Report 2 : 96%
Prelab 2 : 94%

Constructor University Bremen

Natural Science Laboratory

Electronics

Fall Semester 2024

Lab Experiment 2- Diode

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Experiment conducted by: Wanzia Nambule, Agustin Aristizabal
Place of execution: Teaching Lab EE
Bench 3

Date of execution: 19 November, 2024

INTRODUCTION

A diode is a straightforward electronic component, that allows current flow in only one direction and exhibits an exponential current-voltage (I-V) relationship. The operational states of a diode encompass reverse bias and forward bias conditions.

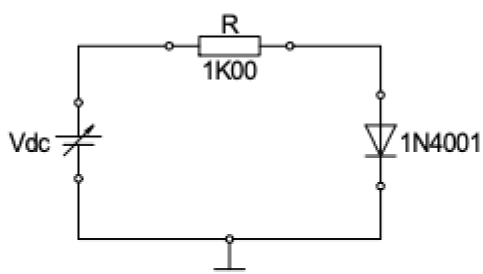
OBJECTIVE

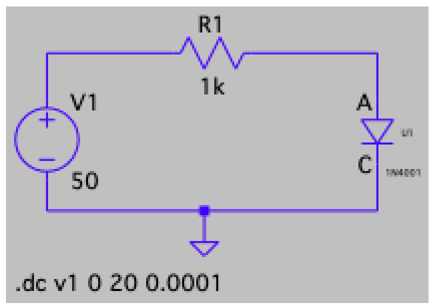
The objective of our Experiment was to understand the properties and behavior of semiconductor diodes, including rectifier and Zener diodes, and to explore their practical applications. Circuits such as rectifiers, voltage regulators, clampers, and clippers were analyzed to gain hands-on experience with these essential components.

Prelab

Problem 1 : Current/voltage characteristic of a diode

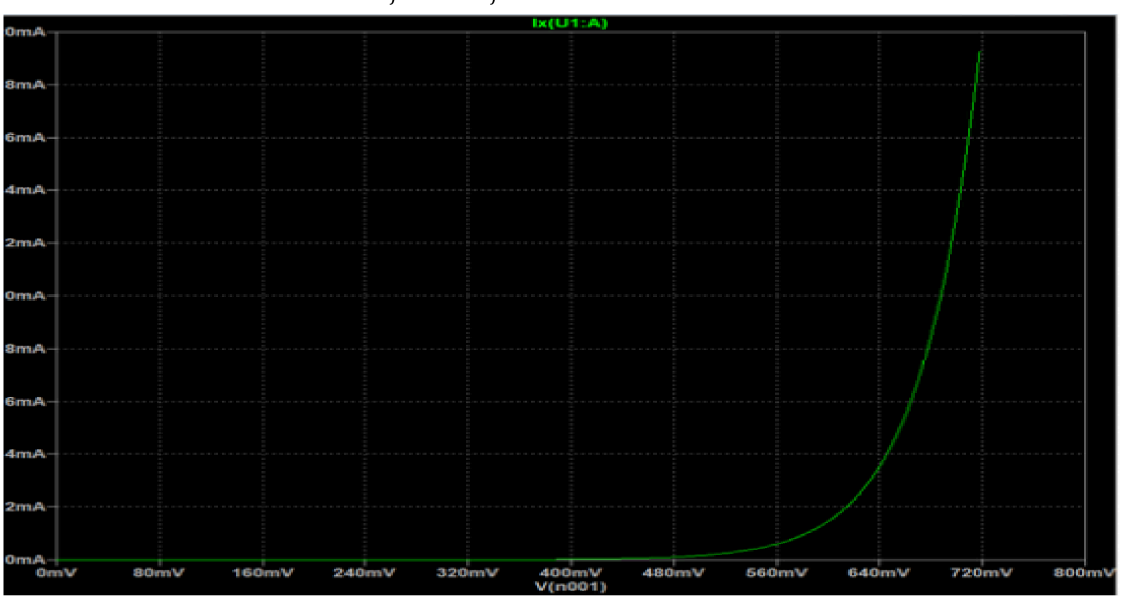
Implementing the following circuit using LTSpice:





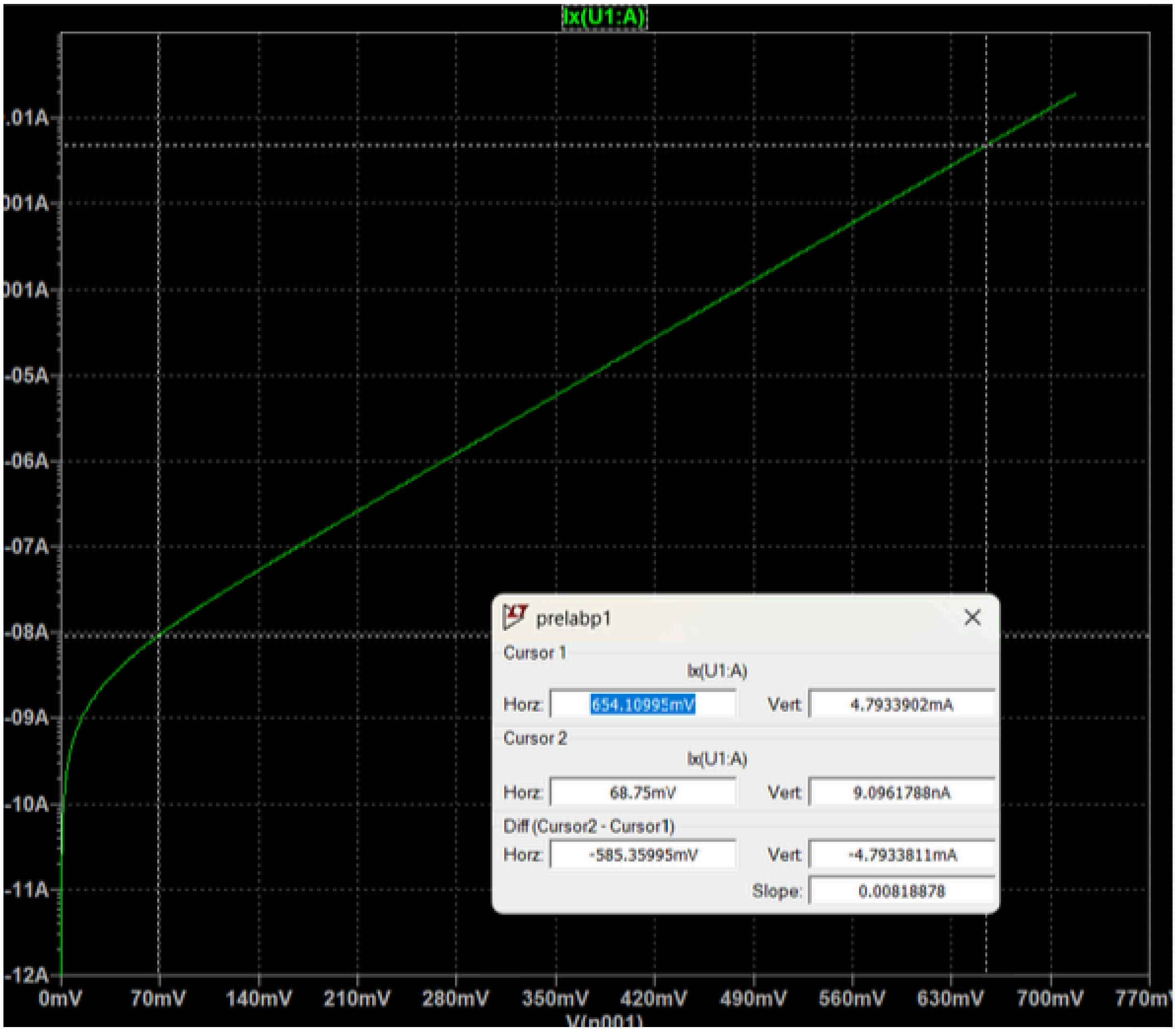
Performing a DC sweep analysis:

1. Plotting the diode characteristic $I_f = f(V_f)$, we get:



The plot above illustrates the current behavior in a diode, showing that the minimum voltage required to activate the diode is approximately 0.07V to 0.75V, at which point the current begins to increase.

2. Plotting the diode characteristic $log(I_f) = f(V_f)$, we get:



3. Extracting the values of ideality, n, and the saturation current I_s from the graph, assuming the voltage VT is 26mV.

$I_1 = I_s Exp(\frac{V_1}{nV_T})$

$I_2 = I_s Exp(\frac{V_2}{nV_T})$

From the two equations above we can divide them and get n:

$\frac{I_1}{I_2} = Exp(\frac{V_1 - V_2}{nV_T})$

Making n the subject of the formula:

$n = \frac{V_1 - V_2}{ln(I_1) - ln(I_2)} \frac{1}{V_T}$

Using the two points (266.27219mV, 916.53383nA) and (563.60947mV, 651.61395µA) from the plot:

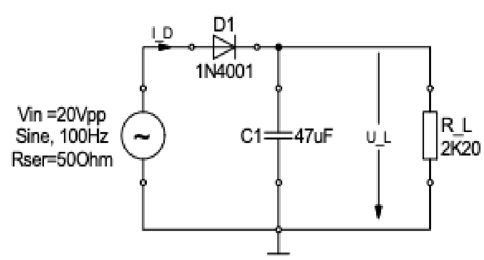
$$n = \frac{564mV - 266mV}{ln(652\mu A) - ln(917nA)} \frac{1}{26mV}$$
$$n = 1.74$$

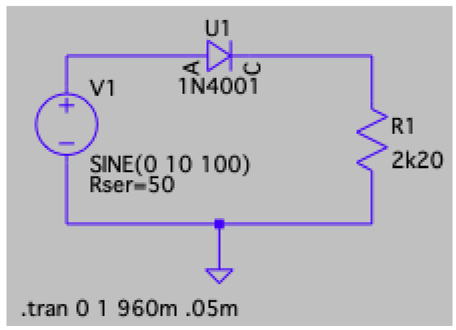
The saturation current is:

$$I_s = \frac{1}{Exp(1/nV_T)}$$
$$I_s = 2.03 \times 10^{-9}$$
$$I_s = 2.03nA$$

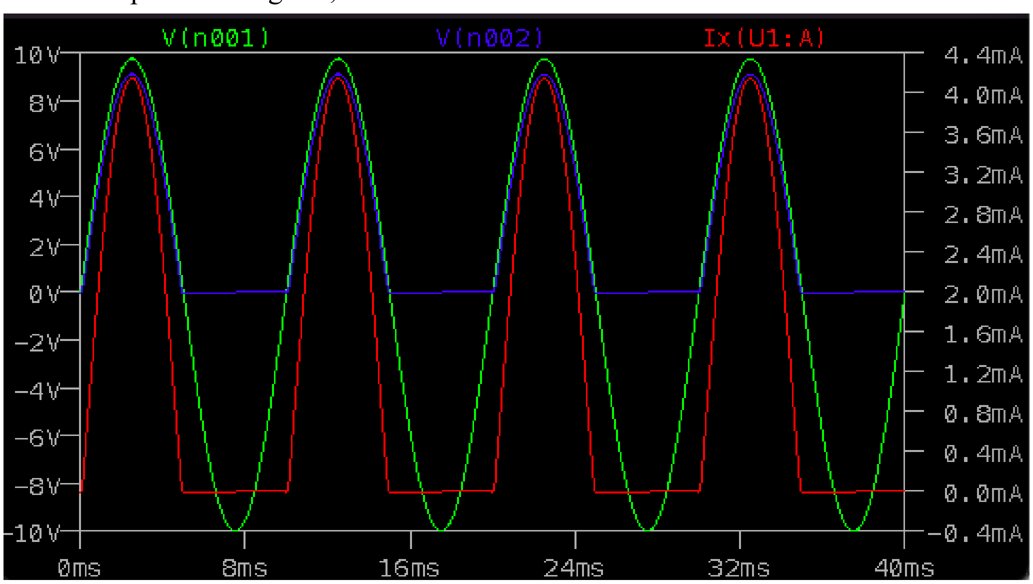
Problem 2 : Halfwave rectifier

Implementing the following circuit using LTSpice, but without C1:

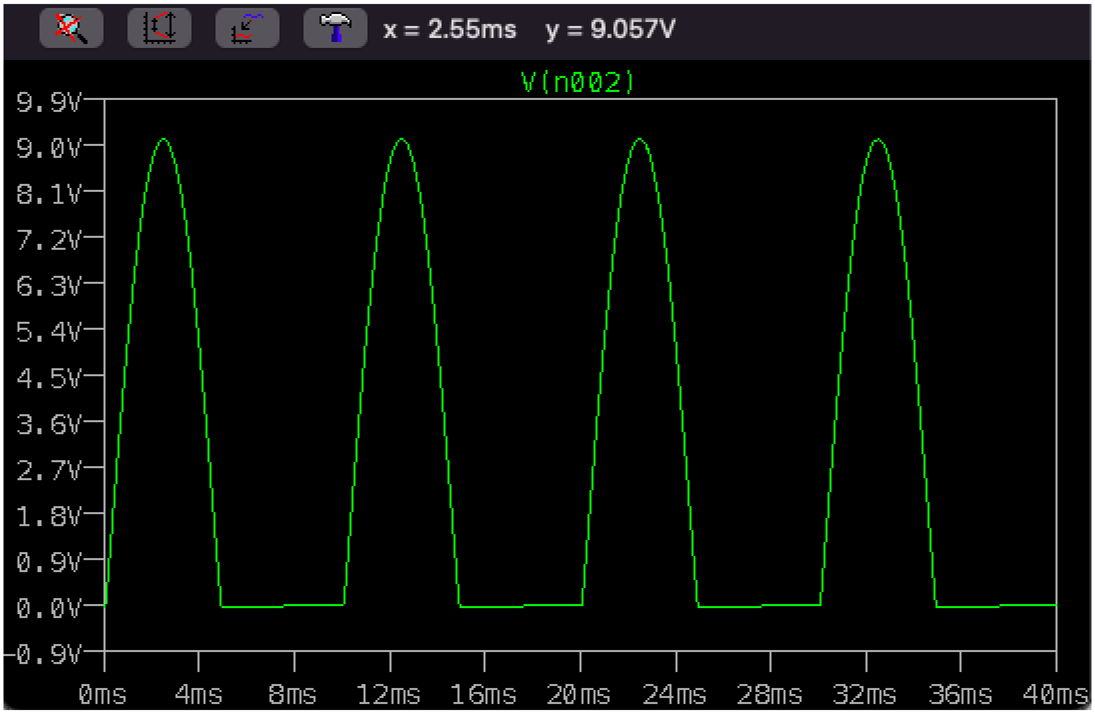




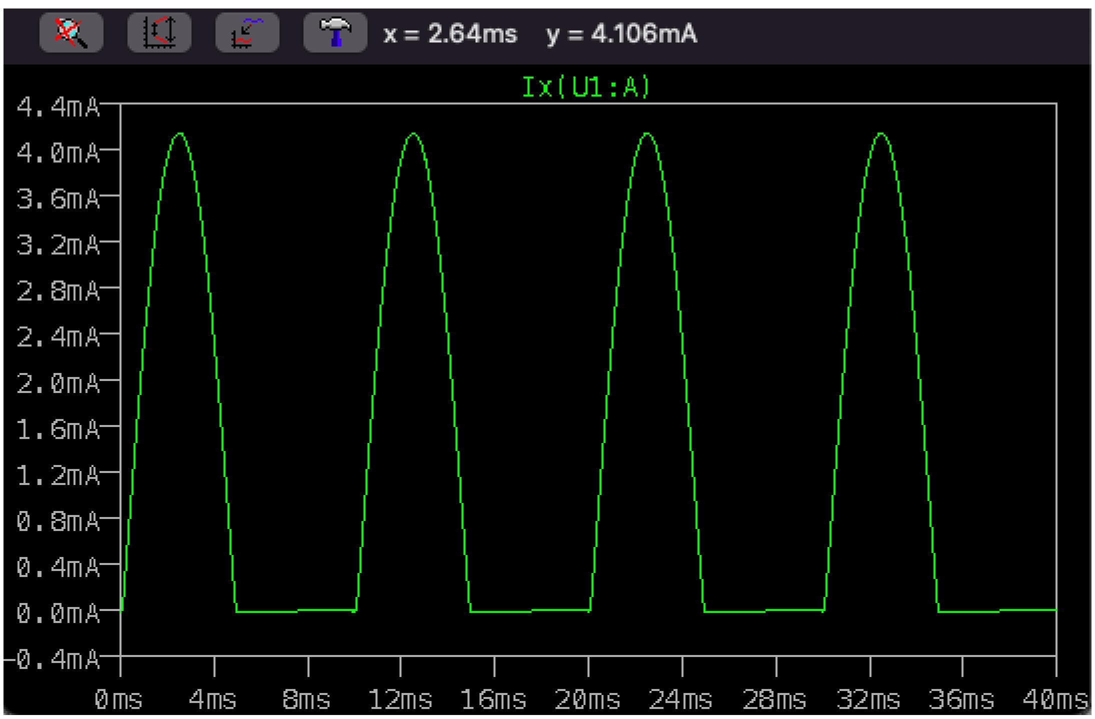
Below is a plot showing VL, Vin and ID without C1:



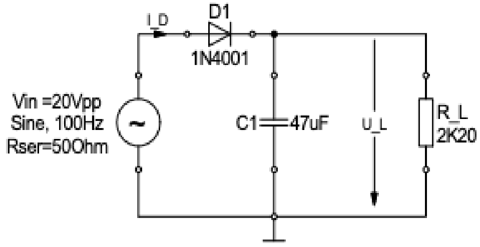
Below is a plot showing peak voltage value at RL:

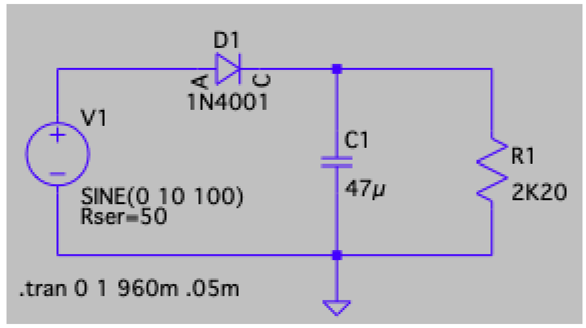


Below is a plot showing peak current value at ID:

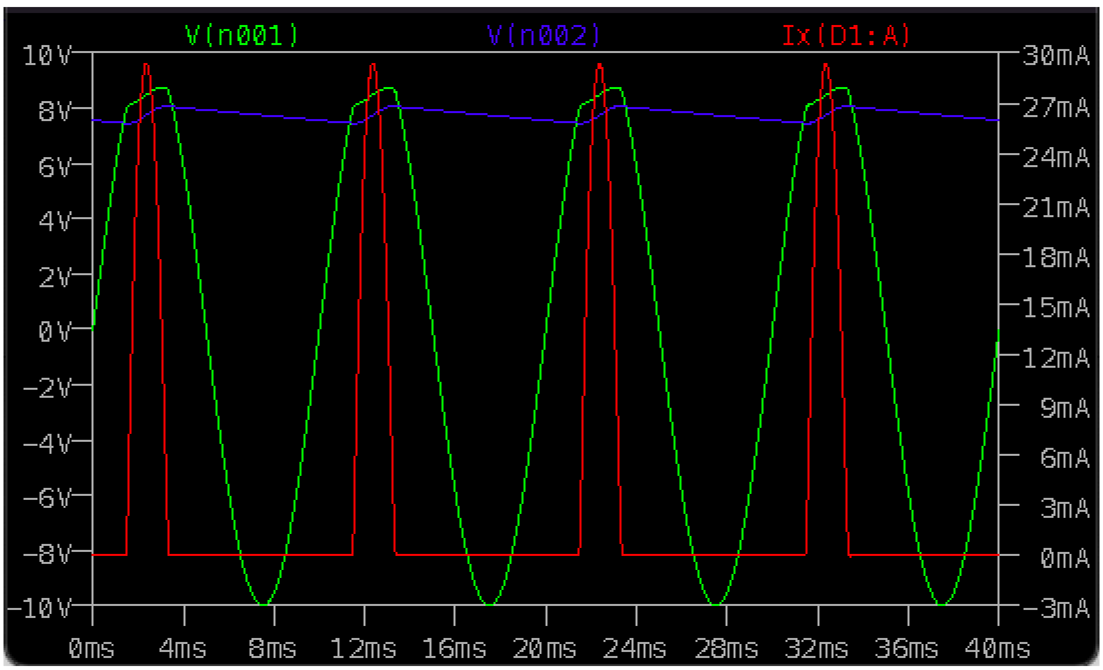


Implementing the following circuit using LTSpice:

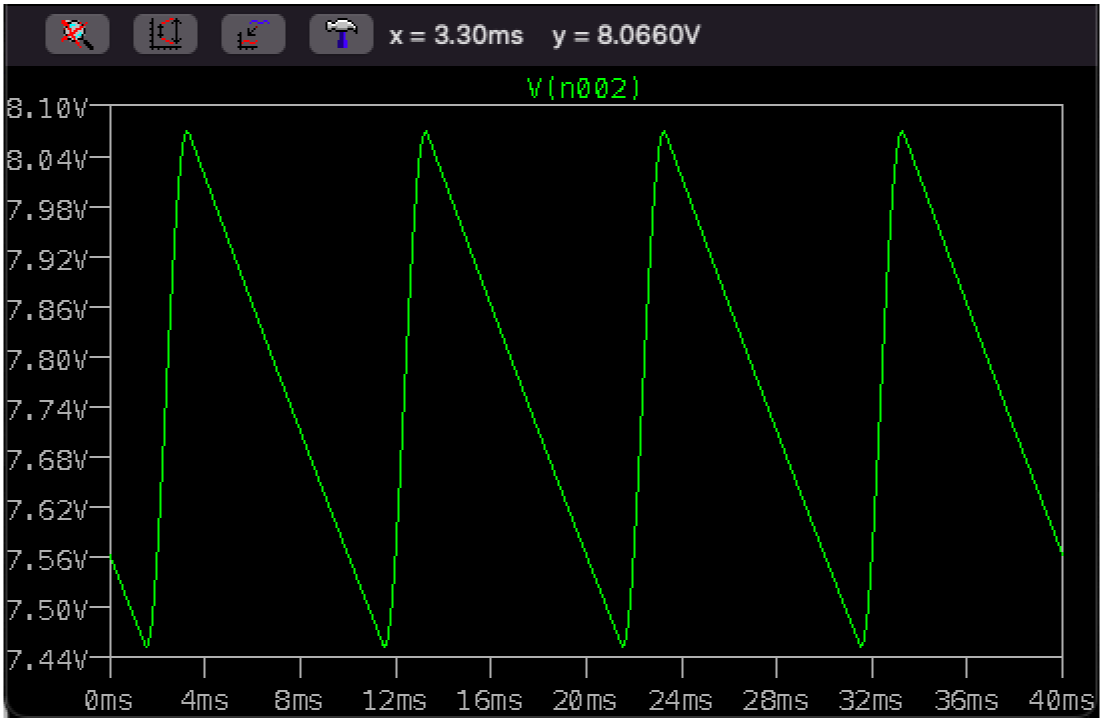




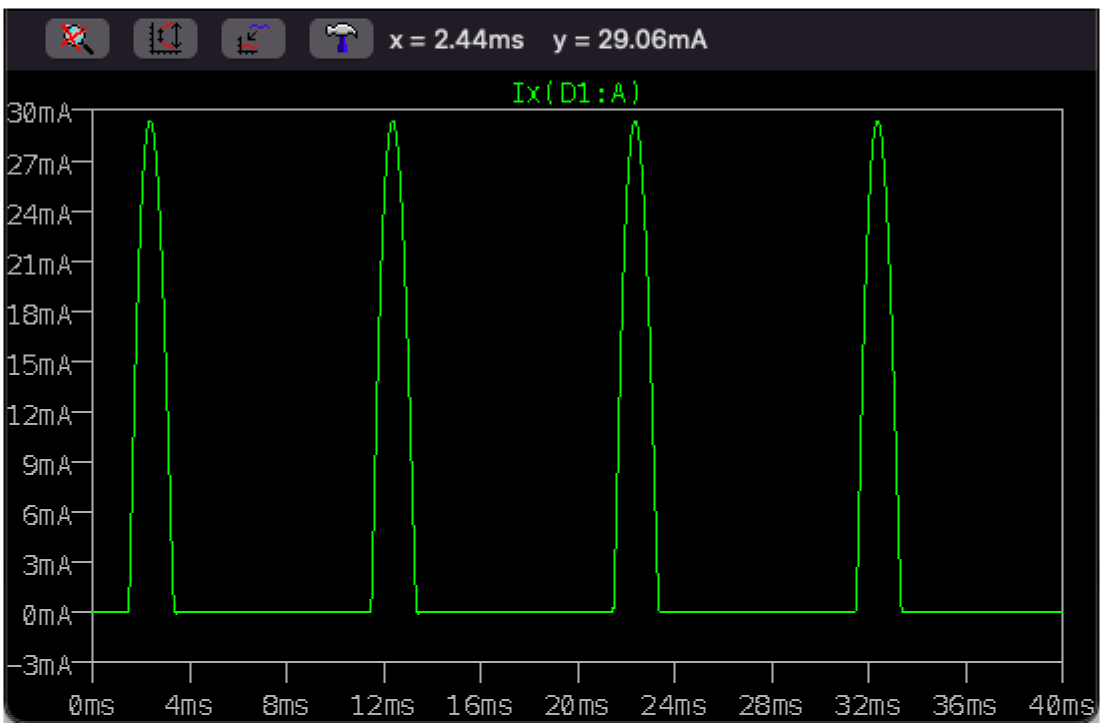
Below is a plot showing VL, Vin and ID with C1:



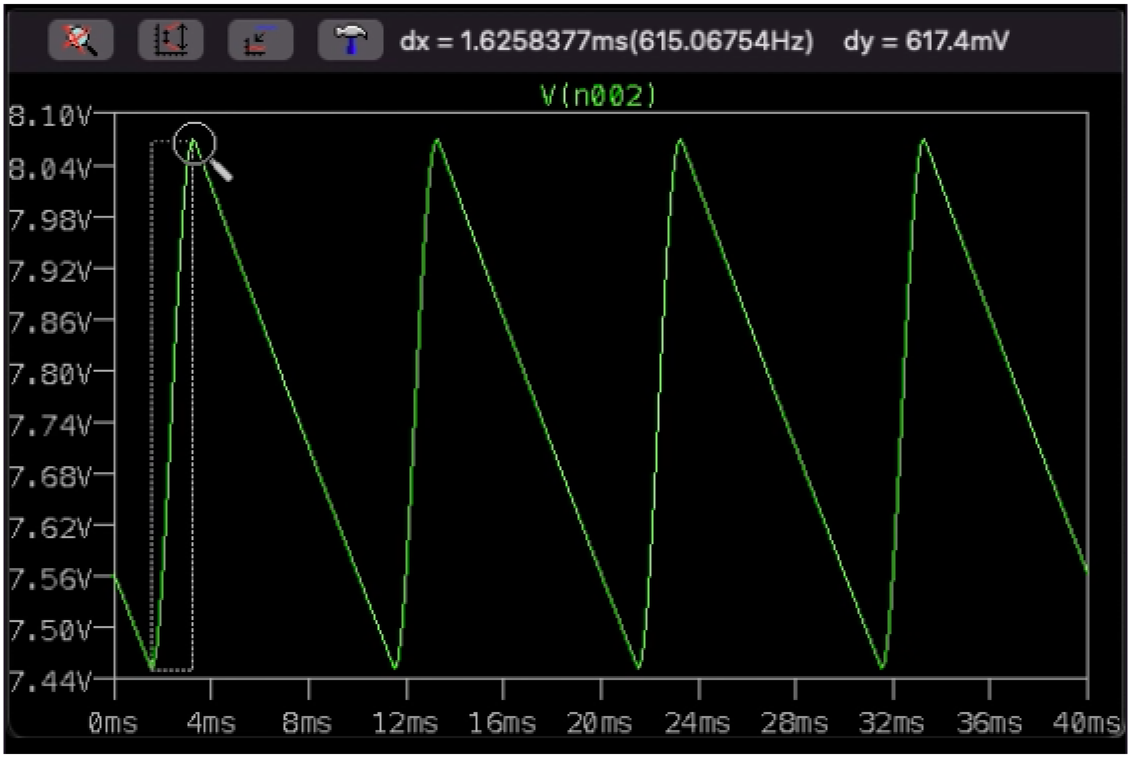
Below is a plot showing peak voltage value at RL:



Below is a plot showing peak current value at ID:



Below is a plot showing ripple voltage value at RL:



Calculating the ripple voltage at VL:

$$V_r = \frac{V_p}{fCR_L}(1 - \sqrt[4]{\frac{R_i}{R_L}})$$

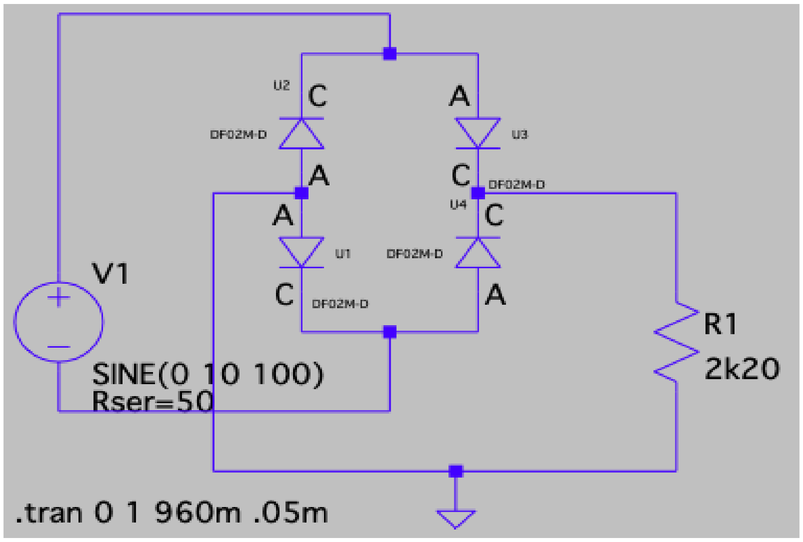
$$V_r = \frac{10}{100\times47\times10^{-6}\times2k20}(1 - \sqrt[4]{\frac{50}{2k20}})$$

$$V_r = 0.592V$$

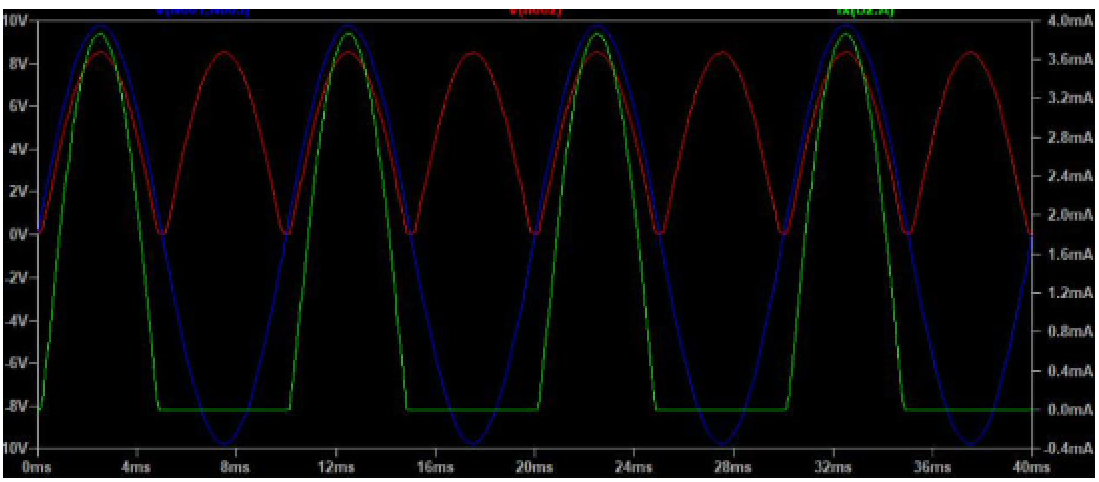
The result from LTSpice is **0.617 V**, while the calculated value is **0.592 V**. The slight variation between the two results can be attributed to the precision limitations of the LTSpice software, as well as the fact that the formula used is an estimation and may not yield the most exact result.

Problem 3 : Full Wave rectifier

Below is the circuit Implementation in LTSpice without C1:

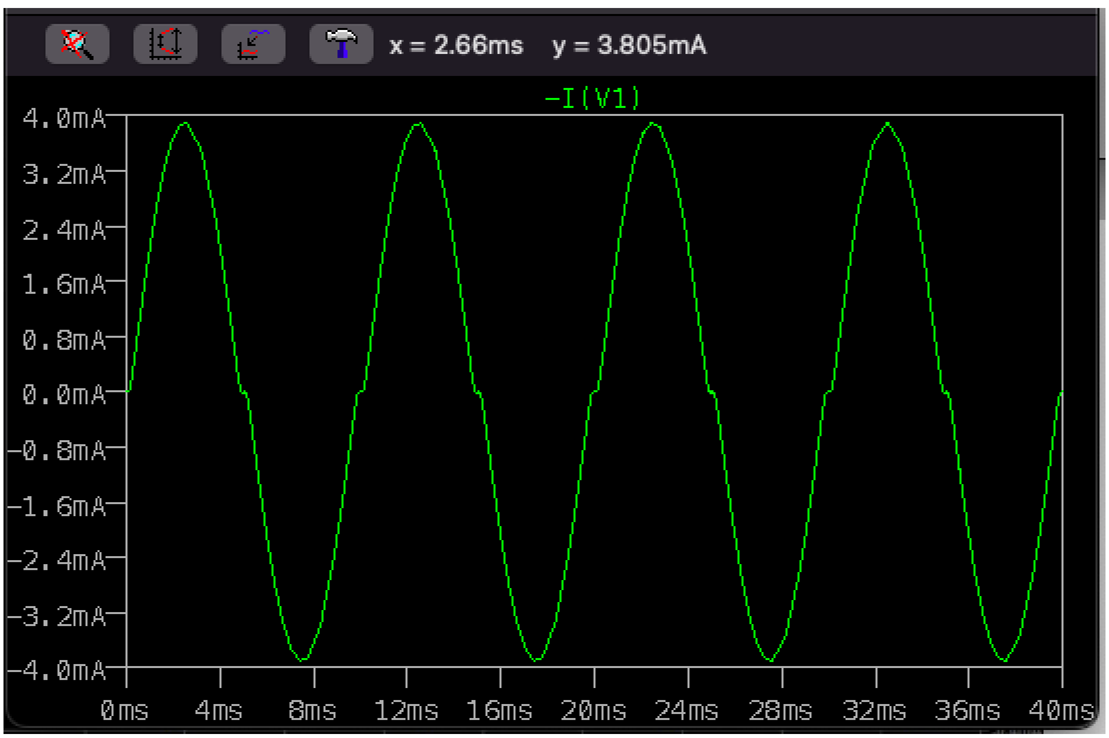


Below is a plot showing VL, Vin and ID without C1:

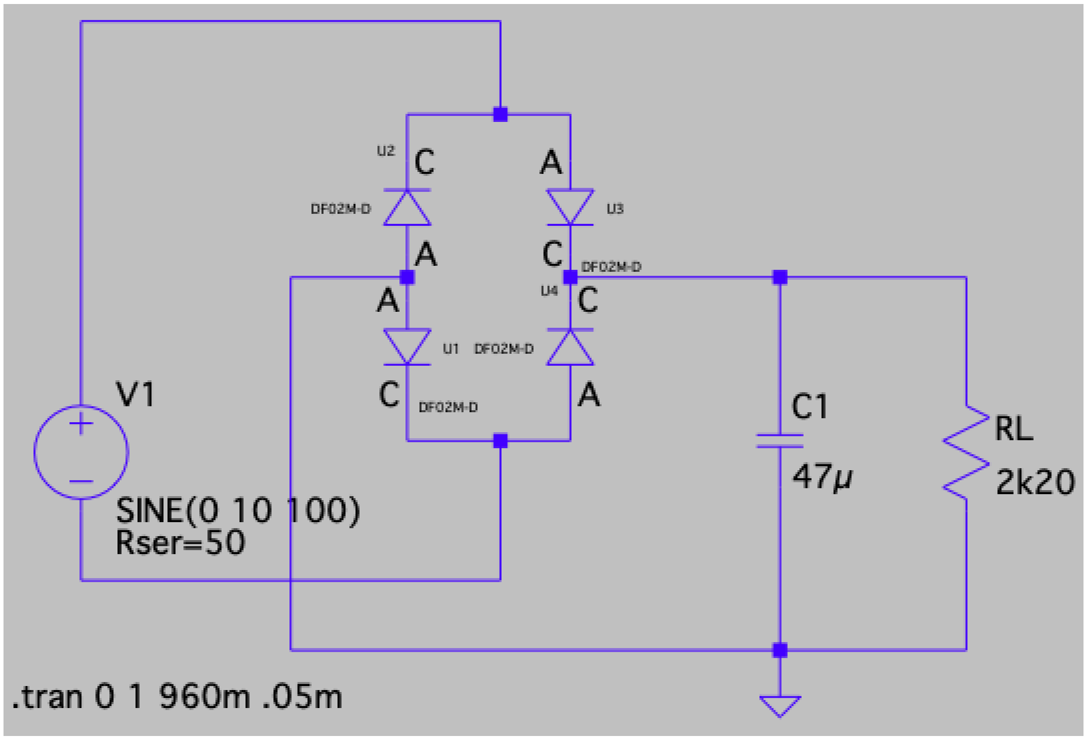


Below is a plot showing peak voltage value at RL:

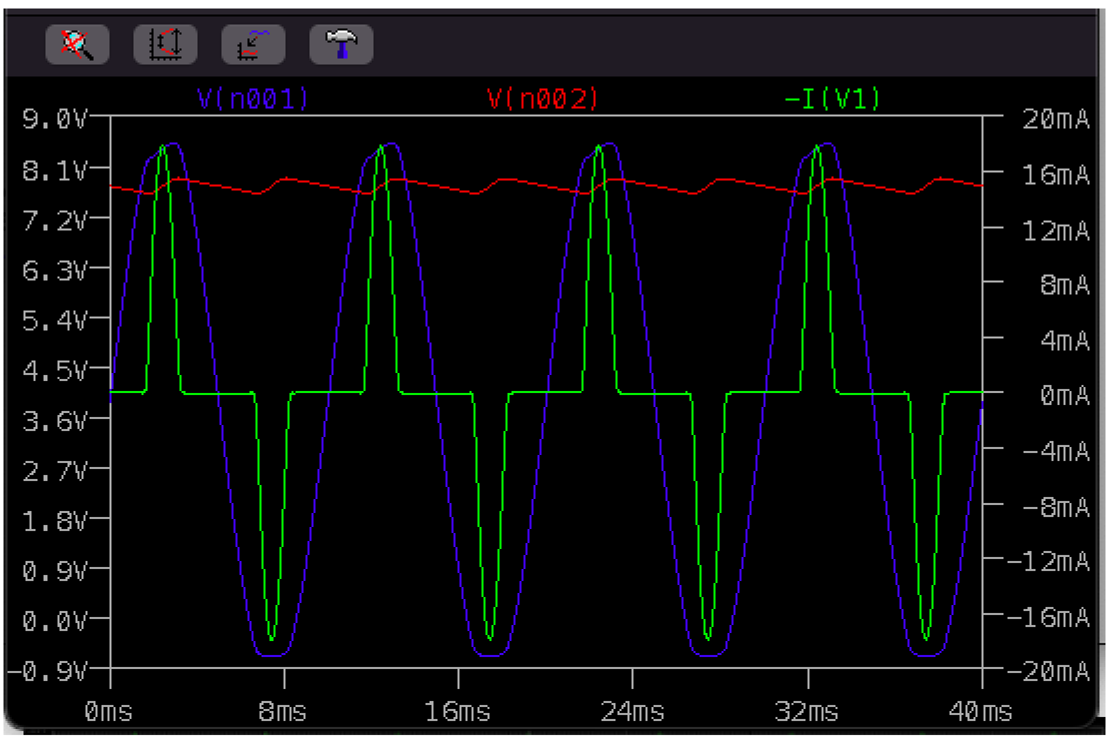
Below is a plot showing peak current value at ID:



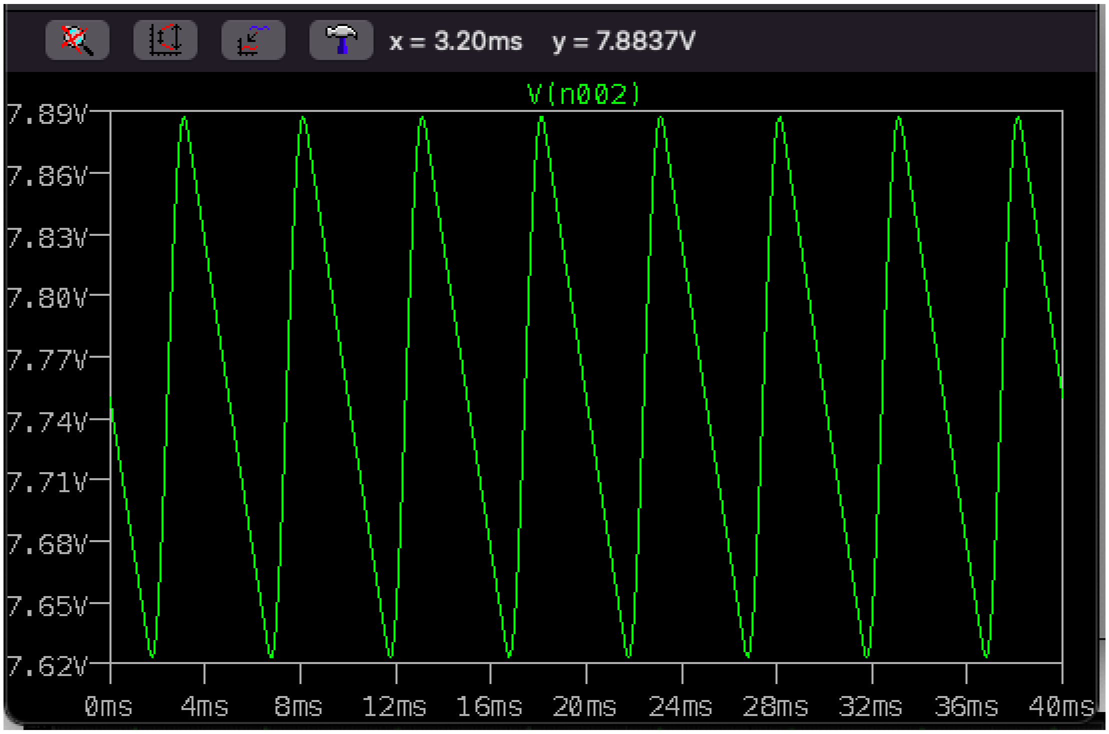
Below is the circuit Implementation in LTSpice with C1:



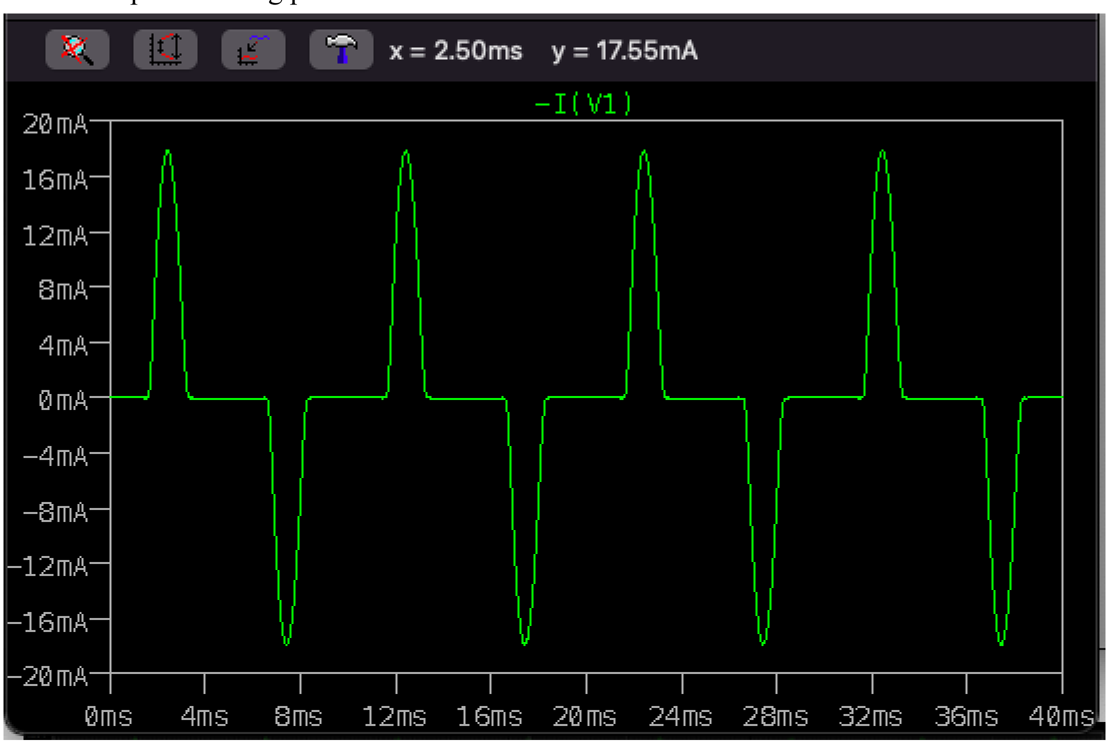
Below is a plot showing VL, Vin and ID with C1:



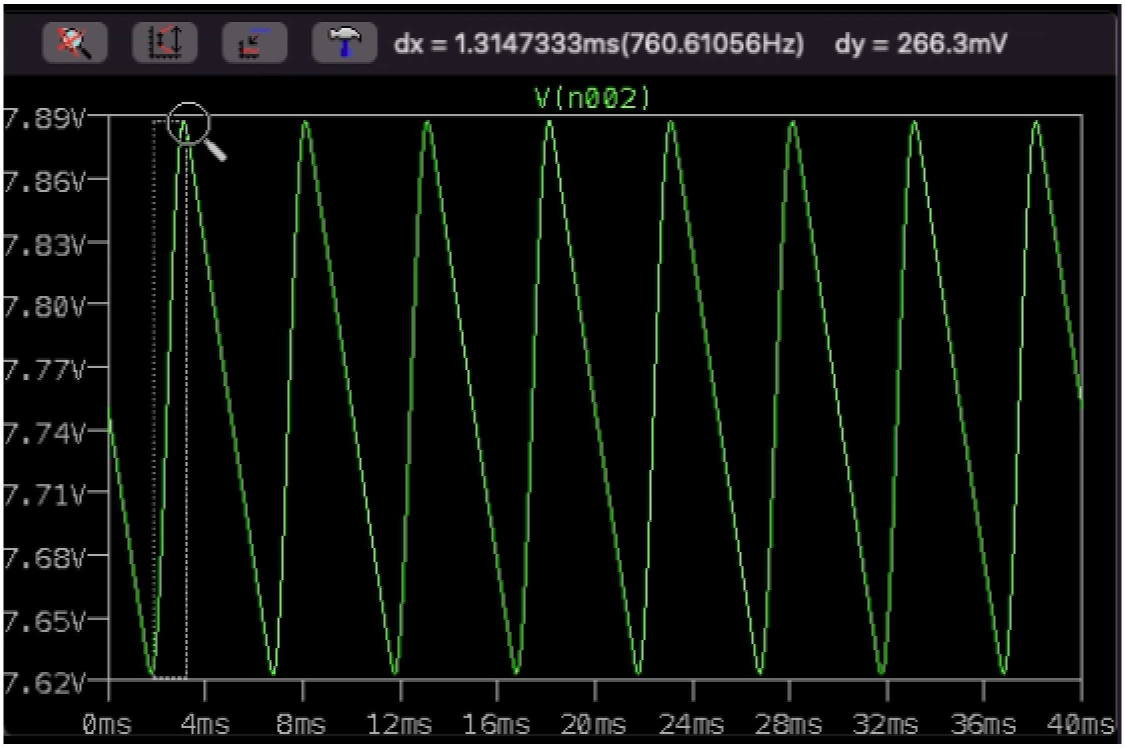
Below is a plot showing peak voltage value at RL:



Below is a plot showing peak current value at ID:



Below is a plot showing ripple voltage value at RL:



Calculating the ripple voltage at VL:

$$V_r = \frac{V_p}{fCR_L}\left(1 - \sqrt[4]{\frac{R_i}{R_L}}\right)$$

$$V_r = \frac{0.5\times10}{100\times47\times10^{-6}\times2k20}\left(1 - \sqrt[4]{\frac{50}{2k20}}\right)$$

$$V_r = 0.296V$$

The results from LTSpice are 0.2663 V, while the calculated value is 0.296 V. The discrepancies between these results can be attributed to the precision limitations of the LTSpice software and the fact that the formula used is an approximation, which may not yield an exact result.

Problem 4 : Rectifier

A rectifier circuit is designed to convert alternating current (AC) into direct current (DC). In such circuits, a capacitor is used to smooth the output DC voltage by reducing the ripple. Acting as a filter, the capacitor minimizes fluctuations in the rectified output. When connected in parallel with the load, it charges to the peak voltage and discharges during the intervals when the rectifier's output decreases, effectively filling in the gaps and delivering a more stable DC voltage. The images above for both half-wave and full-wave rectifiers illustrate this smoothing effect.

Below is a table showing the voltage values at the load:

	With C1 (V)	Without C1 (V)
Half wave	8.06	9.13
Full Wave	7.88	8.15

In both half-wave and full-wave rectifiers, the diode voltage drop plays a crucial role in determining the output voltage. In a half-wave rectifier, current flows through a single diode during each half-cycle, resulting in the output voltage being reduced by the forward voltage drop of that diode compared to the peak amplitude of the input sine wave. In contrast, a full-wave rectifier requires current to pass through two diodes per half-cycle, causing the output voltage to be reduced by twice the forward voltage drop. This leads to a difference in output voltages, with the full-wave rectifier having a slightly lower output voltage than the half-wave rectifier due to the additional diode voltage drop.

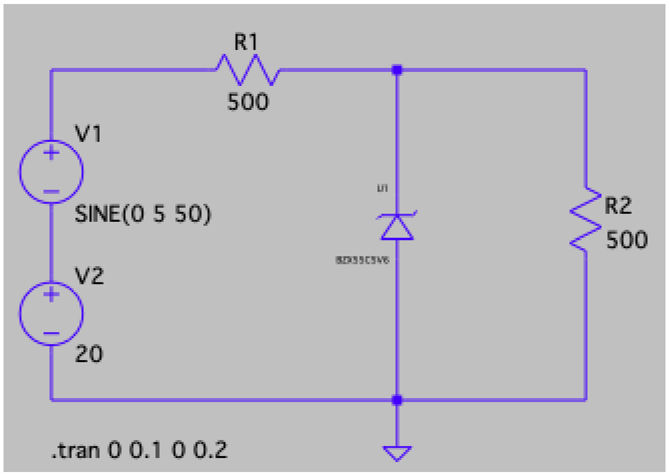
Below is a table showing the voltage values at the load:

	With C1 (V)	Without C1 (V)
Half wave	29.34	4.15
Full Wave	17.86	3.90

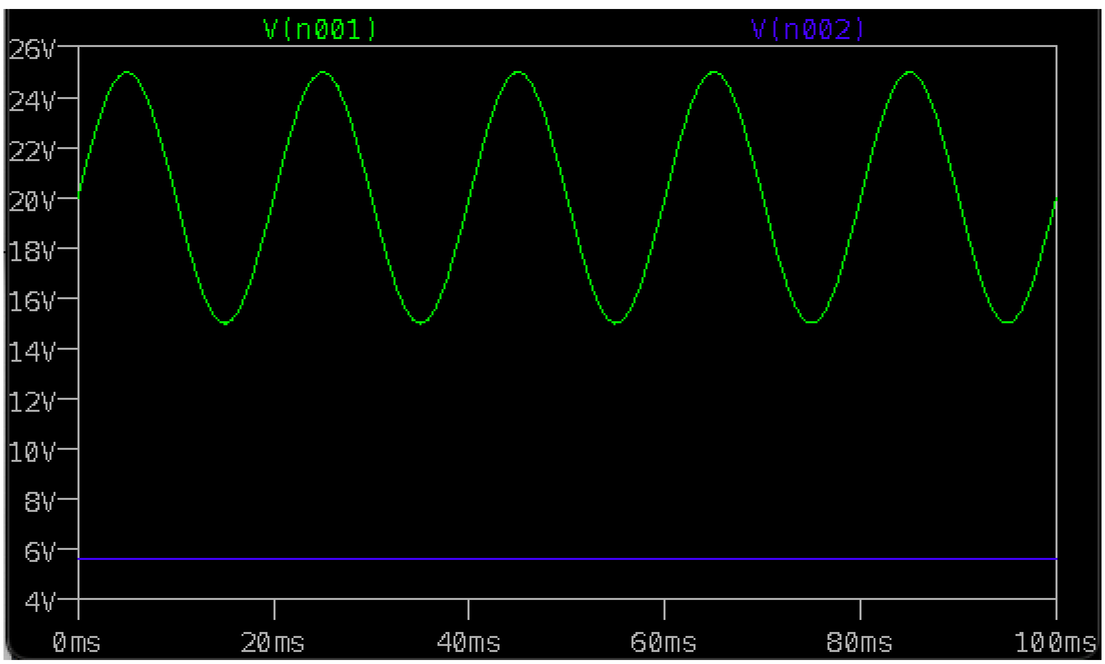
Placing a capacitor in parallel with the load decreases the circuit's overall impedance, resulting in an increase in the total current flow. The $C \cdot R_L$C \cdot R_L ratio plays a vital role in determining the circuit's smoothing effect. A higher $C \cdot R_L$C \cdot R_L product enables the capacitor to store more charge and discharge more gradually, producing a steadier and higher-quality DC output. This reduces ripple and ensures a more consistent DC voltage across the load.

Problem 5 : Zener Diode

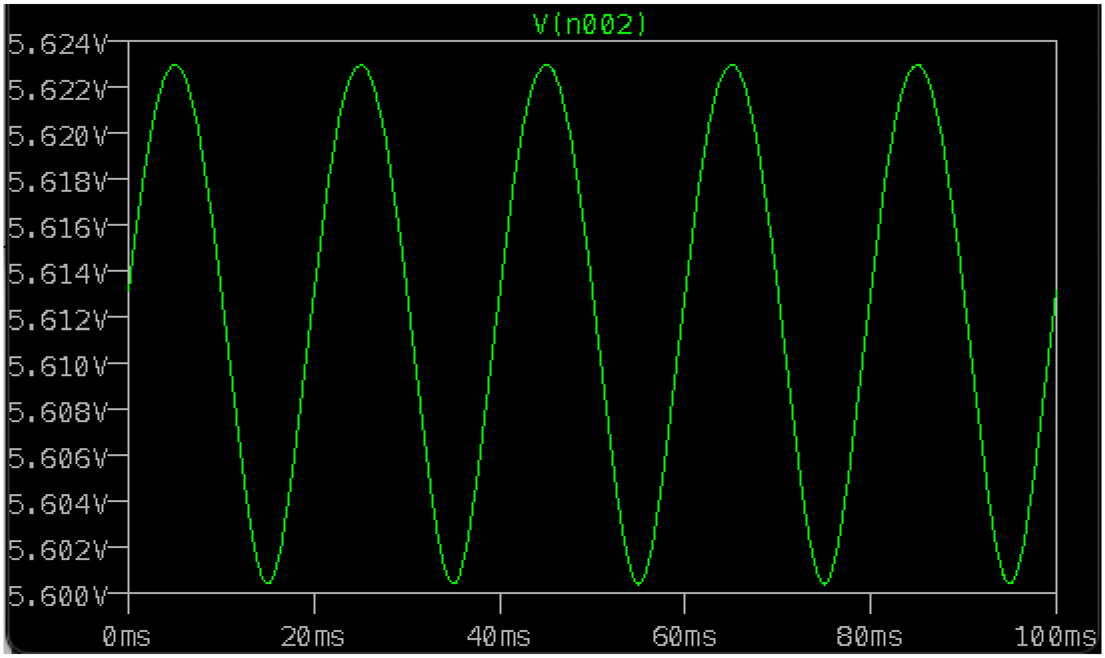
Below is the circuit Implementation in LTSpice:



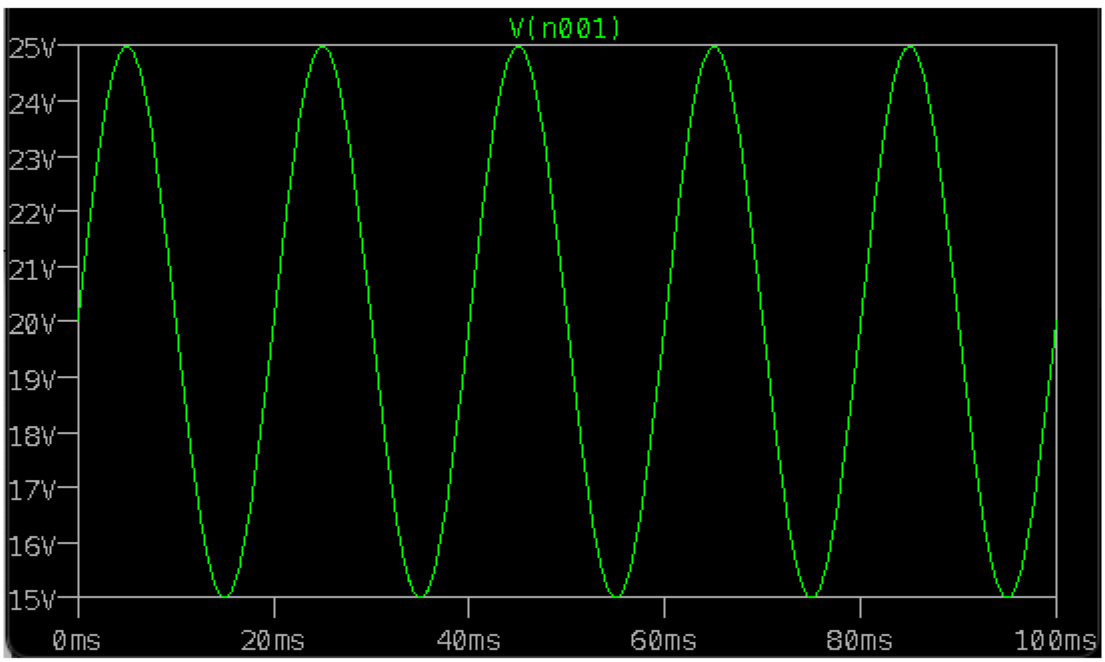
Below is the plot of the input voltage (DC + AC voltage) and the output voltage across the load resistor



Below is the plot of the output voltage across the load resistor:



Below is the plot of the input voltage (DC + AC voltage):



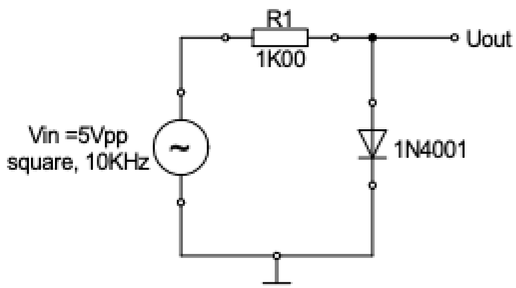
The circuit operates as a voltage regulator by incorporating a Zener diode in parallel with the load resistor. When the load voltage rises, the Zener diode conducts more current, reducing the current through the load resistor and increasing the voltage drop across it. This action stabilizes the output voltage at a constant value (e.g., 6V). Conversely, if the ~~load~~ voltage decreases, the Zener diode conducts less current, lowering ~~the voltage drop across the load~~ resistor and maintaining the desired voltage across the load. This regulation ensures a stable output voltage, even with fluctuations in input voltage or load current. ?

the load resistance increases/ decreases.
voltage should be stable over the load
there is a current divider between z-diode and load..

EXECUTION

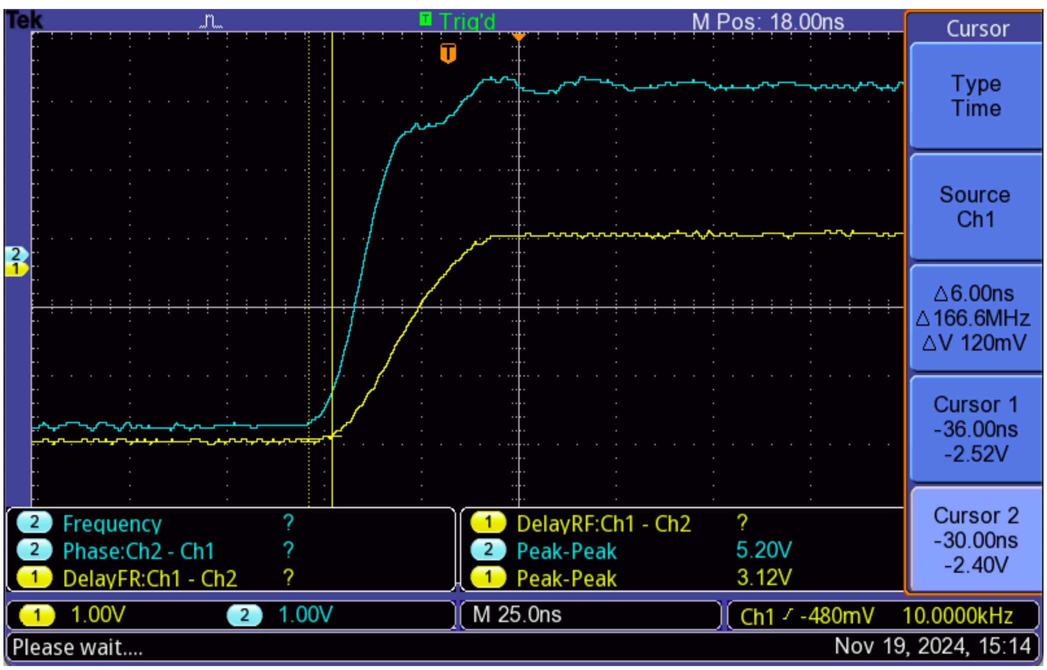
Problem 1 : Diode Switching Characteristic

The goal of this part of the experiment was to investigate the reverse/forward and forward/reverse transition behavior of a rectifier and a signal diode. The following circuit was assembled on the breadboard:

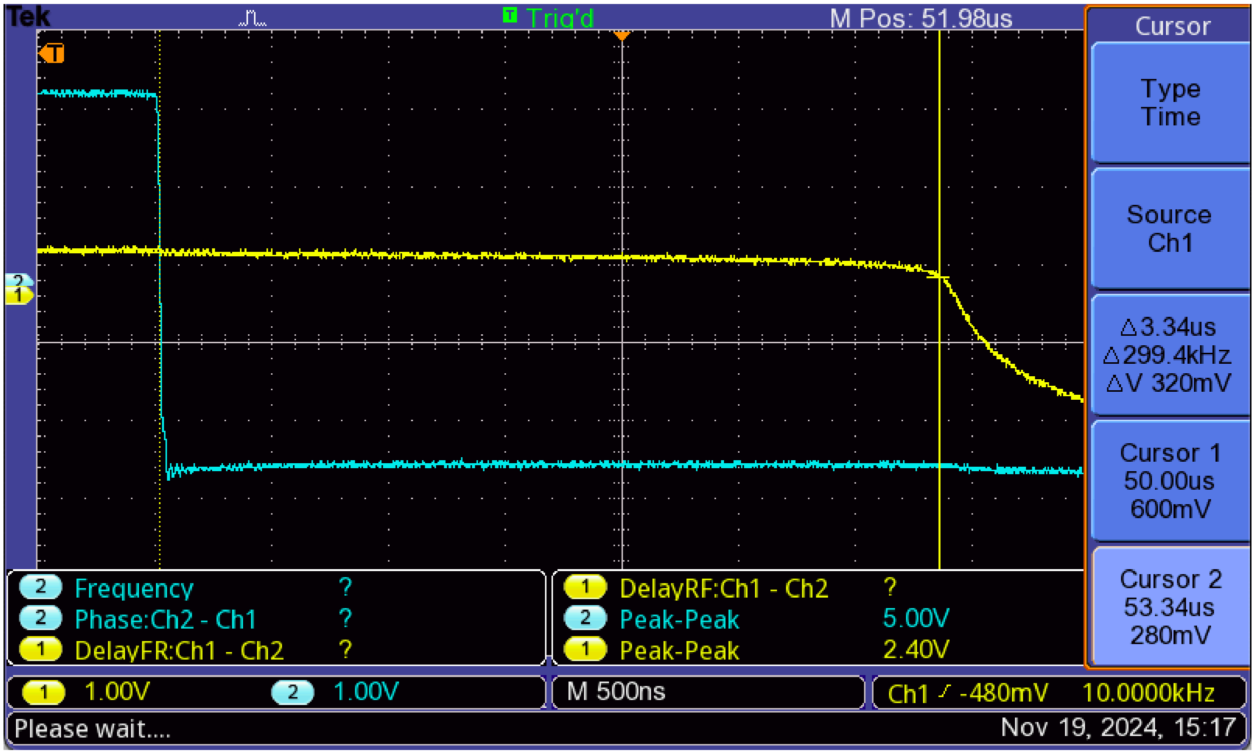


A delay time was observed during the reverse-to-forward transition, and a storage time occurred after the forward-to-reverse transition. The values of the delay time (*td*) and storage time (*ts*) are depicted in the graphs below:

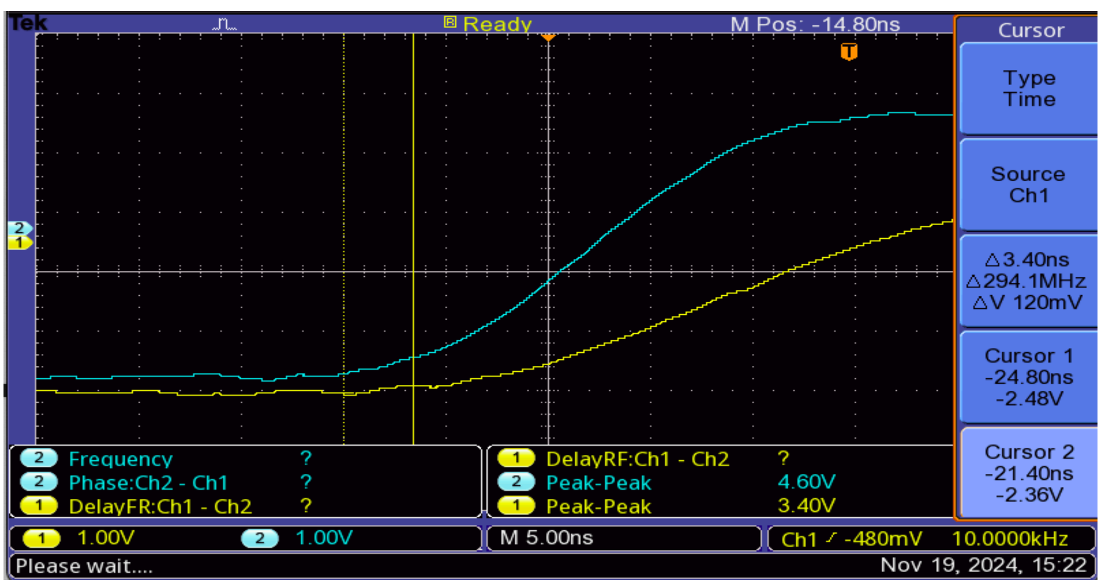
Below is a hard copy showing t_d of the 1N4001 rectifier diode:



Below is a hard copy showing t_s of the 1N4001 rectifier diode:



Replacing the 1N4001 rectifier diode by a 1N4148 signal diode and repeating the same process as before:
Below is a hard copy showing t_d of the 1N4148 rectifier diode:

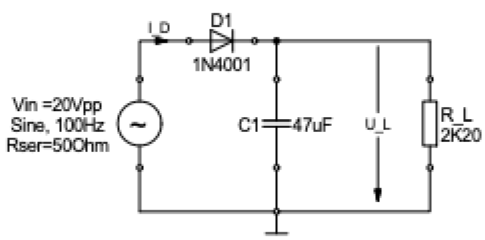


Below is a hard copy showing t_s of the 1N4148 rectifier diode:

Problem 2 : Rectifier

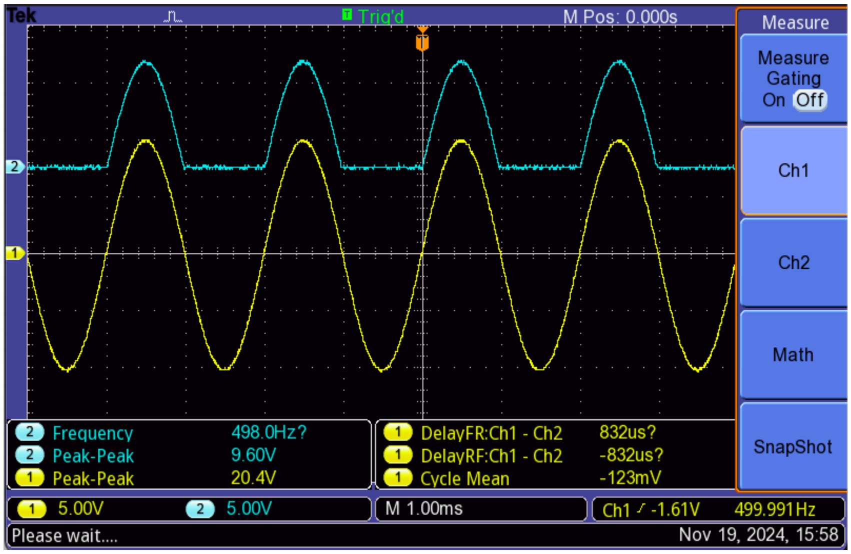
Half-wave rectifier.

The following half rectifier circuit was built on the breadboard:

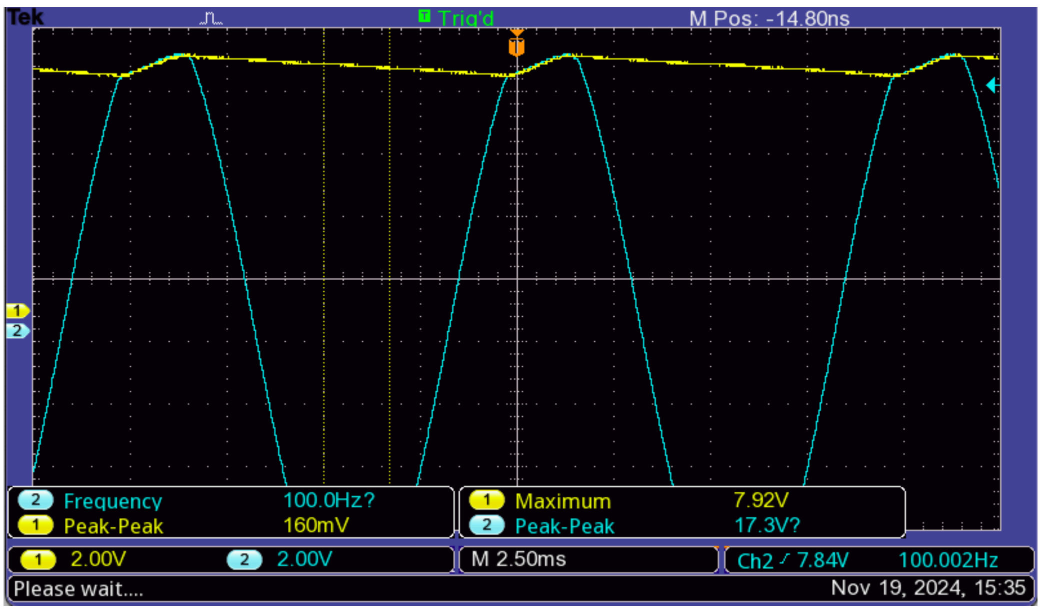


We began by removing C1 from the circuit above and measuring the peak voltage of Vin and VL.

Below is a hardcopy showing both signals together with their measurements.

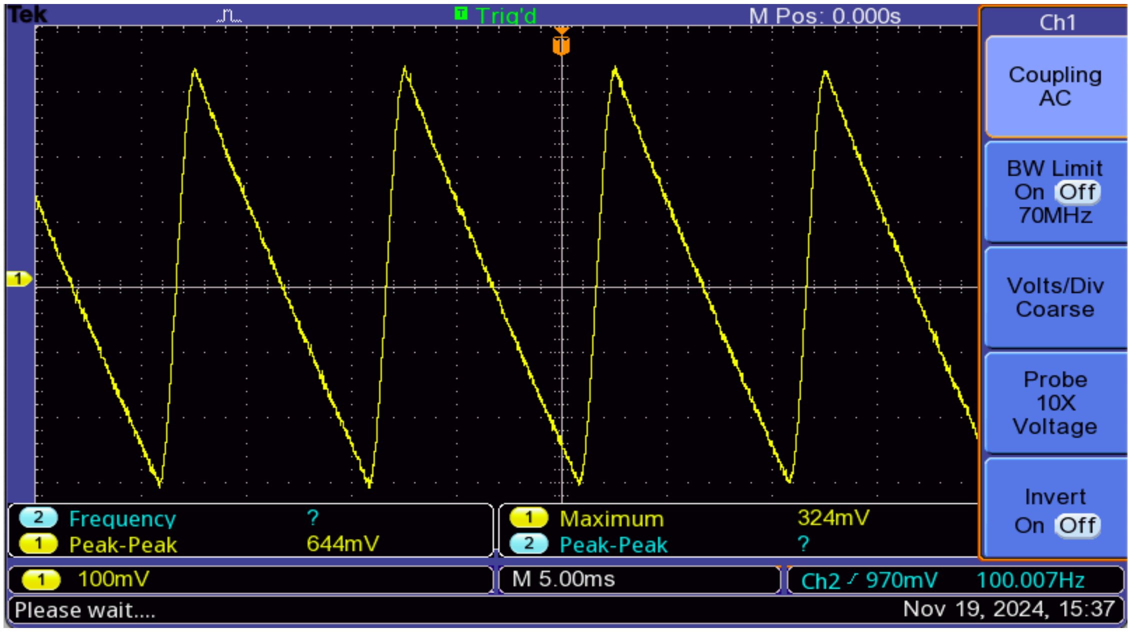


We then inserted C1 back into the circuit above and measured the peak voltage of Vin and VL. Below is a hardcopy showing both signals together with their measurements:



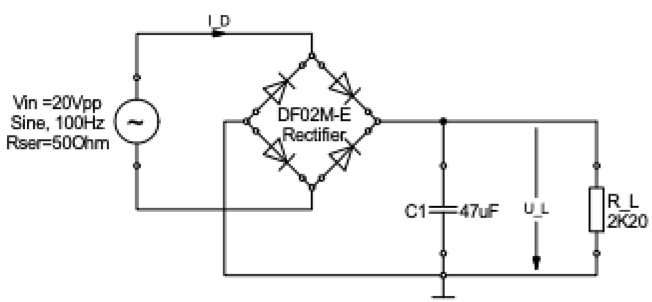
We then measured the peak-to-peak voltage of the ripple using the oscilloscope, zooming into the ripple voltage at VL. The AC-Coupling setting in the channel menu was applied. A hard copy of the signal, along with the measurements, was captured, and the results are presented below.

Below is a hardcopy showing ripple voltage and measurement of peak to peak:



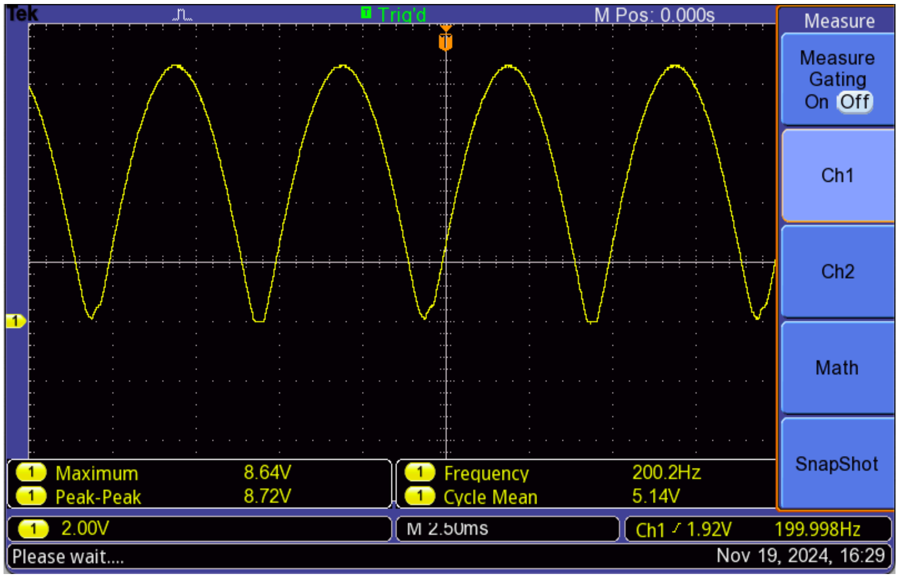
Full-wave rectifier.

The following full rectifier circuit was built on the breadboard

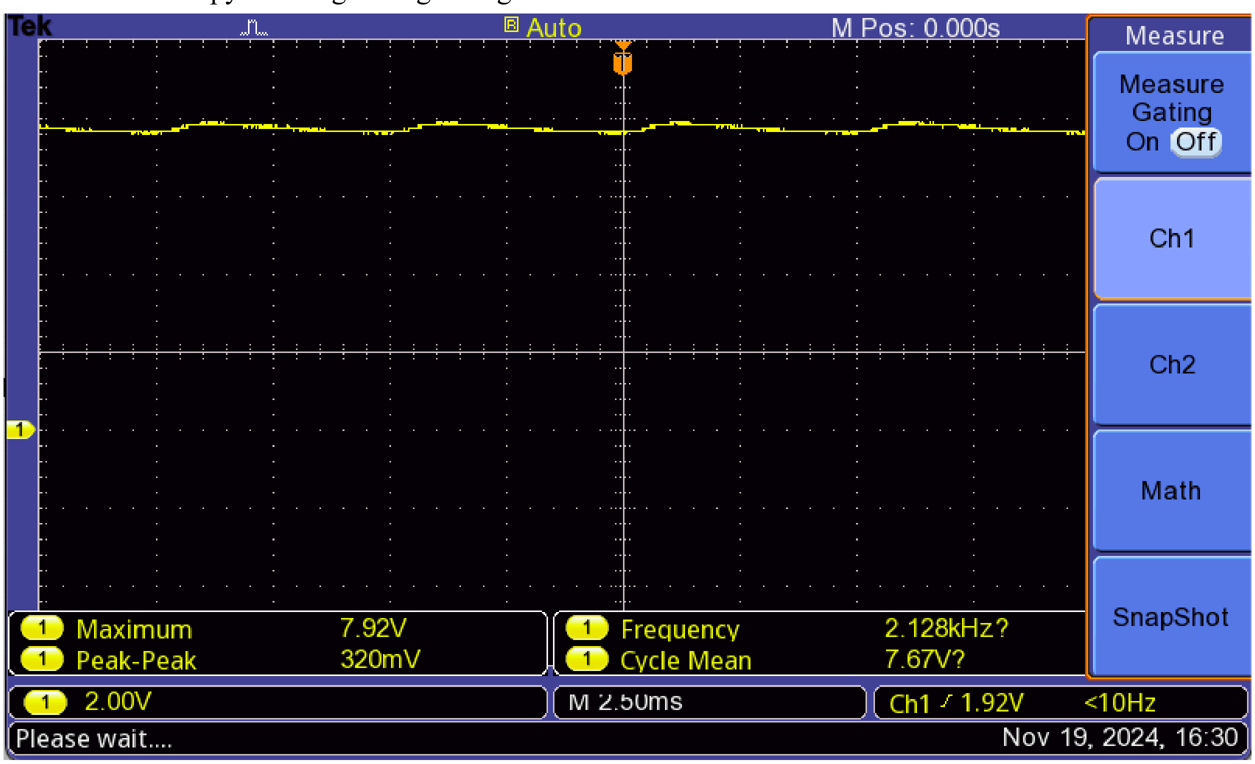


In this part of the experiment we began by removing C1 from the circuit above and measuring the peak voltage of VL.

Below is a hardcopy showing the signal together with its measurements:

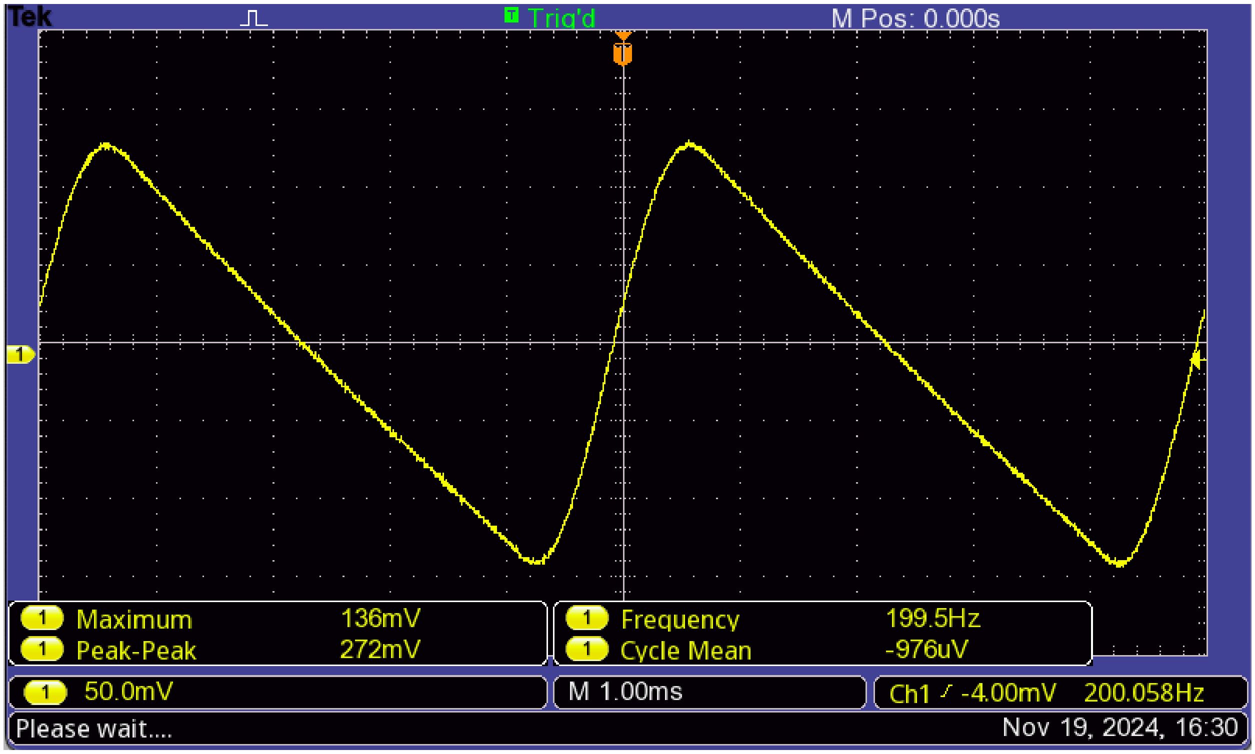


We then inserted C1 back into the circuit above and measured the peak voltage of VL.
Below is a hardcopy showing the signal together with its measurements:



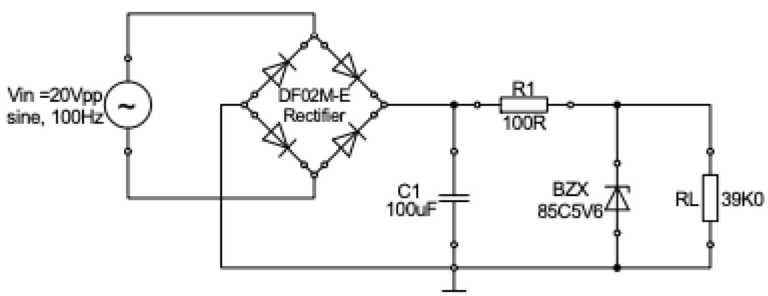
We then measured the peak-to-peak voltage of the ripple using the oscilloscope, zooming into the ripple voltage at VL. The AC-Coupling setting in the channel menu was applied. A hard copy of the signal, along with the measurements, was captured, and the results are presented below.

Below is a hardcopy showing ripple voltage and measurement of peak to peak:



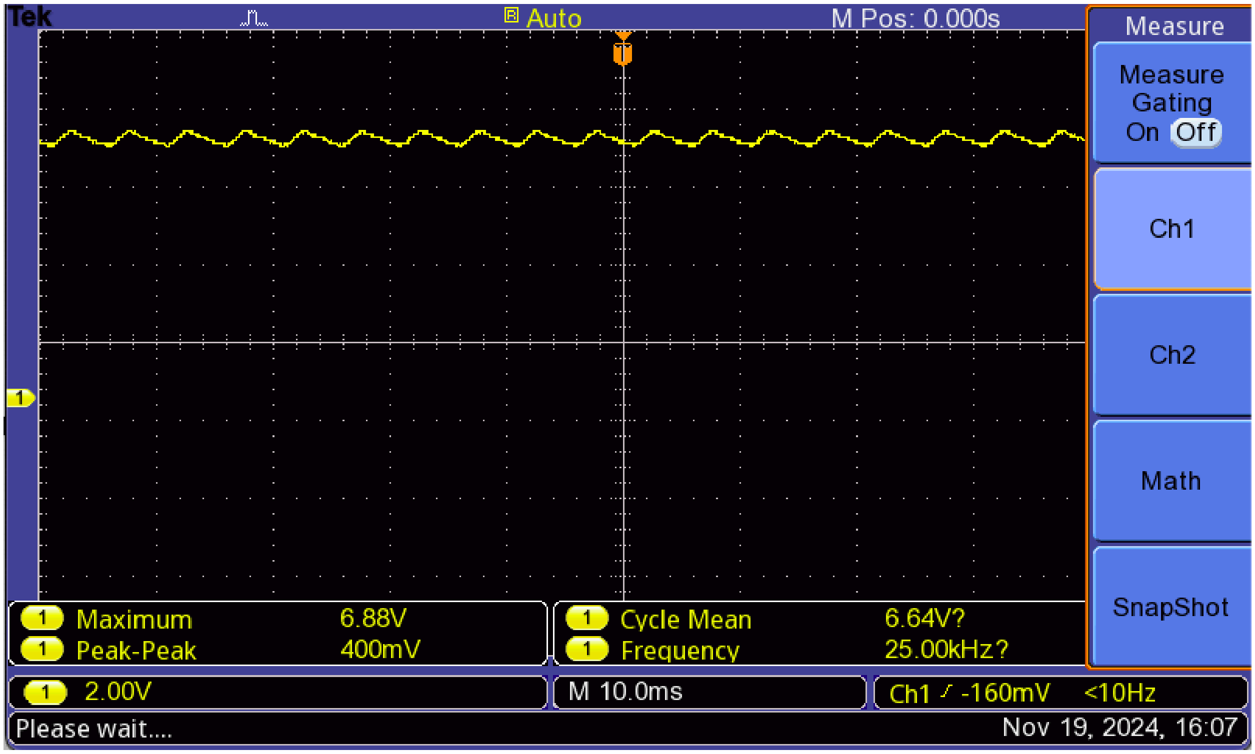
Problem 3 : Zener diode

The following circuit was built on the breadboard

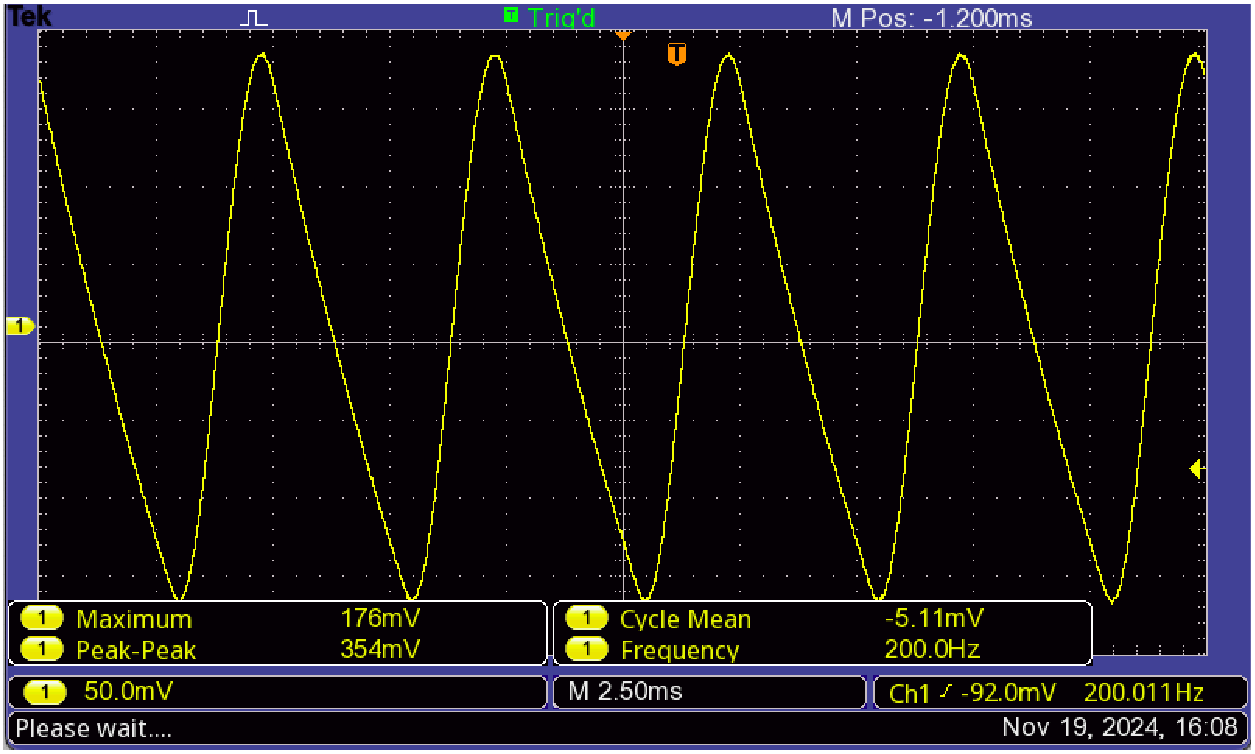


In this part of the experiment we measured the DC and ripple voltages at C1, as well as the output DC voltage and ripple voltage across the load resistor RL. Hard copies of the signals and their corresponding measurements were recorded.

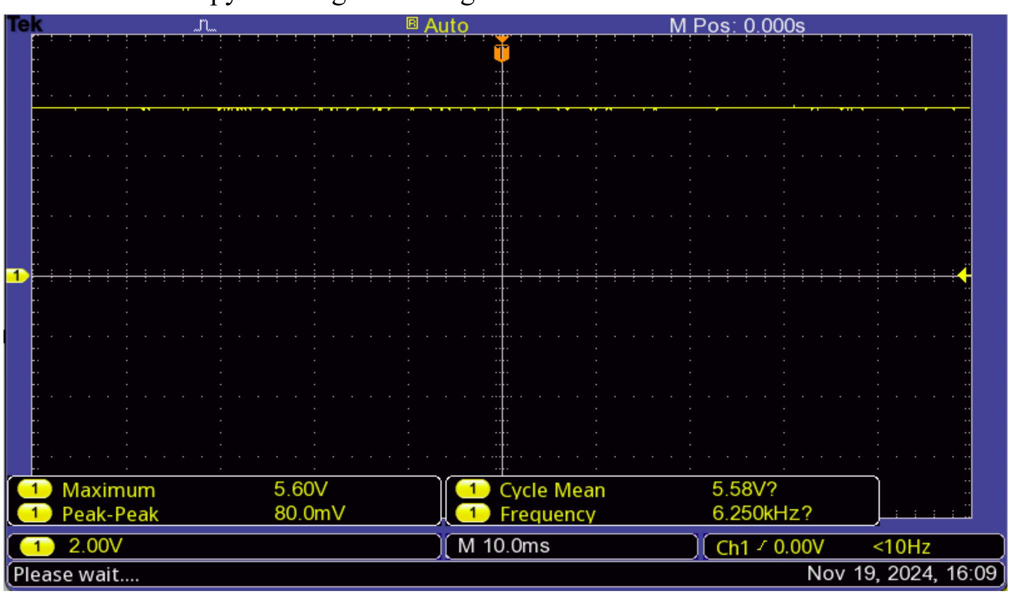
Below is a hardcopy showing DC voltage at C1:



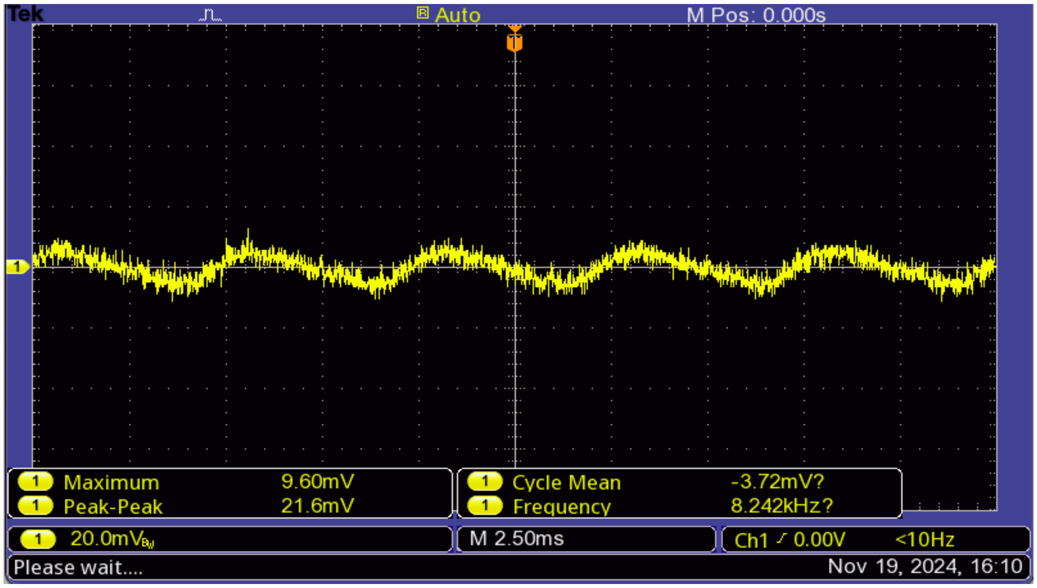
Below is a hardcopy showing ripple voltage at C1:



Below is a hardcopy showing DC voltage at RL:

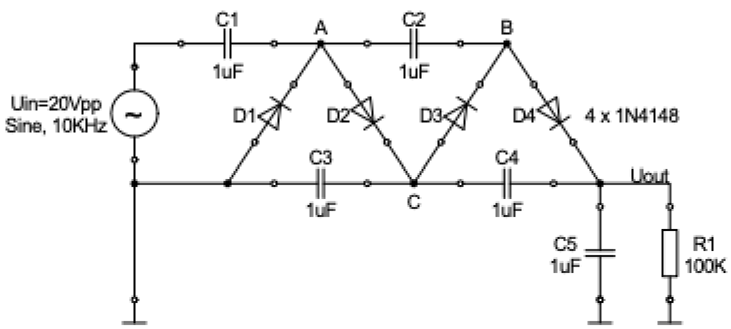


Below is a hardcopy showing ripple voltage at RL:

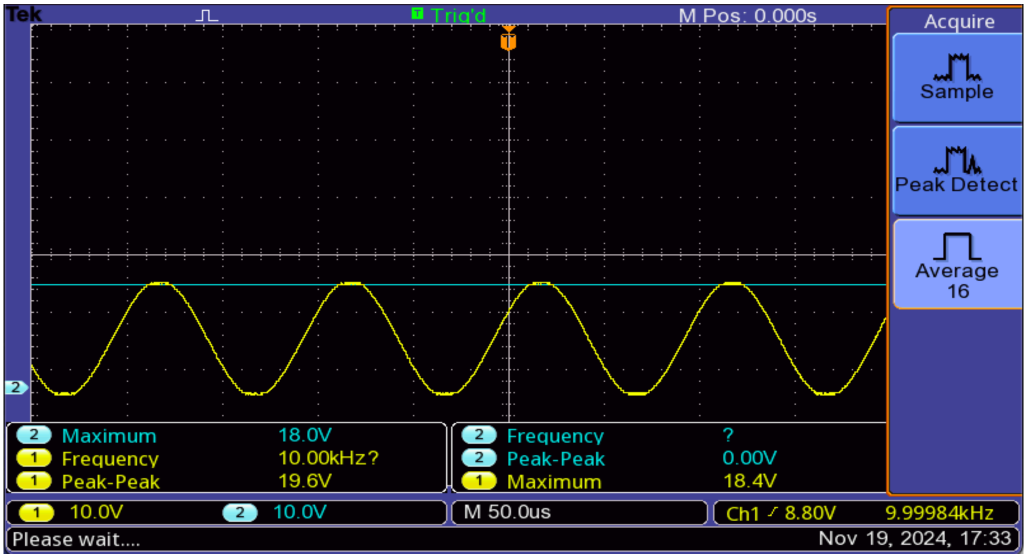


Problem 4 : Voltage Multiplier

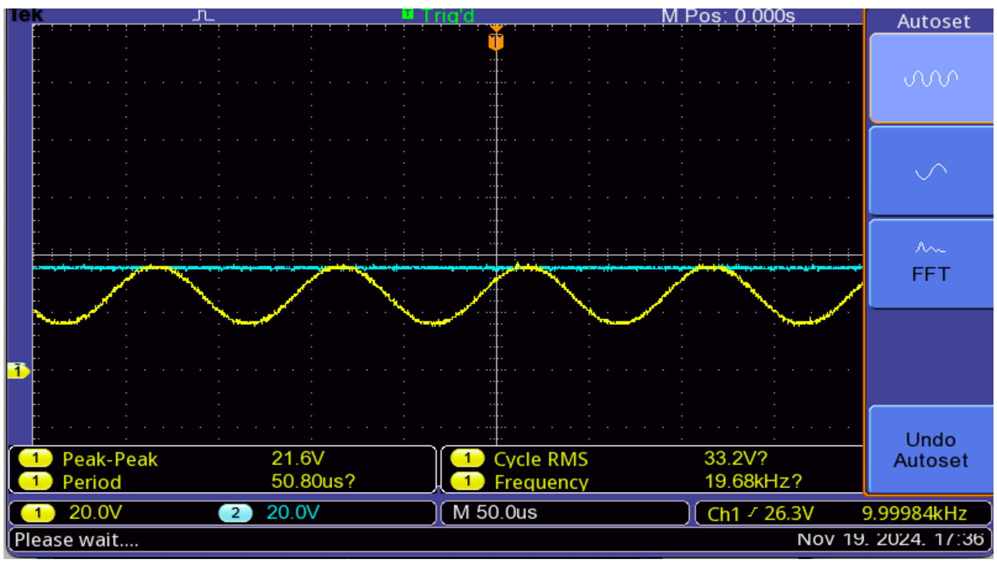
The following circuit was built on the breadboard



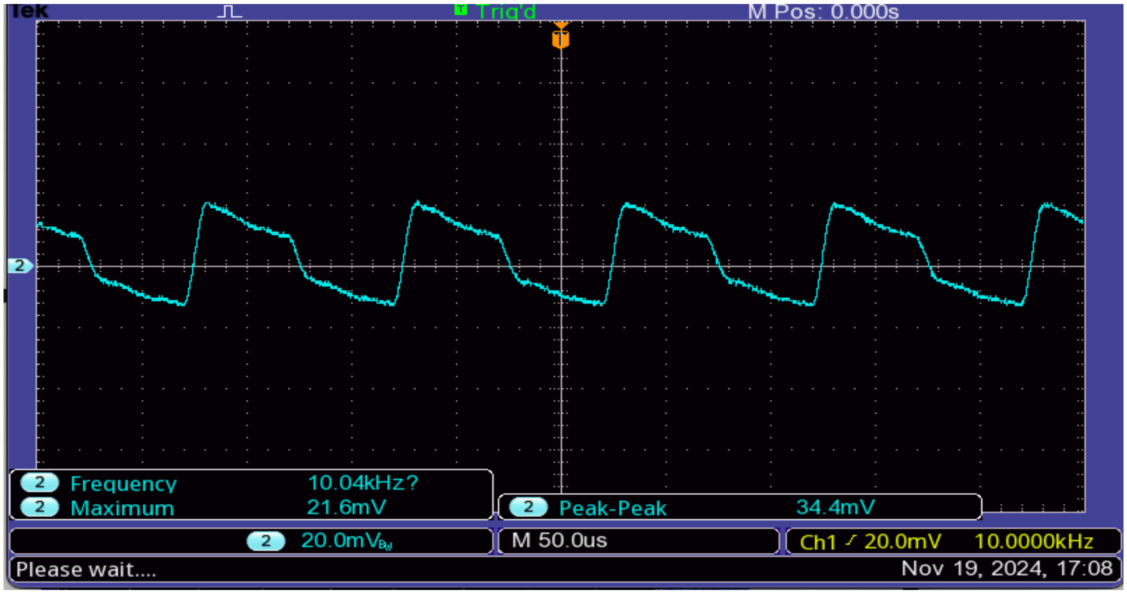
In this part of the experiment, we first used the oscilloscope to measure the voltage at the given points. Below is a hardcopy showing the voltage at A and C:



Below is a hardcopy showing the voltage at B and U*out*:



Below is a hardcopy showing the ripple voltage at U*out*:



We then measured the voltage at C and U*out* using the multimeter..

Voltage at C (V)	Voltage at U*out* (V)
18.952	37.762

EVALUATION

Problem 1 : Diode Switching Characteristic

1. Compare the two storage times. What is the reason why the diodes needs that long time to switch off?
2. What are the consequences for using these diodes in different applications? Think of the AM demodulation experiment when using several 100KHZ!

Diode Type	t_s	t_d
1N4001	3.34μs	6.00ns
1N4148	15.6ns	3.40ns

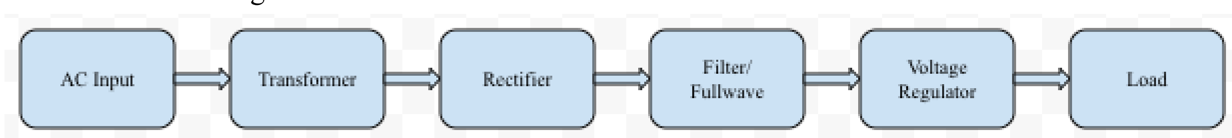
The properties and types of diodes play a significant role in their switching behavior. One critical factor is the reverse recovery time, which measures the time a diode takes to switch from a forward-biased to a reverse-biased state. Fast recovery diodes are specifically designed to minimize this time, while standard diodes typically exhibit longer reverse recovery times. For instance, experimental results show that the 1N4001 diode, suitable for low-frequency applications, has slower switching characteristics due to its longer reverse recovery time, which is common in diodes handling higher currents and voltages. Its reverse recovery time ranges between 2 and 4 microseconds, as indicated in the table above. In contrast, the 1N4148 diode, designed for high-frequency applications, demonstrates significantly faster switching behavior.

The longer switching time, especially the reverse recovery time, is attributed to the process of clearing charge carriers (electrons and holes) from the diode's junction when transitioning from a forward-biased to a reverse-biased state.

The 1N4001 diode, with its slower switching characteristics, is less suitable for high-frequency applications. At higher frequencies, its reverse recovery time, typically in the microsecond range, can cause signal distortion or degrade signal quality. Conversely, the 1N4148 diode performs exceptionally well in high-frequency applications but may be excessive for very low-frequency signals. However, compared to the 1N4001, the 1N4148 may struggle with handling higher voltages, which could also lead to signal distortion or loss of quality.

Problem 2 : Rectifier

1. Draw a schematic diagram showing the building blocks of a DC power supply and explain the needs of each building block.



The process starts with an alternating current (AC) supplied by the source, which is directed to a transformer. The transformer adjusts the AC voltage to the desired level by modifying its turns ratio. The transformer's output then serves as the input to the rectifier circuit. Within the rectifier, the AC voltage is converted into a pulsating direct current (DC) voltage, typically achieved using a bridge rectifier or a full-wave rectifier.

The rectified voltage, however, contains significant ripple, which is undesirable. To produce a smooth, ripple-free DC output, a filter is used. As shown in the diagrams, a capacitor is commonly employed to reduce the ripple in the DC current. Following the filtering stage, a voltage regulator ensures the output voltage remains stable, regardless of variations in input voltage or load conditions, providing a consistent DC output that meets the required specifications.

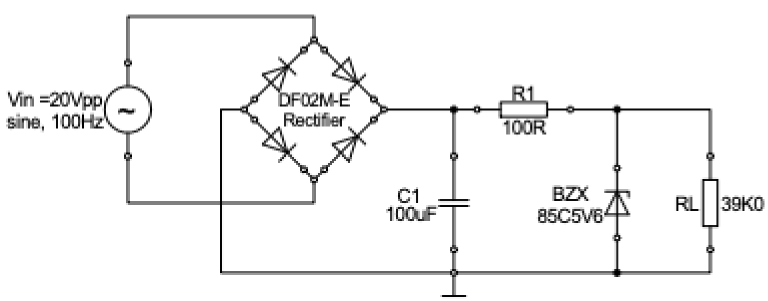
Finally, the regulated DC output is delivered to the load. Additional filtering or protection components may be included to enhance the quality and safety of the output voltage.

2. Compare the measured values of the peak-to-peak ripple voltages with the prelab values from simulation and calculation. Discuss the differences.

	Calculated Value (mV)	Simulated Value (mV)	Measured Value (mV)
Half Wave	592	613.834	636
Full Wave	296	263.3	272

The differences between the measured, simulated, and calculated values can be attributed to several factors:
- The precision limitations of LTSpice software and the approximations in the calculation equations.
- Experimental factors such as component tolerances (e.g., capacitor or resistor values differing slightly from their nominal values), breadboard wiring imperfections, and external noise that may have affected the measured values.

Problem 3 : Zener diode



1. Calculate the approximate current through the Z-diode!
Let the current flowing through R1 be IR, through the diode be IZ and through RL be IRL.
$I_R = I_Z + I_{RL}$

Since BZX and RL are parallel to each other, they share the same voltage. The voltage across RL=5.6V was measured in LTSpice and remained constant, therefore the voltage at BZX is also 5.6V.
$I_{RL} = \frac{5.6}{39k0}$

$$I_{RL} = 1.4359 \times 10^{-4}A$$

To get IR, we need the voltage at the capacitor (VC1), which we already have from the oscilloscope values.

$$I_R = \frac{V_{C1} - V_z}{R_1}$$

$$I_R = \frac{6.80 - 5.60}{100}$$

$$I_R = 1.2 \times 10^{-2}A$$

$$I_Z = I_R - I_{RL}$$

$$I_Z = (1.2 \times 10^{-2}) - (1.4359 \times 10^{-4})$$

$$I_Z = 1.186 \times 10^{-2}A$$

Problem 4 : Voltage Multiplier

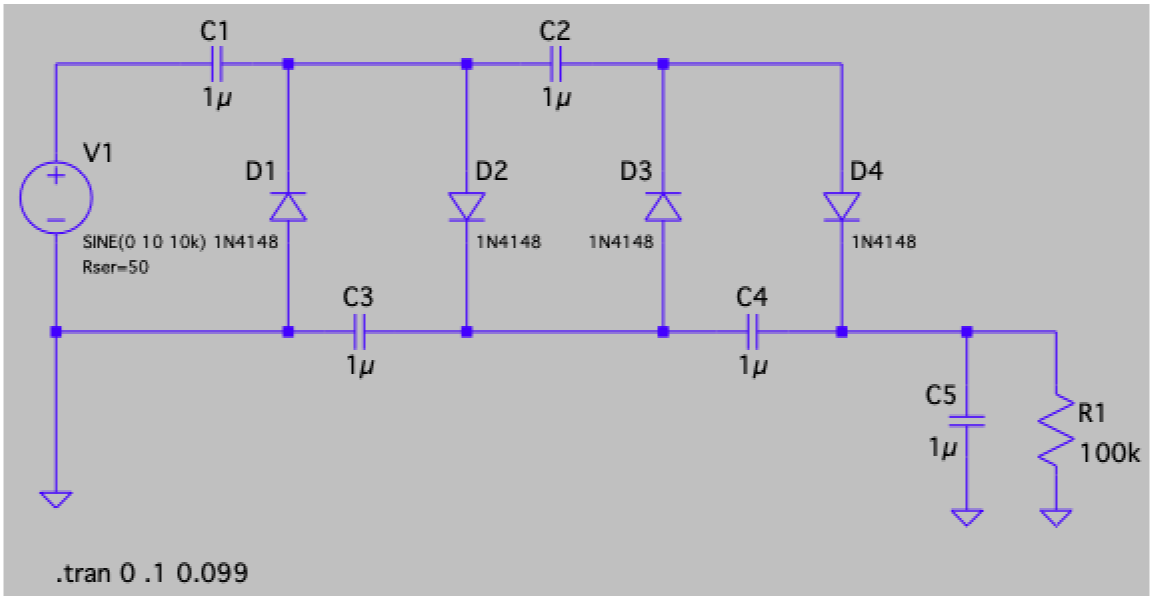
1. From which circuits in the Diode Application part of the handout this circuit is composed?
2. Explain the function.
3. What is the multiplication factor between input amplitude and output voltage? Compare the measured to the ideal one. Why is there a difference?
4. For which maximum voltage each element has to be selected?
5. What happens to Uout if the frequency of the input voltage is reduced to 100 Hz (Voltage & ripple!)? Explain in words!!! Show a prove of your statement using PSpice!

The setup consists of a Rectifier and Clamping Circuit. The rectifier diode eliminates the negative cycles from the input AC voltage, enabling the signal to be smoothed and converted into DC voltage. When a clamper circuit is incorporated, it shifts the entire waveform by introducing a DC voltage level. As a result, the waveform's shape remains unchanged, but its lowest peak is clamped at 0, effectively shifting the entire waveform upward. This combination of rectification and clamping produces a more stable and usable DC voltage output.

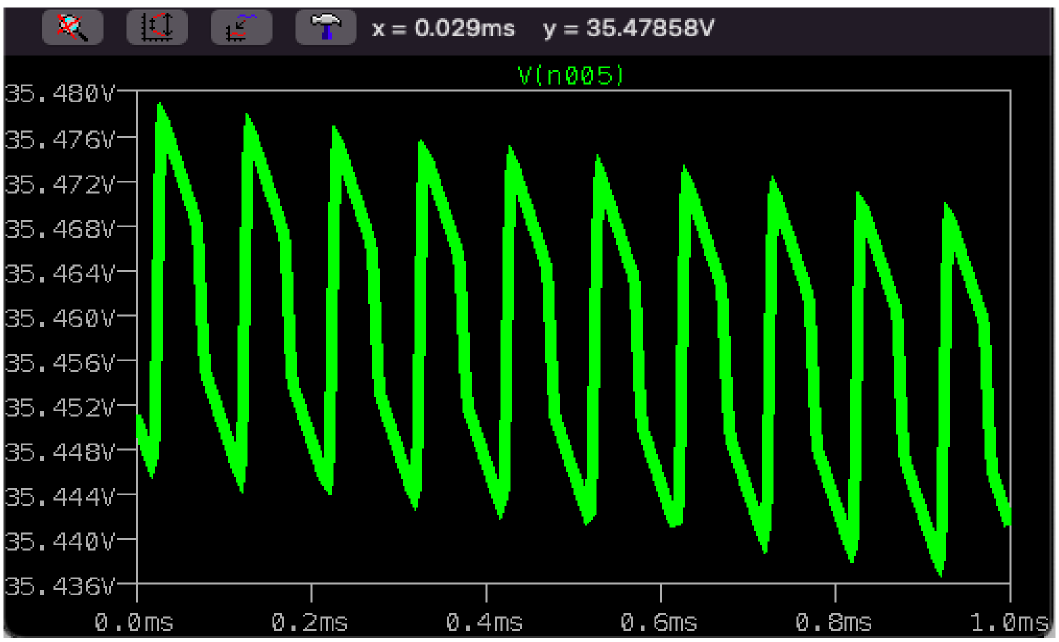
At point C, the expected DC voltage is 20V, which is double the input voltage, indicating a multiplication factor of two between the input amplitude and the output voltage. Consequently, the anticipated DC voltage at Vout is 40V, representing a fourfold increase in the input amplitude.

why it's not 4x in real?

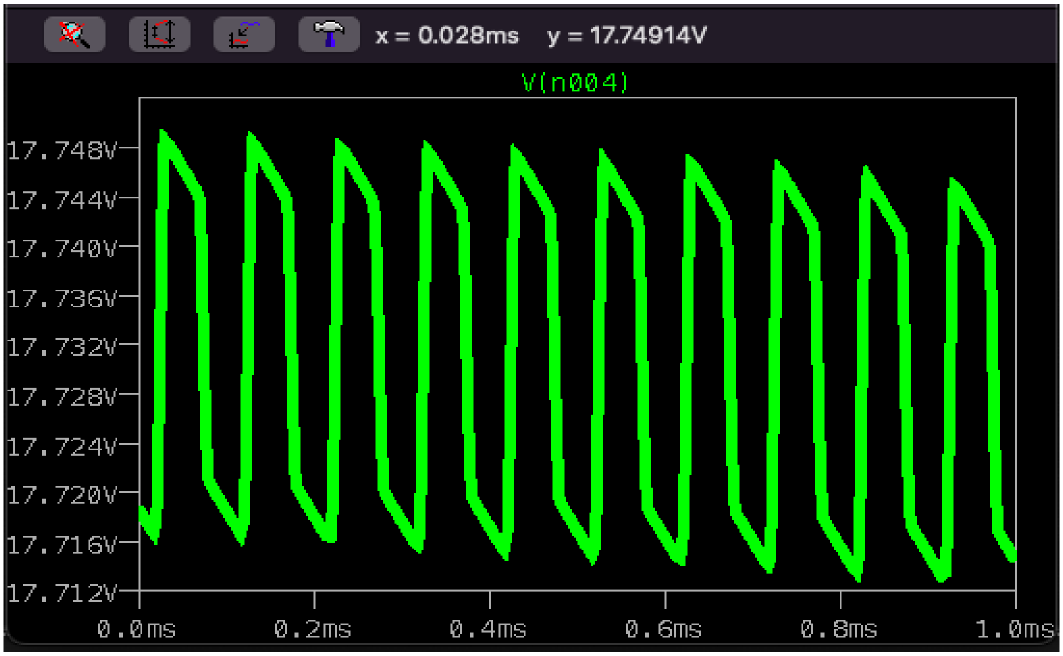
Below is a picture showing implemented circuit in LTSpice with 10kHz frequency:



Below is the picture showing the plot and voltage output value at Uout:



Below is the picture showing the plot and voltage output value at C:

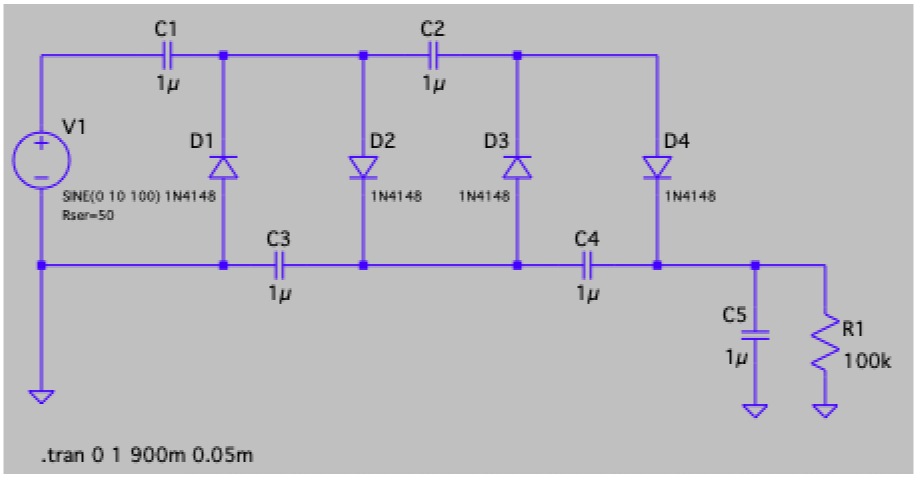


	Voltage at C (V)	Voltage at Uout (V)
Oscilloscope	19.2	34.4
TENMA	18.952	37.762
Theory	2.40	7.60
Simulation	17.74914	35.47858
Maximum	18.4	36.4

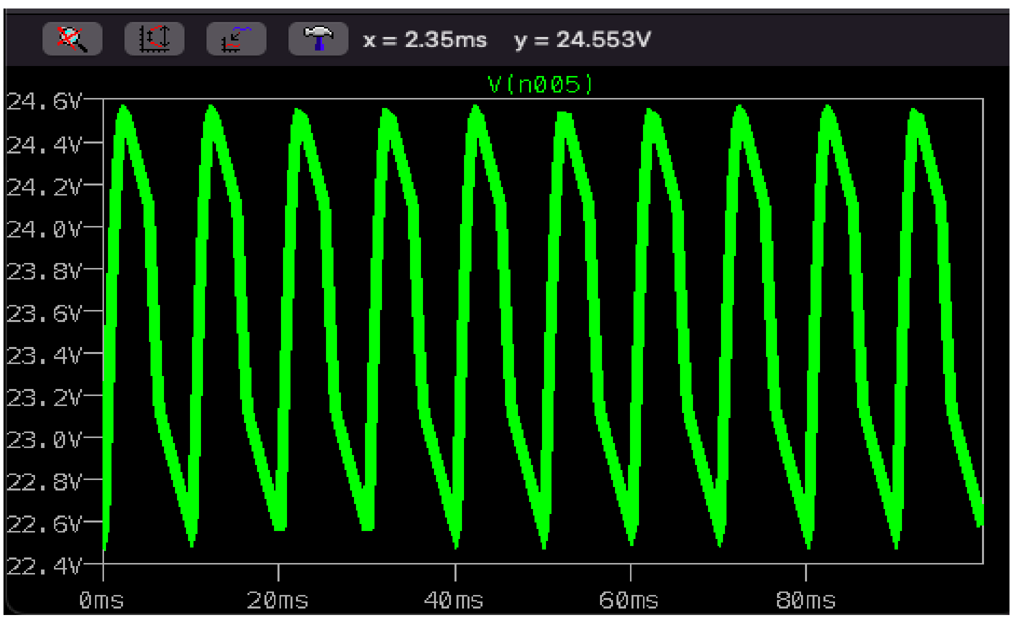
The experimental values obtained from the Tenma device and the LTSpice simulation show excellent agreement, with only minor differences attributed to the varying resolutions of the instruments. LTSpice, however, offers higher resolution. The multiplication factors closely align with the ideal values. For diodes, critical voltage ratings include the maximum forward voltage (Vf), peak inverse voltage (PIV) or maximum reverse voltage (VRR), and maximum DC reverse voltage (VR), which are essential for selecting diodes capable of reliable performance without damage.

In this cascade, the maximum peak voltage at each element was determined from the hardcopy data. The capacitors experienced a maximum peak voltage of approximately **18.4 V**, while the output voltage peaked at **36.4 V**. These results were consistent between the simulation and experimental measurements, providing a reliable basis for selecting diodes with voltage ratings higher than these values to ensure safe operation and prevent breakdown.

Below is a picture showing implemented circuit in LTSpice with 100Hz frequency:



Below is the picture showing the plot and voltage output value at Uout at 100Hz:



When the input voltage frequency is reduced from 100 kHz to 100 Hz, the voltage multiplier circuit has less opportunity to charge and discharge effectively. This leads to a lower output voltage compared to higher input frequencies. Furthermore, at lower frequencies, the ripple becomes more pronounced because the capacitors have longer intervals between charging and discharging cycles, resulting in a less smooth output. For instance, at 100 kHz, the output waveform appears as a smooth, stable line at the clamped section. However, when the frequency drops to 100 Hz, noticeable ripples emerge, causing the output to become less smooth and more irregular.

CONCLUSION

The performance of diodes, including their reverse recovery time and frequency response, plays a crucial role in influencing signal delay and storage time. During the lab experiment, it was observed that increasing the frequency in the Zener diode circuit resulted in more pronounced ripples due to the reduced time for the capacitors to charge and discharge effectively. The measured and calculated values were in close agreement, supporting the theoretical assumptions of the experiment. The slight discrepancies can be attributed to the oscilloscope's resolution limitations and the inherent properties of the components used. Furthermore, the experiment highlighted that LTSpice offers higher resolution and greater accuracy compared to the oscilloscope.

REFERENCES

1. Uwe Pagel & Prof. Dr. Ing. Mojtaba Joodaki, Constructor University Bremen
2. CO-526-B Electronics Lab Manual