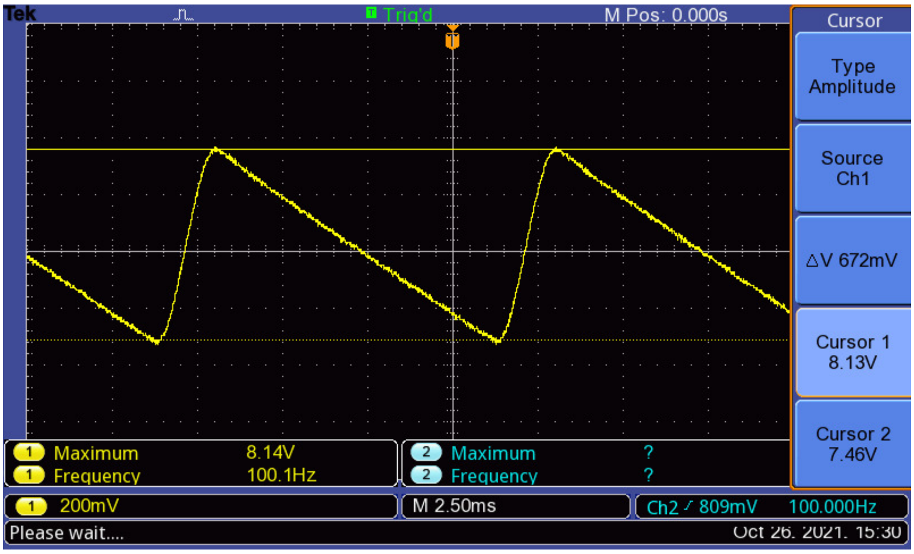


Figure 16: Ripple voltage

3.2.2 Full-wave rectifier

The circuit from Figure 17 was built.

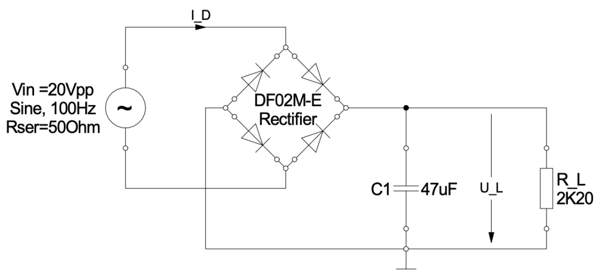
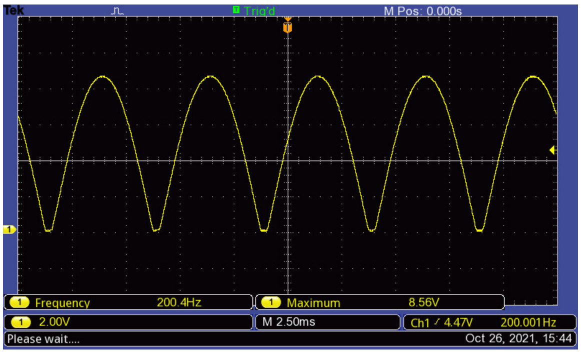
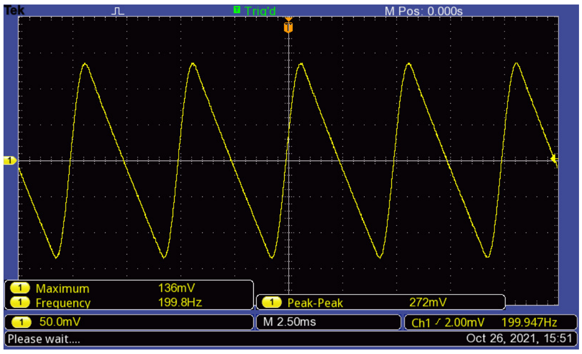


Figure 17: Circuit

First, the capacitor was removed and the output voltage across R_L was recorded. The result is shown in Figure 18a. Then, with the connected capacitor, the same voltage was measured and can be seen from Figure 18b. In this part, there was no need to expend the ripple voltage.



(a) With the capacitor



(b) Without the capacitor or Ripple voltage

Figure 18: Voltage across R_L

3.3 Problem 3: Zener diode

The circuit shown in Figure 19 was constructed on the breadboard.

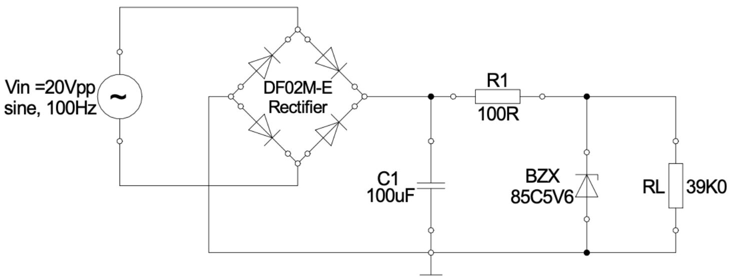
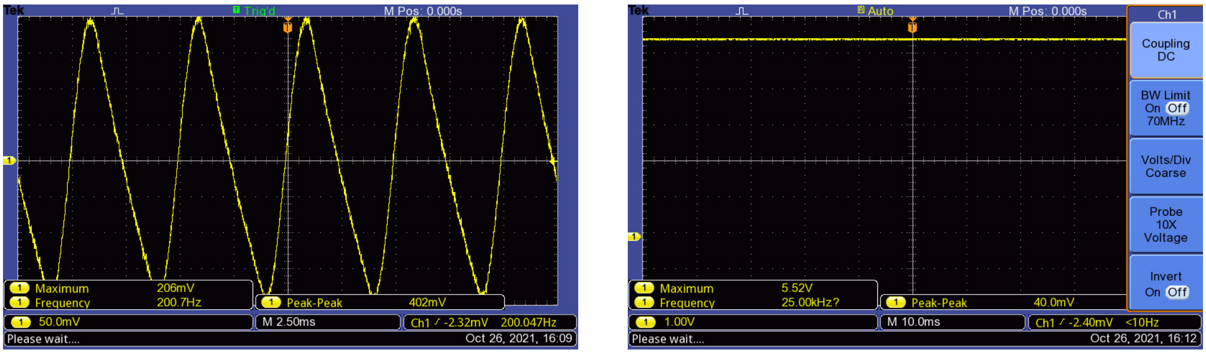


Figure 19: Circuit

Then, hard-copies of the voltage over capacitor, of the output DC voltage, and of the ripple voltage across the load resistor R_L were taken. Figure 20 shows the first two hard-copies and Figure 21 shows the last hard-copy.



(a) Voltage across the capacitor (b) Output DC Voltage

Figure 20: Hard-copies

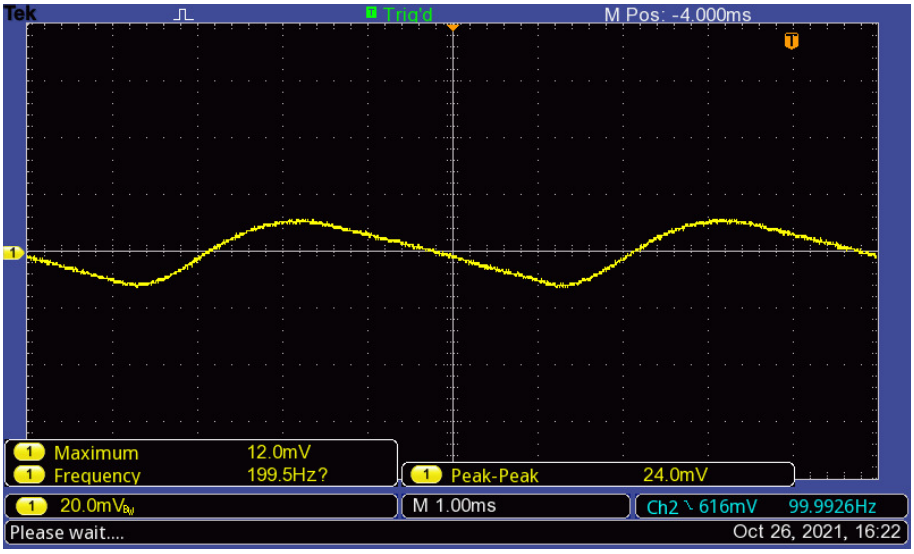


Figure 21: Ripple voltage across the load

3.4 Problem 4: Voltage Multiplier

The circuit from Figure 22 was built.

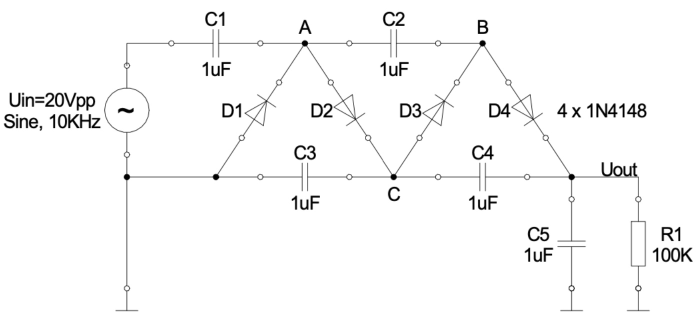
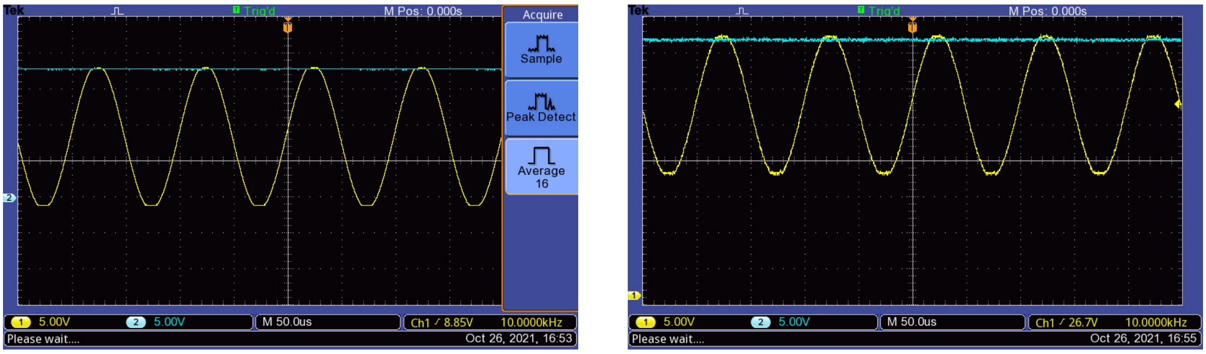


Figure 22: Circuit

After assembling the circuit, the oscilloscope was used to measure the voltage at 'A' and at 'C'. The hard-copy is shown in Figure 23a. Then, the voltage at 'B' and 'V_{out}' were recorded as well. Figure 23b shows the result. The ripple voltage at 'V_{out}' was measured using oscilloscope. Figure 24 shows the hard-copy. Finally, the Elabo multimeter gives the following numbers for voltages at 'C' and at 'V_{out}':

$$V_C = 17.757V \qquad V_{out} = 35.44V$$



(a) Voltage at 'A' and at 'C'

(b) Voltage at 'B' and at 'U_{out}'

Figure 23: Hard-copies

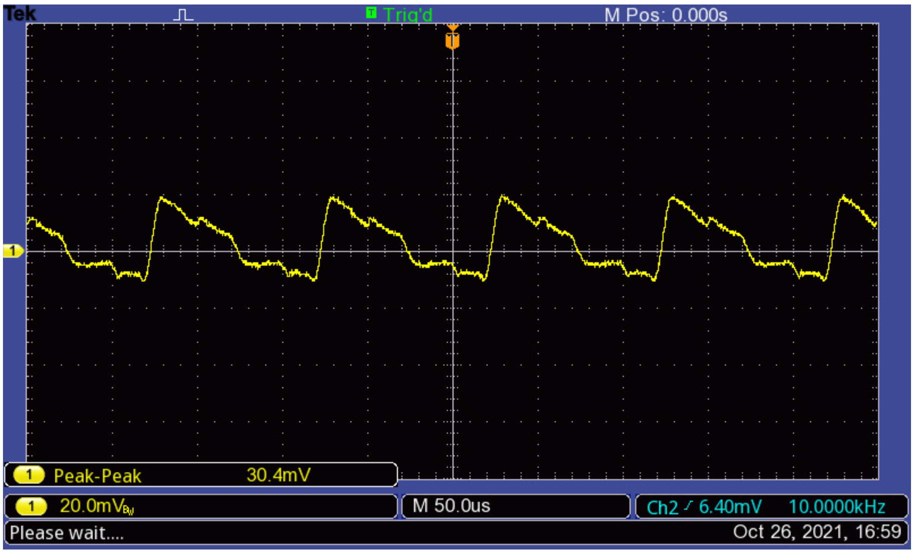


Figure 24: Ripple voltage

4 Evaluation Diodes

4.1 Problem 1: Diode Switching Characteristic

1. Since it takes some time for the carriers to flow across the junction, there will be some amount of time when current still flowing. It means that electrons have to get back to n-region and holes have to get back to p-region before the diode is turned off completely.

2. From hard-copies, it can be concluded that the 1N4001 rectifier diode is very slow, by taking 3.6 microsecond before being off completely. It means that this kind of diode can not be used for high speed switching. Next input wave could catch up the previous one, making the output signal meaningless. On the other hand, the 1N4148 signal diode is very fast (20 nanoseconds). This diode can be used with high speed switches.

4.2 Problem 2: Rectifier

1. A rectifier circuit is used to convert AC voltage (sinusoidal voltage) into unidirectional voltages using Diodes. Output of a Rectifier circuit is a pulsating DC (unidirectional voltage with half sinusoids) consisting of a DC component as well as superimposed ripple. Filter Circuits reduce the ripple (unwanted AC components) to the required levels. In our case, this filter consists only of the capacitor. Since the magnitude of output DC voltage may vary because of input AC voltage or because of the magnitude of the load current, there is a stringent need of constant output DC voltage. This can be achieved by a regulator.

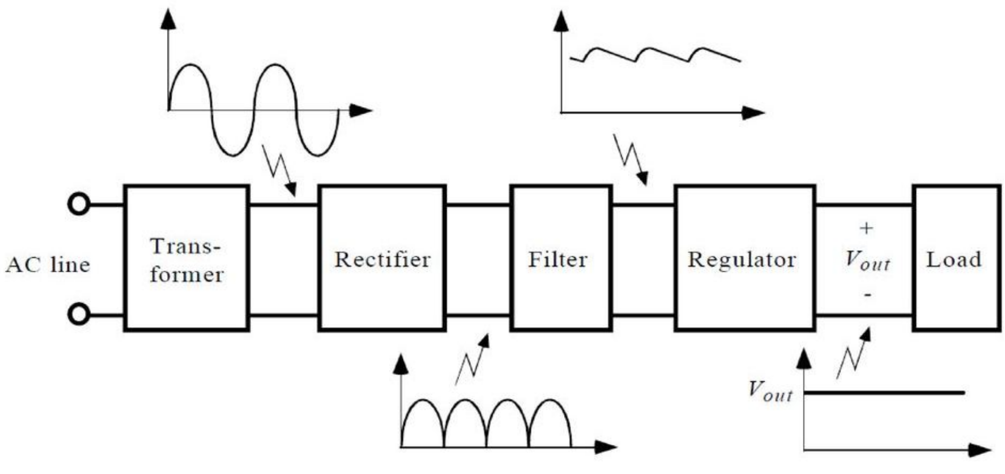


Figure 25: Diagram

2. By comparing the calculated, measured values and values from simulation (Table 1), it can be concluded that the numbers are similar. However, they are not close enough. It means that there were some errors. For example, the generator can not generate

exactly desired signal and it is hard to say exactly capacitance and resistance of the components, that were used in the circuit.

	Calculated	Simulated	Measured
Half-wave rectifier	591.61mV	614.57mV	672mV
Full-wave rectifier	295.81mV	263.60mV	272mV

Table 1: Comparing ripple voltage

4.3 Problem 3: Zener diode

1. Let's consider the circuit shown in Figure 26. Let I_1, I_Z, and I_2 be the current through R_1, the diode, and R_L respectively.

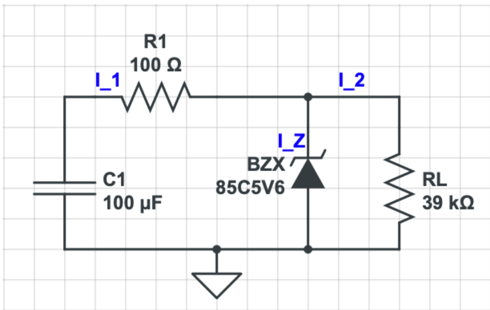


Figure 26: Circuit

Also, during the experiment, the voltage across the capacitor and across the load resistor were measured. It means that using Ohm's law, I_1 and I_2 can be calculated.

$$I_2 = \frac{5.52V}{39k\Omega} = 141.54\mu A \qquad I_1 = \frac{6.82 - 5.52}{100} = 13mA$$

Finally, KCL gives:

$$I_Z = I_1 - I_2 = 13mA - 141.52\mu A = 12.86mA$$

4.4 Problem 4: Voltage Multiplier

1. The circuit shown in Figure 22 consists of clamper circuits and a diode rectifier. The clampter circuit adds DC voltage to the circuit, resulting the same signal which is centered above zero. Then, the rectifier gives DC voltage.

2. As mentioned, clampters are used to add a DC voltage level to a signal. From Figure 23a, we can see the same signal as in the input but above zero. Also, at the point 'C', DC voltage can be observed. The same process happens again, lifting up from zero.

3. The output voltage at point 'A' is an identical signal above zero. The output voltage at point 'C' is supposed to be around $20V$, double the amplitude, but experimentally obtained value was $17.757V$. This is because of the voltage drop of the diodes. The same process happens at points 'B' and 'V_{out}'. It means that the multiplication factor should be 4 and expected output voltage is $40V$. However, measuring it practically gave $35.44V$, which is quite lower because of the same reason.

4. The voltages at points 'C' and 'V_{out}' were measured by using Elabo, and it gave the following numbers: $17.757V$ at point 'C' and $35.44V$ at point 'V_{out}'. Ideally, the maximum voltage for which each element should be selected.

5. Decreasing the input frequency to 100Hz results in increasing the ripple voltage and in decreasing the multiplication factor. Note that only capacitors depends on frequency. At lower frequencies, the reactance of the capacitor will increase. It means that it blocks more AC current. LTSpice gives the output shown in Figure 27 and Figure 28. It is clearly seen that the DC voltage is around $23V$ and the ripple voltage has increased.

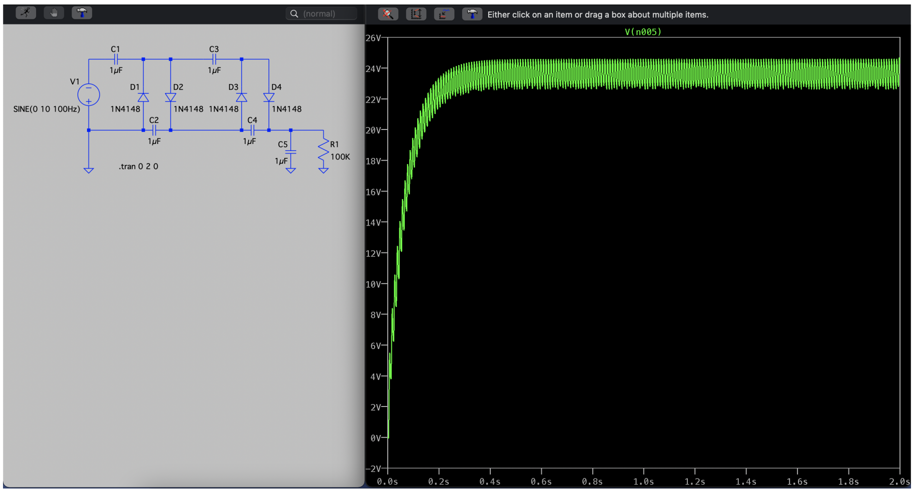


Figure 27: Circuit

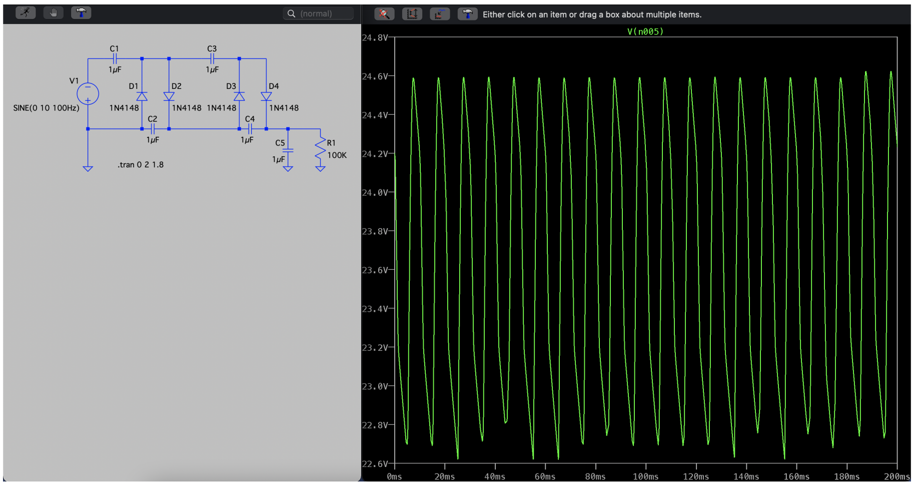


Figure 28: Circuit

5 Conclusion

During the experiment, semiconductor diodes and their applications were studied. The properties and behaviors of these diodes were shown in the prelab using LTSpice. Then, these properties and behaviors were compared to the experimentally obtained results.
When switching off the diode, there is a storage time which is needed to be fully discharged. It was observed by using the oscilloscope. This phenomenon happens because the charge carriers inside the diode need some time to go back. It was concluded that diodes with a large time delay are not suitable for high frequencies.
The main properties of the voltage rectifies and voltage regulators were explained. In conclusion, an AC signal first must go through a filter to reduce the AC component, then through a Zener diode to keep voltage constant.
Finally, one more interesting circuit was considered where diodes and clampers were used to form a voltage multiplier. It led to a constant voltage with the amplitude multiple times higher than input voltage's amplitude. However, there were some difference between practical and theoretical numbers. The main error in this experiment would be the signal generator, circuit components, and the oscilloscope. The signal generator can not deliver a desired signal, the circuit components are quite different from the components used in the LTSpice, and the oscilloscope has some internal errors (bad resolution and inaccurate numbers from using cursor). Overall, the difference between numbers were not so high.

References

[1] CO-526-B Electronics Lab
Instructors: Uwe Pagel and Mojtaba Joodaki.
Fall Semester, 2021

[2] What is a diode?
`https://www.fluke.com/en/learn/blog/electrical/what-is-a-diode`
Link