EXPERIMENT4

Rectifiers and Voltage Regulators (ac to dc Conversion)

Name:

ID:

OBJECTIVES:

- To experimentally explore an important application of diodes, namely rectificationand voltage regulation.
- To understand the importance of filtering and voltage regulation in the process ofac to dc conversion.
- To learn and apply some practical design tips for designing simple ac to dcconversion system.

MATERIALS:

- Laboratory setup, including plug-in panel or a proto-board
- 1 center-tapped transformer
- 2 silicon diodes (Si) (e.g., the 1N4001 rectifier diode)
- 1 Zener diode
- 2 electrolytic capacitors (10 μF, 470 μF)
- 2 resistors (4.7 kΩ, 270 Ω)
- Several wires and bridging plugs

INTRODUCTION

Electronic equipment needs dc power supply to operate. A block diagram of such asystem is shown in Fig. 4.1 [1]. This system involves rectification, filtering and voltage regulation.

A **power transformer** is used to step down the input ac voltage and provide electrical isolation, which is important for safety. A **diode rectifier** uses the unidirectional-current property of diodes to convert an input sinusoid to a unipolar butpulsating output. Acting as a simple low-pass filter, a **filter capacitor** is used to reduce the **ripple** (pulsation) of the resulting output waveform.

The output voltage peak-to-peak ripple $V_{r(pp)}$ is inversely proportional to R_L, or equivalently directly proportional to the dc load current I_L, and inversely proportionalto the capacitance C of the filter capacitor. Therefore, a **shunt voltage regulator** (seethe dotted box sub-circuit in Fig. 4.3) is needed to help keep the dc output voltage fixed *despite possible variations in the load current and/or the ac input voltage*.

There are two main implementations of a full-wave rectifier: the one that utilizes a **center-tapped** transformer and requires only two diodes (see Fig. 4.2) and the **bridge rectifier** that does not require a center-tapped transformer but requires fourdiodes. Please refer to the textbook by Sedra and Smith for further details [1].

Two important ratings are needed to be specified when an engineer needs to select diodes for a given rectifier design: the **p**eak **i**nverse **v**oltage (**PIV**) and current-handling capability. The PIV is the maximum reverse voltage that the diode ever experiences in a given circuit [4].

A manufacturer's **datasheet** gives detailed information on a device so that it canbe used properly in a given application. Appendix C shows the datasheet for general- purpose rectifier diodes (1N4001 – 1N4007).

In those datasheets, manufacturers list a number of important maximum ratings:the **R**epetitive **R**everse voltage **M**aximum that can be applied across the diode, $\mathbf{V_{RRM}}$, the maximum average rectified forward current at T_A=75°C, $\mathbf{I_{F(avg)}}$, and the maximum not repetitive forward **surge** current the diode can sustain, $\mathbf{I_{FSM}}$.

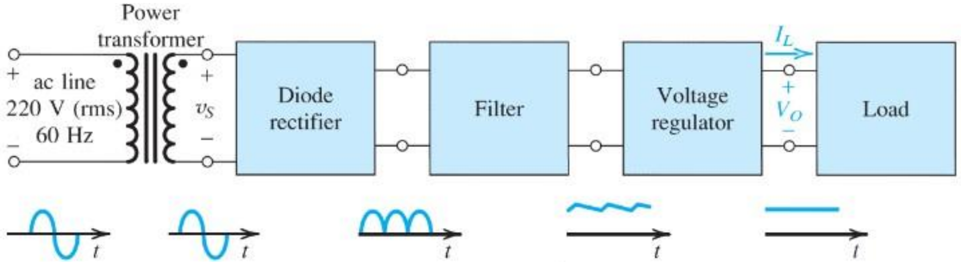


Figure 4.1 A block diagram of a dc power supply [1].

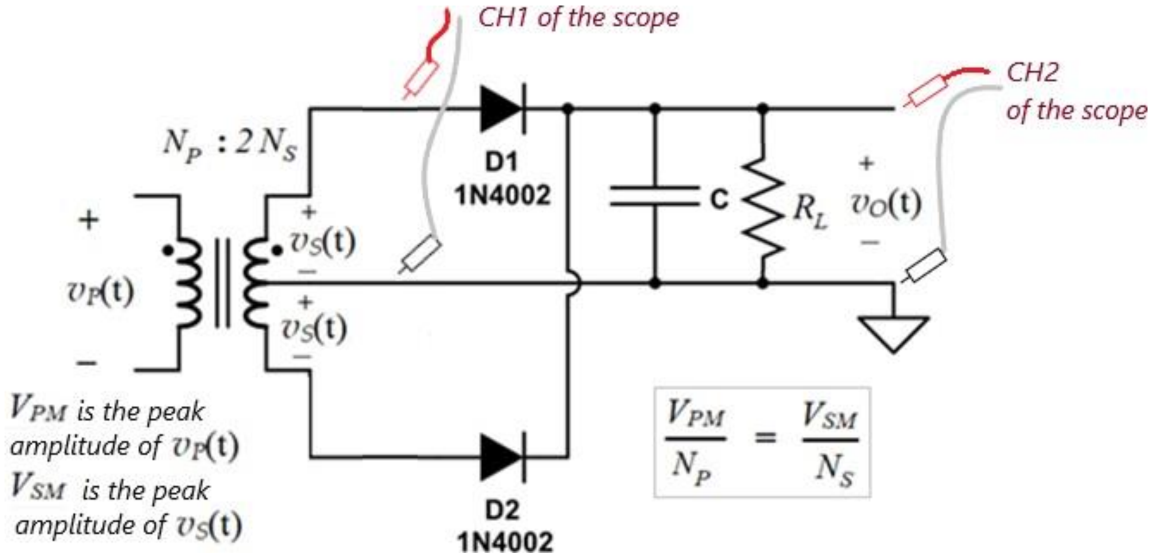


Figure 4.2 Rectifier circuit which uses a center-tapped transformer, with a filter capacitor.

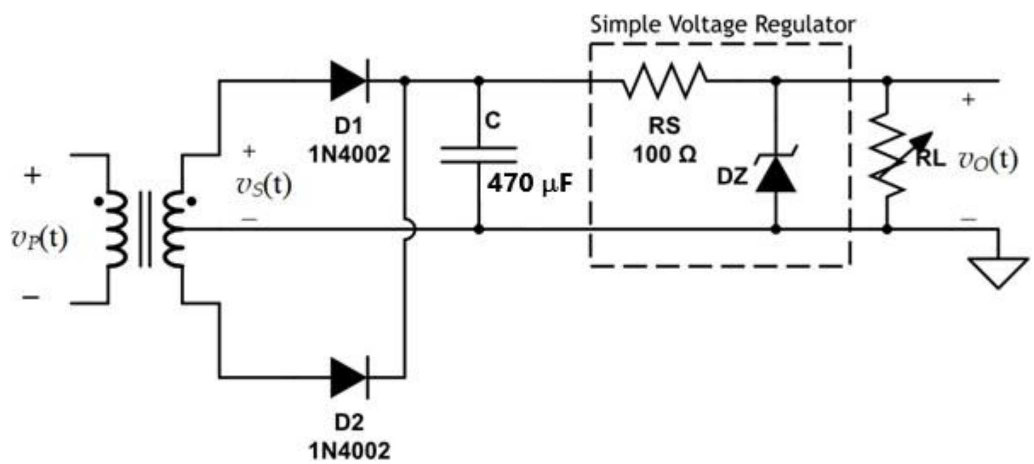


Figure 4.3 Simple Regulated dc Power Supply.

PROCEDURE A

The Rectifier Action:

Assemble the circuit shown in Fig. 4.2, with $R_L = 4.7\ \mathrm{k\Omega}$, and initially ***without*** acapacitor.

1. Use a coaxial cable to connect the input of your circuit, *as shown on the circuitdiagram*, to **CH1** of an oscilloscope, and another cable to connect the output of your circuit to **CH2** of the scope.
2. Turn on your scope.
3. Connect the transformer to an appropriate ac power outlet.
4. If not already activated press the **CH1** key of the scope.
5. Use the leftmost bottom-menu key to select **DC** from the ***coupling*** options, thenpress the **Menu OFF** key.
6. If not already activated press the **CH2** key of the scope.
7. Use the leftmost bottom-menu key to select **DC** from the ***coupling*** options, thenpress the **Menu OFF** key.
8. Use the **POSITION** knobs of both channels of the scope to align the zero referencefor the input and output waveforms at the centerline of the grid. The zero reference is indicated by the symbol .
9. Use the **SCALE** knobs of **CH1** and **CH2** to obtain a scale of **5 V/div** for each one.
10. If necessary, use the **SCALE** knob from the ***Horizontal*** **Controls** to obtain anappropriate timebase (time/div) to display convenient number of cycles.

11. Press the **Measure** key. Select **Add Measurement** from the bottom side menu. Select **V/I** from the right side menu. Use the **VARIABLE** knob to highlight the appropriate item (**Pk-Pk, Max. Min. and Mean**) then press the **Select** key to addanyone of them.

12. Change the right-side menu option **Source 1** to **CH2**,

    then add all themeasurements for **CH2** as well.

13. To add frequency measurement for the output, select **Time** from the

    right side menu. Use the **VARIABLE** knob to highlight the

    Frequency, then press the **Select**key.

14. Press the **Menu OFF** key twice.

15. Record the waveforms of v_S(t) and v_O(t) Fig. 4.4.

Read off the automatic measurements for v_S(t) and v_O(t) waveforms from thescope and enter them in Table 4.1

PROCEDURE B

Solving the Load-Dependent Ripple Problem by Using a Voltage Regulator:

16. Disconnect the transformer from ac power.

17. Append a voltage regulator to the original circuit and relocate R_L

    to its new position, in parallel with D_Z (see Fig. 4.3). Initially use

    the 4.7 kΩ resistor as aload.

18. Relocate the two leads of the coaxial cable connected to **CH2** of the

    scope to putthem across R_L in its new position.

19. Reconnect the transformer to ac power.

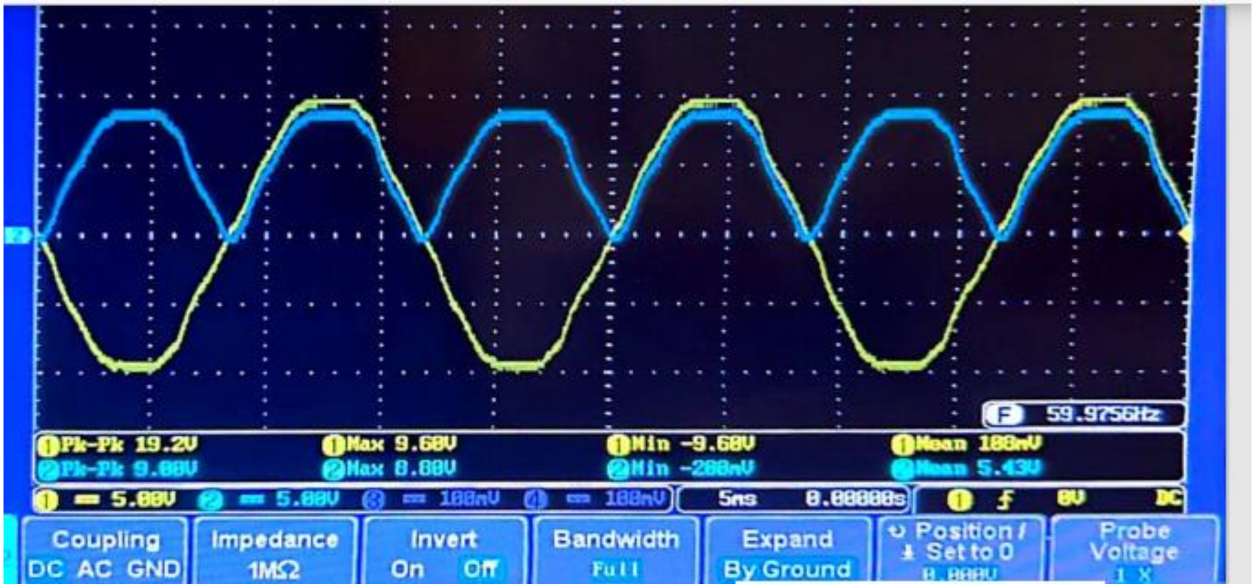
20. Observe how the output waveform *peak to peak ripple* changes as you reduce R_L

    from 4.7 kΩ to 270 Ω. Calculate the ***change*** in the peak to peak ripple, i.e.

    $\Delta V_{r(pp)}$, of the output and record that in Table 4.2.

21. Compare this change to the change you observed in step 27 of Procedure A.

Procedure A: The Rectifier Action
Observations



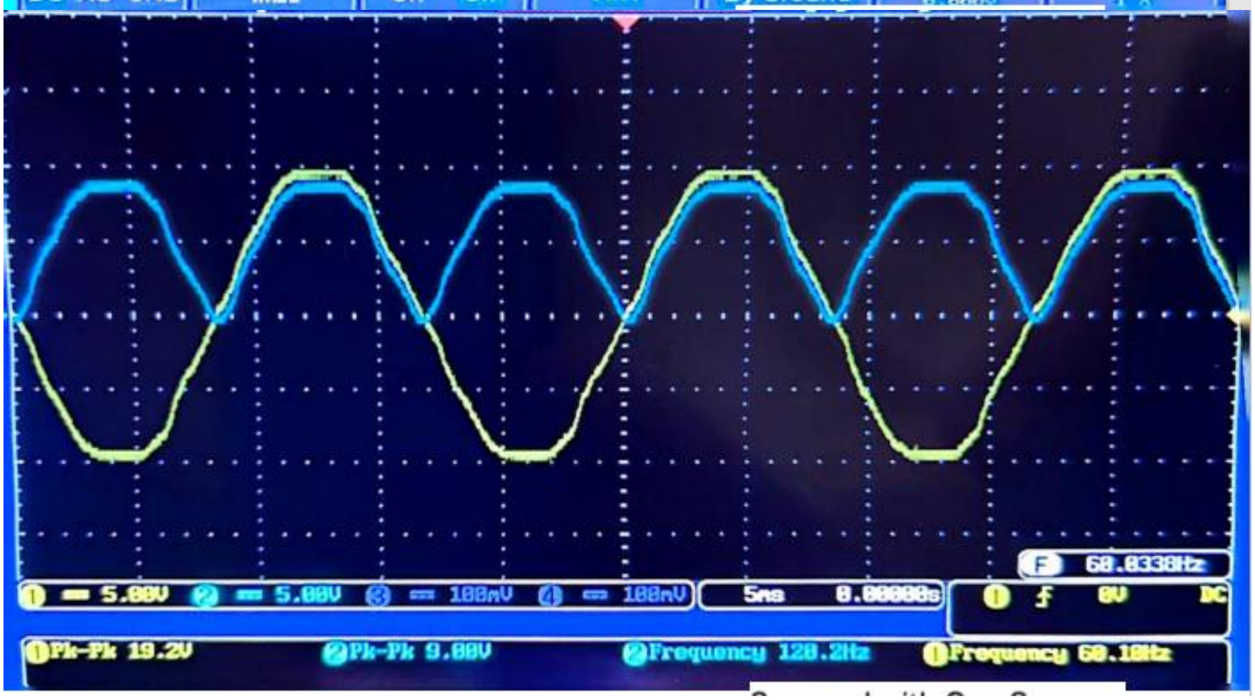


Table 4.1: Observations from Figure 1 & Figure 2

Measurement	**vS(t) (CH1)**	**vO(t) (CH2)**	**Frequency**
Pk-Pk	19.2V	9.88V	60Hz
Max.	9.68V	8.88V	120Hz
Min.	-9.68V	-20V	
Mean	108mV	5.43V	

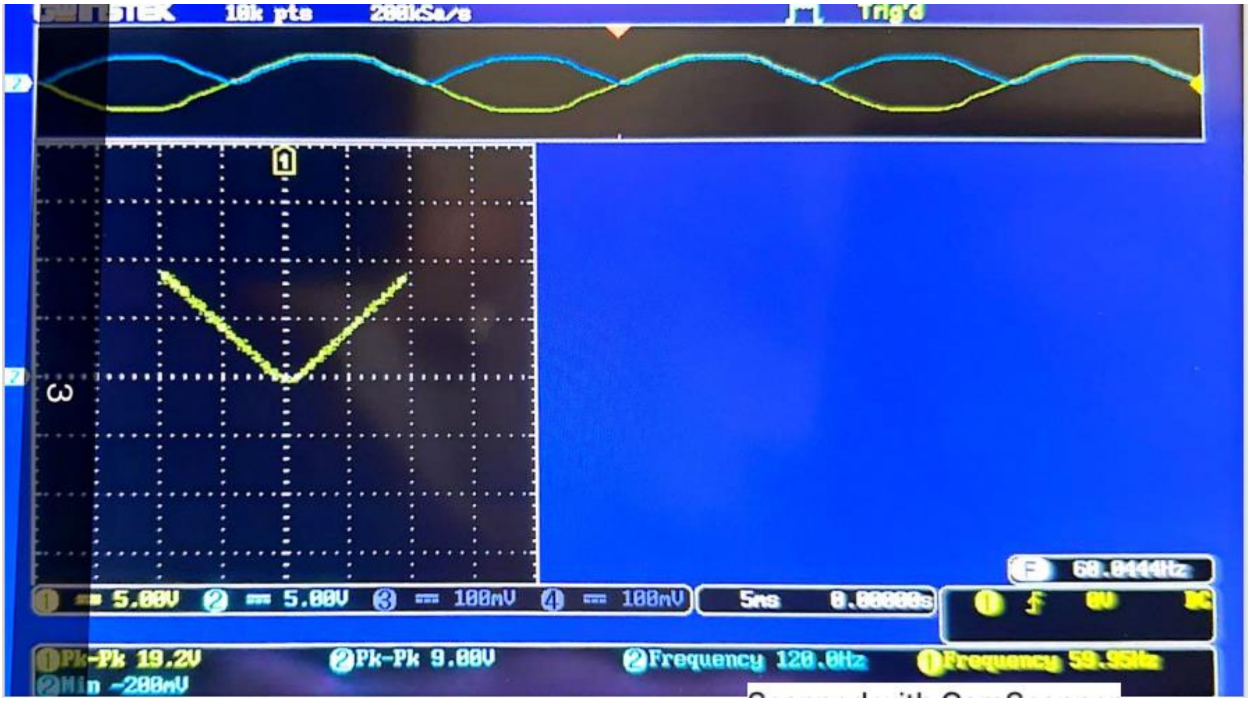


Figure 3:
The waveform becomes flattened at the input where the waveform is negative. On the output, all waveforms are positive in all intervals equally. The oscilloscope shows a V-shaped waveform with equal magnitudes on both the positive and negative x-axis.

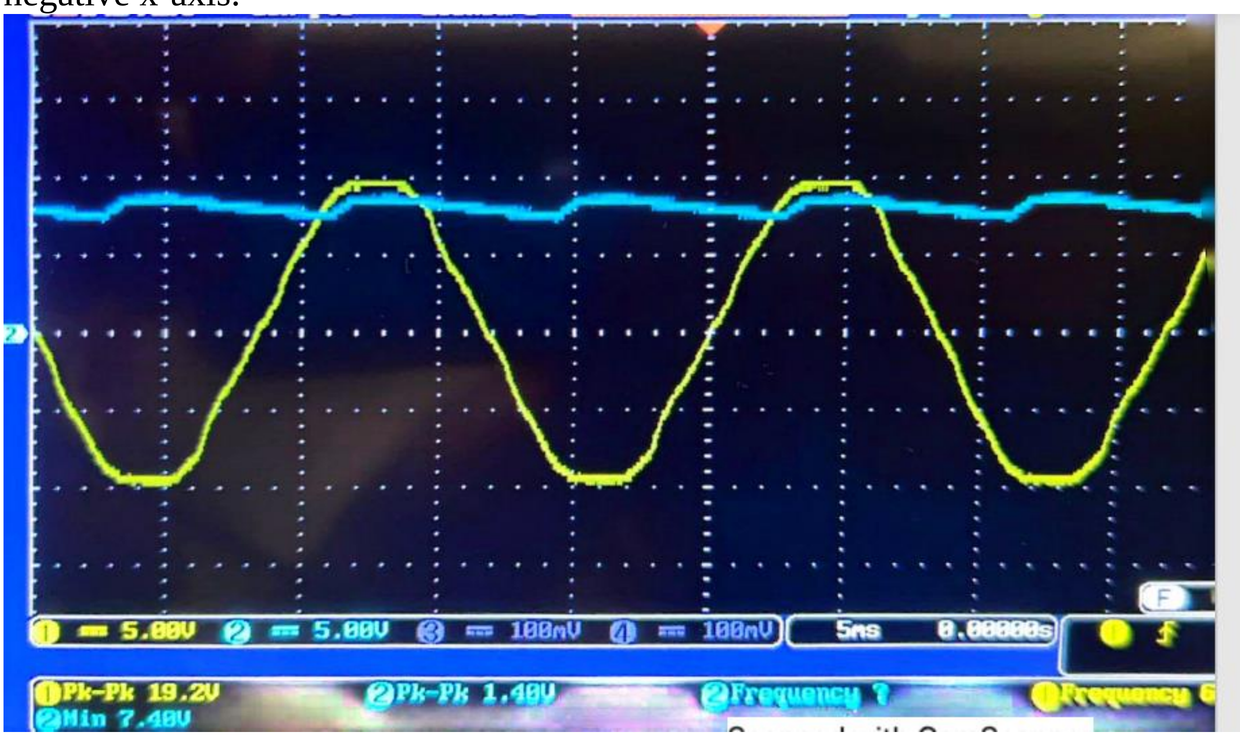


Figure 4:
The filtered waveform has the following characteristics:

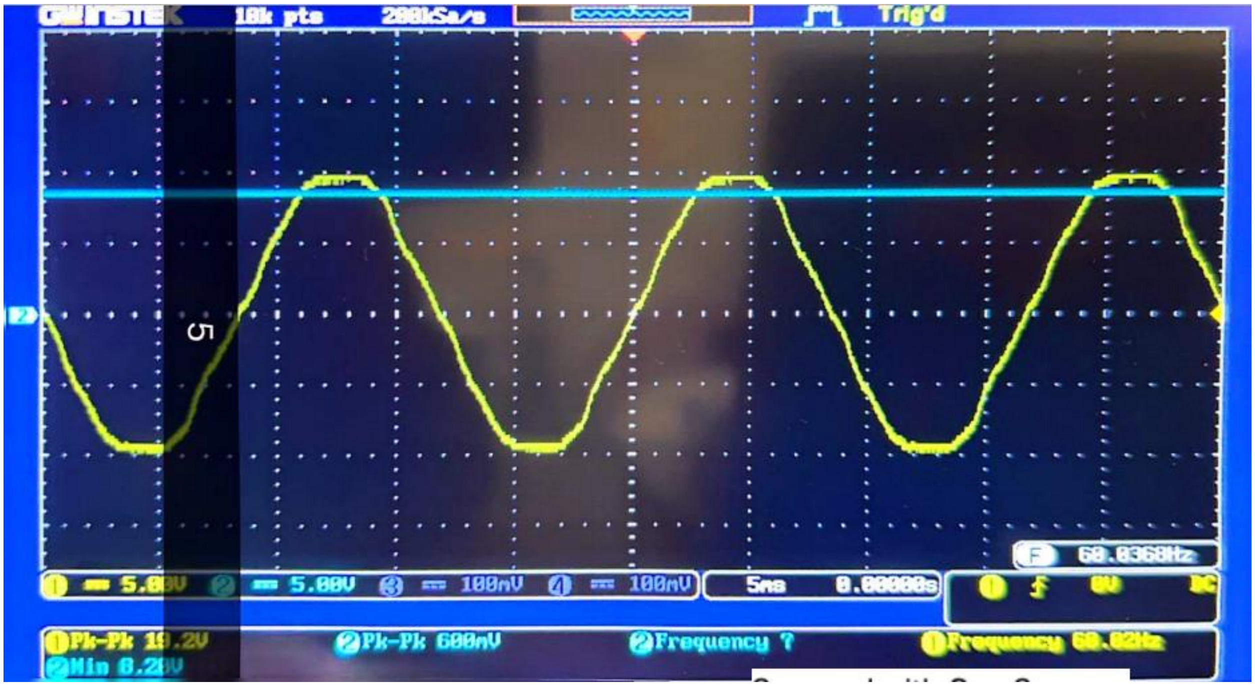
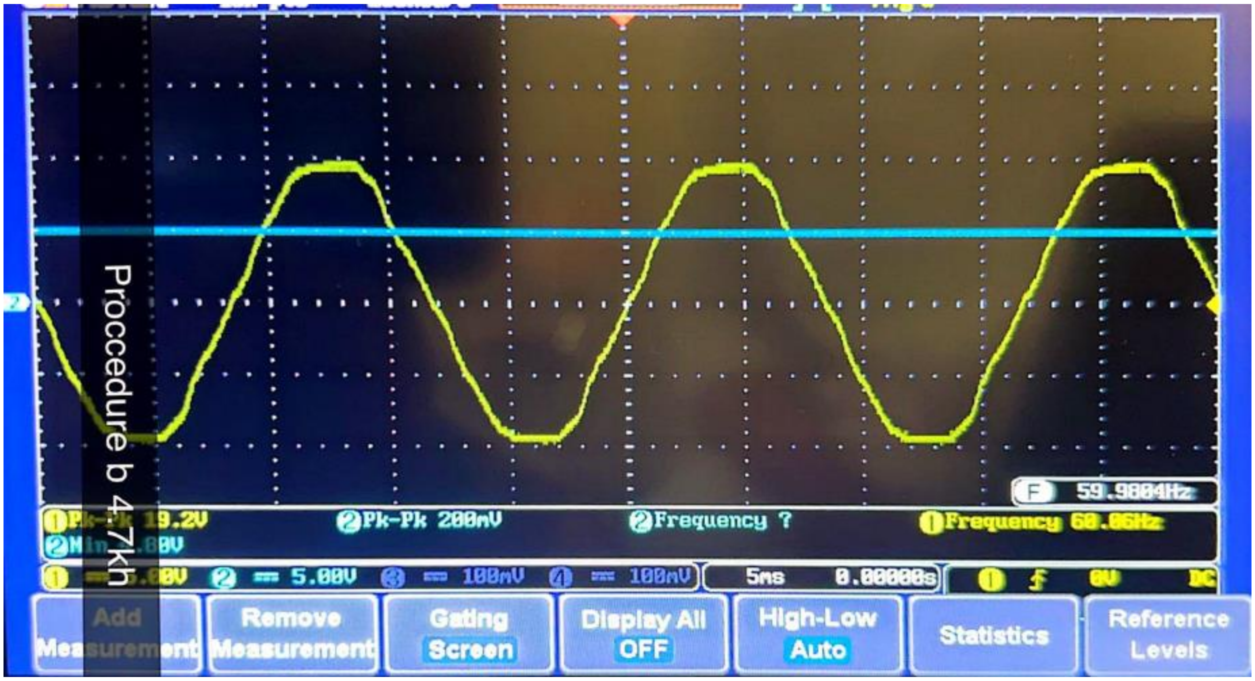
Pk-Pk: 1.40V
Min: 7.40V


Figure 5:
The output is a complete DC waveform with the following characteristics:

Pk: 600mV
Min: 8.28V

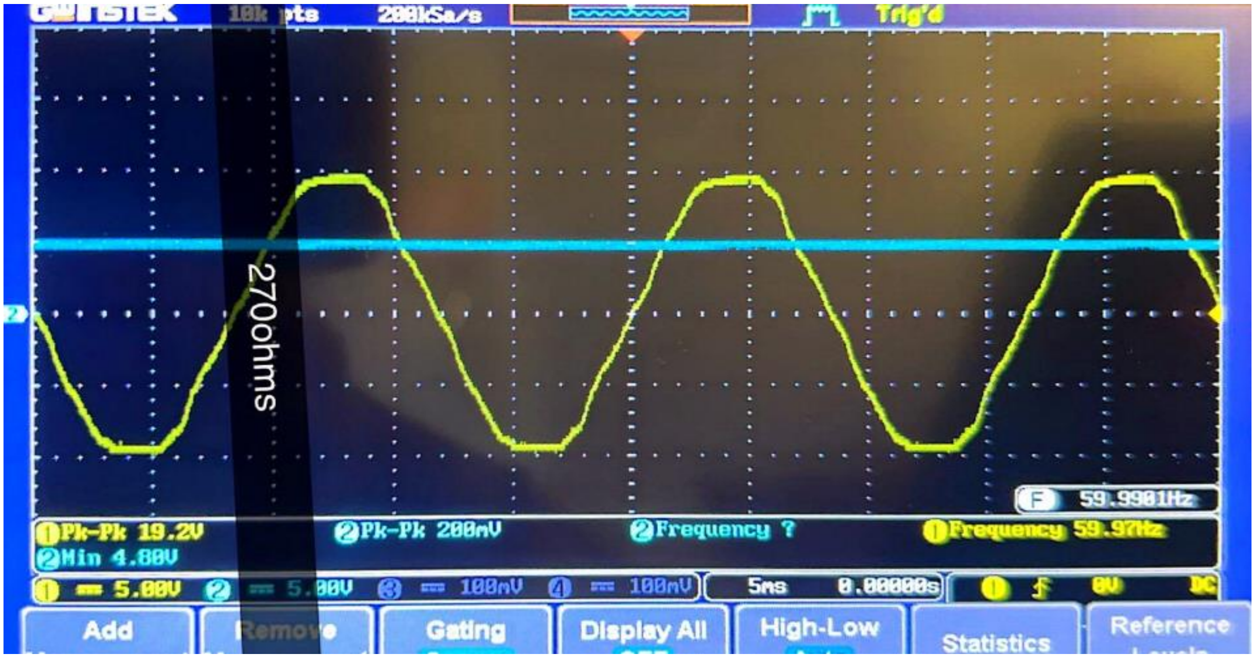

Figure 6:
The output DC waveform is slightly distorted, showing:

Pk-Pk: 600mV
Min: 8.00V



Procedure B: Solving Load-Dependent Ripple Using Voltage Regulator
Observations
Table 4.2: Observations for Procedure B

Measurement	**vO(t) (CH2)**	**Frequency**
Pk-Pk	200mV	60Hz
Min	4.88V	



When a 4.7 kΩ resistor is used, the output is as above.
With a 270 Ω resistor, the output remains the same,
indicating that the voltage regulator is effectively maintaining the output characteristics.

Discussion and Analysis
Procedure A: Rectification
Half-Wave Rectification

Figures 1 and 2: In both figures, the input signal has a pk-pk of 19.2V, a max of 9.68V, and a min of -9.68V. The output signal, however, is different with a pk-pk of 9.88V, a max of 8.88V, and a min of -20V.

Frequency Change: One interesting observation is the frequency doubling from 60Hz to 120Hz. This is a classic symptom of a full-wave rectifier, where both half-cycles of the AC signal are used, effectively doubling the frequency of the waveform.

Mean Value: It's notable that the mean value of the input is just 108mV, while for the output, it has dramatically increased to 5.43V. This indicates that the circuit is performing some kind of amplification or DC offset, in addition to rectification.

Full-Wave Rectification
Figure 3: Here, the negative waveform at the input is flipped to the positive side at the output. This indicates a full-wave rectification. The waveform is "V-shaped," implying a high degree of symmetry, which is usually a good sign in a rectifier circuit.

Procedure B: Filtering and Load Resistance

Filtering
Figure 4: The output has a pk-pk value of just 1.4V and a min value of 7.4V, indicating a filtered signal. The significant drop in the pk-pk value compared to the input suggests strong filtering action, likely smoothing out the waveform.

Figure 5: Here, we observe that the output has become a DC waveform with a pk of 600mV and a min of 8.28V. This could indicate a very well-filtered signal, approaching DC characteristics.

Load Resistance
Figure 6: With a 4.7kOhm resistor, the output shows minor distortions. The minimum voltage is 8.00V with a pk-pk of 600mV, which indicates the circuit is still maintaining most of its DC characteristics under load but showing some signs of stress or drop.

Figure 7: When the resistance is dropped to 270 Ohms, the output remains similar to that with 4.7kOhm. This could indicate that the circuit is robust to variations in load resistance, at least within the range tested.

Questions and Answers

1. **Observe what happens when you disconnect a bridging plug between D2 and the transformer. What kind of rectifier is this now?**

- Disconnecting a diode in a full-bridge rectifier circuit will effectively convert it into a half-wave rectifier. In a half-wave rectifier, only one half of the AC waveform (either positive or negative) passes through to the output, while the other half is blocked.

2. **How does the output peak to peak ripple change if the capacitance of the capacitor is increased?**

- Increasing the capacitance of the smoothing capacitor generally reduces the peak-to-peak ripple voltage at the output. A larger capacitor will store more energy and will be able to better "smooth out" the fluctuations in the rectified voltage, resulting in a more stable DC output.

3. **How does the output peak to peak ripple change if the value of RL is reduced?**

- Reducing the value of the load resistance (RL) would increase the current flowing through the circuit. This might result in a higher ripple because the capacitor will discharge faster between the peaks of the input AC signal. Therefore, a smaller RL would generally lead to a larger peak-to-peak ripple.

4. **Comment on the ability of the voltage regulator to reduce the ripple resulting from varying RL.**

- Without using a voltage regulator: Without a voltage regulator, the output ripple will be highly dependent on the load resistance and the capacitance of the smoothing capacitor. Any change in RL would have a direct impact on the ripple.
- Using a voltage regulator: A voltage regulator can significantly reduce the ripple by maintaining a constant output voltage despite variations in RL or the input voltage. Voltage regulators can be highly effective in "cleaning up" the ripple and providing a stable output voltage, even when RL varies.

Conclusion

Double Frequency in Half-Wave Rectifier: The data shows that the output frequency doubles when using a half-wave rectifier, as confirmed by the change from 60Hz to 120Hz.

Effect of Filtering: With filtering, the ripple voltage was significantly reduced, as seen in the change from Figure 4 to Figure 5.

Voltage Regulation: Voltage regulation was effective in maintaining output characteristics even when the load resistance changed from 4.7 kΩ to 270 Ω, as evident in Procedure B.

•A thorough understanding of how the elements of a rectifier circuit, such as diodes, load resistance, and smoothing capacitors, impact the output can aid in designing more efficient and stable power supplies. The use of a voltage regulator can substantially improve the quality of the DC output, making it less susceptible to variations in load conditions and other external factors.

Appendix

Input Frequency: The initial frequency was maintained at 60Hz for all experiments except the last, which does not specify the frequency.

Components Used: The experiment does not specify the types and ratings of the diodes, resistors, and capacitors used. These can have a significant impact on the performance of the circuit and should be noted for complete analysis.

Oscilloscope Settings: For a more detailed analysis, the settings on the oscilloscope used to measure these signals could provide additional insights.

Calculation for Mean: The mean value of voltage is usually calculated using specific mathematical formulas depending on the type of waveforms involved. Since these weren't specified, qualitative comparisons were made based on the provided values.

Theoretical vs. Experimental Values: It's important to compare these observed values to theoretical calculations based on circuit parameters to validate the experiment's success.