Faculty of Engineering and Technology

Department of Electrical and Computer Engineering

ENEE 2103

CIRCUITS AND ELECTRONICS LABORATORY

Report #2, Experiment #6

“Diode Characteristic and Applications”

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■ *Abstract*

- *Objectives :*

1. To investigate the operation of PN junction, and the VI characteristics of the silicon diode.

2. To investigate some applications of the P-N junction like Rectification, Clamping and Clipping.

3- measuring the average value (dc value) of the output waveform voltage in all PN junction applications experimentally and comparing this measure to theoretical one.

- *Methods used:*

The circuits were built using wires connected to a Feedback Prototype Board and a TK286 [0-20V] DC power supply, as well as a function wave generator (GFG-8215a) to produce various types of electrical waveforms such as sine waves, square waves, triangular waves, and sawtooth shapes over a wide frequency range. In addition, a TDS 2002B Oscilloscope was used to graphically represent varying signal voltages. Measuring the current flowing through the diode and the voltage between its two terminals, then recording the data in tables to determine the diode's characteristics.

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2 . Theory

2.1 Diode:

A diode is a two-terminal electronic component that conducts current primarily in one direction (asymmetric conductance); it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other. A diode vacuum tube or thermionic diode is a vacuum tube with two electrodes, a heated cathode and a plate, in which electrons can flow in only one direction, from cathode to plate. A semiconductor diode, the most commonly used type today, is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals.Semiconductor diodes were the first semiconductor electronic devices. The discovery of asymmetric electrical conduction across the contact between a crystalline mineral and a metal was made by German physicist Ferdinand Braun in 1874. Today, most diodes are made of silicon, but other semiconducting materials such as gallium arsenide and germanium are also used.[1]

- Figure 1 shows the diode function and depletion region

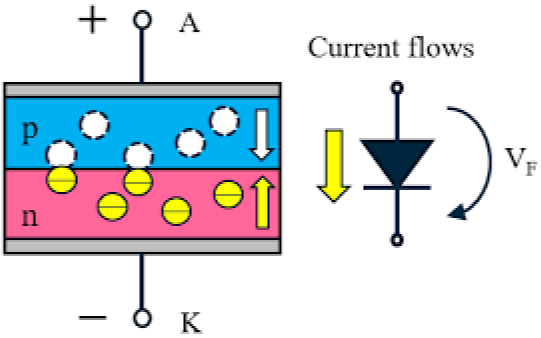

Figure 1: Diode Function and Depletion Region

2.2 Diode characteristics:

A diode is simply a PN junction, but its applications are extensive in electronic circuits. Three important characteristics of a diode are, first of all, the forward voltage drop. Under a forward bias condition, this should be about .7 volts. Then there is the reverse voltage drop. In the reverse, when we reverse bias the diode the depletion layer widens and usually, the applied voltages are felt across the diode. Then there is the reverse breakdown voltage. Reverse voltage drop that will reverse current flow and in most cases destroy the diode.[2]

There are two operating regions and three possible “biasing” conditions for the standard Junction Diode and these are:

1) Zero Bias: No external voltage potential is applied to the PN junction diode $VD = 0v$ so $ID = 0A$.

2) Reverse Bias: The voltage potential is connected negative, (-ve) to the P-type material and positive, (+ve) to the N-type material across the diode which has the effect of Increasing the PN junction diode’s width.

3) Forward Bias: The voltage potential is connected positive, (+ve) to the P-type material and negative, (-ve) to the N-type material across the diode which has the effect of Decreasing the PN junction diodes width, $VD = 0.7\ v$ for the silicon, $VD = 0.3\ v$ for germanium in this bias.

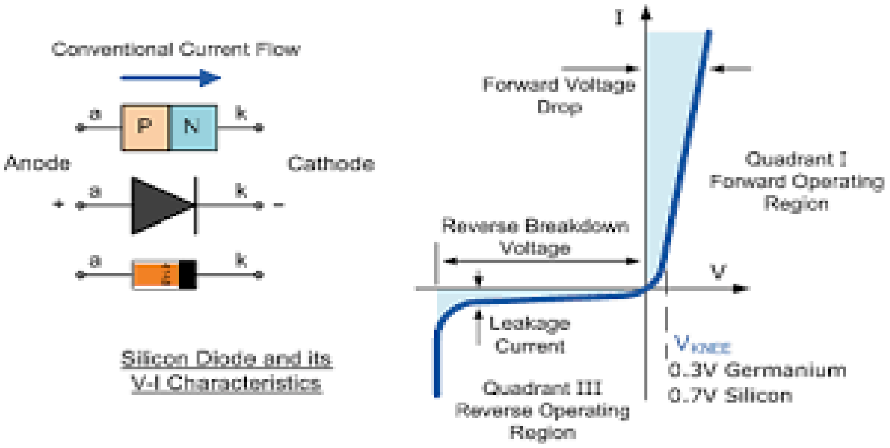

Figure 2 Diode I-V characteristic

2.3 RECTIFICATION:

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The reverse operation is performed by the inverter. This diode is capable to conduct the values of current which changes from mA to a few kA & voltages up to a few kV. The symbol of a rectifier diode symbol is shown in Figure 3[1]

Rectifier diode has many types classified based on their output. The simplest kinds of rectifier circuits are:

1) The half-wave rectifier.

2) The Full-wave rectifier.

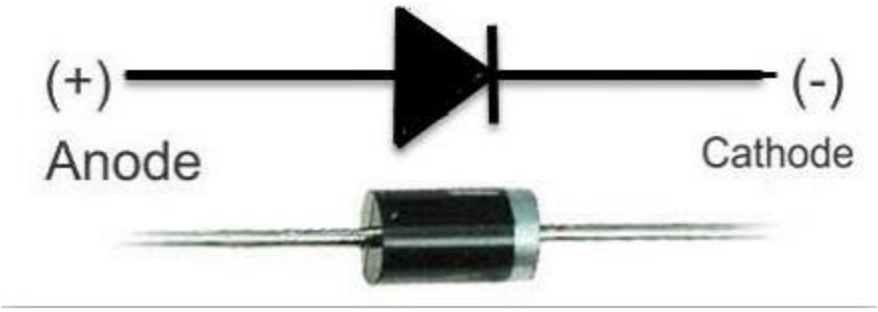

Figure 3Rectifier Diode Symbol

2.3.1 Half – Wave Rectification:

In half-wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, mean voltage is lower. Half-wave rectification requires a single diode in a single-phase supply, or three in a three-phase supply. Rectifiers yield a unidirectional but pulsating direct current; half-wave rectifiers produce far more ripple than full-wave rectifiers, and much more filtering is needed to eliminate harmonics of the AC frequency from the output. The no-load output DC voltage of an ideal half-wave rectifier for a sinusoidal input voltage is:

$$V_{\mathrm{rms}} = \frac{V_{\mathrm{peak}}}{2}$$

$$V_{\mathrm{dc}} = \frac{V_{\mathrm{peak}}}{\pi}$$

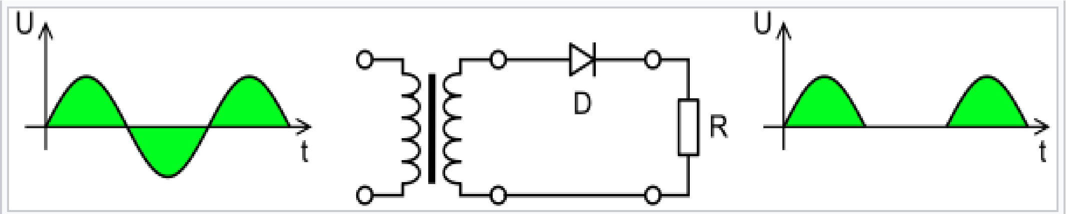

Figure 4Half-Wave Rectifier

In a positive Half-Wave Rectifier, the diode is forward biased and current flows through it during the positive half cycle of the AC voltage; in this case, the diode appears as a short circuit. The diode will be reverse biased and current flow will be blocked during the negative half cycle of the AC voltage . The final output voltage waveform on the secondary side (DC) is shown in Figure 5

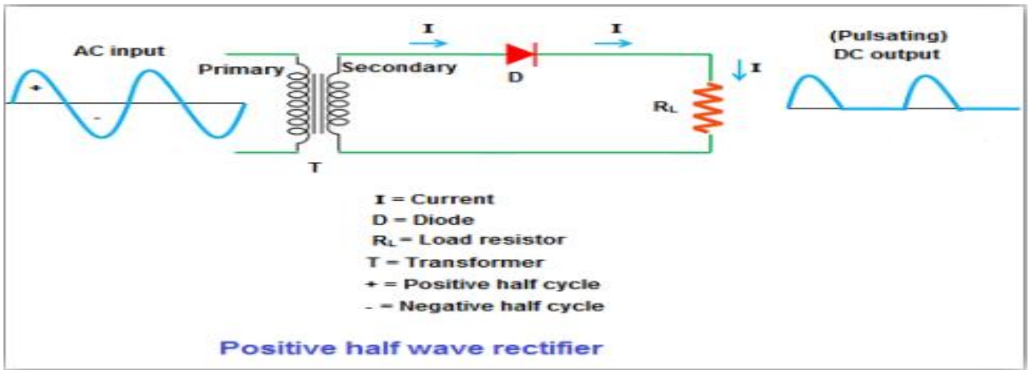

Figure 5Positive half-wave rectifier

When reversing the diode in a negative Half-Wave Rectifier, the diode enters reverse bias mode, allowing no current to pass through it during the positive half cycle of the AC voltage; in this case, the diode appears as an open circuit, and the output voltage is nil. During the positive half cycle of the AC voltage, current flow will be blocked. The final output voltage waveform on the secondary side (DC) is shown in Figure 6

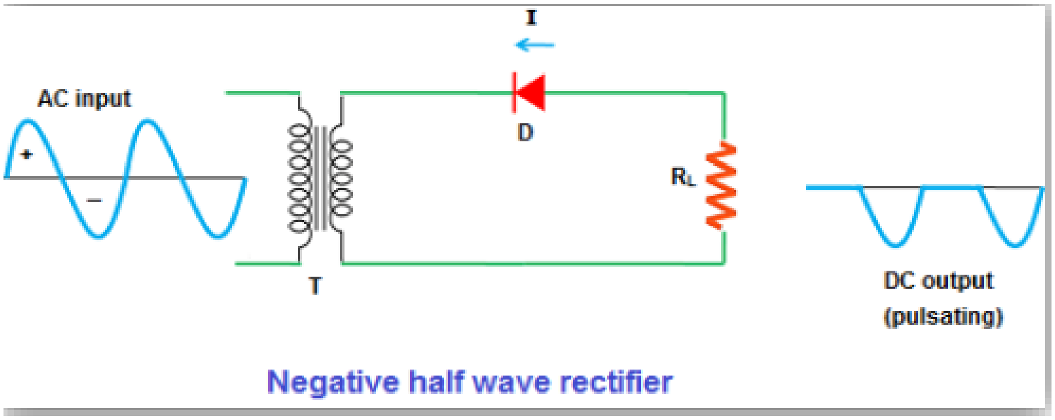

Figure 6 Negative half-wave rectifier

2.3.1.1 Half Wave Rectifier Capacitor Filter:

The main function of half wave rectifier is to change the AC (Alternating Current) into DC (Direct Current). However, the acquired output DC is not pure and it is an exciting DC. This DC is not constant and varies with time. Whenever this changing DC is given to any type of electronic device, then it may not function correctly, and that may get damaged. Due to this reason, it willnot be applicable in most of the applications.

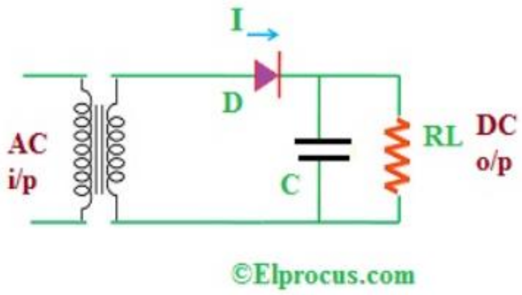

Figure 7Half-Wave Rectifier Capacitor Filter

Thus, we require a DC that does not change with time. To overcome this problem and to get a smooth DC, there will be solutions namely filter. The energetic DC mainly includes both AC & DC components. So here filter is used to remove or reduce the AC components at the output. The filter can be built with components like resistors, capacitors, and inductors. The circuit diagram of half wave rectifier using a capacitor filter is shown above. This circuit is built with a resistor and capacitor. Here, the connection of the capacitor 'C' is in shunt with the 'RL' load resistor.[3]

2.3.2 Full – Wave Rectification:-

The main function of full wave rectifier is to convert an AC into DC. As the name implies, this rectifier rectifies both the half cycles of the i/p AC signal, but the DC signal acquired at the o/p still have some waves. To decrease these waves at the o/p this filter is used.

In the full wave rectifier circuit using a capacitor filter, the capacitor C is located across the RL load resistor. The working of this rectifier is almost the same as a half wave rectifier. The only dissimilarity is half wave rectifier has just one-half cycles (positive or negative) whereas in full wave rectifier has two cycles (positive and negative).[3]

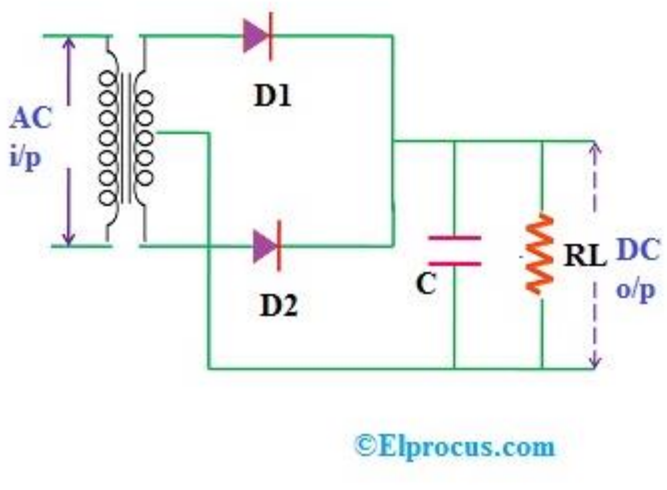

Figure 8Full-wave Rectifier with Capacitor Filter

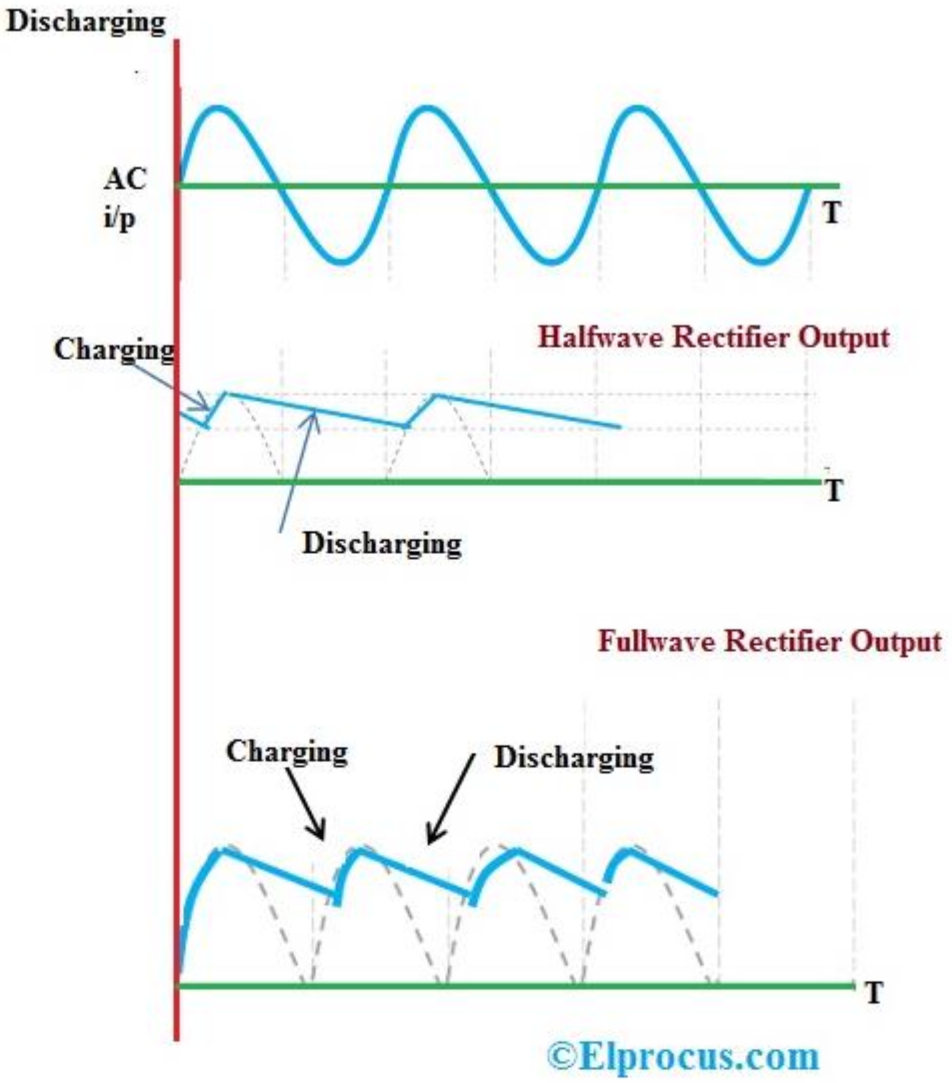

Figure 9Halfwave & Full-wave Rectifier with Capacitor Filter Outputs

there are two types of full wave rectifier Transformer:

1) Bridge Rectifier.

2) Center-Tap Rectifier.

2.3.2.1 Bridge Rectifier:-

A Bridge rectifier is an Alternating Current (AC) to Direct Current (DC) converter that rectifies mains AC input to DC output. Bridge Rectifiers are widely used in power supplies that provide necessary DC voltage for the electronic components or devices. They can be constructed with four or more diodes or any other controlled solid-state switches.[4]

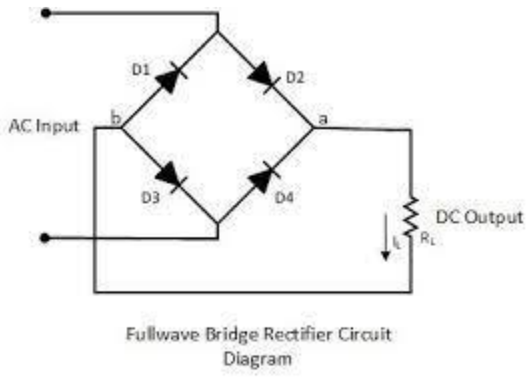

Figure 10: Circuit Diagram of Bridge Rectifier Diode

Characteristics of Bridge Rectifier:

- **Ripple Factor:** The smoothness of the output DC signal is measured by a factor known as the ripple factor. The output DC signal with fewer ripples is considered a smooth DC signal while the output with high ripples is considered a high pulsating DC signal [5]. Mathematically, the ripple factor is defined as the ratio of ripple voltage to the pure DC voltage [5]. The ripple factor for a bridge rectifier is given by: $r\%$ = √($Vrms$ 2 VDC) − 1 (1) For bridge rectifiers, the ripple factor is 0.48, in the formula above VDC means average voltage, $Vrms$ = Vpk √2

- **Peak Inverse Voltage:** The maximum voltage that a diode can withstand in the reverse bias condition is known as a peak inverse voltage. During the positive half cycle, the diodes D1 and D3 are in the conducting state while D2 and D4 are in the non-conducting state. Similarly, during the negative half cycle, diodes D2 and D4 are in the conducting state, and diodes D1 and D3 are in the non-conducting state[5]

2.3.2.2 Center-Tap Rectifier:

he Center Tapped Full Wave Rectifier employs a transformer with the secondary winding AB tapped at the centre point C. It converts the AC input voltage into DC voltage. The two diode D1, and D2 are connected in the circuit as shown in the circuit diagram below.

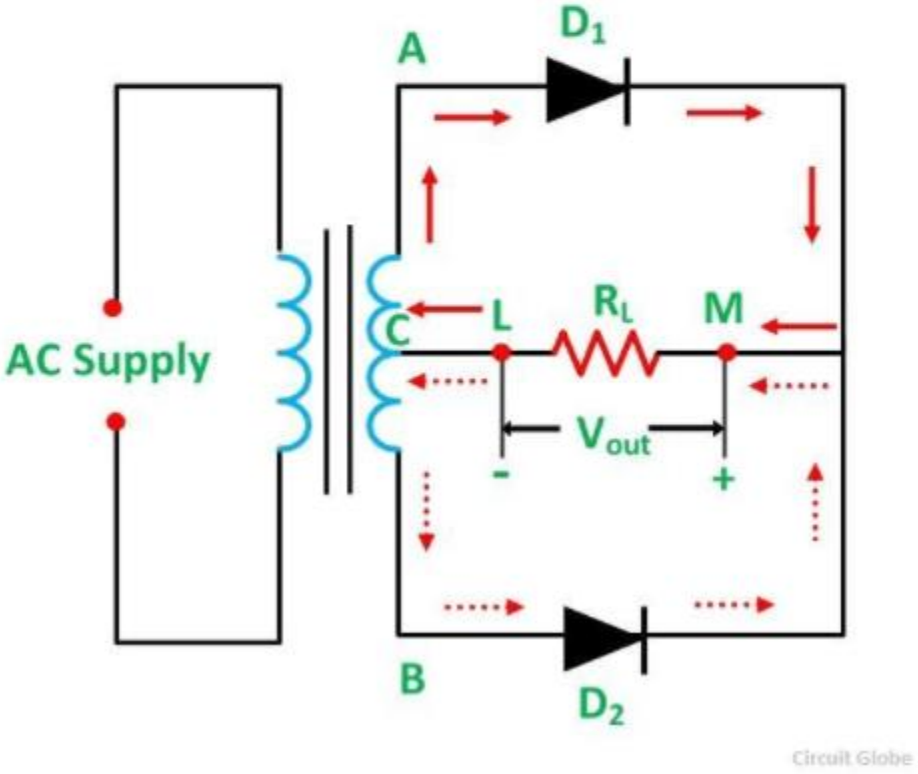

Figure 11Circuit Diagram of center tap Rectifier Diod

Each diode uses a one-half cycle of the input AC voltage. The diode D1 utilizes the AC voltage appearing across the upper half (AC) of the secondary winding for rectification. The diode D2 uses the lower half (CB) of the secondary winding.

2.4 Other applications for the diodes:

2.4.1 Clipping:

is a wave shaping circuit that takes an input waveform and clips or cuts off its top half, bottom half or both halves together. This clipping of the input signal produces an output waveform that resembles a flattened version of the input. For example, the half-wave rectifier is a clipper circuit, since all voltages below zero are eliminated.

- **Positive Diode Clipping Circuits**

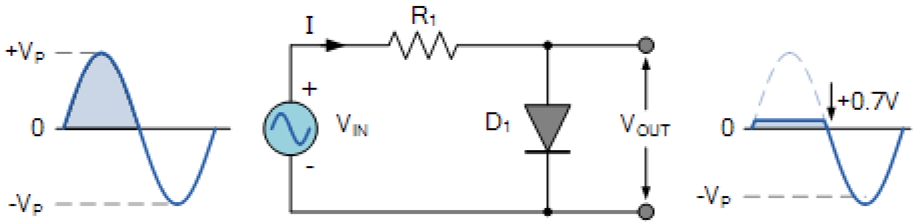

Figure 12Positive Diode Clipping Circuits

In this diode clipping circuit, the diode is forward biased (anode more positive than cathode) during the positive half cycle of the sinusoidal input waveform. For the diode to become forward biased, it must have the input voltage magnitude greater than +0.7 volts (0.3 volts for a germanium diode).

When this happens the diodes begins to conduct and holds the voltage across itself constant at 0.7V until the sinusoidal waveform falls below this value. Thus the output voltage which is taken across the diode can never exceed 0.7 volts during the positive half cycle.

- ## Negative Diode Clipping Circuits

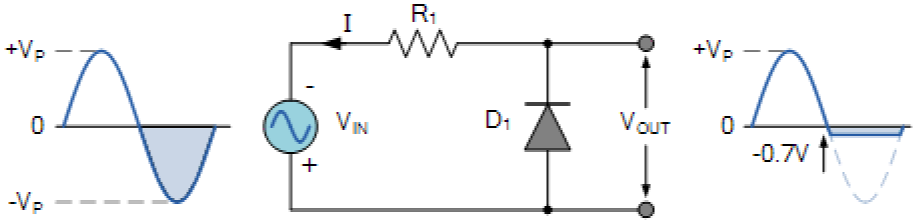

Figure 13Negative Diode Clipping Circuits

Here the reverse is true. The diode is forward biased during the negative half cycle of the sinusoidal waveform and limits or clips it to –0.7 volts while allowing the positive half cycle to pass unaltered when reverse biased. As the diode limits the negative half cycle of the input voltage it is therefore called a negative clipper circuit.[7]

2.4.2 Clamping:

A clamping circuit is used to place either the positive or negative peak of a signal at a desired level. The dc component is simply added or subtracted to/from the input signal. The clamper is also referred to as an IC restorer and ac signal level shifter.

In some cases, like a TV receiver, when the signal passes through the capacitive coupling network, it loses its dc component. This is when the clamper circuit is used so as to re-establish the dc component into the signal input. Though the dc component that is lost in transmission is not the same as that introduced through a clamping circuit, the necessity to establish the extremity of the positive or negative signal excursion at some reference level is important.[7]

- Positive Clamper Diode

  The circuit will be called a positive clamper, when the signal is pushed upward by the circuit. When the signal moves upward, as shown in figure (a), the negative peak of the signal coincides with the zero level.[8]

- Negative Clamper Diode

  The circuit will be called a negative clamper, when the signal is pushed downward by the circuit. When the signal is pushed on the negative side, as shown in figure (b), the positive peak of the input signal coincides with the zero level.[8]

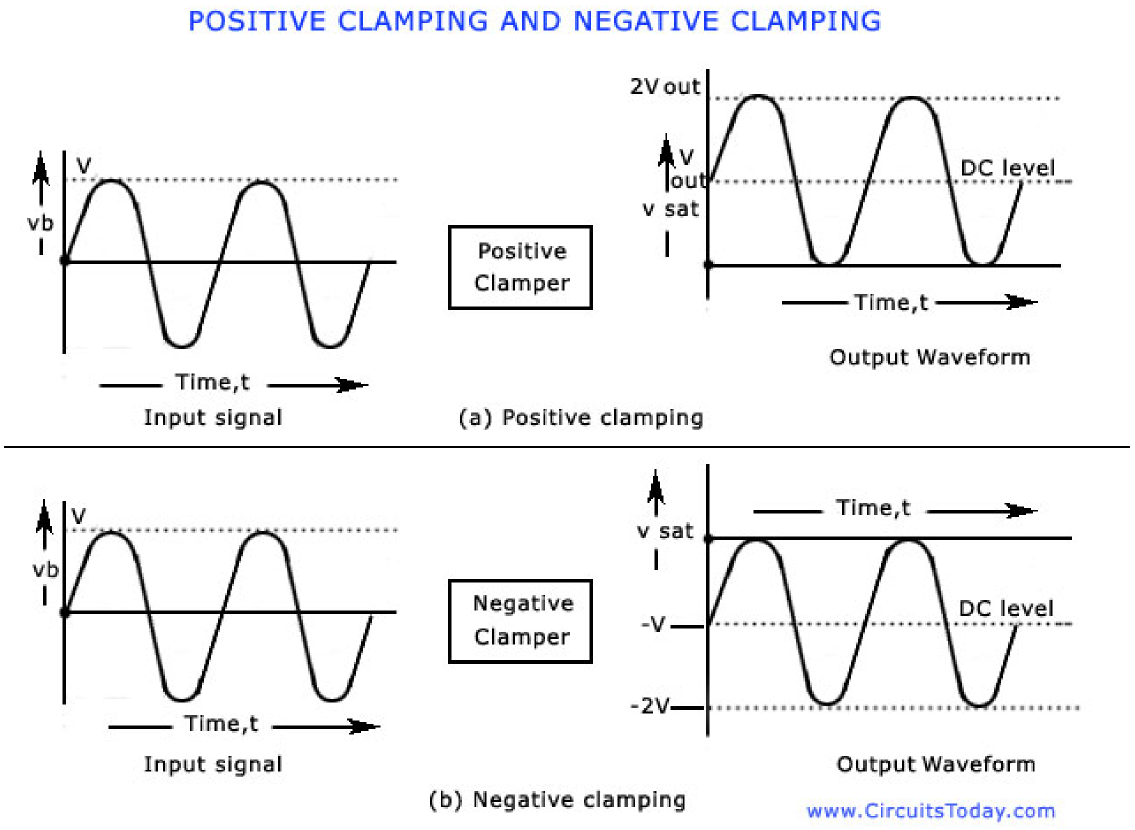

Figure 14Positive & Negative Diode Clamping Circuits

2.4.3 Voltage Multiplier Circuits:

A **voltage multiplier** is an electrical circuit that converts AC electrical power from a lower voltage to a higher DC voltage, typically using a network of capacitors and diodes.

Voltage multipliers can be used to generate a few volts for electronic appliances, to millions of volts for purposes such as high-energy physics experiments and lightning safety testing. The most common type of voltage multiplier is the half-wave series multiplier, also called the Villard cascade (but actually invented by Heinrich Greinacher).[9]

3. Procedure

3.1 Diode Characteristics

First, the circuit was connected using wires, Diode (1N4002),resistor with value 100 Ω and the variable dc power supply to a feedback prototype board, then the oscilloscope was connected to the diode terminals to get VD and ID values then to the resistor terminals to get its VR value as shown in Figure 15 below.

When the voltage response displayed on the oscilloscope screen, the resistor voltage, diode voltage, and current were measured at various dc power supply values

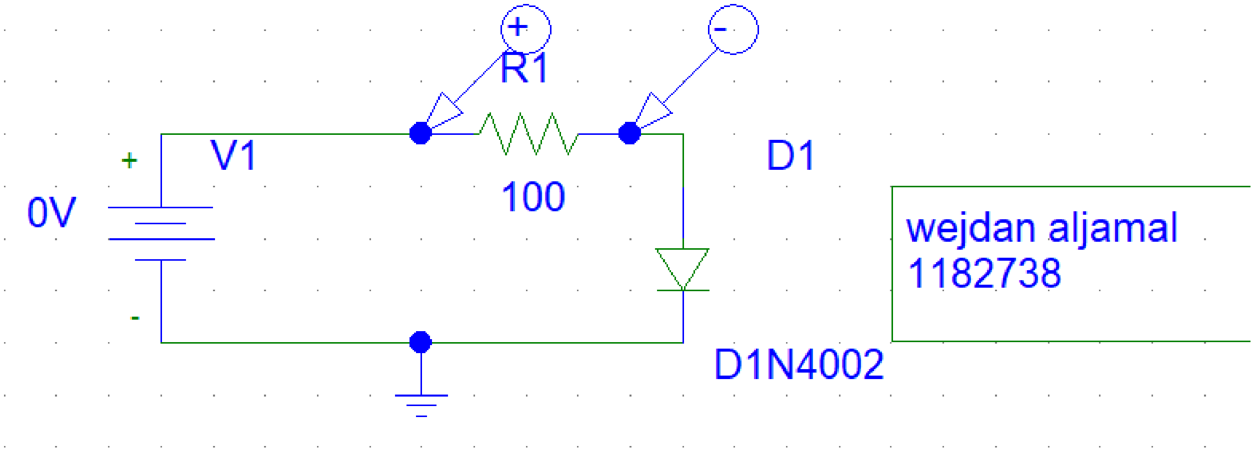

Figure 15RD series circuit implementation

3.2 Rectification:

3.2.1 Half-Wave Rectification

First, , the circuit in Figure 16 below was connected using wires, Diode with type (D1N4148), resistor with value 10 kΩ and the signal generator to generate sinusoidal wave AC voltage source with 10 $Vp{-}p$ and frequency = 200 Hz to a feedback prototype board.

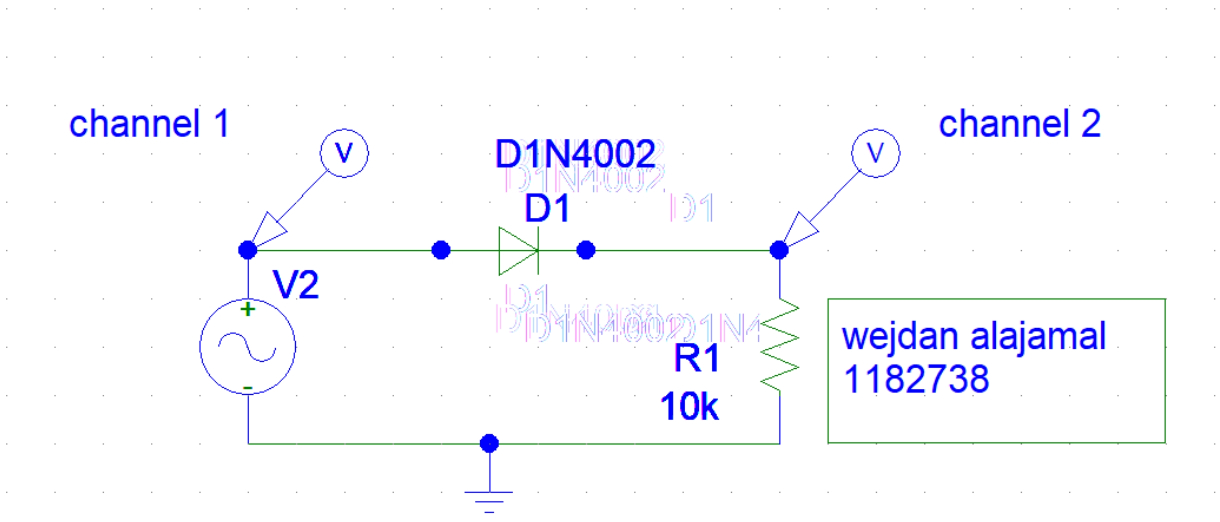

Figure 16Half-Wave Rectification circuit implementation

Then the oscilloscope was connected to the diode terminals to get the graph of the voltage response ,When the voltage response displayed on the oscilloscope screen, the peak voltage was taken to determine the value of the dc value $Vavg$.

- **Reverse the diode**

  the diode was reversed to get the graph of the voltage response after reversing the diode as shows in Figure 17below.

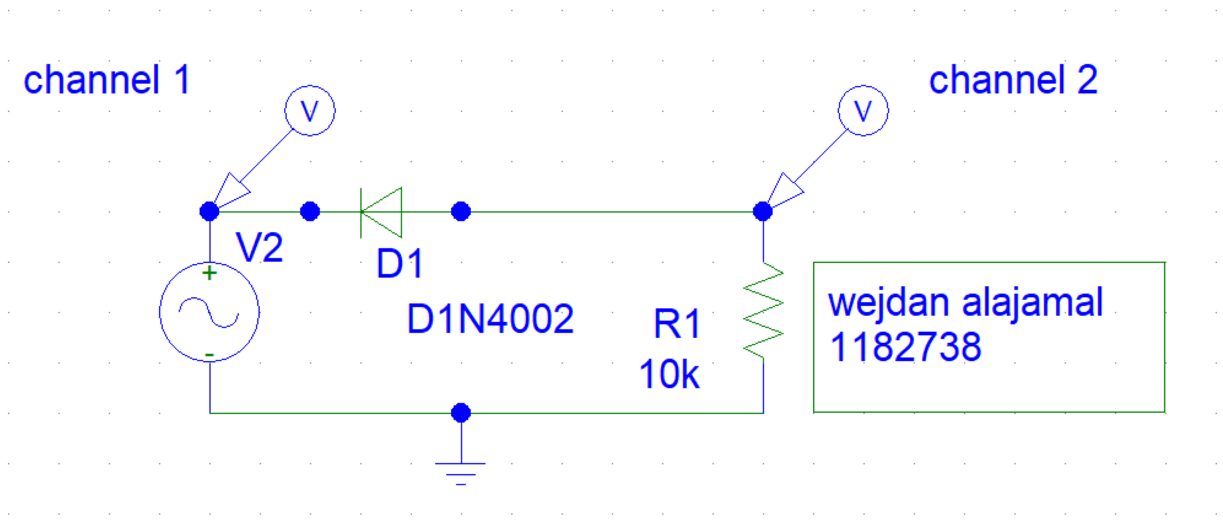

Figure 17Half-Wave Rectification circuit implementation after reversing the diode

- **Adding capacitor of 2.2 μF:**

  add a filter capacitor of 2.2 μF in parallel with the load resistor as shown in Figure 18 below

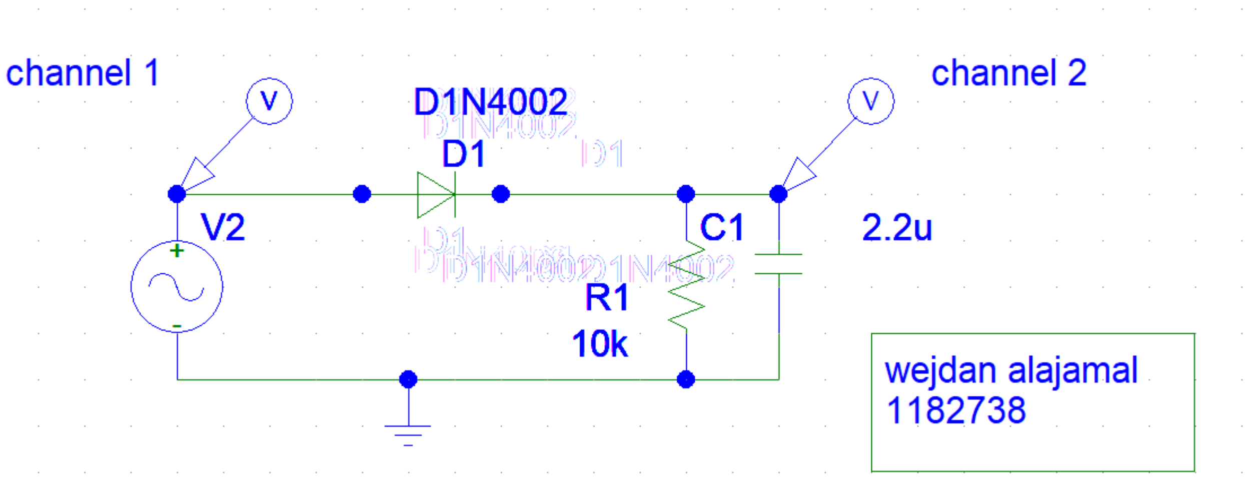

Figure 18Half-Wave Rectification circuit implementation after adding 2.2 µF capacitor

When the voltage response displayed on the oscilloscope screen, the peak to peak voltage was taken to determine the value of peak to peak ripple and rms ripple voltage, also the mean value of the output voltage was measured to find the ripple factor.

- **Replacing the 2.2 μF capacitor with capacitor of 47 μF one**

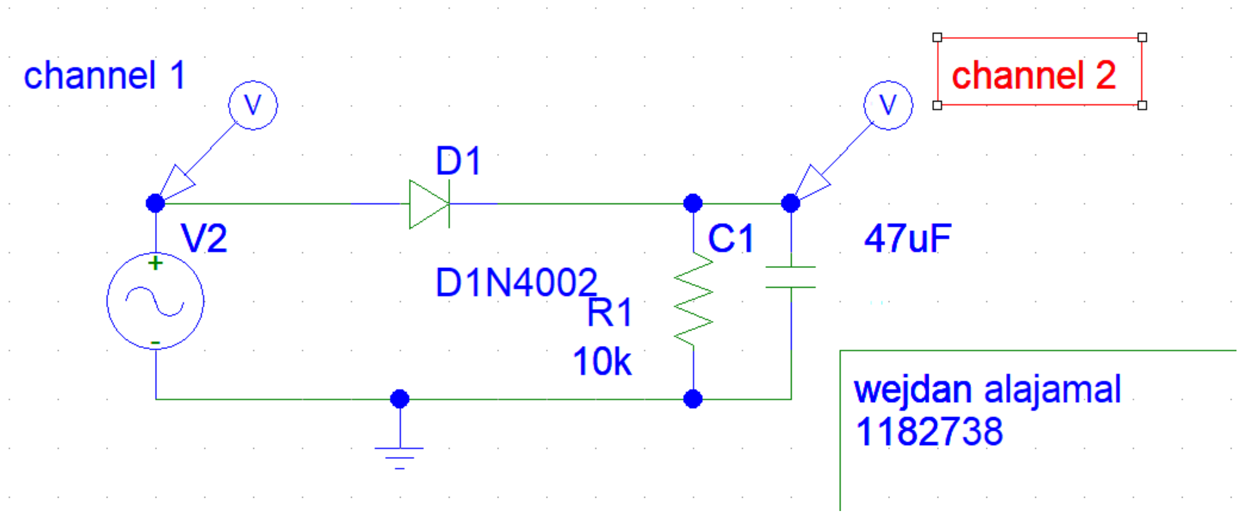

Figure 19Half-Wave Rectification circuit implementation after adding 47 µF capacitor

3.2.2 Full-Wave Rectification:

the circuit was connected using wires, four Diodes with type (D1N4148), resistor with value 10 kΩ and the signal generator to generate sinusoidal wave AC voltage source with 20 $Vp{-}p$ and frequency = 2000Hz to a feedback prototype board.

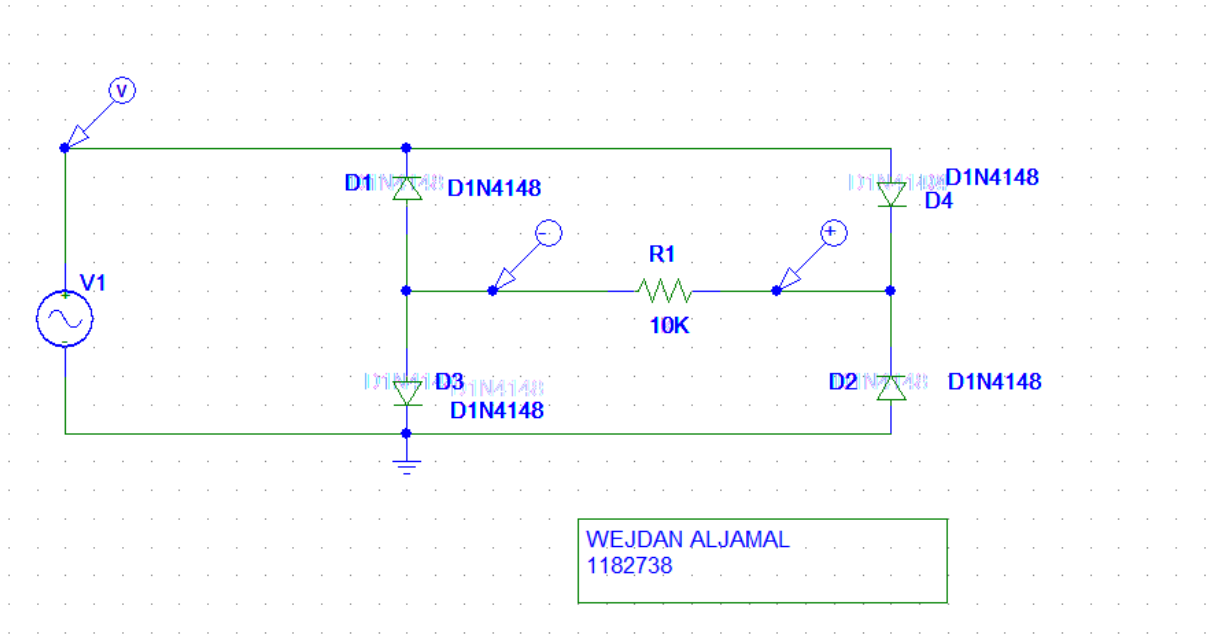

Figure 20Full-Wave Rectification circuit implementation

When the voltage response displayed on the oscilloscope screen, the peak voltage was taken to determine the value of the dc value Va , also the period was measured for the output voltage.

Adding capacitor of 2.2 μF

When the voltage response displayed on the oscilloscope screen, the peak to peak voltage was taken to determine the ripple factor after calculating the mean value of the output voltage

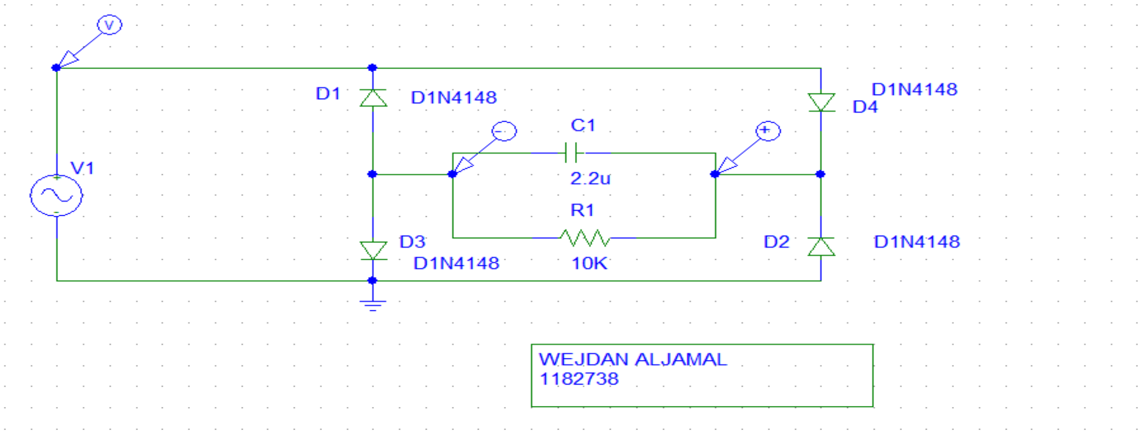

Figure 21Full-Wave Rectification circuit implementation after adding 2.2 µF capacitor

3.3 Other Applications

3.3.1 Clipping

This circuit was connected using wires, Diode with type (D1N4002), resistor with value 10 k Ω, dc power supply variable and the signal generator to generate sinusoidal wave AC voltage source with 6 $Vp{-}p$ and frequency = 200 Hz to a feedback prototype board.

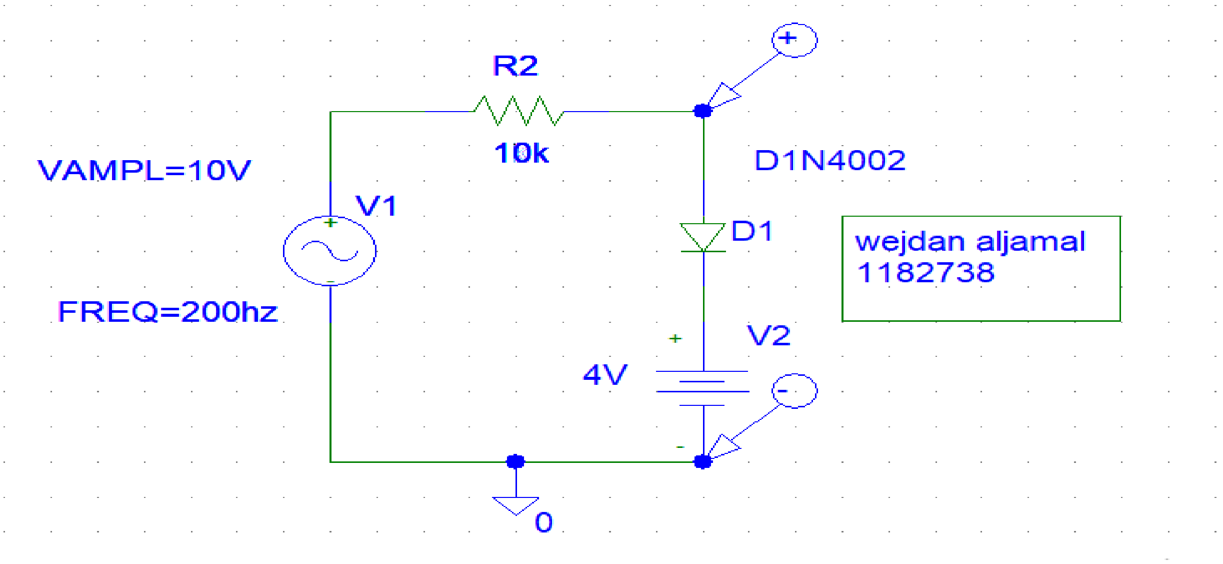

Figure 22Clipping circuit implementation

3.3.2 Clamping

in Figure 23 was replaced by 1 μF capacitor as seen in Figure 3.3.2.1 below.

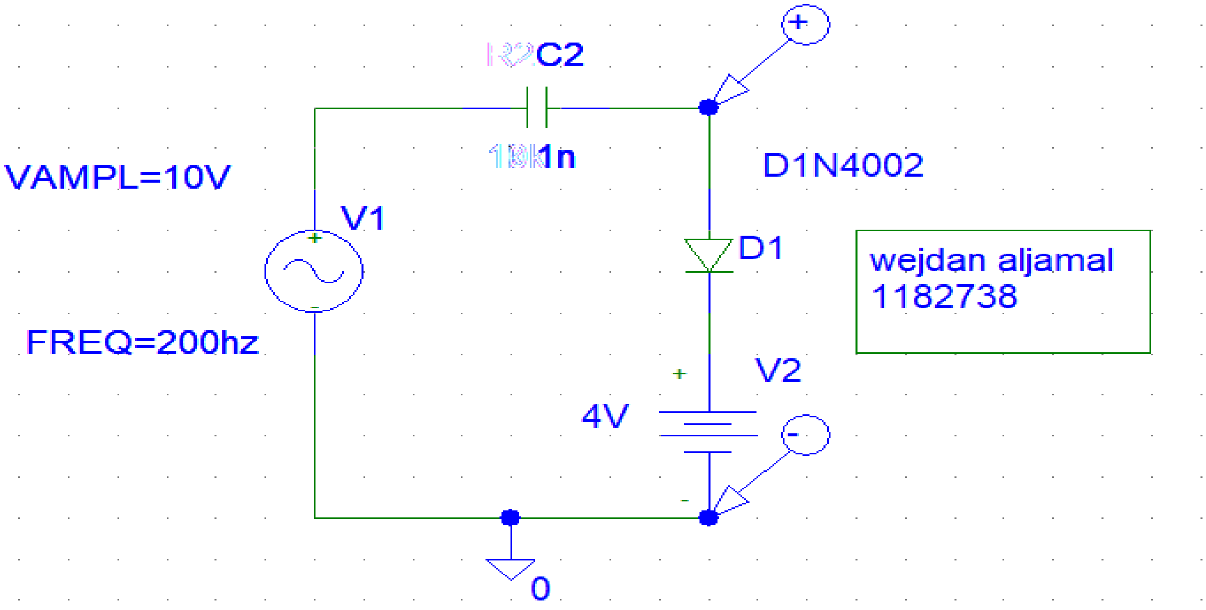

Figure 23Clamping circuit implementation

3.3.3 Voltage Multiplier circuits

the circuit in Figure 24 below was connected using wires, three Diodes with type (D1N914), three capacitors of 1 μF and the signal generator to generate sinusoidal wave AC voltage source with 6 $Vp\text{–}p$ and frequency = 1000 Hz to a feedback prototype board.

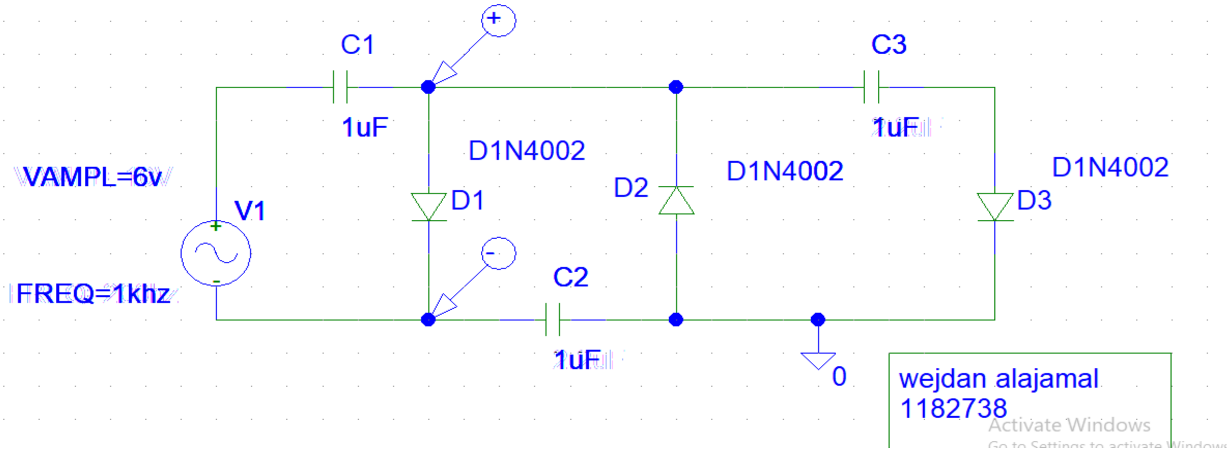

Figure 24Voltage Multiplier circuit implementation

4. Data, Calculations, and Analysis of results

4.1 Diode Characteristics:

the results of finding VR, VD and ID at different values of dc power supply using the output voltage response in Figure 25

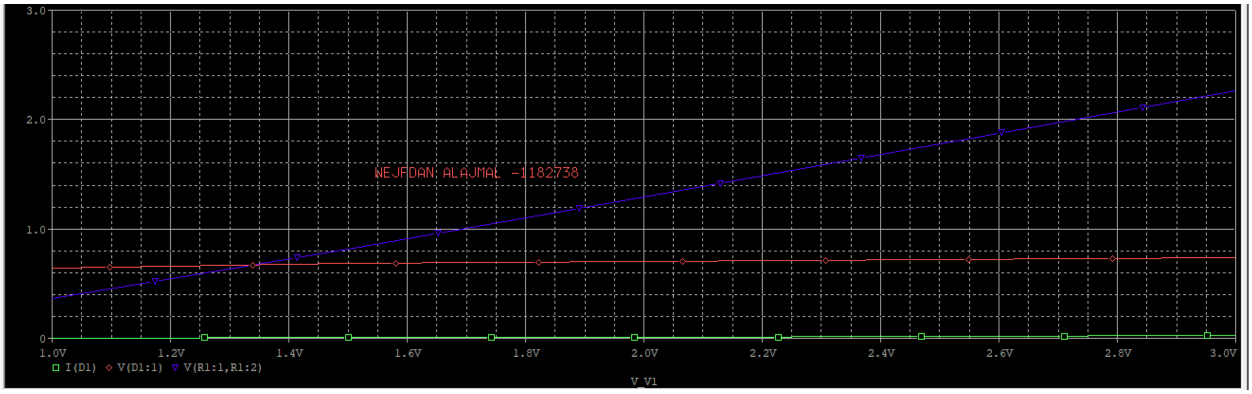

Figure 25Diode characteristic voltage response

VS	VR	VD	ID
0	0	0	0
0.1	0	0	0
0.2	0	0	0
0.3	0.7	0	0
0.4	0.004	0	0
0.5	0.0219	0	0
0.6	0.0442	0	0
0.7	0.102	0.598	0.00102
0.8	0.217	0.583	0.00217
0.9	0.26	0.64	0.0026
1	0.45	0.55	0.0045
1.5	0.84	0.66	0.0084
2	1.37	0.63	0.0137
2.5	1.85	0.65	0.0185
3	2.3	0.7	0.023

Figure 26 T able1: Diode characteristics results table

the diode is on since it is forward biased The current increases exponentially with the voltage. And it follows the equation below.

$ID = IS\,(e\,\frac{VD}{VT} - 1)$ (1)

Where ID is the current through the diode , VD the voltage across the diode the parameters IS and Vt are constants characterizing the diode. Is called the reverse saturation current and it is independent of the diode voltage VD. For silicon diodes it is 10-12 A or less. The parameter Vt = $kT\ q$ ≡ is called the thermal voltage. At room temperature 26 Mv.

Questions!!!

1) At what approximate value of VD does the current ID begin to rise noticeably?

We can notice that the current increases when the diode on (Forward), the voltage on the anode is more positive than cathode. We can see that from our results after 0.7Volt.

2) Does VD rise much above this value for larger values of ID?

The voltage of the diode stop increasing when it reaches approximately 0.7 while the current keep increasing.

3) What happens if the diode is reversed?

If the diode is reversed then it will be in the reversed biased condition since cathode voltage is greater than the Anode voltage. The reverse current remains constant over a large part of reverse voltage. When the reverse voltage of a diode is increased from the start, there is a very slight change in the reverse current. At the breakdown voltage (VBR) point, current increases very rapidly. The voltage across the diode remains reasonably constant at this time.

4.2 Rectification

4.2.1 Half-Wave Rectification

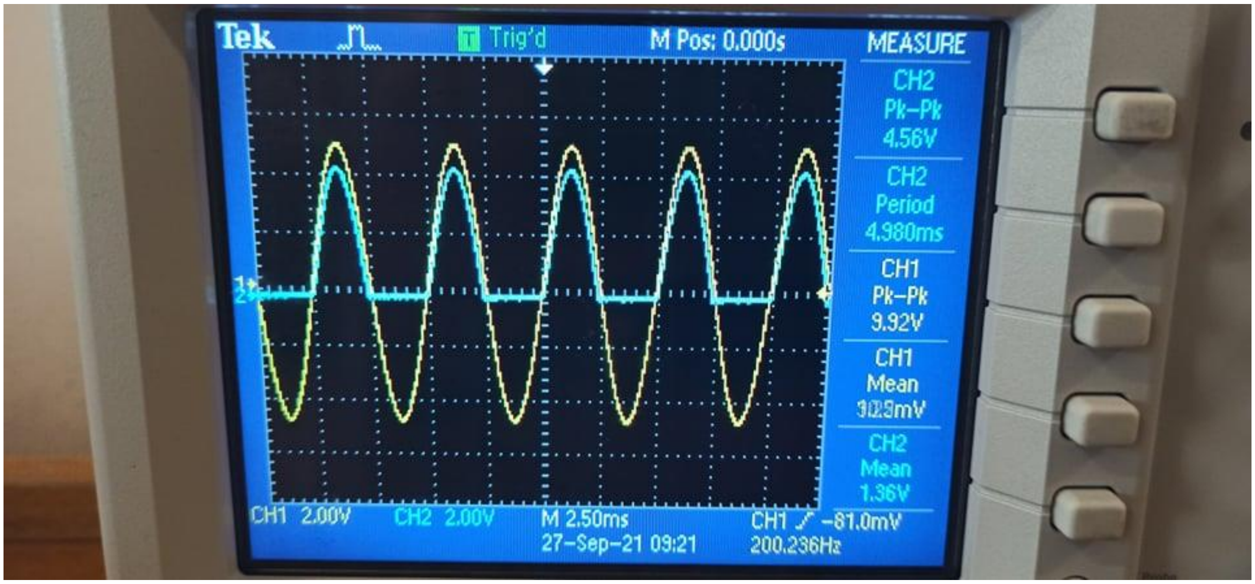

Figure 27 Half-Wave Rectification voltage response

- Period T and dc value:

$peak\ value\ Vpk$ (experimentally) = 4.56v

$$dc\ value = \frac{vpk}{\pi} = 1.4522v$$

$$T = \frac{1}{F} = \frac{1}{200} = 5MS$$

$$AC\ experimenthy = 1.682v$$

When the diode gets ON conduct for positive half cycles of input signal. Hence, a current flows in the circuit and there will be a voltage drop across the load resistor. The diode gets OFF for negative half cycles and hence the output for negative half cycles will be, Id=0 and Vo=0.

By comparing the observed value of Vpeak by the theoretical value we notice that there is a voltage drop approximately equal to the voltage threshold of the diode (0.7V).

Questions!!!

1) Is Vpk nearly equal to the peak voltage of the supply.

The Vpeak is less than the voltage of the supply .

2) Why will Vpk not be exactly equal to the source peak voltage ?

Because there is a voltage drop caused by the diode.

3) How much will it differ?

It is approximately equal to the voltage threshold of the diode (0.7)

4) How could you obtain a negative voltage relative to zero?

By reversing the diode we can get the negative half of the inpu

- **When Reverse the diode**

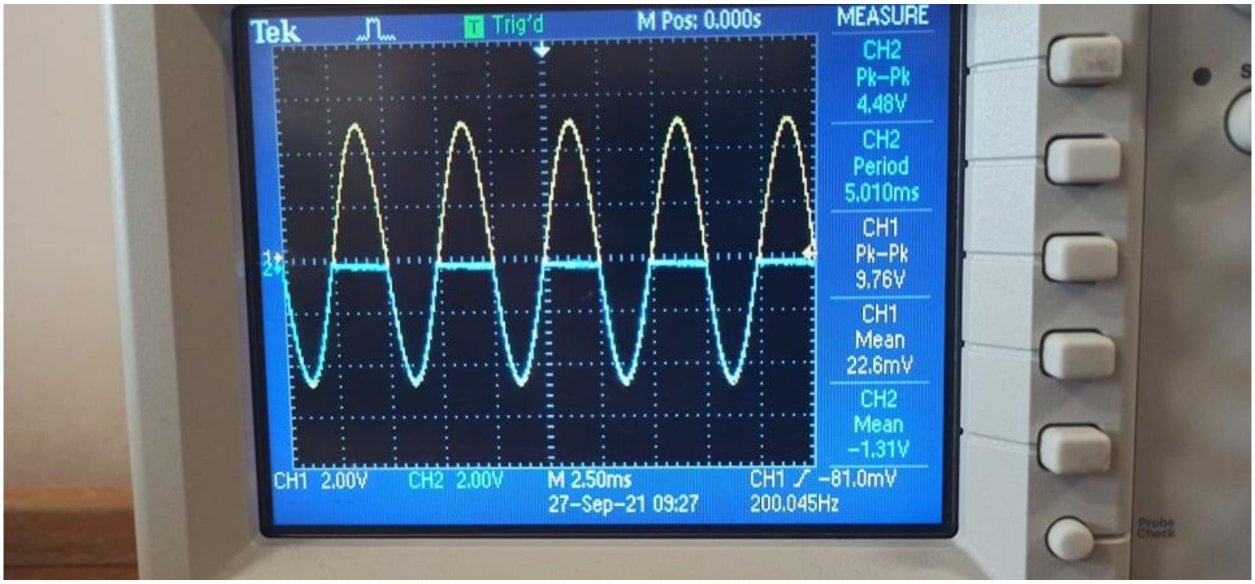

Figure 28 Half-Wave Rectification when reverse the diode voltage response

The diode gets OFF for positive half cycles and hence the output for positive half cycles will be, Id=0 and Vo=0.

- **When Adding C = 2.2 μF**

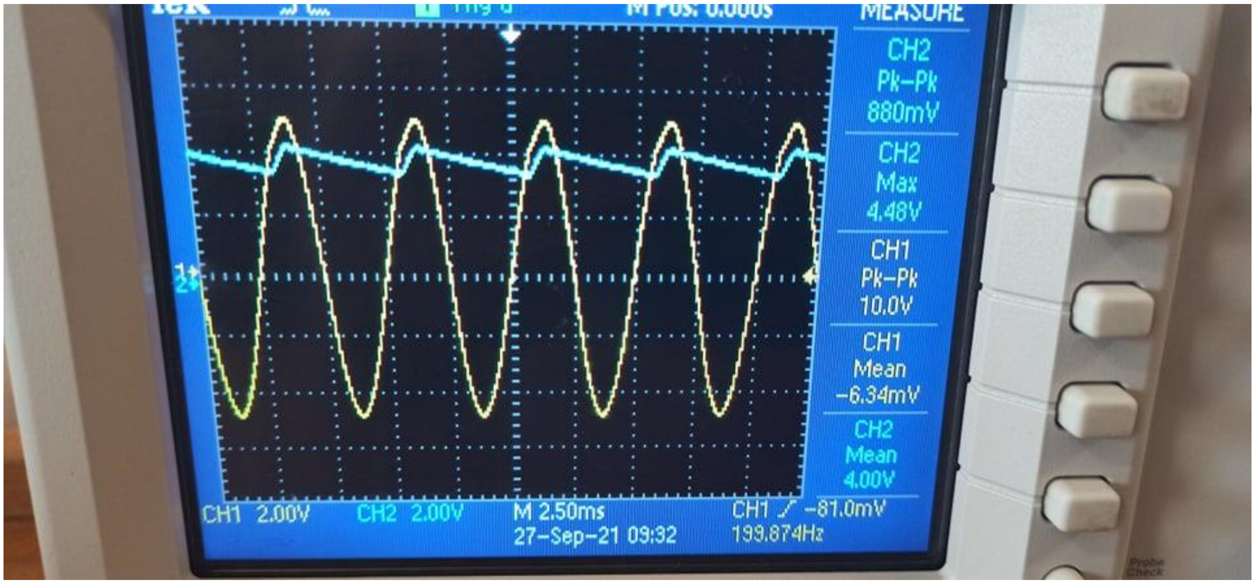

Figure 29Half-Wave Rectification when adding the capacitor of 2.2 µF voltage response

- dc value:

$$peak\ value\ Vpk\ (experimentally)\ =\ 4.48V$$

- $Vl,p-p = 4.48 - 4 = 0.48v$
- $dc\ value(expermintally) = vavg = vpk - 0.5vl,p-p = 4.48 - 0.5 * 0.48 = 4.24v$

- ripple factor:

$$r\%\ \text{theoriticall}\ = \frac{1}{\sqrt{3}[2 \times 200 \times 10 \times 10^{3} \times 2.2 \times 10^{-6} - 1]} \times 100\%\ =\ 7.4\%$$

- **Using C = 47 μF**

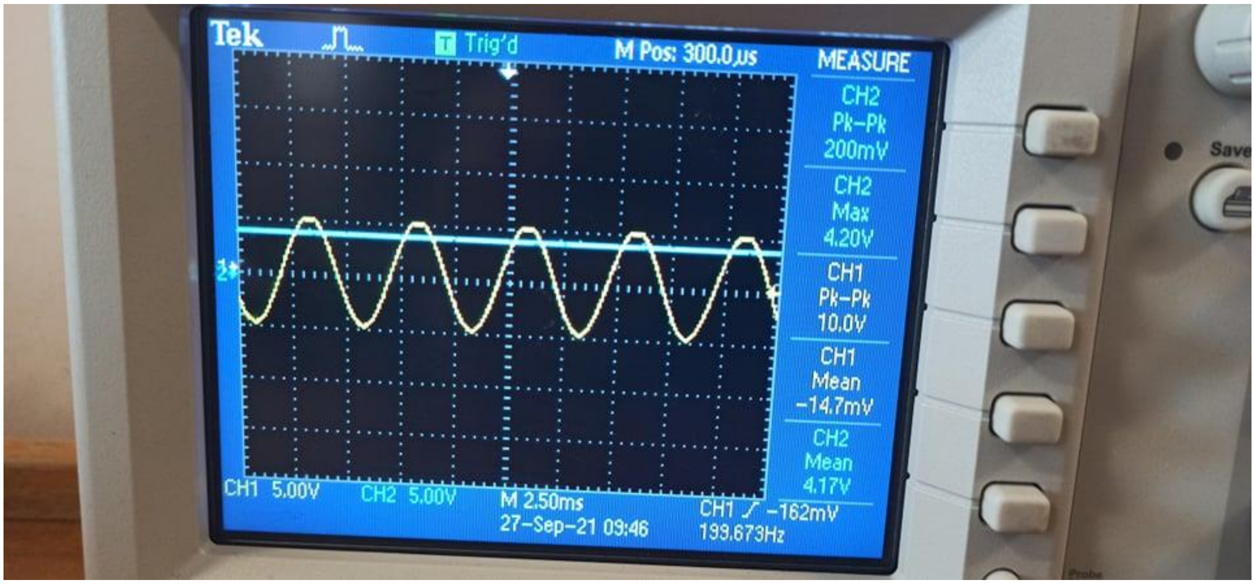

Figure 30Half-Wave Rectification when adding the capacitor of 47 µF voltage response

- Dc value

- $peak\ value\ Vpk\ (experimentally) = 4.20V$
- $Vl,p-p = 4.20 - 4.17 = 0.03\ v$
- $dc\ value = vavg = vpk - 0.5vl,p-p = 4.20 - 0.5 * 0.03 = 4.185v$

- Ripple factor

$$r\%\ \text{theoriticall} = \frac{1}{\sqrt{3[2 \times 200 \times 10 \times 10^{3} \times 2.2 \times 10^{-6} - 1]}} \times 100\% = 7.4\%$$

We conclude that when the capacitor's value is increased, the ripple factor decreases and the value of the mean voltage increases. The output of the Half Wave rectifier is passed through a capacitor so the output will be filtered Initially, diode is on and capacitor charges to VP - 0.7 V. While Vs < Vc , diode is off capacitor discharges through load resistor

Questions!!!!

1) Is the ripple now less than or more than it was with the lower value of the capacitor?
   Increasing the capacitive will reduce the ripple since the capacitor is inversely proportional to VLrp-p
2) Is the mean rectified voltage now greater or less?
   The mean is increased since the ripple factor is decreased.

4.2.2 Full-Wave Rectification

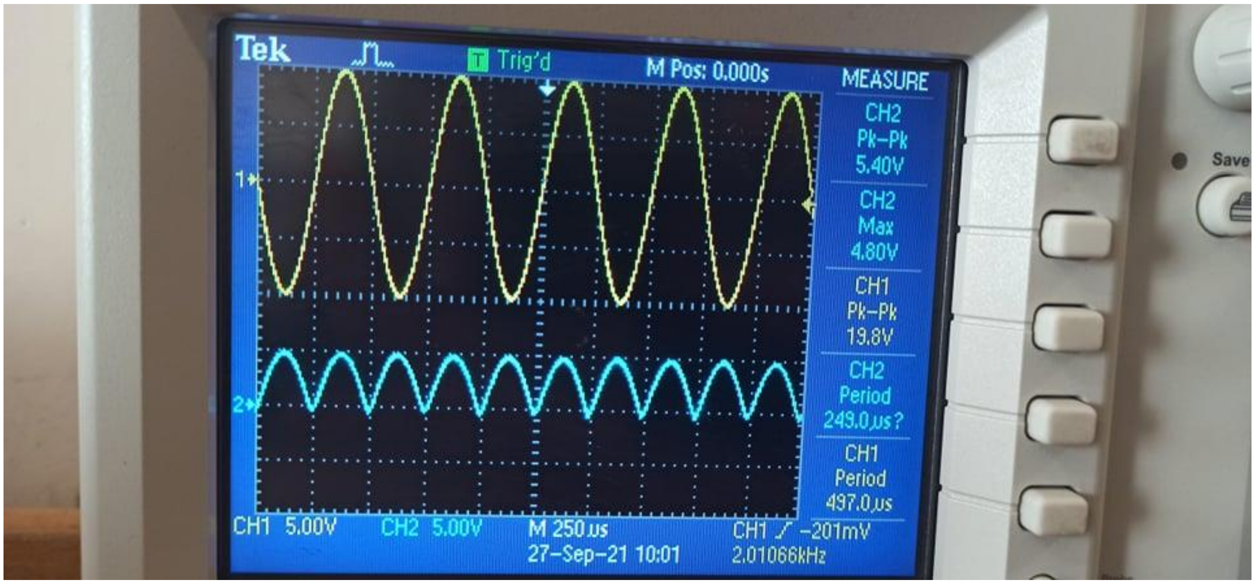

Figure 31Full-Wave Rectification voltage response

- **Period T and dc value:**

- $Vpk\ (experimentally) = 4.80$v

- $dc\ value = \frac{Vpk}{\pi} = 1.4267v$

- $T = \frac{1}{f} = \frac{1}{2000} = 0.5ms$

■ **When Adding C = 2.2 μF**

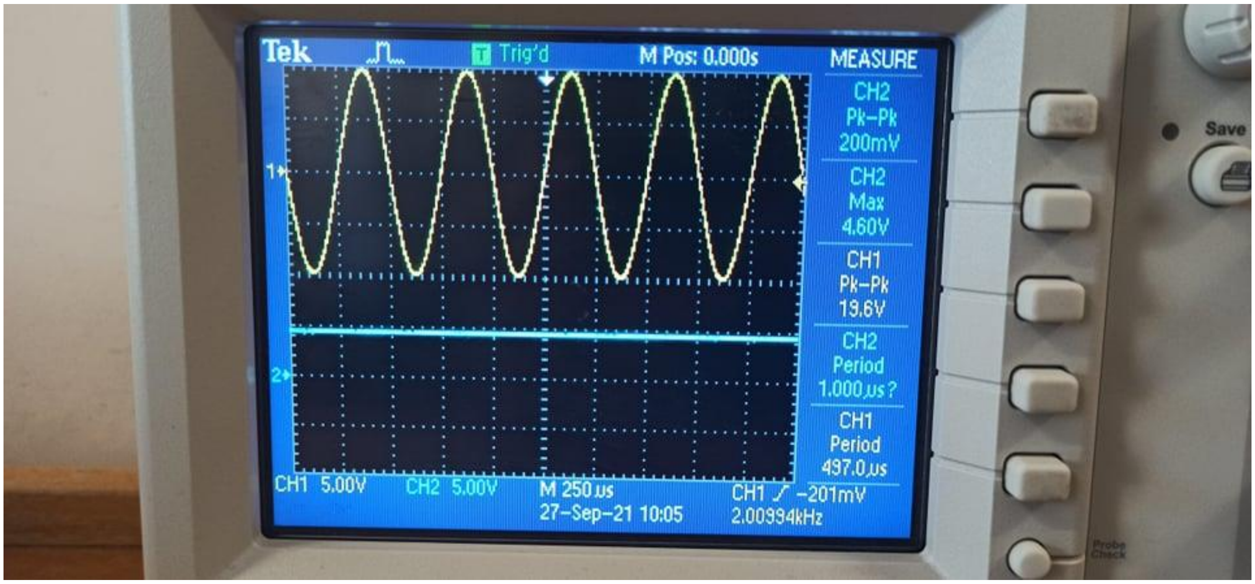

Figure 32Full-Wave Rectification when adding the capacitor of 2.2 µF voltage response

- **dc value:**

$v\ max = 4.6v$

$vp - p = 200mv$

- **ripple factor:**

$$r\%\ \text{theoriticall} = \frac{1}{\sqrt{3[4 \times 200 \times 10 \times 10^{3} \times 2.2 \times 10^{-6} - 1}} \times 100\% = 3.3\%$$

Placing a capacitor in parallel with the load, turns the circuit into a full-wave peak rectifier. It behaves essentially the same as the half-wave peak rectifier except with twice the frequency (half the period).

Questions!!!

1) When the capacitor connected, what is the change on the waveform, why?
The Full-wave waveform will be filtered using the capacitor.

2) Does the ripple voltage change with frequency?
Yes , since it is follows the below relation
$r\% \ (theoritically)$ = 1 √3 [$4f0RC$ − 1] $*$ 100%

2) What is the effect of frequency on the ripple?
When the input frequency is reduced, do you need a larger or a smaller capacitor to achieve the same ripple? Increasing the frequency will reduce the ripple factor , in-order to get the same ripple with reduced frequency we should increase the capacitor.

4.3 Other Applications

4.3.1 Clipping

When dc=0v

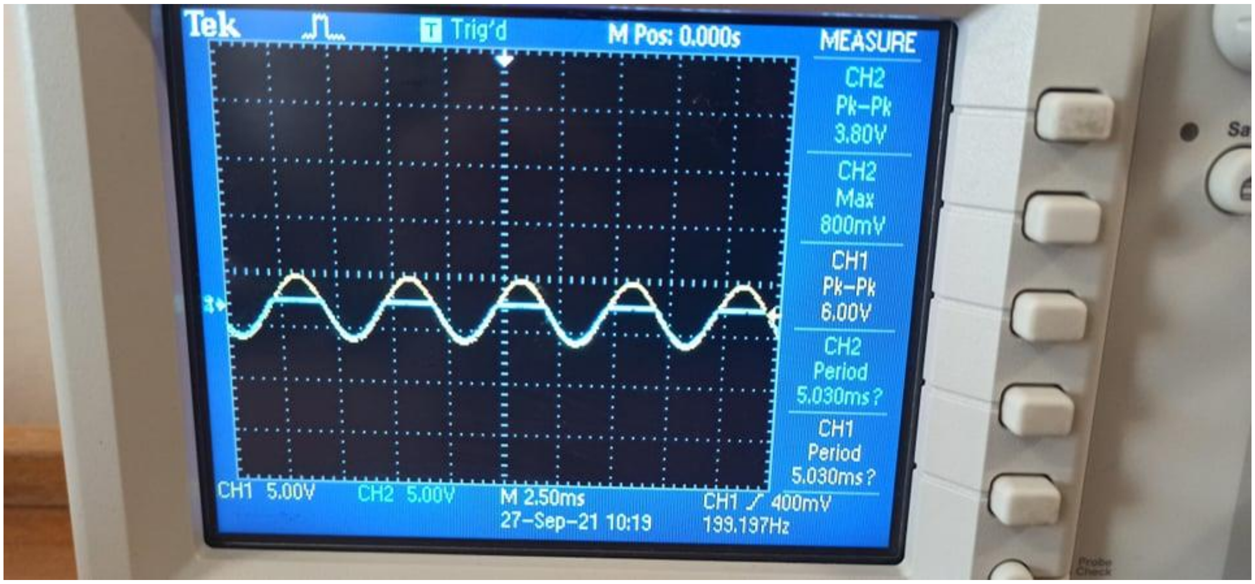

Figure 33 : Clipping voltage response dc=0v

When dc=1.5v

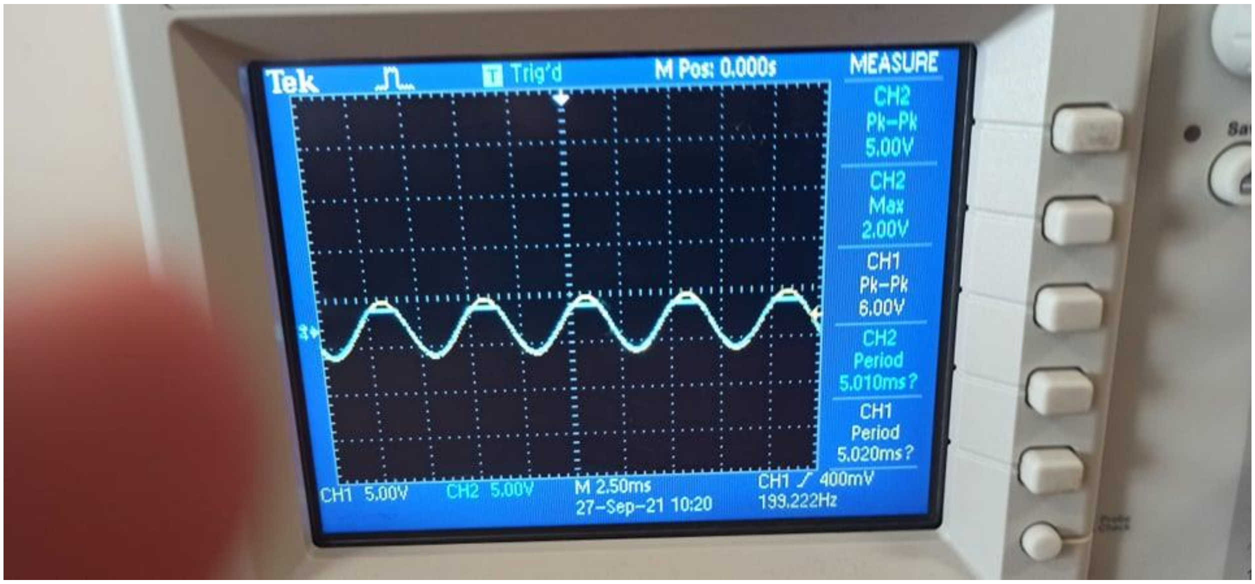

Figure 34 Clipping voltage response dc=1.5v

When dc=4v

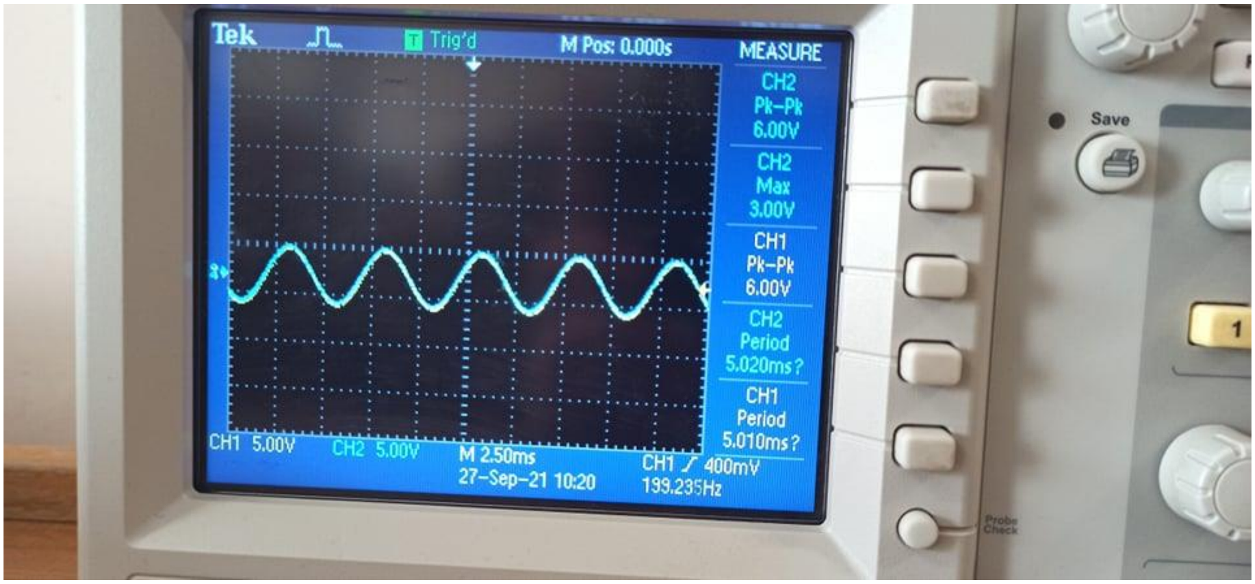

Figure 35Clipping voltage response dc=4v

Questions!!!

1- What difference is there between the input and output wave?

The difference is that the output is chopped

2- At what voltage is the output wave form chopped off?

when Vd+Vdc

3- If the dc is 2V, at what voltage are the positive peaks chopped off?

At 2.7

4- If the ac is 10V p-p, does the clipping voltage change?

Yes , since the waveform will not be chopped if the Vdc+Vd is greater than the input.

5- What is the relationship between the clipped level and the dc voltage in the two cases?

clipped level=Vdc+Vd

4.3.2 Clamping

When dc =0v

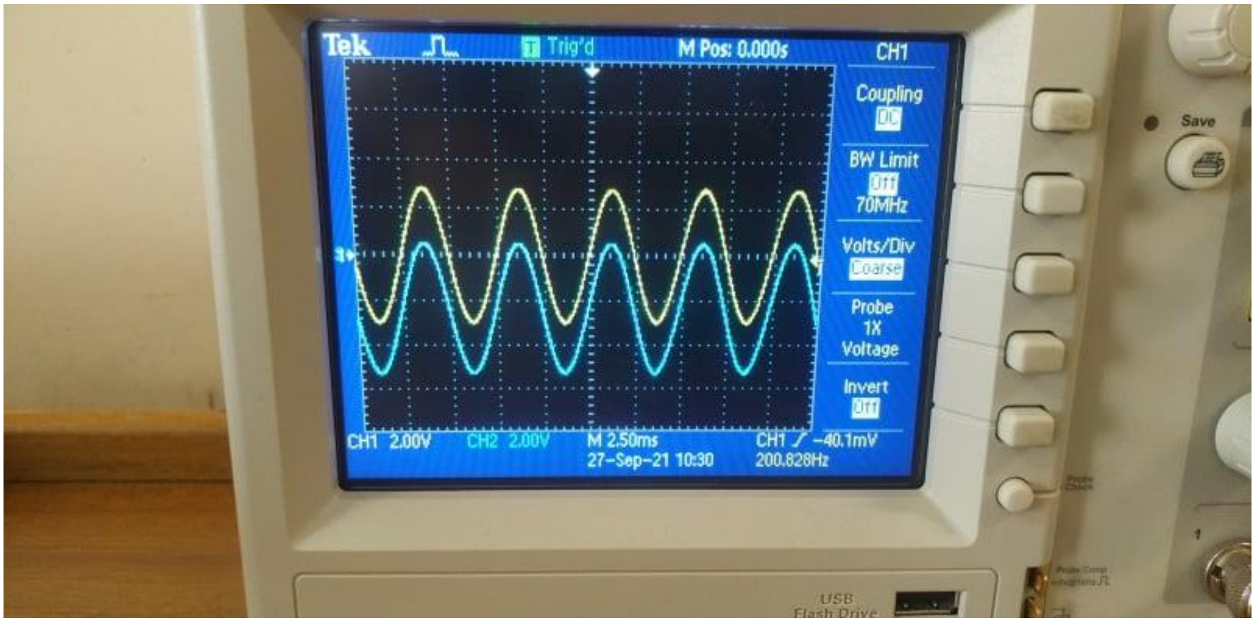

Figure 36Clamping voltage response dc=0v

When dc = 1.5 v

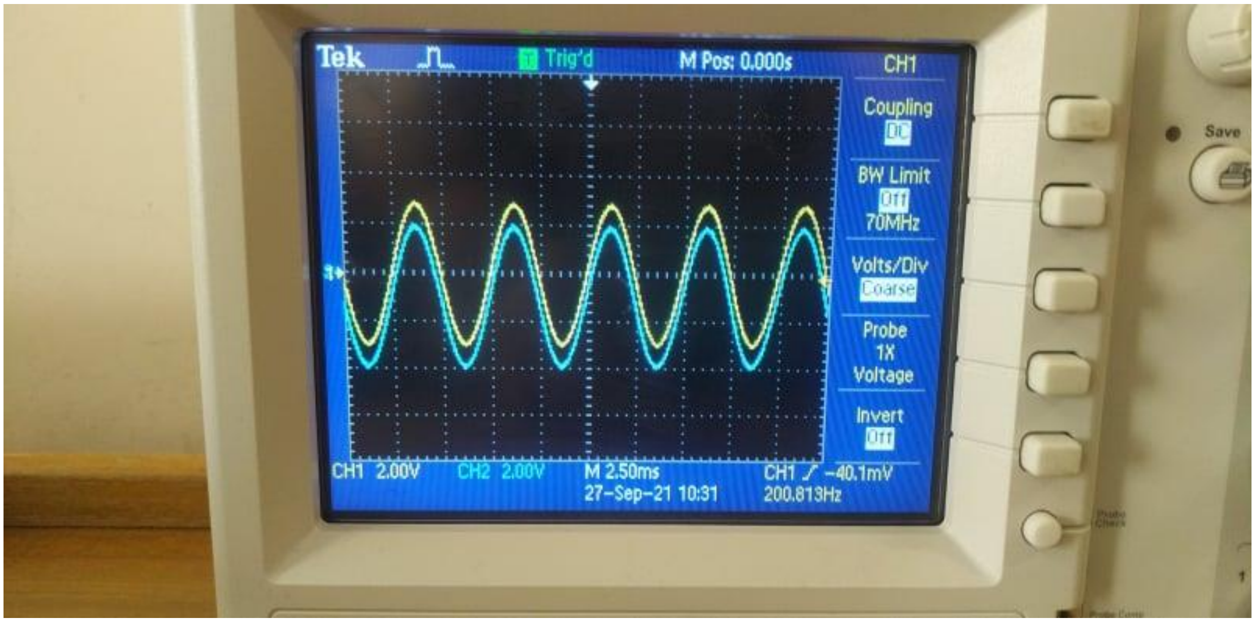

Figure 37Clamping voltage response dc=1.5v

When dc =4v

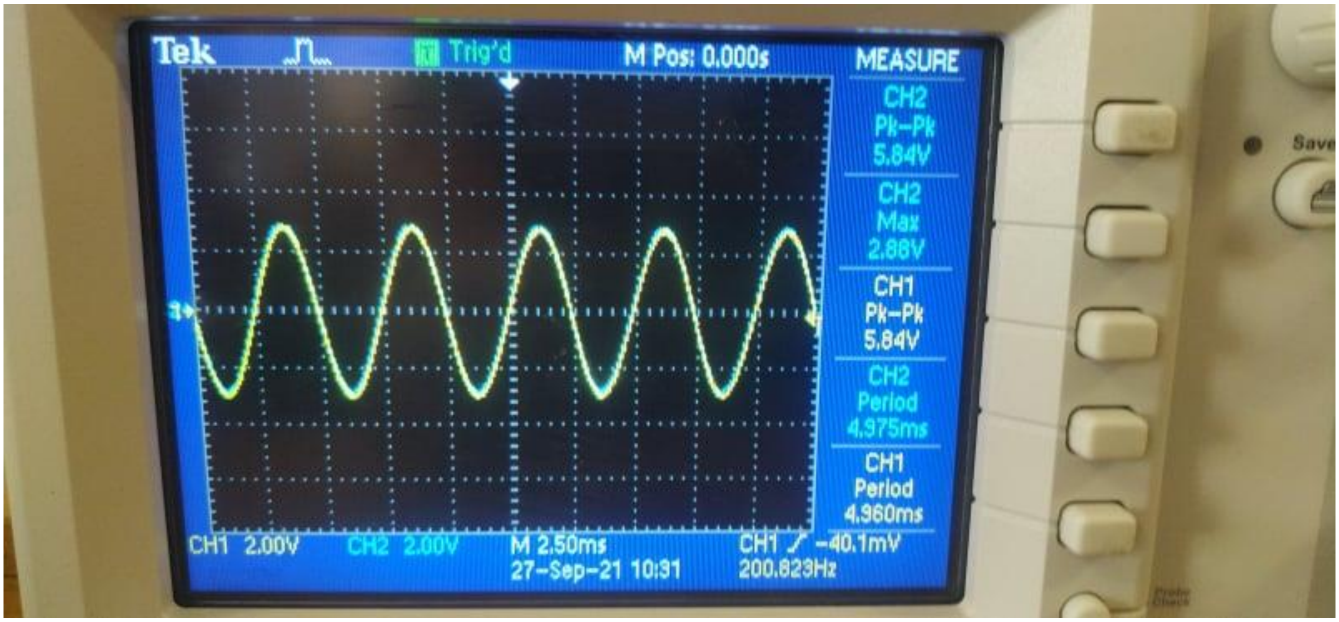

Figure 38 Clamping voltage response dc=4v

5. Conclusions

In this experiment, we learnt diodes characteristics, and how it behave, and so the its main operation is rectification since it passes the current in one direction and blocks it in the other one. We also learnt about some of its applications, such as half and full wave rectifiers, which used to convert AC Signals to DC (or may be pulsating DC which can be filtered for more smoothness), Clippers and Clampers were also introduced, and it was understood how one can control the clipping or clamping level using a variable DC source. Finally, we saw the voltage multiplier, the doubler and the tripler, which used for increasing the input voltage using some diodes and capacitors, basically.

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