

Jacobs University Bremen

**Natural Science Laboratory
Electronics Lab**

Spring Semester 2019

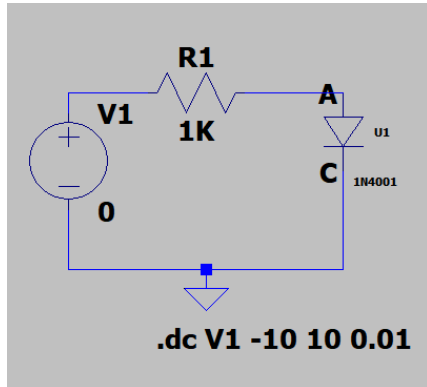
Lab Experiment 2 – Diodes

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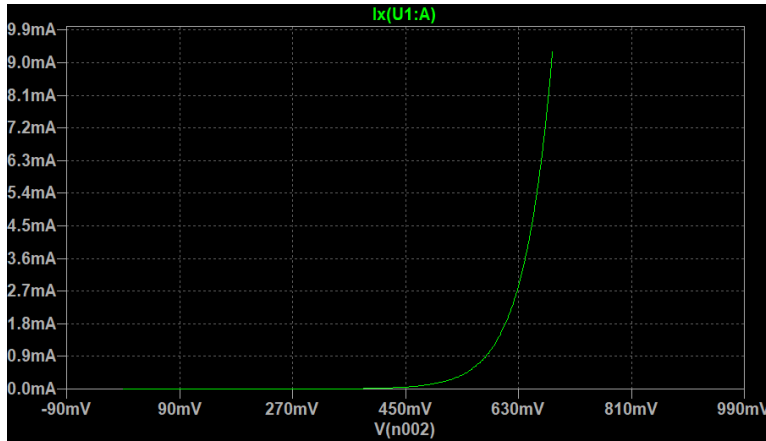
Experiment conducted by	: Hayoung Kim, Mohammed Mahfoud
Place of execution	: Research 1 EE Lab 55
Date of execution	: March. 26, 2019

1 Introduction - Prelab

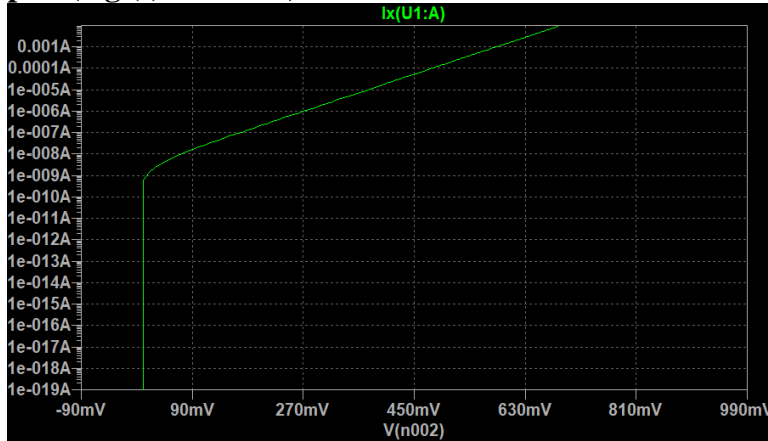
1.1 Problem 1



(1) Plot the forward diode current I versus the diode voltage V using a linear scale.



2. Plot the forward diode current I versus the diode voltage V using a semi log plot ($\log(I)$ versus V).



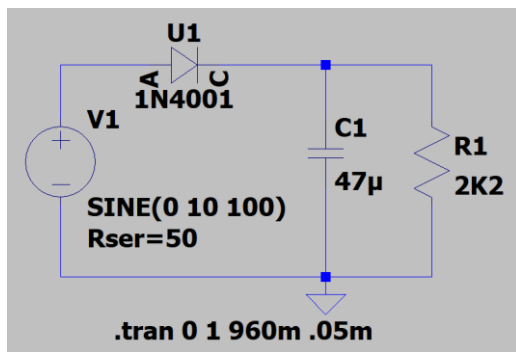
3. Extract the values of ideality or diode factor, n , and the saturation current I_s from the graph. See Eq. (4.3). The voltage V_T can be assumed to be 26mV

$I = I_s(e^{\frac{V}{nV_T}} - 1)$ Two points on the log graph was chosen and plugged into the equation to get I_s and n . Points used: $(V, I) = (0.450, 54.0\mu), (0.611, 1.867m)$

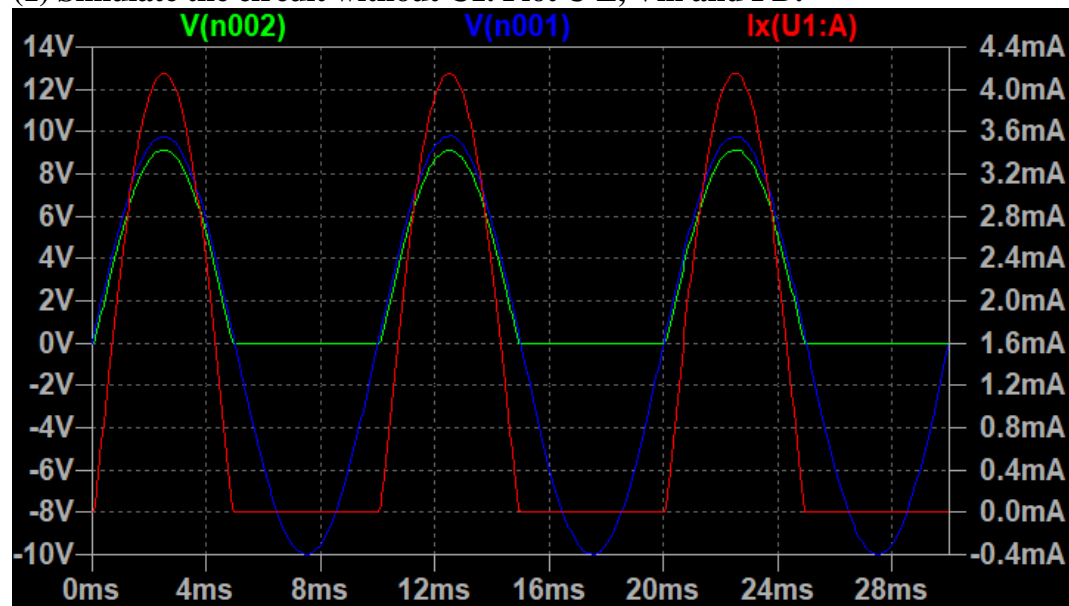
$I_s = 2.201nA$

$n = 1.712$

1.2 Problem 2 Halfwave rectifier



(1) Simulate the circuit without C1. Plot U_L , V_{in} and I_D .



$$V(n001) = V_{in}$$

$$V(n002) = U_L$$

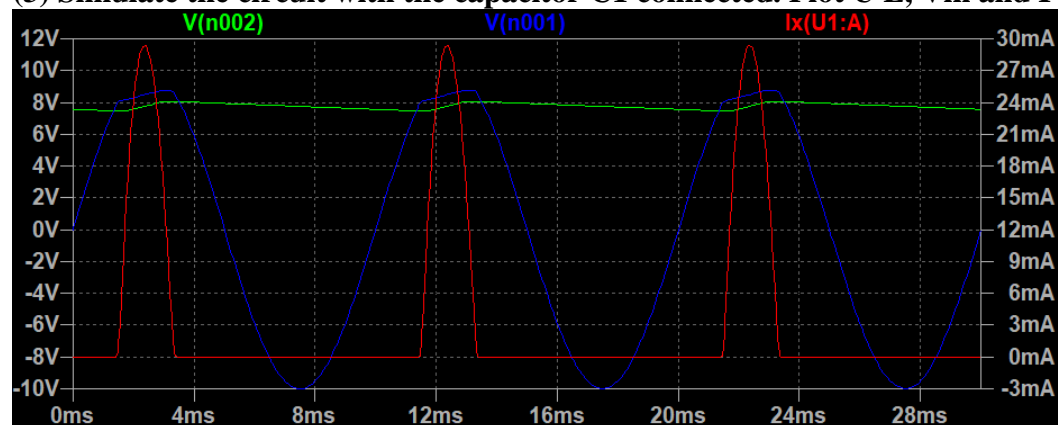
$$I_x = I_D$$

(2) Measure the peak voltage at R_L and the peak current I_D . (Use the cursors from the LTSpice display)

$$U_L = 9.13 \text{ V}$$

$$I_D = 4.149 \text{ mA}$$

(3) Simulate the circuit with the capacitor C1 connected. Plot U_L , V_{in} and I_D .



$$V(n001) = V_{in}$$

$$V(n002) = U_L$$

$$I_x = I_D$$

4. Measure the peak voltage and the peak current.

$$U_L = 8.07 \text{ V}$$

$$I_D = 29.40 \text{ mA}$$

5. Measure the ripple of the voltage at the load resistor. Use the formula from the handout to calculate the ripple value. Compare!

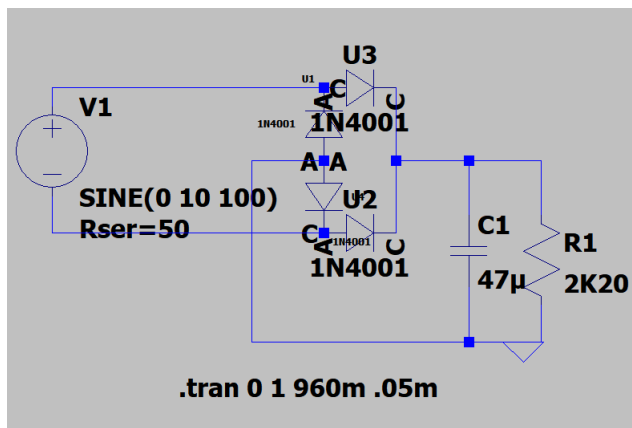
Ripple without capacitor: 9.14 V

Ripple with capacitor: 0.62V

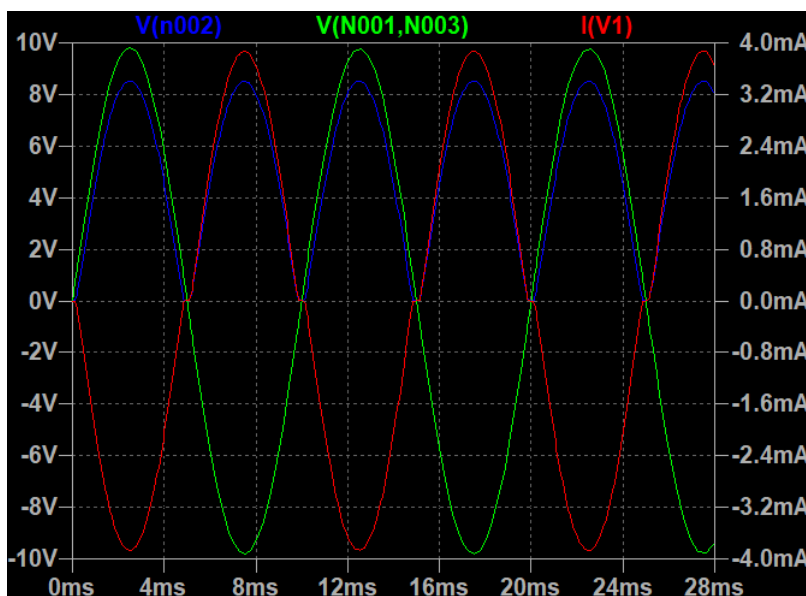
Theoretical ripple voltage

$$V_r = \frac{V_p}{fCR_L} \left(1 - \sqrt[4]{\frac{R_i}{R_L}}\right) = \frac{8.07}{100 \cdot 47 \cdot 10^{-6} \cdot 2200} \left(1 - \sqrt[4]{\frac{50}{2200}}\right) = 0.4774 \text{ V}$$

1.3 Problem 3 Full wave rectifier



(1) Simulate the circuit without C1. Plot U_L , V_{in} and I_D .



$$U_L = V(002)$$

$$V_{in} = V(N001, N003)$$

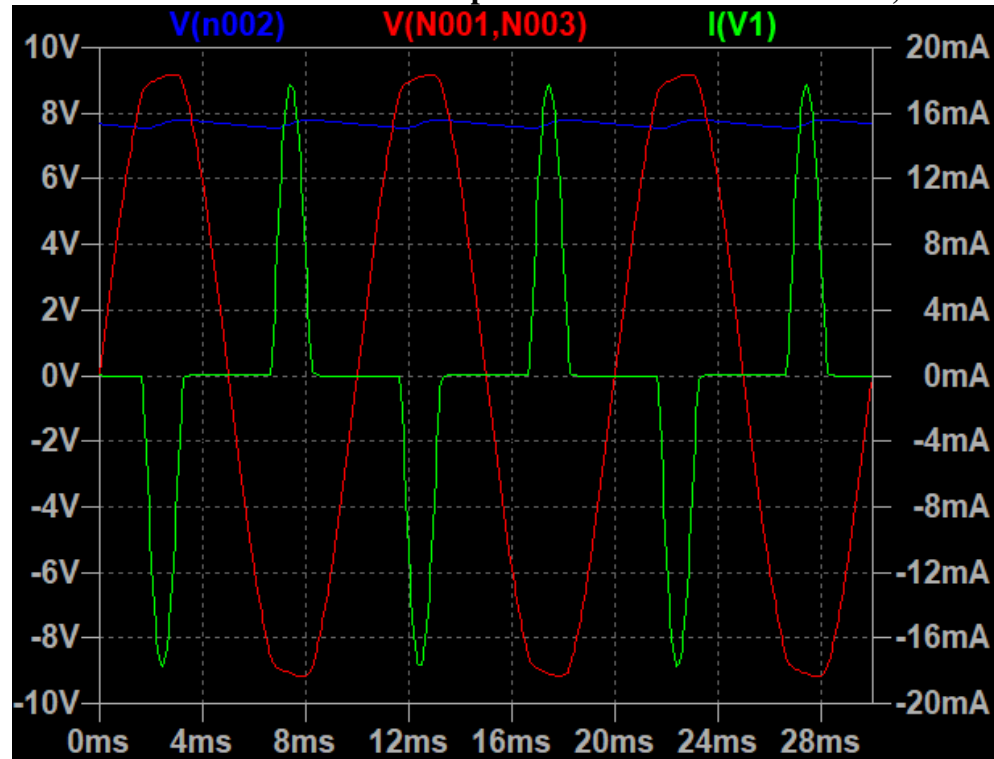
$$I_D = I(V1)$$

2. Measure the peak voltage at R L and the peak current I D. (Use the cursors from the LTSpice display)

$$U_L = 8.50V$$

$$I_D = 3.86mA$$

3. Simulate the circuit with the capacitor C1 connected. Plot U L, Vin and I D.



$$U_L = V(002)$$

$$V_{in} = V(N001, N003)$$

$$I_D = I(V1)$$

4. Measure the peak voltage and the peak current.

$$U_L = 7.80V$$

$$I_D = 17.68mA$$

5. Measure the ripple of the voltage at the load resistor. Use the zoom to improve the accuracy. Use the formula from the handout to calculate the ripple value and compare!

Ripple without capacitor: 8.50V

Ripple with capacitor: 0.26V

Theoretical ripple voltage

$$V_r = \frac{V_p}{2fCR_L} \left(1 - \sqrt[4]{\frac{R_i}{R_L}}\right) = \frac{8.07}{2 \cdot 100 \cdot 47 \cdot 10^{-6} \cdot 2200} \left(1 - \sqrt[4]{\frac{50}{2200}}\right) = 0.2387V$$

1.4 Problem 4 Rectifier

(1) What are the maximum peak voltages at the load for each rectifier? Why are these values different from the input sine amplitude? Why is there a difference between half- and full-wave rectifier?

For half wave rectifier, the maximum peak voltage is less than 0.7V and for full wave rectifier the maximum peak voltage is less than 1.4 V. Which implies the half wave rectifier has a one diode voltage drop while full wave rectifier has two diode voltage drop.

2. Explain the differences of the current I_D for all cases. What is the consequence for the used diode in a rectifier circuit?

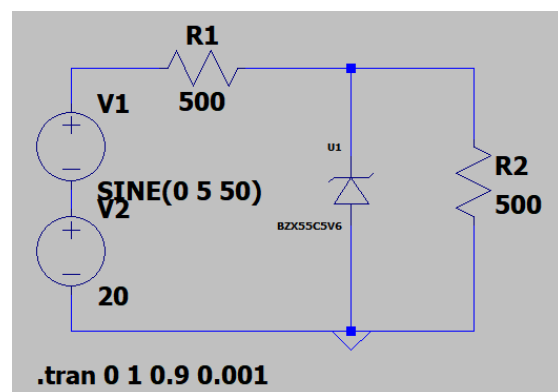
When there is no capacitor, the current flows when the diode is forward.

When there is capacitor, the current only flows when the capacitor is charging.

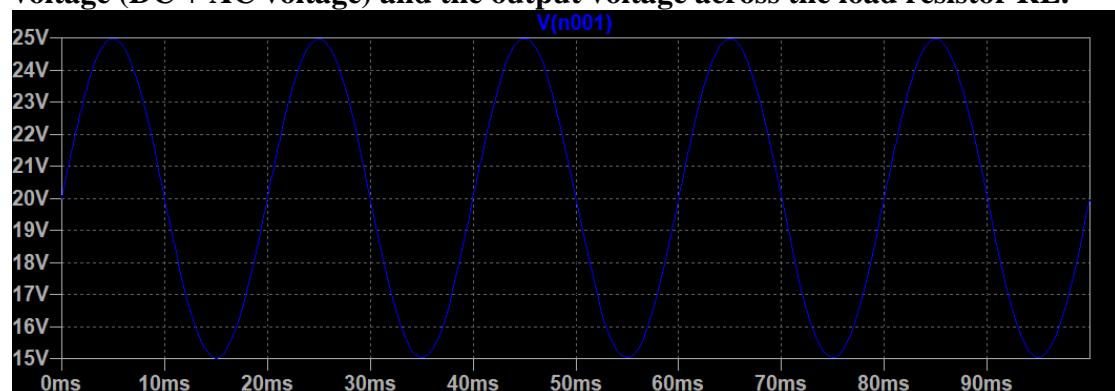
3. What is the influence of the ratio $C \cdot R_L$ to the quality of the output DC?

When $C \cdot R_L$ is high, the ripple voltage is lower. Slower the capacitor discharges, smaller the ripple voltage.

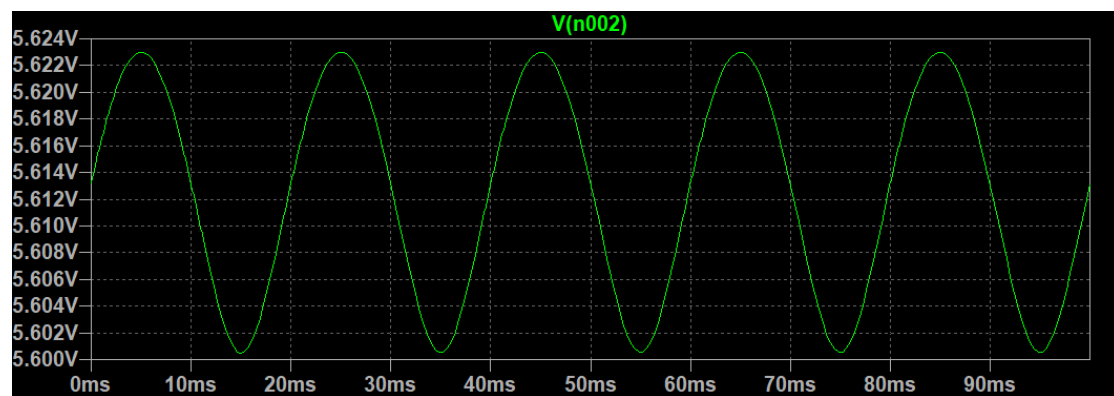
1.5 Problem 5 Zener Diode



(1) Perform a transient analysis (5 cycles of the sinusoidal input). Plot the input voltage (DC + AC voltage) and the output voltage across the load resistor R_L .



Input voltage



Over R_L

(2) Explain the operation of the circuit.

The Zener diode regulates voltage by keeping the voltage drop across the diode constant.

2 Execution, Evaluation

2.1 Experiment Setup

Used tools and instruments:

- Breadboard, Tools box from workbench
- Oscilloscope Tektronix, Function Generator

2.1.1 Experiment Part 1: Diode Switching Characteristic – Setup

- Objective

Understand diode delay time for reverse/forward transition and storage time after forward/reverse transition.

- Test circuit

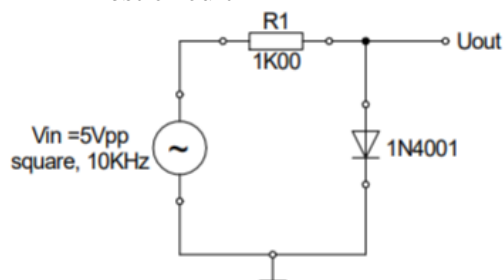


Figure 1 Circuit of problem 1

2.1.2 Experiment Part 1 – Execution and Results

- Description of the measurement procedure.

Set up the circuit and measure with the oscilloscope the voltage of the output and the input. Use 1N4001 diode for the first measurement and 1N4148 diode for the second measurement.

Results:

(1) Delay time (t_d)

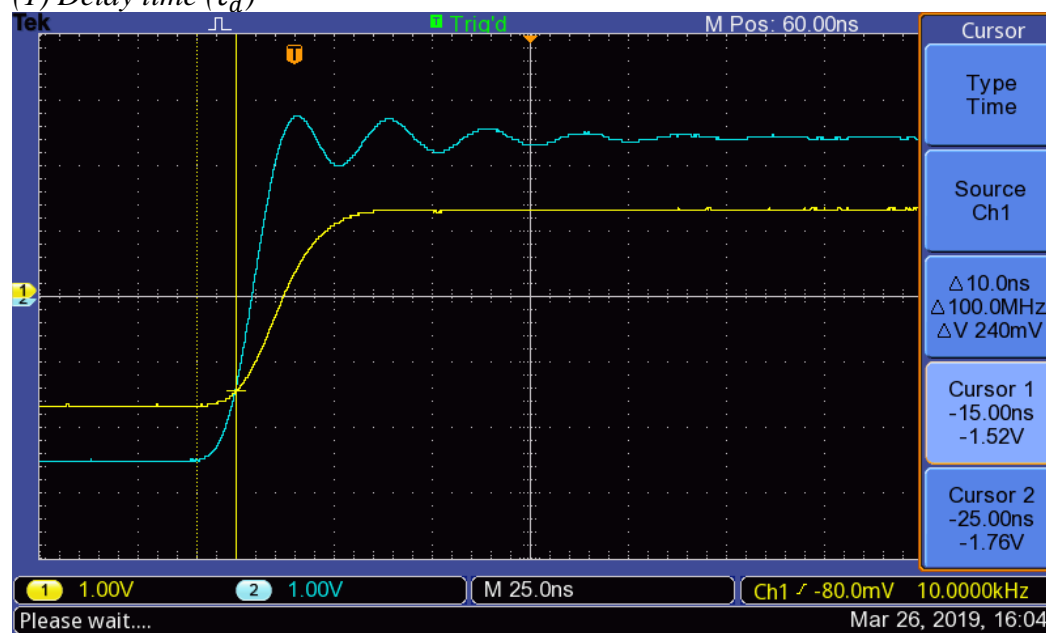


Figure 2 t_d measurement Source - channel 2, V_D - channel 1

(2) Storage time (t_s)

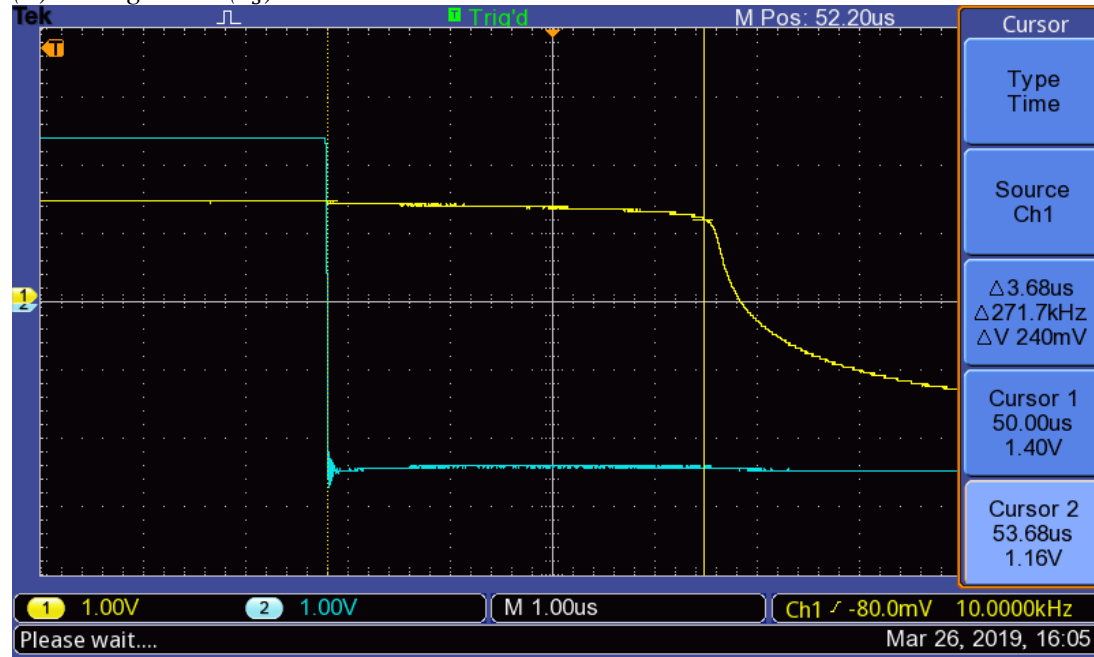


Figure 3 t_s measurement, Source - channel 2, V_D - channel 1

(3) Delay And Storage time of diode 1N4148

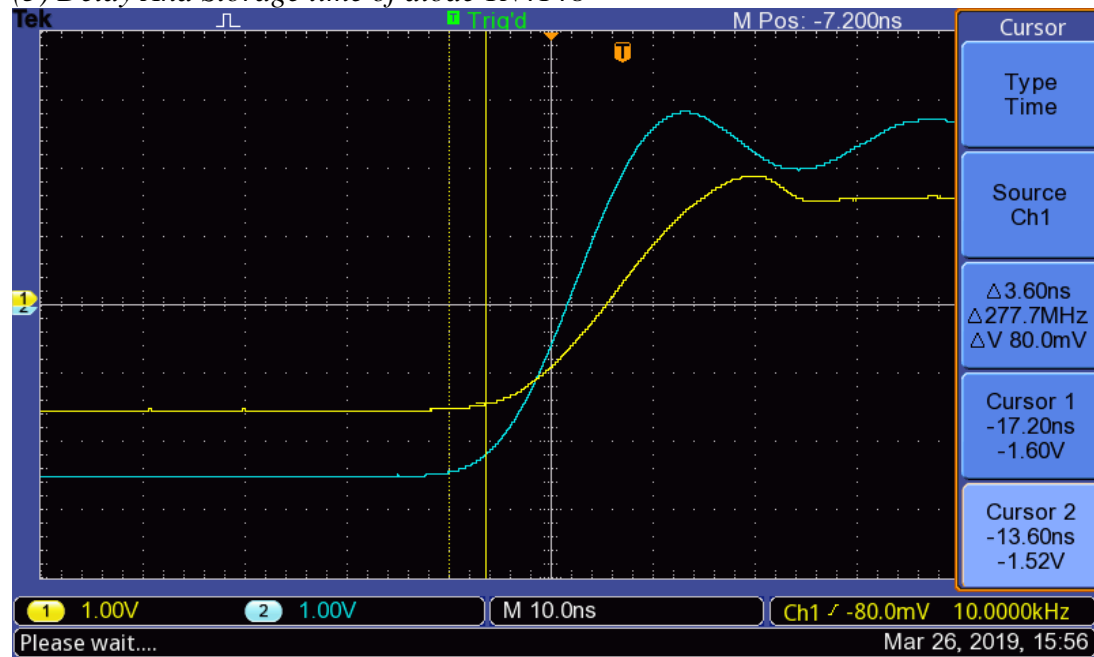


Figure 4 t_d measurement Source - channel 2, V_D - channel 1

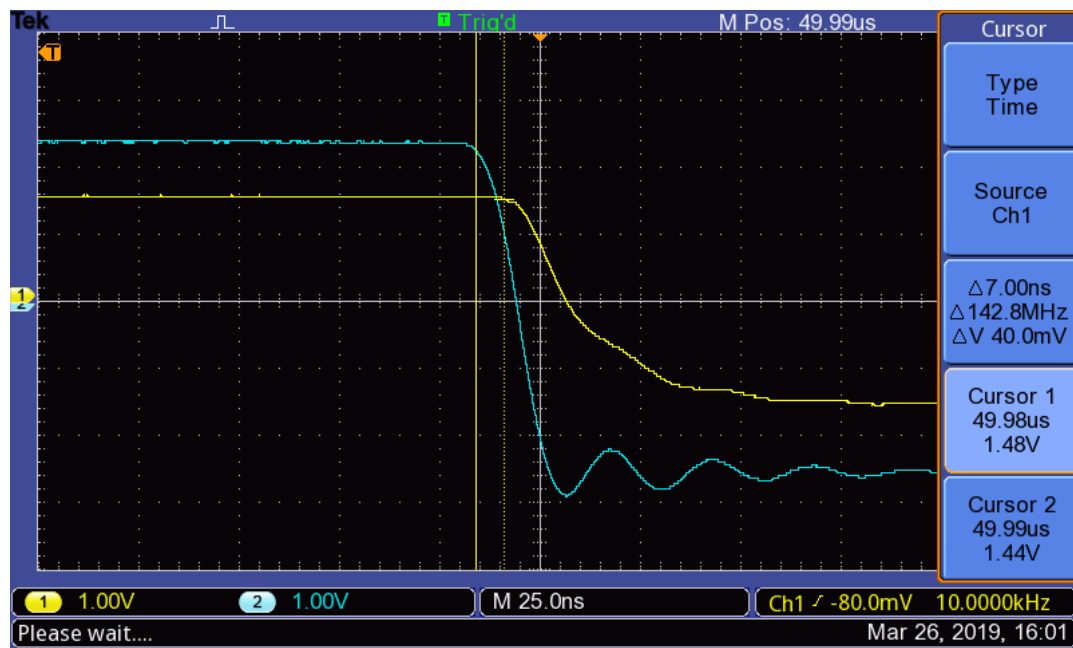


Figure 5 t_s measurement, Source - channel 2, V_D - channel 1

Table 1 Delay and storage time of diodes

	1N4001	1N4148
t_d	10.0 ns	3.60 ns
t_s	3.68 μs	7.00 ns

Evaluation:

1. Compare the two storage times. What is the reason why the diodes need that long time to switch off?

Excess carriers that are stored in the PN junction need to be removed when the diode switches to reverse bias. This causes more time when switching off the diode.

2. What are the consequences for using these diodes in different applications?

Higher the signal frequency, the circuit needs a fast turn-off diode. (Shorter storage time. For example if the signal has 300kHz, the signal period is 3.3 μs . In this case 1N4001 diode cannot be used because the storage time (t_s) is large enough to make the current keep on flowing (Diode is kept on). In this case, the diode acts as a capacitor.

2.1.3 Experiment Part 2: Rectifier – Setup

- Objective

Understand half - wave rectifier and full - wave rectifier

- Test Circuit:

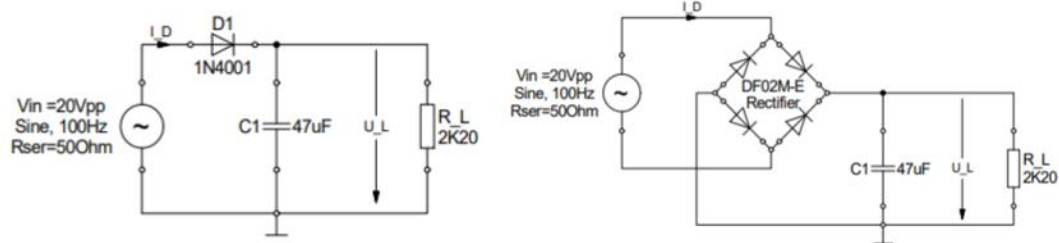


Figure 6 (left) half wave rectifier, (right) full-wave rectifier

2.1.4 Experiment Part 2 – Execution and Results

- Description of the measurement procedure.

Build the circuit and measure the peak voltage and the ripple voltage

Results:

(1) Half – wave rectifier

(a) C_1 Removed, output voltage across R_L

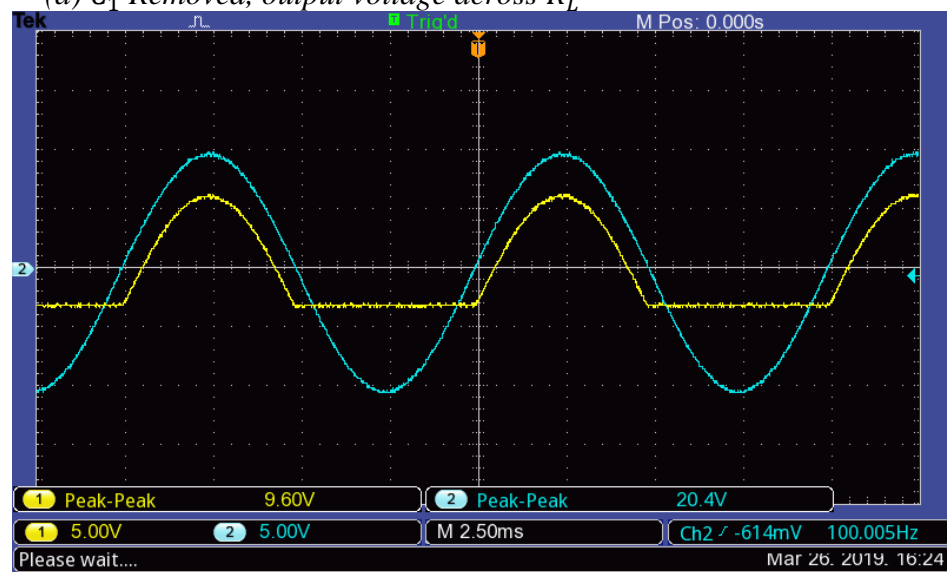


Figure 7 Without C_1 , channel 1 - output voltage, Channel 2 - Input

Peak to peak voltage of $R_L = 9.60V$

(b) $C_1 = 47\mu F$, output voltage across R_L

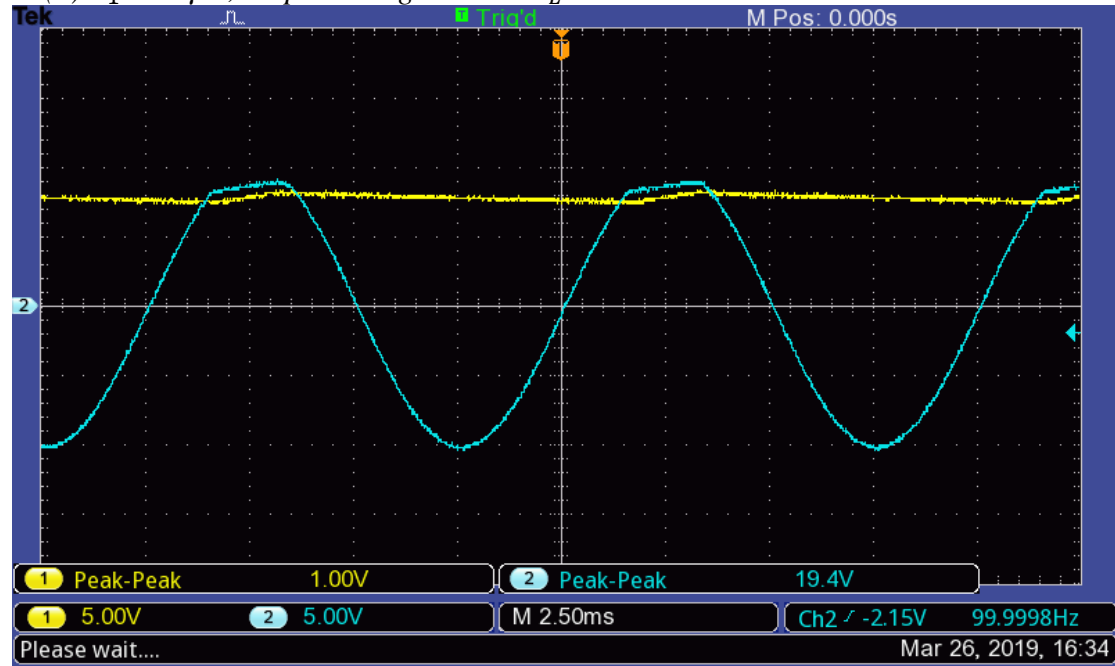


Figure 8 Half wave rectifier, Channel 1 - output voltage, Channel 2 - Input

Peak to peak voltage of $R_L = 1.00V$

(c) Ripple voltage

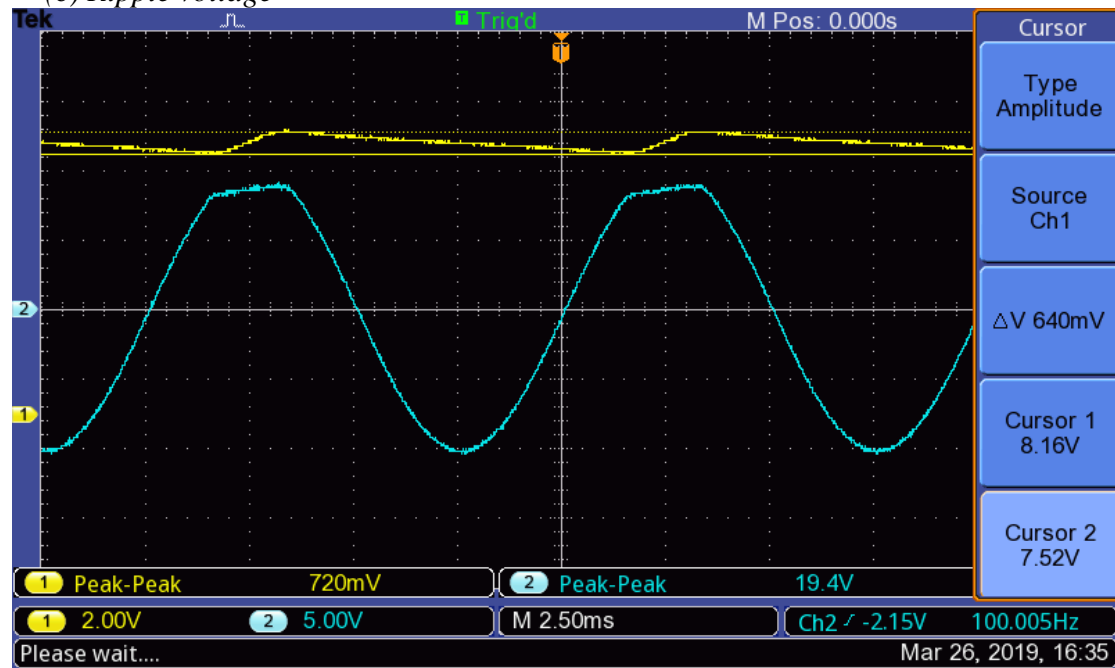


Figure 9 Ripple voltage channel 1 - output voltage, Channel 2 - Input

Ripple voltage = 640 mV

(2) Full – wave rectifier

(a) C_1 Removed, output voltage across R_L

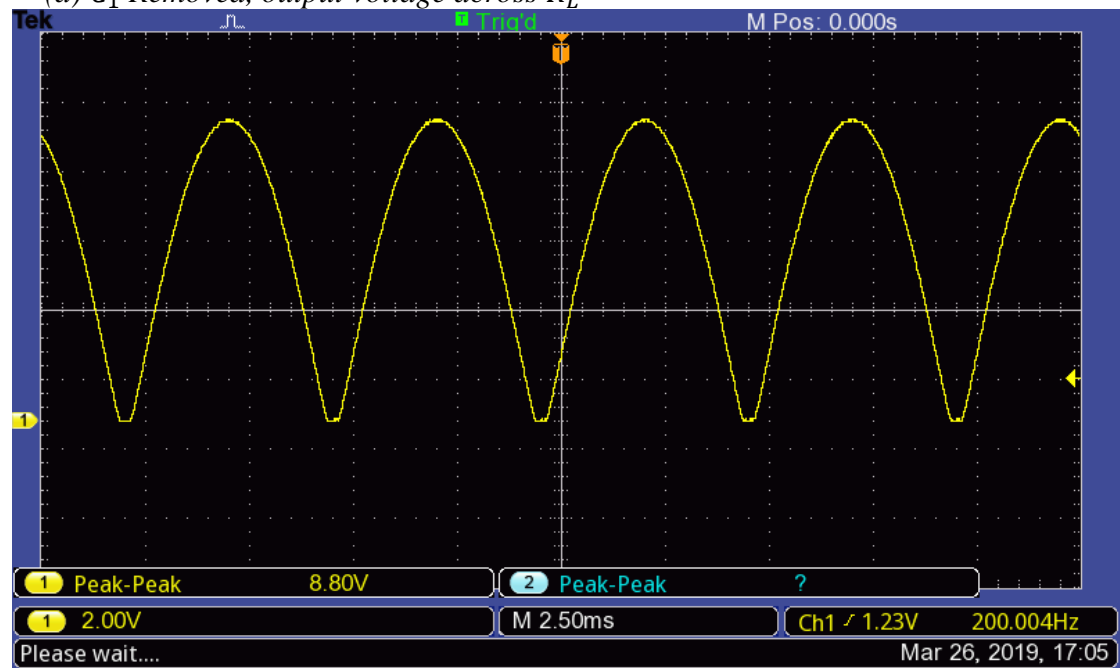


Figure 10 Full wave rectifier Without C, output voltage

Peak to peak voltage of $R_L = 8.80V$

(b) $C_1 = 47\mu F$, output voltage across R_L

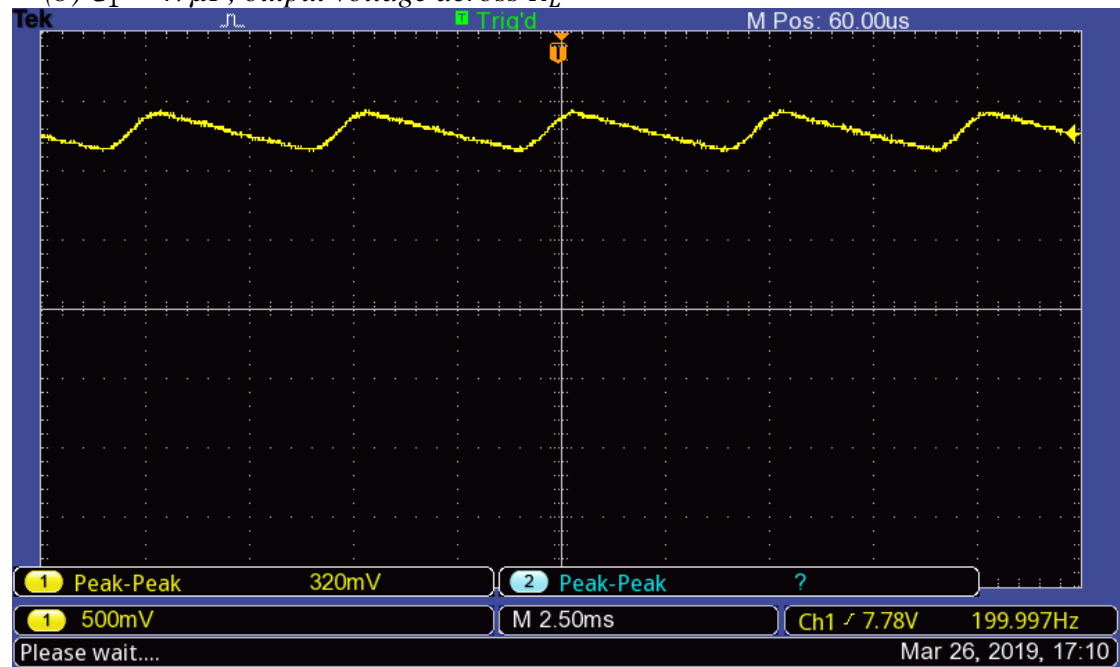


Figure 11 Full wave rectifier output voltage

Peak to peak voltage of $R_L = 320 \text{ mV}$

(c) Ripple voltage

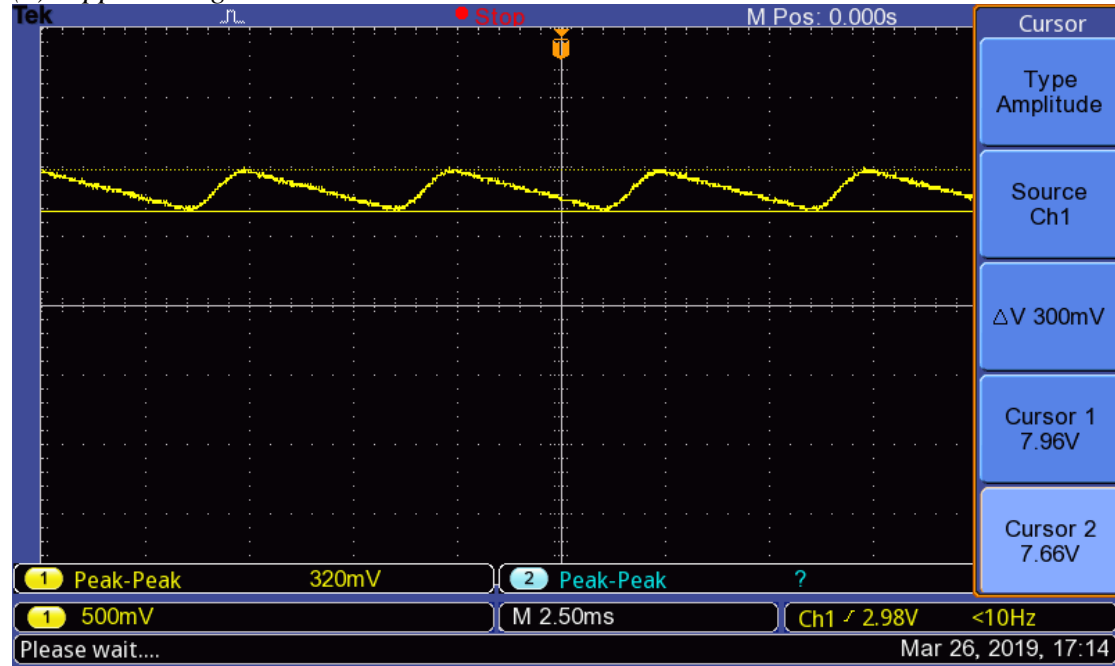


Figure 12 Full wave rectifier Ripple voltage

Ripple voltage = 300mV

Table 2 Half wave, Full wave rectifier voltage

	Half wave rectifier	Full wave rectifier
Without Capacitor Peak to peak voltage of R_L	9.60 V	8.80 V
With Capacitor Peak to peak voltage of R_L	1.00 V	0.320V
Ripple Voltage	0.640 V	0.300 V

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

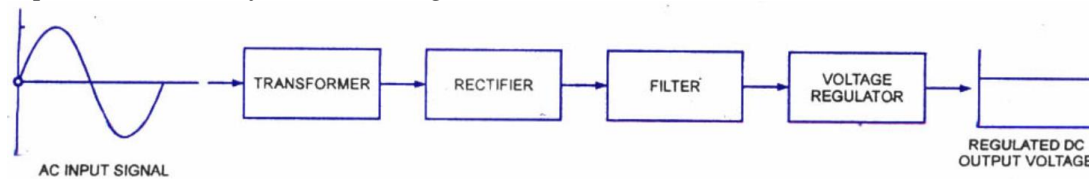


Figure 13 Block diagram of DC power supply

DC power supply converts an unregulated AC input signal to regulated DC output signal.

The transformer step down the voltage to the required voltage value. Then the rectifier converts the signal to have a unidirectional pulsating. In other words, the rectifier converts the signal from AC to DC. Then the filter is needed to have a ripple free DC waveform. The capacitor after the rectifier reduces the ripple voltage, acting as a DC filter. Lastly, voltage regulator is used to remove fluctuation of the output signal by factors such as temperature changes. The regulator helps to maintain a constant output regarding any changes in the signal.

2. Compare the measured values of the peak-to-peak ripple voltage with the values from simulation and calculated using the equations given in the handout.

Table 3 Theoretical and measured ripple voltage

	Measured	Theoretical
Half Wave	0.640 V	0.4774 V
Full Wave	0.300 V	0.2387 V

The theoretical calculation of ripple voltage is shown in prelab problem 2-5 and 3-5. Theoretical values were smaller than the actual measured values.

2.1.5 Experiment Part 3 : Zener diode – Setup

- Objective

Understand the operation of Zener diode

- Test Circuit:

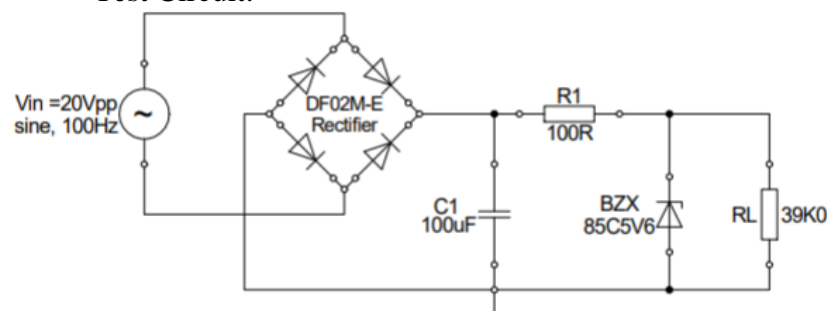


Figure 14 Zener diode circuit

2.1.6 Experiment Part 3 – Execution and Results

- Description of the measurement procedure.

Set up the circuit and measure voltage.

Results:¹

(1) Voltage at C_1

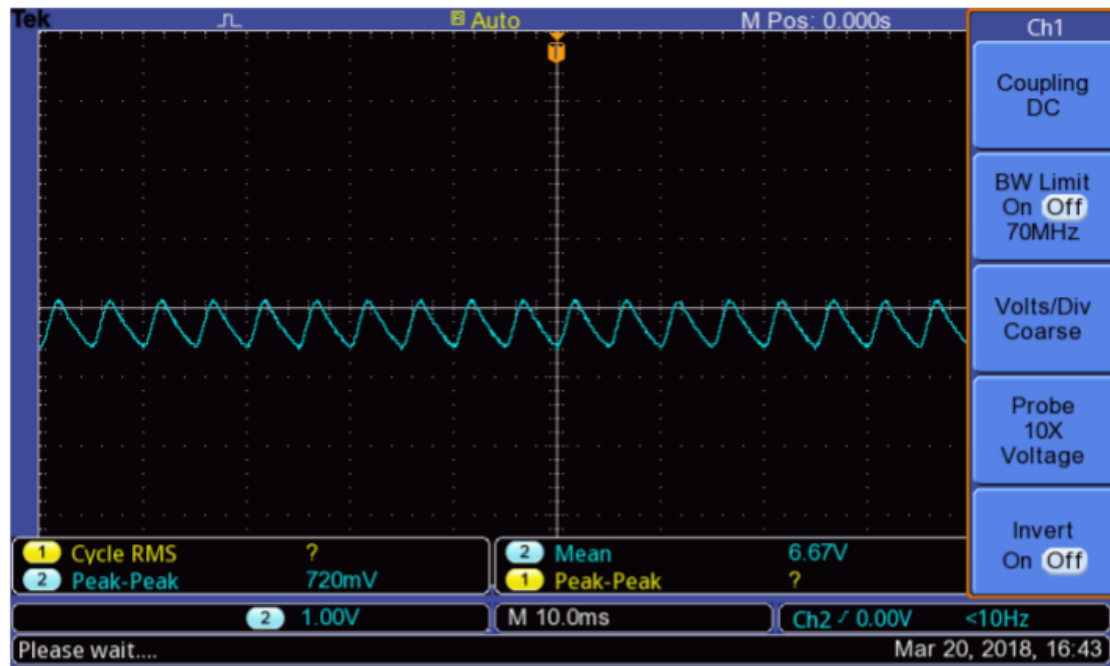


Figure 15 Zener diode C_1 voltage

DC voltage at $C_1 = 6.67 \text{ V}$

(2) Output DC voltage

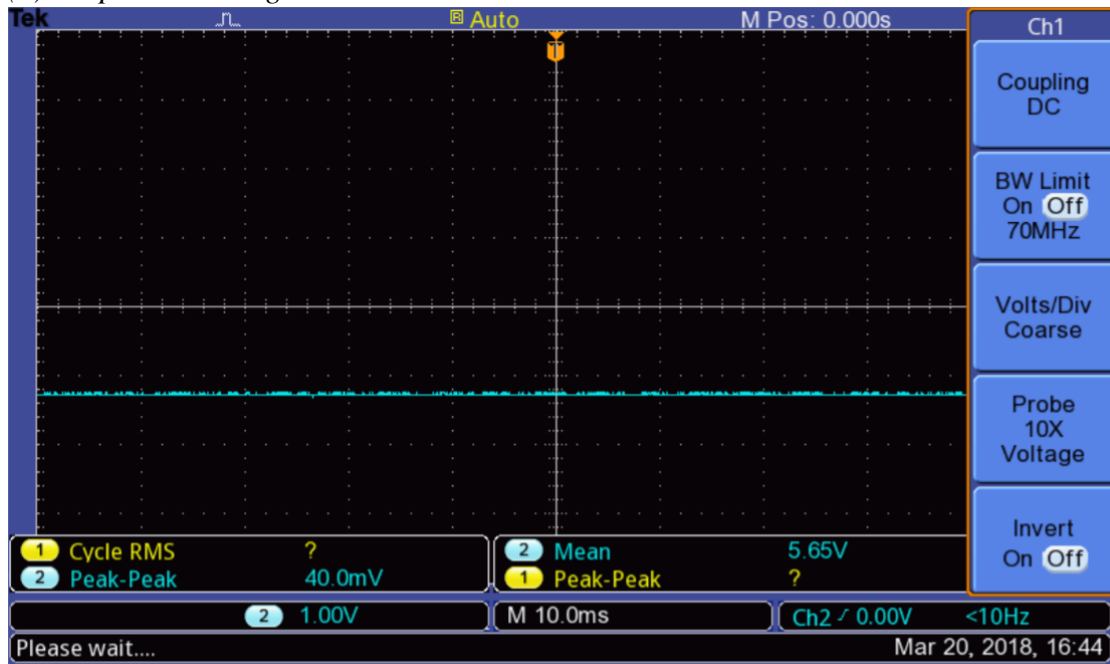


Figure 16 Zener diode output DC voltage

Output DC voltage = 5.65V

¹ Albi's data were used because of wrong measurement of data.

(3) Ripple voltage across load

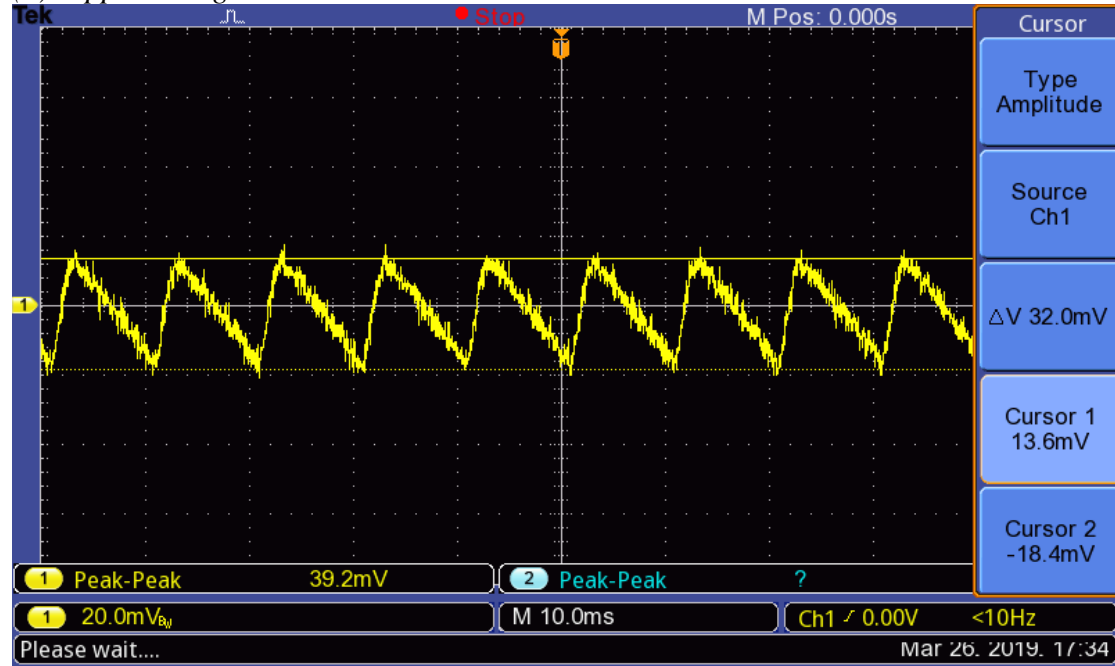


Figure 17 Zener diode Ripple voltage of load resistor

Ripple voltage = 32.0mV

1. Calculate the approximate current through the Z-diode. (I_Z)

DC voltage at $C_1 = 6.67$ V

Output DC voltage = 5.65V

$$I_Z = \frac{V_{C_1} - V_{R_L}}{R_1} - \frac{V_{R_L}}{R_L} = \frac{6.67 - 5.65}{100} - \frac{5.65}{39000} = 0.010055$$

$$\therefore I_Z = 10.055mA$$

2.1.7 Experiment Part 4: Voltage Multiplier – Setup

- Objective

Understand voltage multiplier

- Test Circuit:

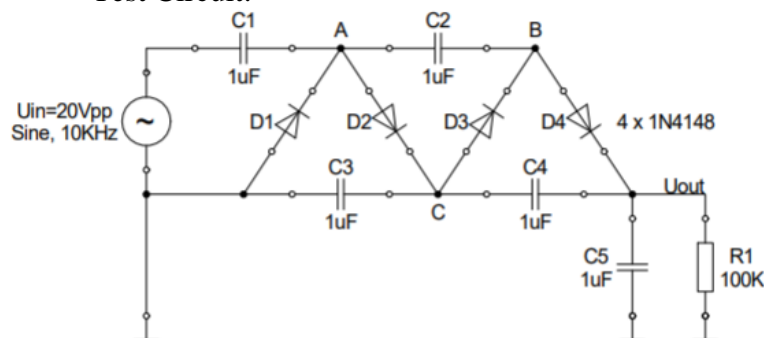


Figure 18 Voltage multiplier circuit

2.1.8 Experiment Part 3 – Execution and Results

- Description of the measurement procedure.

Set up the circuit and measure the voltage across the voltage multiplier.

Results:

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

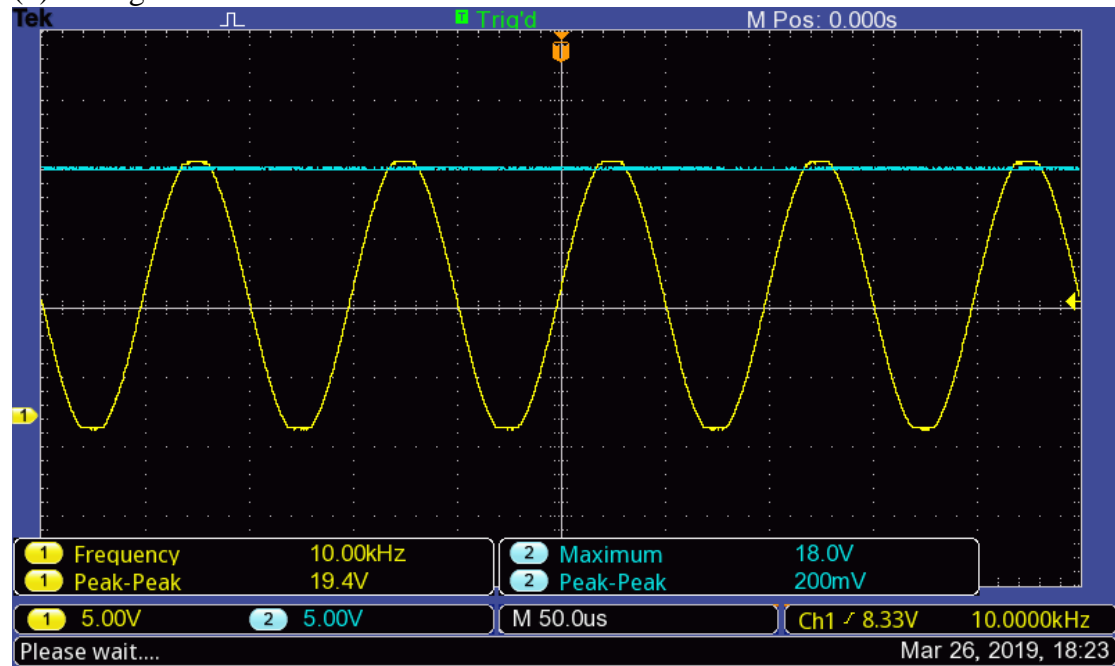


Figure 19 Voltage Multiplier channel 1 - A, channel 2 - C

(2) Voltage at 'B', ' U_{out} '

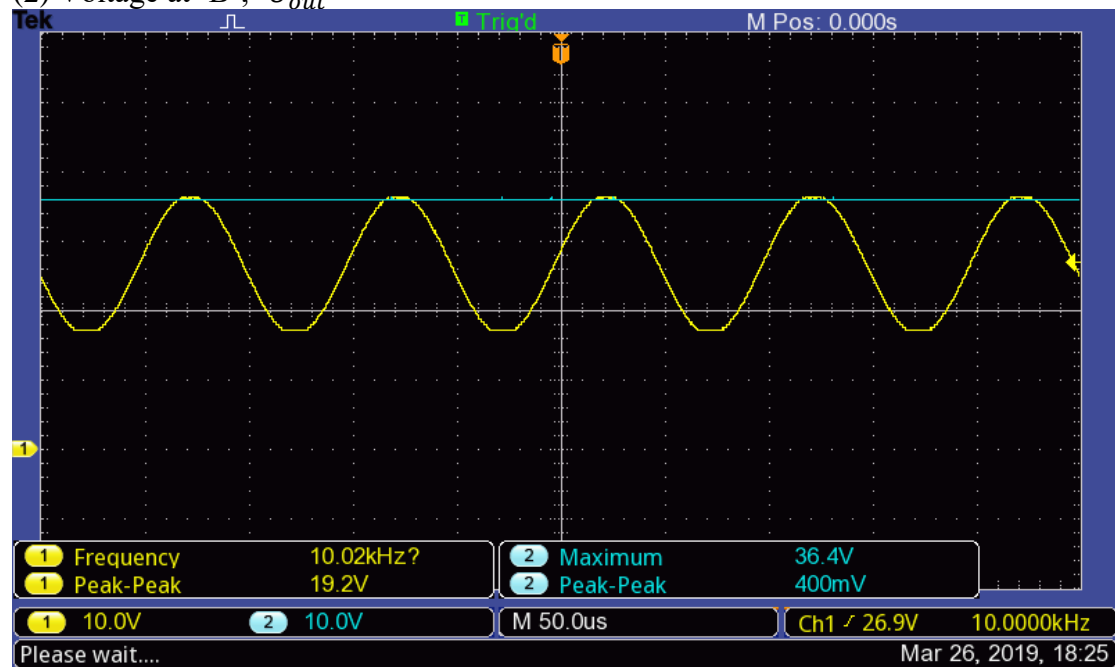


Figure 20 Voltage multiplier channel 1 - B, channel 2 - U_{out}

(3) Ripple voltage at ' U_{out} '

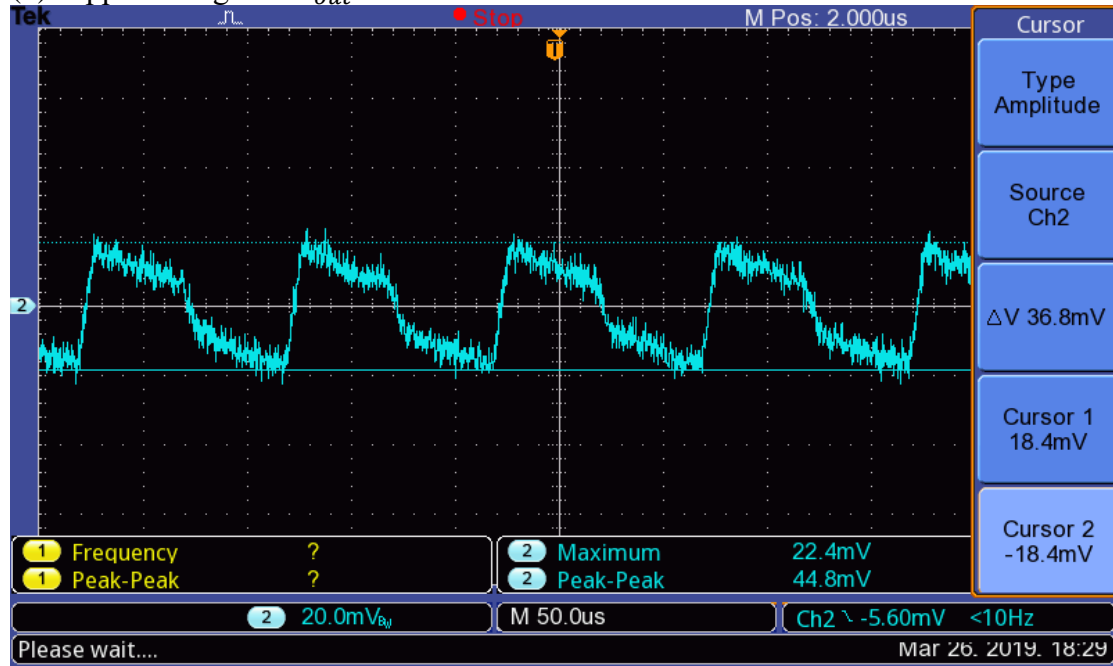


Figure 21 Voltage multiplier Ripple voltage U_{out}

Ripple voltage = 36.8mV

(4) Measured voltage using multimeter

C	U_{out}
17.77V	35.51V

1. From which circuits in the Diode Application part of the handout this circuit is composed?

Clamper circuit, Rectifier circuit. Clamping circuit changes the DC level of a waveform

2. Explain the function.

As the input voltage goes negative, the diode becomes forward biased charging the C_1 capacitor. The voltage across C_1 because the source peak voltage (U_S). When the input voltage change back to positive, the potential of C_1 increases resulting in the current flow in diode 2 (D_2) charging the capacitor C_2 . The same procedure is gone through C_3 and C_4 . Resulting in 4 times the voltage of the source at the output. ($4U_S$)

3. What is the multiplication factor between input amplitude and output voltage?

Comparer the measured to the ideal one. Why there is a difference?

Ideal – voltage is multiplied by factor 4.

The measured output is 35.51V which is resulted in 3.5 times the input voltage. The difference of 3.5V comes from the diode voltage drop of the diode. Each didoes have approximately 0.7V of voltage drop. The circuit of the experiment used 5 diodes in total resulting in 3.5 V of voltage drop.

4. For which maximum voltage each element has to be selected?

The voltage across C_1 is U_S (in the experiment $20V_{pp}$). The diode D_1 should stand voltage as same as C_1 , therefore U_S . The voltage across C_3 is $2U_{SS}$ which the diode D_2 should be able to have. The voltage across C_2 should be $3U_S$ and the diode D_3 should be able to withstand. Also, the voltage across C_4 is $4U_{SS}$ with the diode D_4 .

5. What happens to U_{out} if the frequency of the input voltage is reduced to 100Hz (Voltage & ripple!)? Explain in words!!! Show a prove of your statement using PSpice!

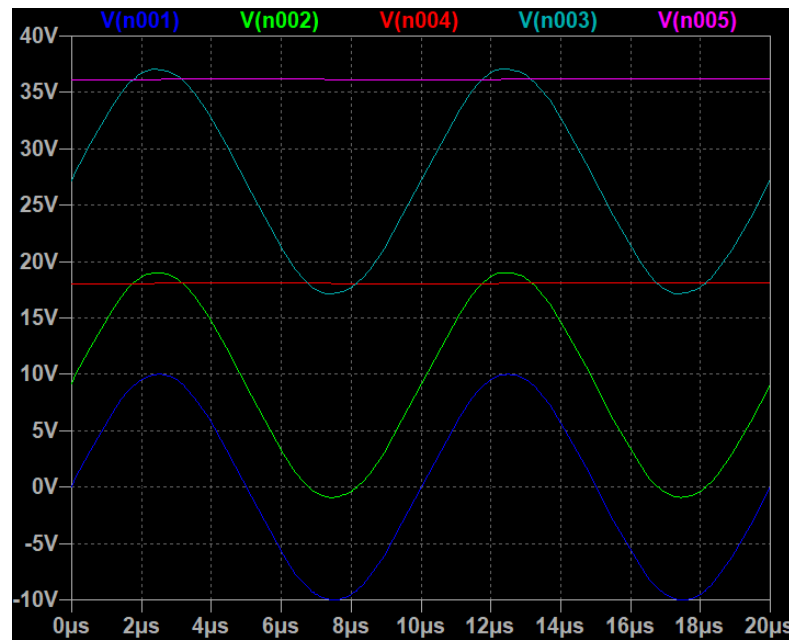


Figure 22 10K Hz voltage multiplier

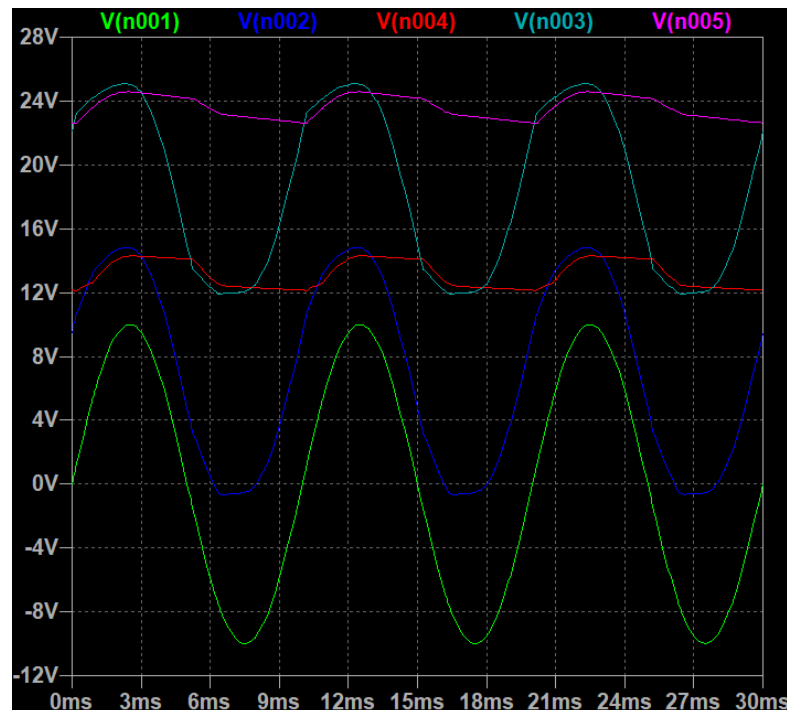


Figure 23 100Hz voltage multiplier

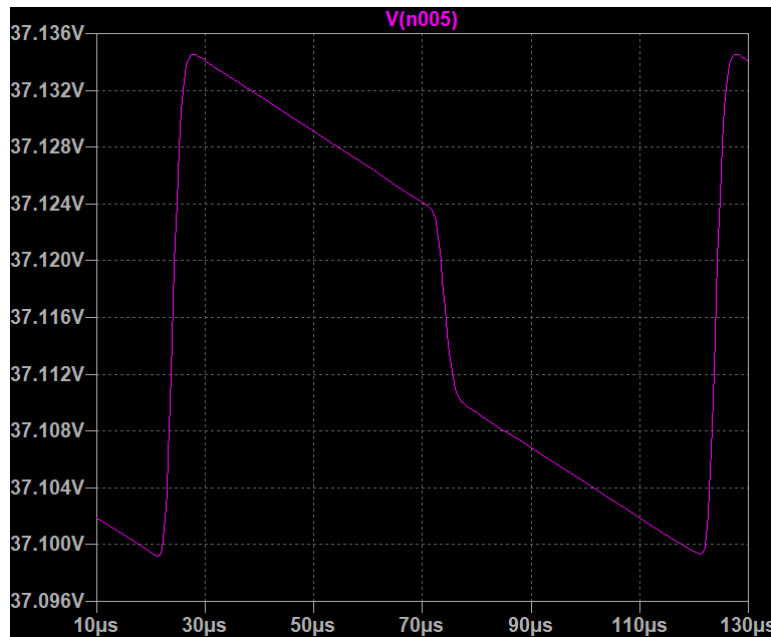


Figure 24 Ripple voltage of 10K Hz

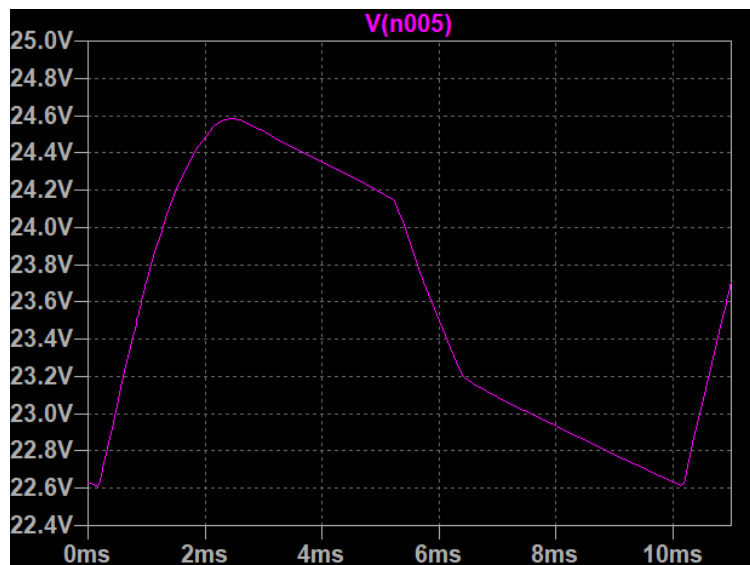


Figure 25 Ripple voltage of 100Hz

As shown in the figure 23, if 100Hz voltage multiplier is used, the voltage is not multiplied 4 times. And the amplitude decreases. In figure24 and 25 it is shown that the ripple voltage of 10kHz is 35mV while the ripple voltage of 100Hz is 1.96V. Therefore the ripple voltage increases.

This is because if the input frequency changes from 10k to 100 Hz, the period increases. This results in the fast charge and discharge in the capacitors compared to the signal. If the capacitor discharges fast, the circuit is unavailable to keep the DC voltage level. Therefore, if the frequency is decreased, the voltage multiplier cannot keep the voltage up to 4 times the input dc values. In addition, the ripple becomes bigger because of the capacitor's fast charging and discharging characteristics. This can be solved by using capacitors with higher capacitance.

3 Conclusion

In the experiment, the properties and application of diodes were examined. The property of diode delay and storage time of different diodes are shown in table 1. Showing that according to the input signal, diode of appropriate turning off time should be used. Half and full –wave rectifier were examined in part 2. The results showed the rectifier changes the AC signal to DC. Zener diode results are shown in part 3 showing the Zener diode holds the voltage across the load resistor constant. In addition the current flowing through the Zener diode are calculated. In part 4, the voltage multiplier characteristics were examined. The circuit multiplied 4 times the voltage of the input. There was a 3.5 V difference in the measured voltage which came from the voltage drop of the diode used in the circuit.

5 References

- [1] Inst. Uwe Pagel: 'Electronics Lab' (2019), 'Diodes', 20-34
- [2] "Storage Time." The Free Dictionary, Farlex, encyclopedia2.thefreedictionary.com/storage time..
- [3] <https://www.digikey.com/en/maker/blogs/zener-diode-basic-operation-and-applications>
- [4] Electrical4U. "Regulated Power Supply: What Are They? (Plus Circuit Diagram)." Electrical4U, 23 Mar. 2019, www.electrical4u.com/regulated-power-supply/.
- [5] "Dc Power Supplies-Introduction." Electronic Circuits and Diagrams-Electronic Projects and Design, 8 Sept. 2009, www.circuitstoday.com/dc-power-supplies
- [6] "Voltage Multiplier." Wikipedia, Wikimedia Foundation, 30 Mar. 2019, en.wikipedia.org/wiki/Voltage_multiplier#Operation.