1. Objective:

The objectives of the lab include:

a) To become familiar with the operating principles of the diode.

b) Operation of half wave rectifier with R and RL loads and freewheeling diode.

c) Operation of full wave rectifier with R and RL loads and freewheeling diode.

2. Equipment Required:

Model	Name
8311	Resistive Load
8325-1X	Smoothing Inductors
8341	Single Phase Transformer
8412-1X	DC Voltmeter/Ammeter
8425	AC Ammeter
8446	Three Phase Wattmeter/Varmeter
8821-2X	Power Supply
8840	Enclosure/Power Supply
8842-1X	Power Diodes

3. Theory and Background:

3.1. Diode: A diode is a two-terminal semiconductor device. The two terminals are called the anode **A** and the cathode **K**. The diode operates as a high-speed switch which has no movable parts.

Figure 1: The diode symbol.

3.2. Half-wave Rectifier: The half-wave rectifier is so called because it delivers a half-cycle of dc output for every full cycle of the applied ac voltage.

With a **resistive load**, the circuit operates as follows: (see Figure 2)

a) $t_0 < t < t_1$:

The diode is forward biased and current flows through the resistor.

b) $t = t_1$:

The current becomes 0 and the diode turns off.

c) $t_1 < t < t_2$:

The diode is reverse biased because E is negative. The diode is therefore in the off- state and no current flows.

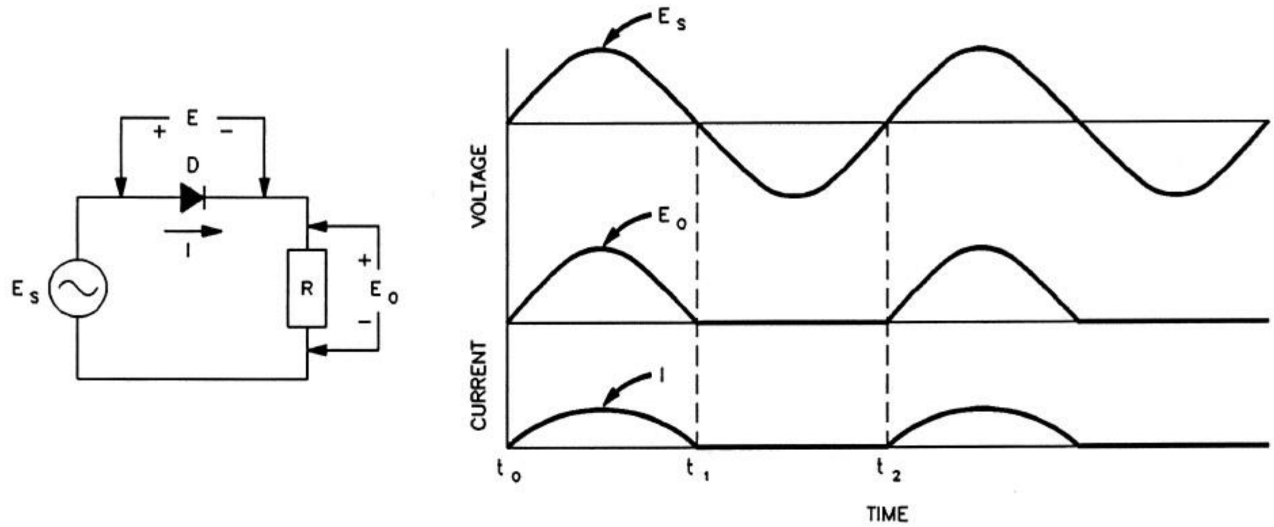


Figure 2: Operation of a diode-resistor circuit.

The conduction angle of a rectifier component is equal to the time that the component conducts current during each cycle, divided by the period, and multiplied by 360°. In Figure 2, the conduction angle is 180°.

With an **<u>inductive load</u>**, the circuit operates as follows (see Figure 3).

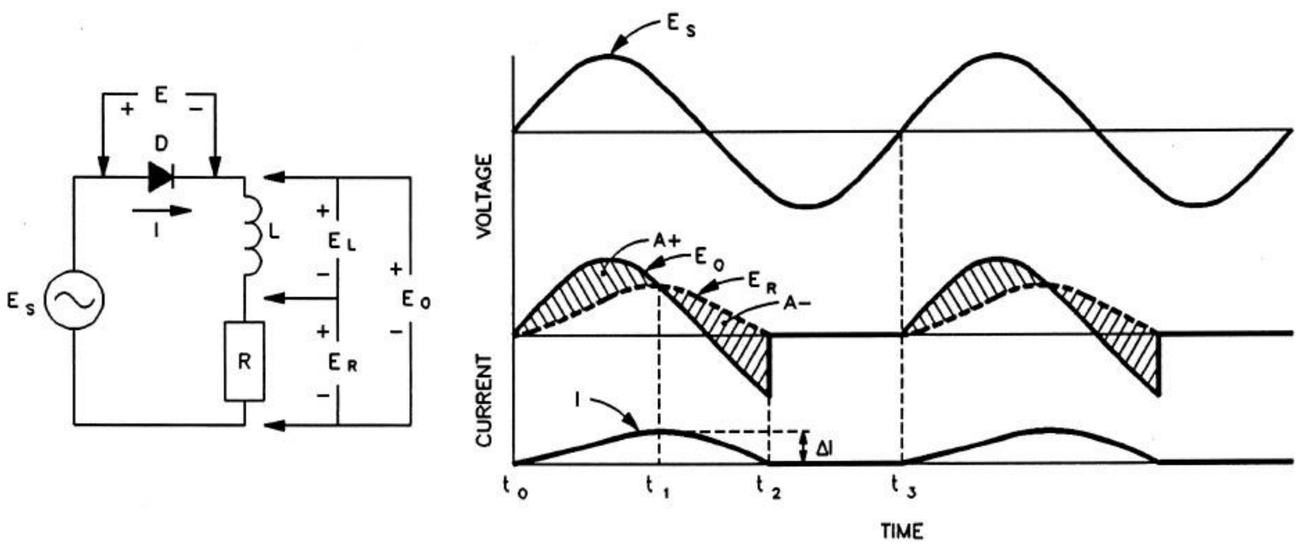


Figure 3. Operation of a diode-resistor-inductor circuit.

a) $t_0 < t < t_1$

The diode is forward biased and is turned on. The inductor voltage E_L is positive because $E_o > E_R$. The current I increases and the inductor stores energy in the created magnetic field. This positive energy corresponds to the A+ region of Figure 3.

b) $t_1 < t < t_2$

The diode is reverse biased because E is negative. The diode therefore remains in the off-state.

The conduction angle of the diode has been increased because the inductor must restore the energy which has been supplied by the source. This principle is fundamental in defining the on state of a diode in inductive circuits. The current in an inductor varies slowly. This is because inductors oppose variations in their current. Also, the phase of I lags that of E.

3.3. Rectifier with free-wheeling diode:

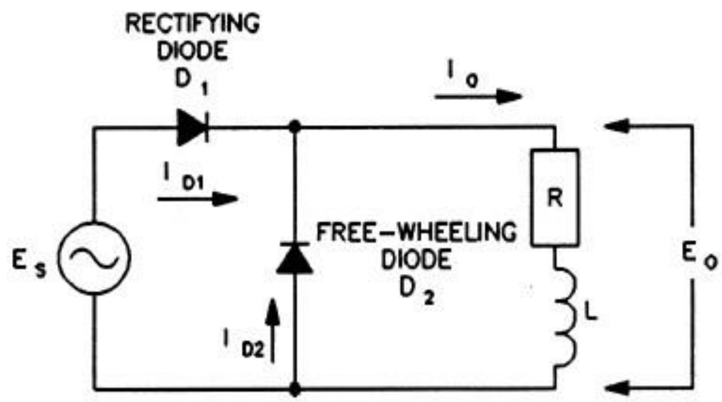


Figure 4: Half-wave rectifier circuit with free-wheeling diode.

When the load is inductive, the negative part of the output voltage waveform reduces the average output voltage. To prevent the output voltage from going negative, a free-wheeling diode can be placed in the circuit as shown in Figure 4.

When the output voltage begins to go negative, the free-wheeling diode starts conducting. This maintains the output voltage at approximately zero while the energy stored in the inductor is being released (see Figure 5). The output voltage waveform is the same as for a purely resistive load, and the average output voltage is therefore greater than it would be without the free-wheeling diode.

3.4. Full-wave bridge rectifier:

With full-wave rectification, current flow is maintained for both the positive and negative halfcycles of the source voltage. This can be accomplished using a bridge rectifier.

Figure 6 shows the circuit representation for a full-wave bridge rectifier and also the resulting output waveform. To understand the operation of this circuit, the rules of operation for diodes are applied to the circuit and waveforms of E_S and $E_o$shown in Figure 7.

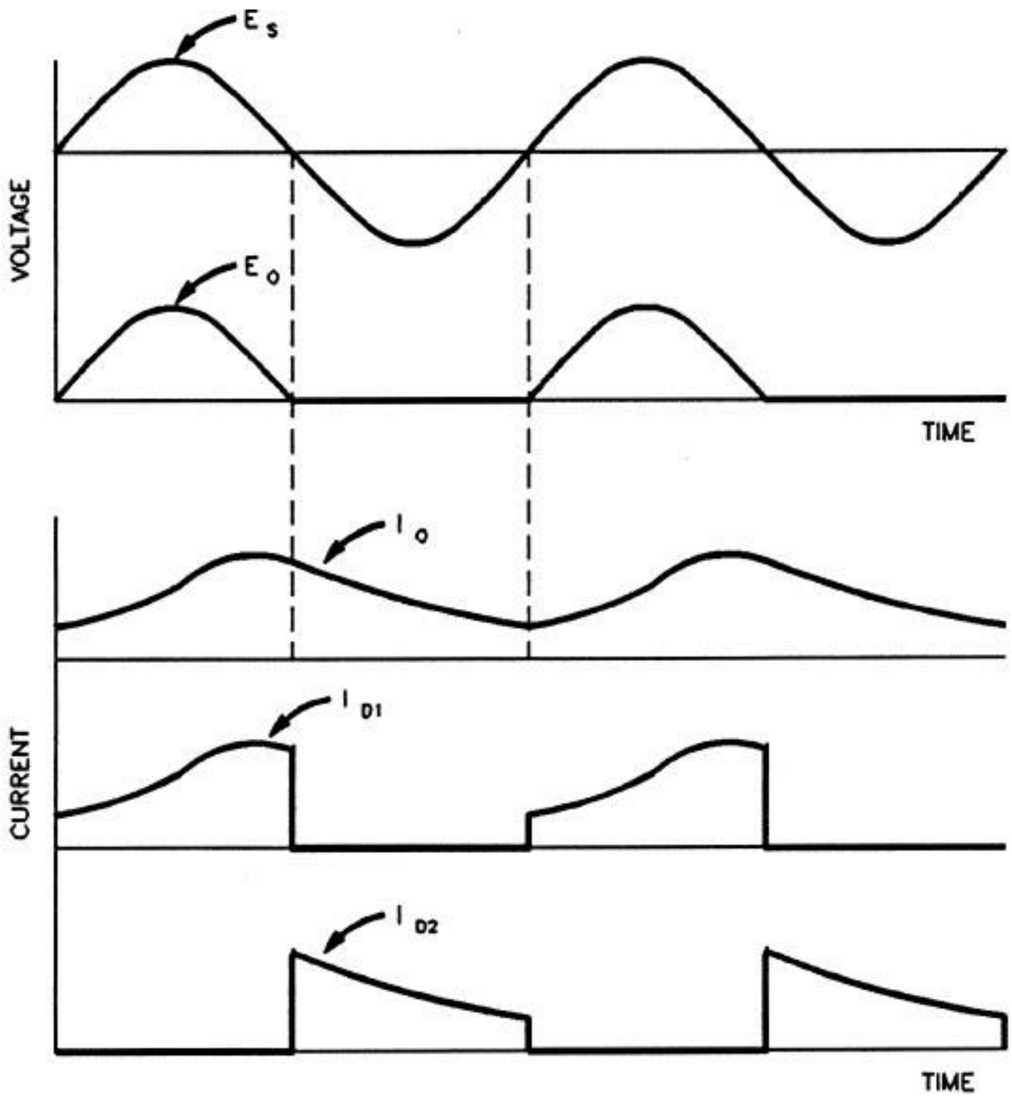


Figure 5: Half-wave rectifier circuit with free-wheeling diode.

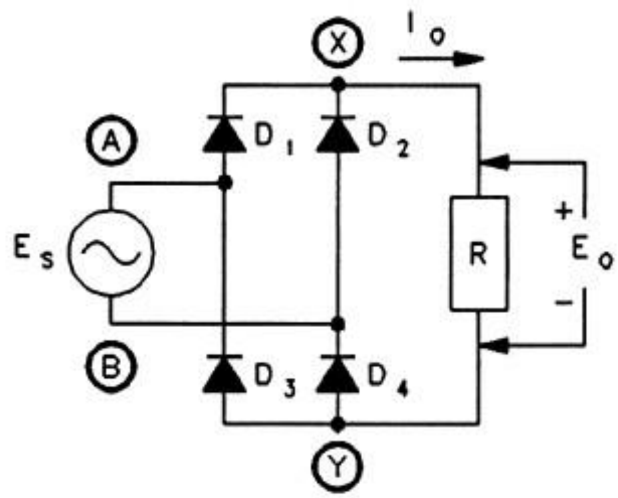


Figure 6: A full-wave rectifier circuit.

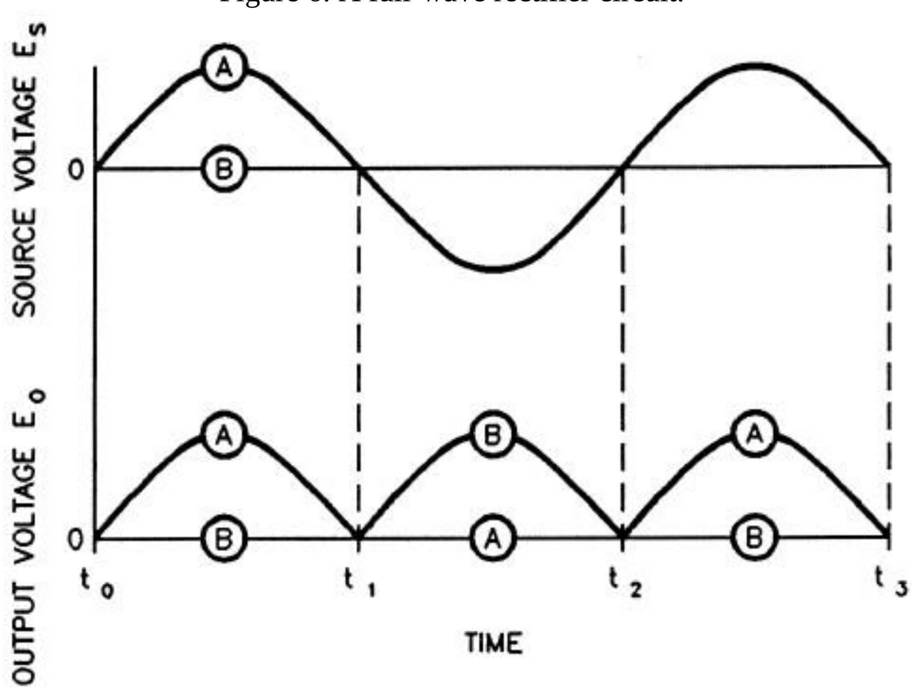


Figure 7. Voltage waveforms associated with full-wave rectifier circuit.

a) $t_0 < t < t_1$

At time $t = t_0$, E_S is zero and the diode act as open switches. As E_S goes positive (point A with respect to point B), diodes D_1 and D_4 become forward-biased and turn on. Therefore, the voltage at point X is the same as point A, and the voltage at point Y, the same as point B. Diodes D_2 and D_3 are reverse-biased and act as open switches. The current I_o flows in the direction of the arrow. **b) $t_1 < t < t_2$**

At time t = t_1, the source voltage has returned to zero and D_1 and D_4 turn off. When E_S becomes negative (B becomes positive with respect to A), diodes D_2 and D_3 become forward-biased. D_1 and D_4 are now reverse-biased. The voltage at X is now the same as that at B, and the voltage at Y is equal to that of A. By examining the circuit and replacing D_1 and D_4 by their open-switch symbols, you will see that the direction of current flow has not changed. It is still in the direction of the arrow. The direction of current flow for rectifiers is unique. It is the same as the arrow symbolizing the diode or thyristor in electrical schematics.

The average voltage of $E_o$can be calculated with the equation:

$$0.9$$

where E_S is the voltage of the source [V ac].

4. Procedure:

CAUTION!

High voltages are present in this laboratory exercise! Do not make or modify any banana jack connections with the power on unless otherwise specified!

1. Make sure that the main power switch of the Power Supply is set to the O (OFF) position. Set the voltage control knob to 0.
2. On the power supply, set the 24-V ac power switch to the I (ON) position.

4.1. Diode characteristics:

4.1.1. Connect the modules as shown in Figure 8.

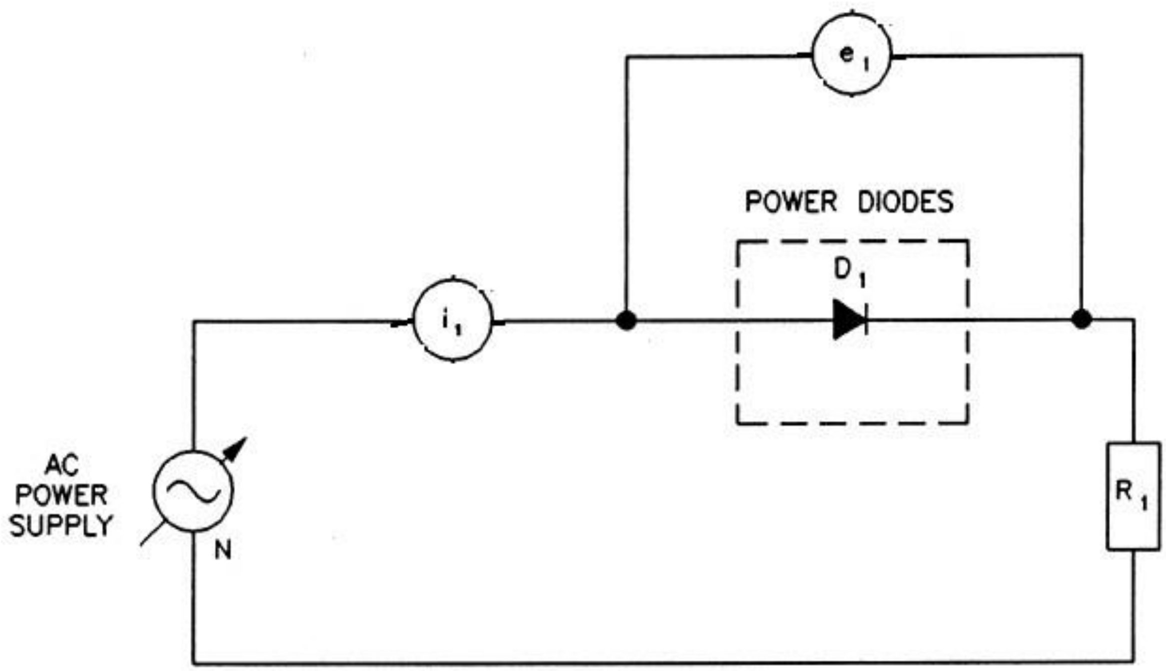


Figure 8: Circuit for observing the characteristics of a diode.

4.1.2. Set the value of $R_1 = 210\ \Omega$

4.1.3. Make the following settings:

On the power supply: Voltage Selector: 4-N On

the oscilloscope:

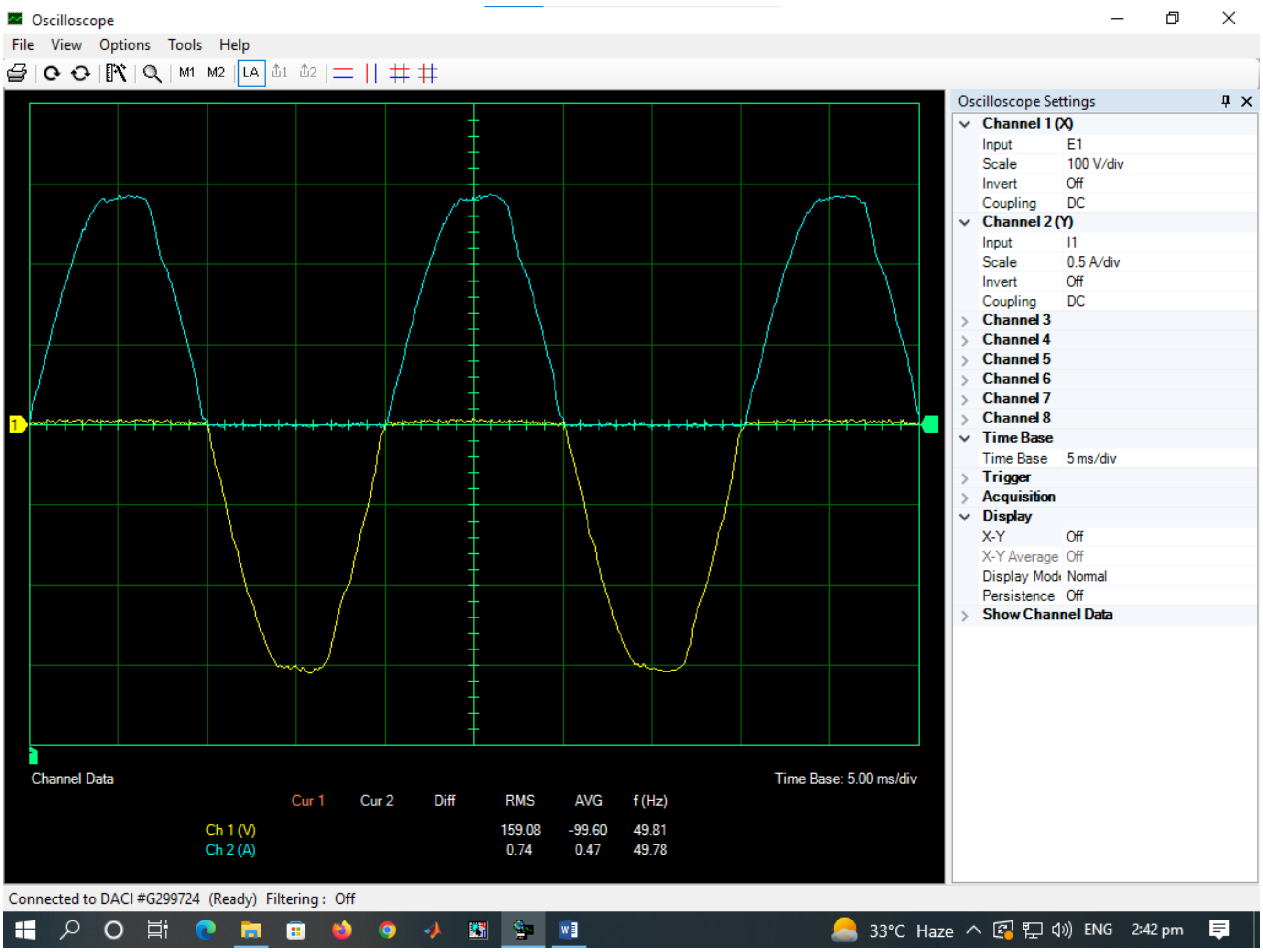
Channel-1 sensitivity: 2V/DIV (Set to GND)

Channel-2 sensitivity: 1V/DIV (Set to GND)

Time Base: X-Y

Use the horizontal (X) and vertical (Y) position controls on the oscilloscope to position the spot in the centre of the screen. Then set both channels to dc coupling.

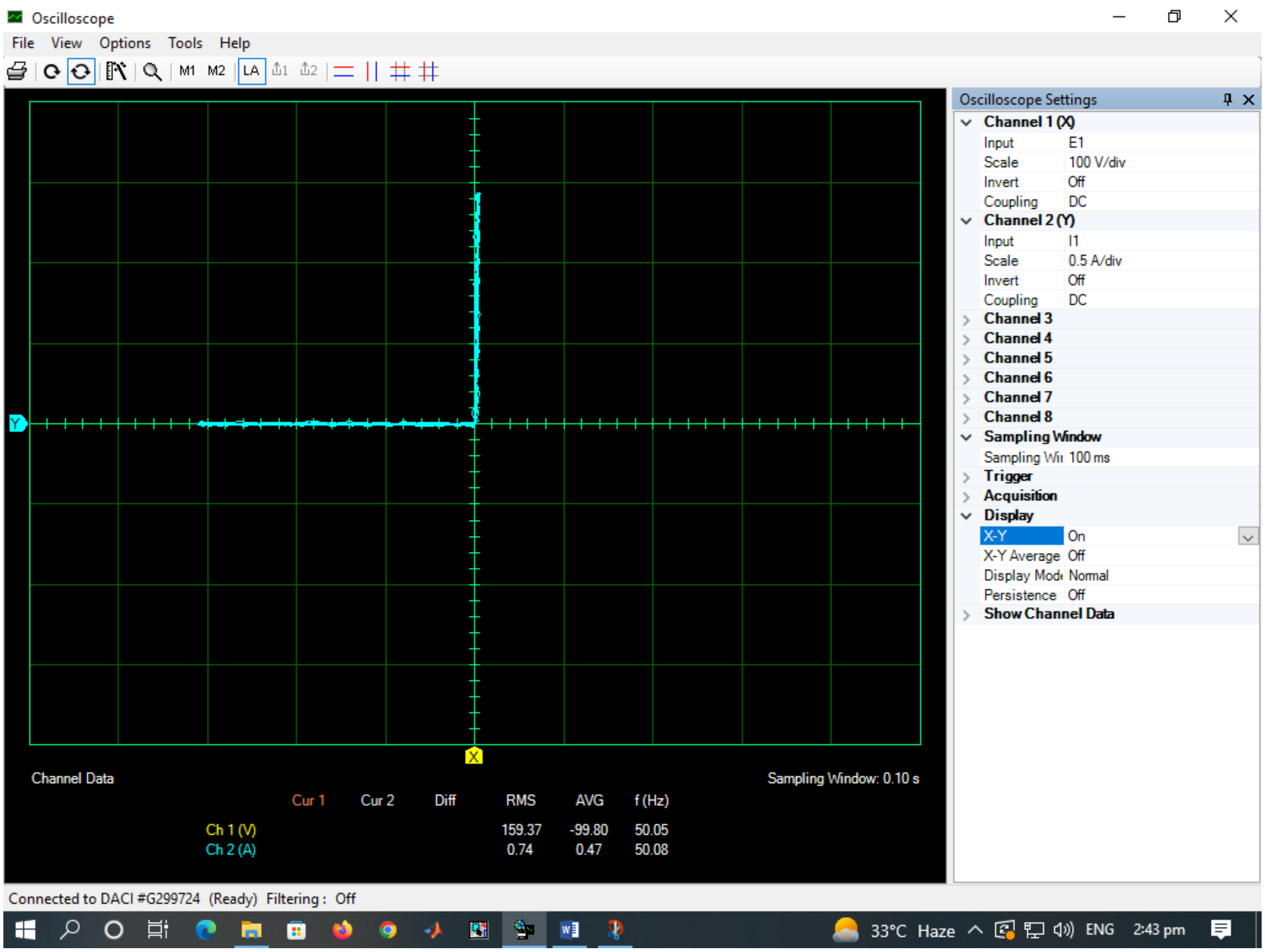
Voltage and Current Graph w.r.t Time



4.1.4. On the power supply, set the main power switch to I (ON), and set the voltage control knob to 100 %.

4.1.5. Observe the curve displayed on the oscilloscope screen. The horizontal axis represents the instantaneous value of the voltage across the diode and the vertical axis the instantaneous value of the current through the diode. Use Figure 9 to reproduce the curve displayed on the screen.

Voltage-Current Characteristic of a Diode.



5.

Figure 9: The voltage-current characteristic of a diode.

5.1.1. On the power supply, set the voltage control knob to 0 then set the main power switch to O (OFF).

5.1.2. **Can you conclude from the appearance of the curve that current flows in one direction only?**

A non-Zero current flows through the diode when positive voltages appear across the diode. In the graph, the current is zero when voltage is negative.

5.1.3. **Can you also conclude that the diode operates as a switch? Explain.**

Yes, it acts as a switch. When voltage is positive, it closes and when voltage is negative is it open and no current hence the behavior is more like a switch.

5.2. Half-wave rectifier circuit:

5.2.1. Set up the circuit of Figure 10 using the resistive load Z_1 (a).

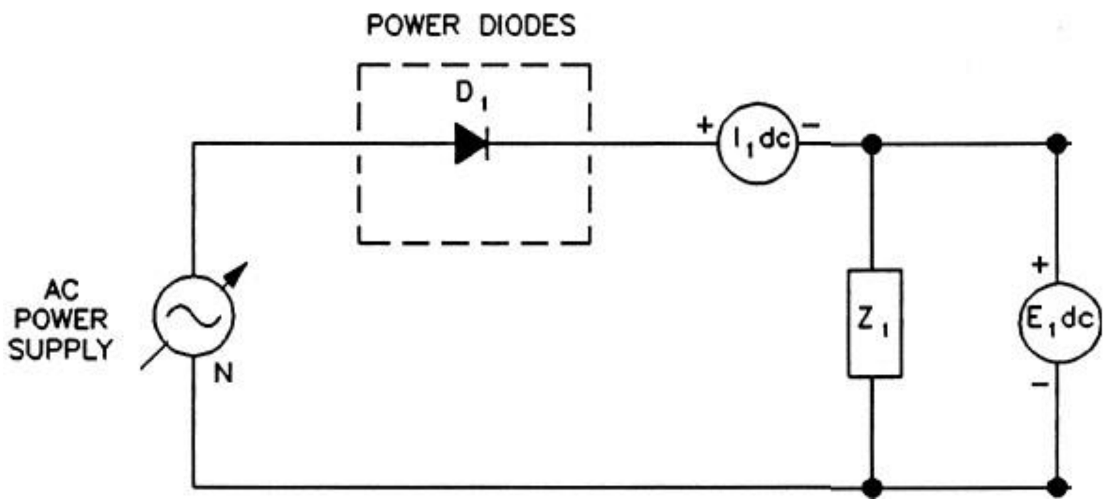


Figure 10: Circuit for observing current and voltage waveforms.

5.2.2. Set Z_1 (a) = 220 Ω

5.2.3. Make the following settings on the oscilloscope:

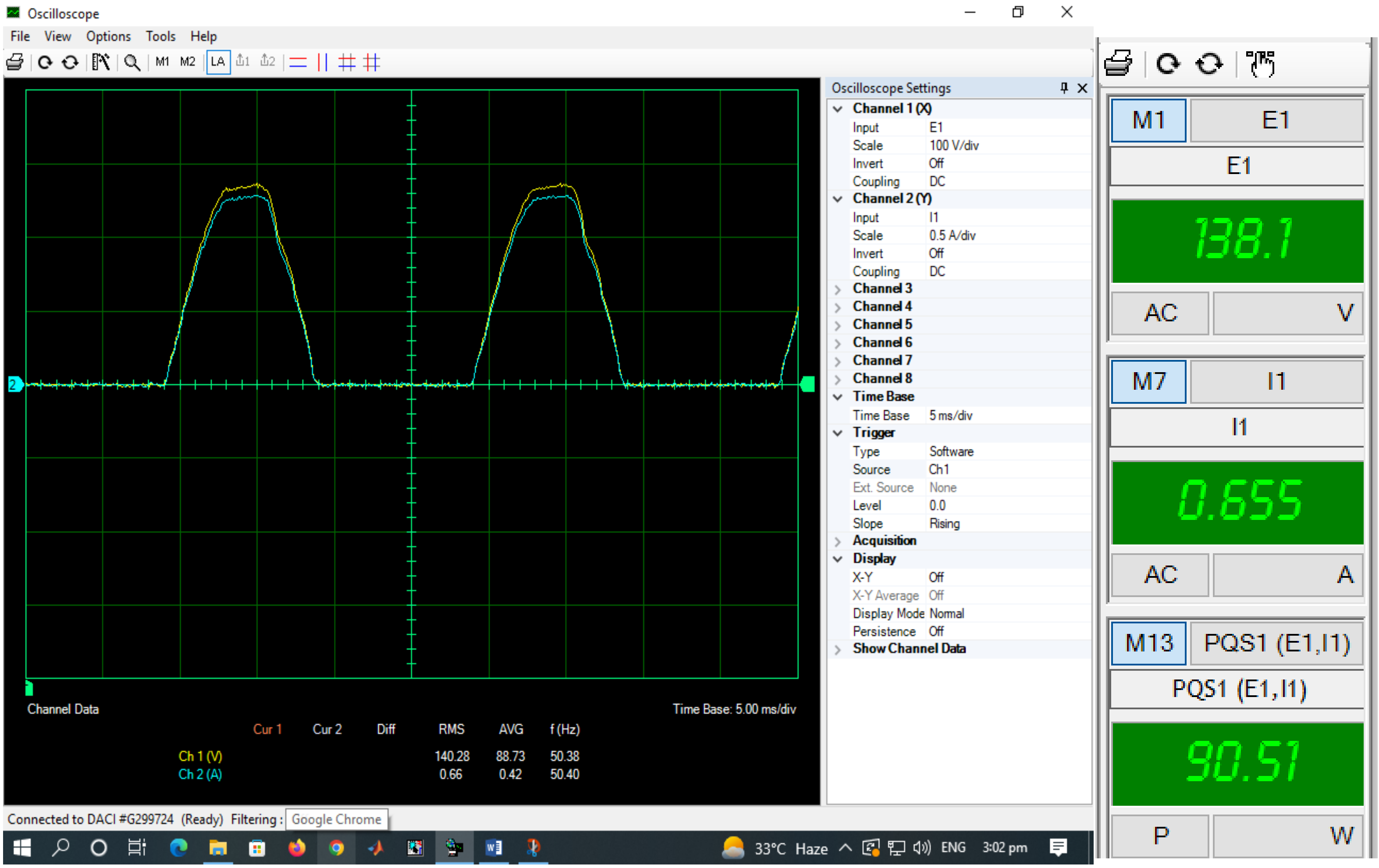
Channel-1 sensitivity: 2V/DIV

Channel-2 sensitivity: 1V/DIV

Time Base: 5ms/DIV

Trigger: LINE

Voltage-Current Characteristic of a Diode (Resistive Load)



5.2.4. On the power supply, make sure that the voltage control knob is set to the 0 position, then set the main power switch to I (ON). Set the voltage control knob so that the voltage indicated by the power supply voltmeter is equal to 90% of the nominal line-to-neutral voltage.Sketch the voltage and current waveforms displayed on the oscilloscope in Figure 11. A sine wave is provided in this figure as a reference. You may find it helpful to change the time base of the oscilloscope. For example, you could adjust the time base so that one complete cycle of the waveform occupies 6 horizontal divisions. Each horizontal division would then represent 60^{o}.Record the ripple frequency (frequency of the rectified waveform). Ripple frequency: ___**50**__ Hz

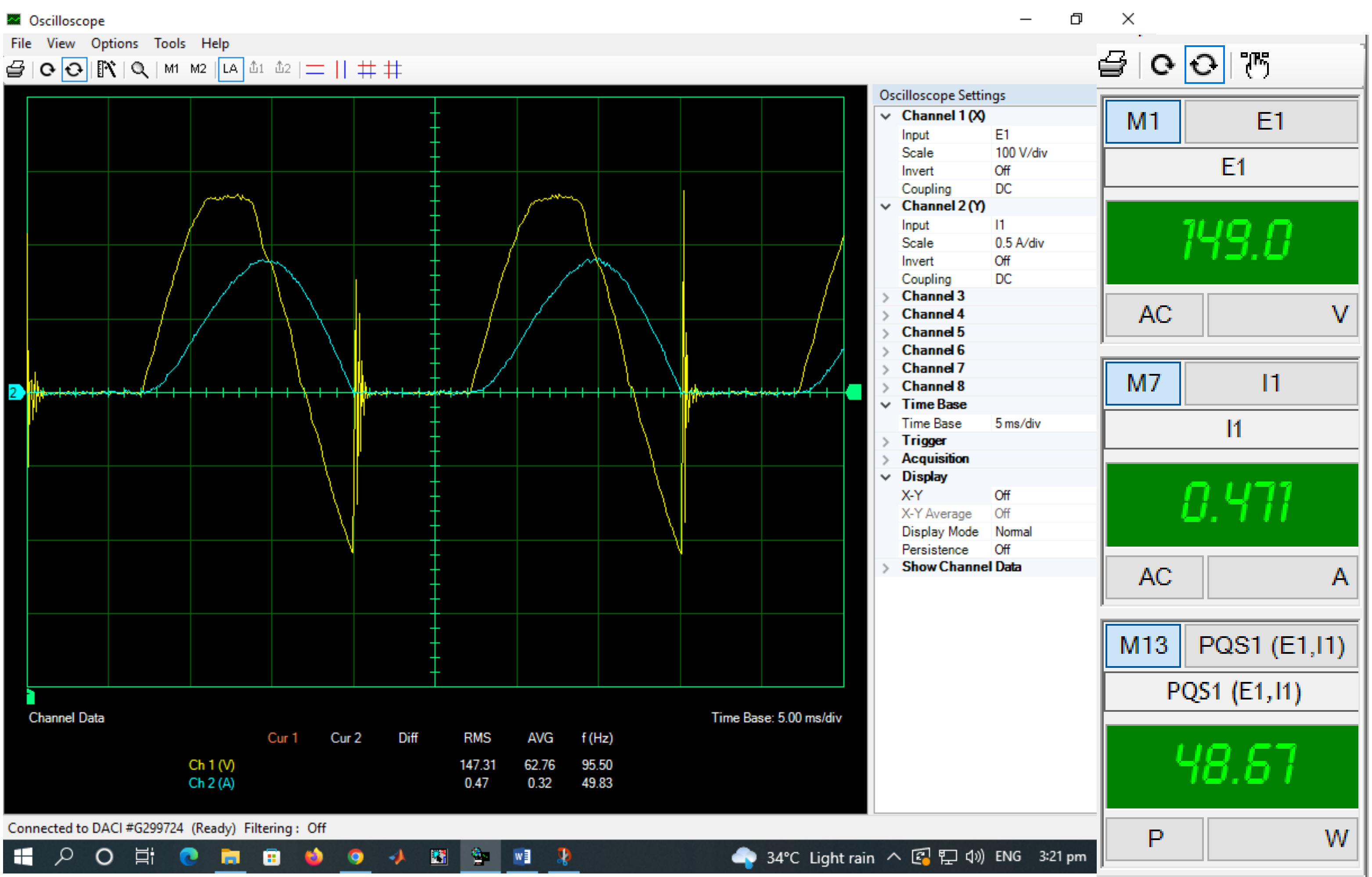
5.2.5. Record the output voltage, current, and power of the rectifier circuit in the first row of the

Table 1. Enter the conduction angle of the diode in Table 1.

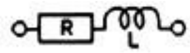
Table 1. Measurements for half-wave rectifier circuit.

Load Z_1	Output Voltage E_1 dc	Output Current I_1 dc	Output Power $P_o = E_1 \times I_1$	Conduction Angle
	V	A	W	degrees
(a) Resistive	138.1	0.655	90.57	Refer to graph
(b) Inductive	149	0.471	48.67	Refer to graph

Voltage-Current Characteristic of a Diode (Inductive Load)



5.2.6. On the power supply, set the voltage control knob to the 0 position then set the main power switch to the O position.

5.2.7. Change the load in the circuit to the inductive load Z_1 (b) i.e. 

with R= 220 Ω and L = 0.8 H. Repeat the procedure steps necessary to complete the Table 1 and Figure 11.

5.2.8. **Explain the effect of an inductive load on the voltage and current waveforms and on the conduction angle**.

Following are the changes that were observed by the addition of inductive load:

i) The current varies slowly for the inductive load because it opposes the variation in current

ii) The current lags the voltage in inductive load whereas you can observe that voltage and current are in phase for resistive load.

iii) For resistive load, there are no negative voltages but the voltage becomes negative by the addition of inductor

iv) The conduction angle of the diode is more for inductive load because the inductor must restore the energy which has been supplied by the source. This principle is fundamental in defining the on state of a diode in inductive circuits.

5.2.9. On the power supply, set the voltage control knob to the 0 position then set the main power switch to the O position.

5.2.10.

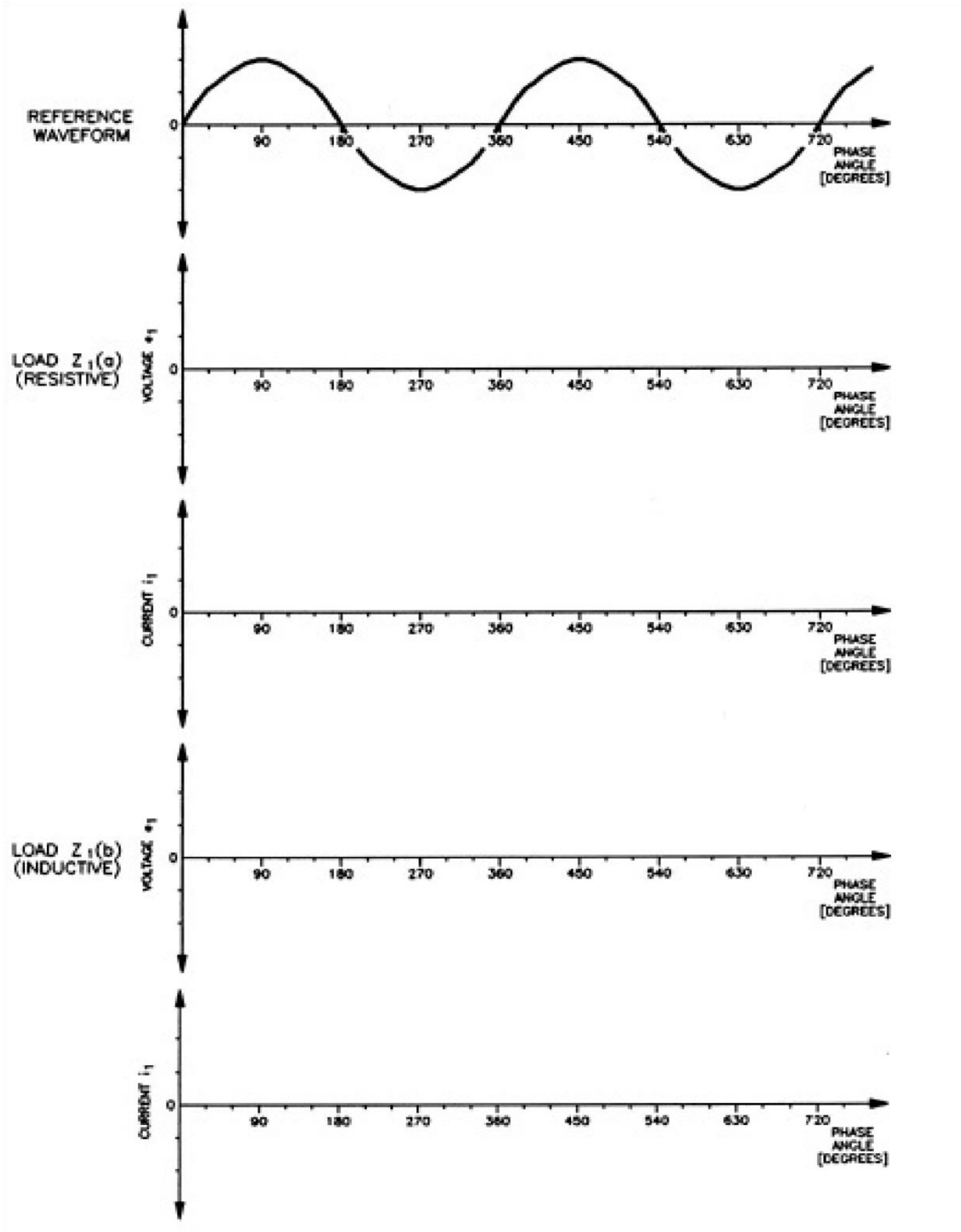


Figure 11. Voltage and current waveforms for half-wave rectifiers.

5.3. Rectifier with free-wheeling diode

5.3.1. Add a free-wheeling diode to the circuit as shown in Figure 12.

5.3.2. On the power supply, set the main switch to I (ON), and set the voltage control knob so that the voltage indicated by the power supply voltmeter is equal to 90 % of the nominal line-toneutral voltage.

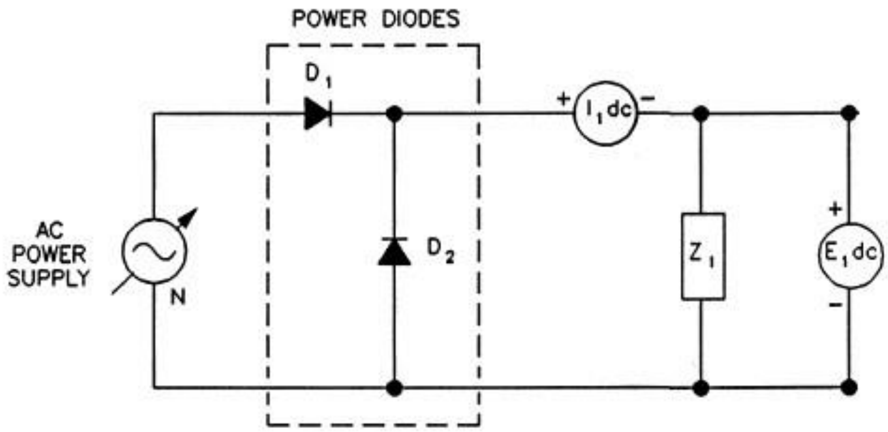
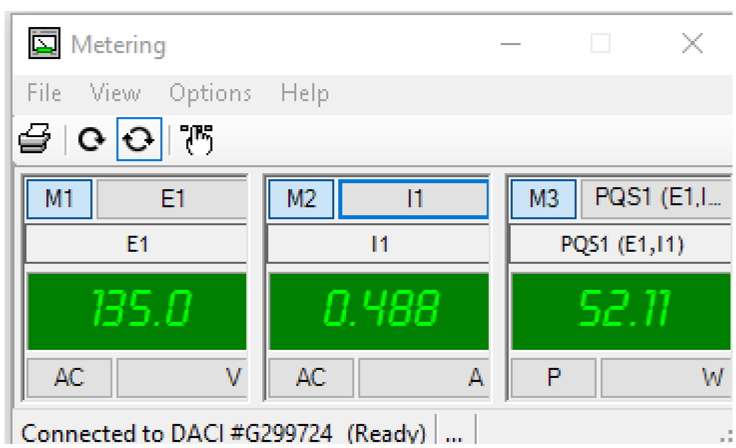
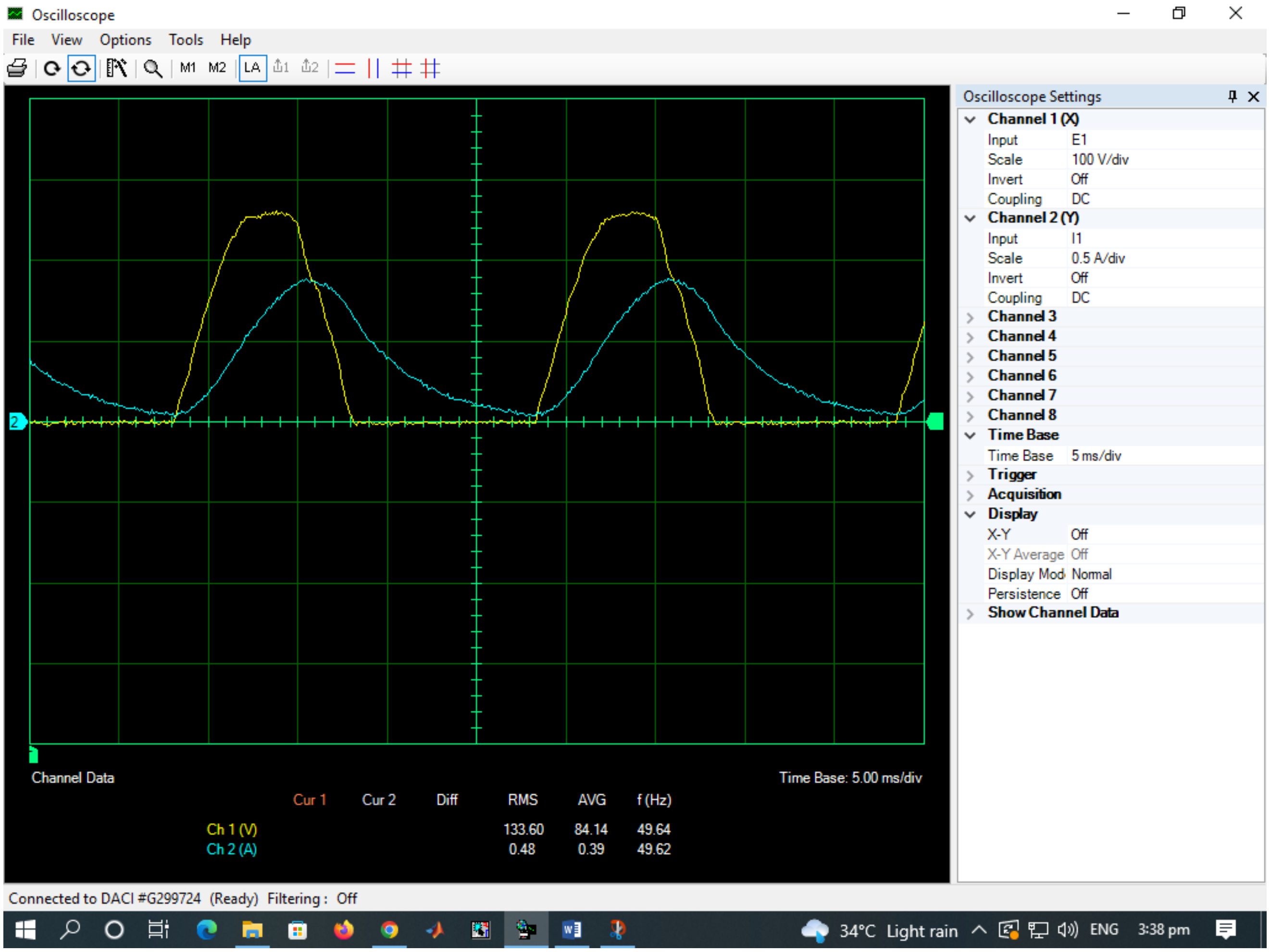


Figure 12. Rectifier circuit with free-wheeling diode.

Free-Wheeling diode





5.3.3. Fill in Table 2.

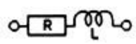
Table 2. Measurements for controlled rectifier circuit with free-wheeling diode			
Load Z_1	**Output Voltage E_1 dc**	**Output Current I_1 dc**	**Output Power $P_o = E_1 \times I_1$**
	V	**A**	**W**
(b) Inductive	135	0.488	52

5.3.4. **What effect does free-wheeling diode have on the operation of the circuit and on the parameters measured?**

The addition of free-wheeling diode has removed the fluctuations due to the inductive load. When the output voltage begins to go negative, the free-wheeling diode starts conducting. This maintains the output voltage at approximately zero while the energy stored in the inductor is being released. The output voltage waveform is the same as for a purely resistive load, and the average output voltage is therefore greater than it would be without the free-wheeling diode.

5.4. Full-wave rectifier

5.4.1. Set up the circuit as shown in Figure 13. On the power supply, set the main power switch to the I (ON). Set the voltage control knob so that the voltage indicated by the power supply voltmeter is equal to 90 % of the nominal line-to-neutral voltage. The value of resistive load is

Z_1 (a) = 220 Ω and inductive load is Z_1 (b) , 

, is R = 220 Ω and L = 0.8 H.Sketch the voltage and current waveforms in Figure 14. Record the ripple frequency.

Ripple frequency = **100 Hz**

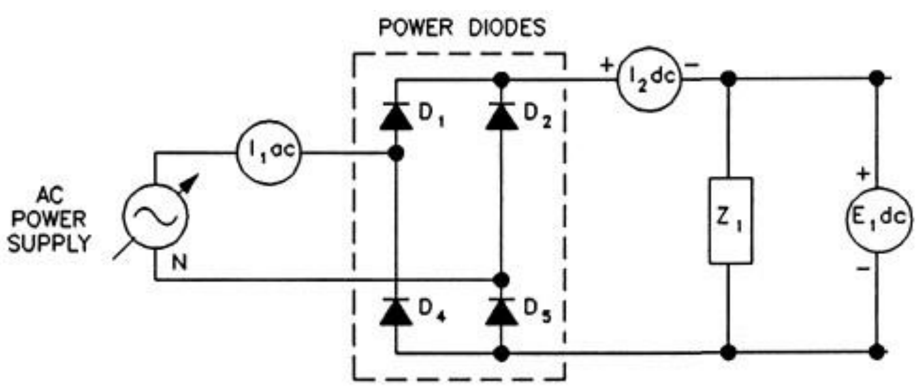


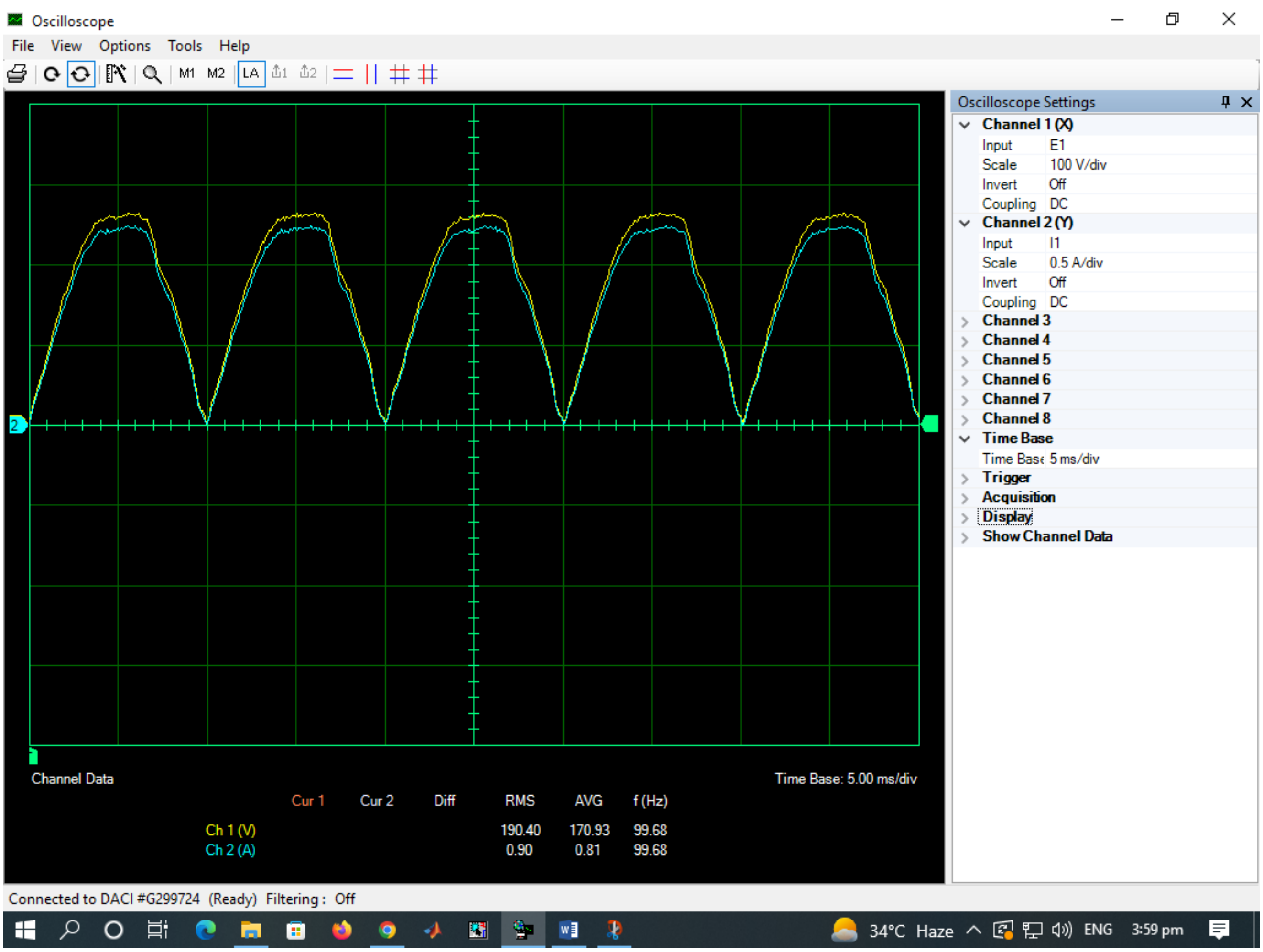
Figure 13. Full-wave bridge rectifier circuit.

Record the output voltage, current, and power of the rectifier circuit in the first row of Table 3.

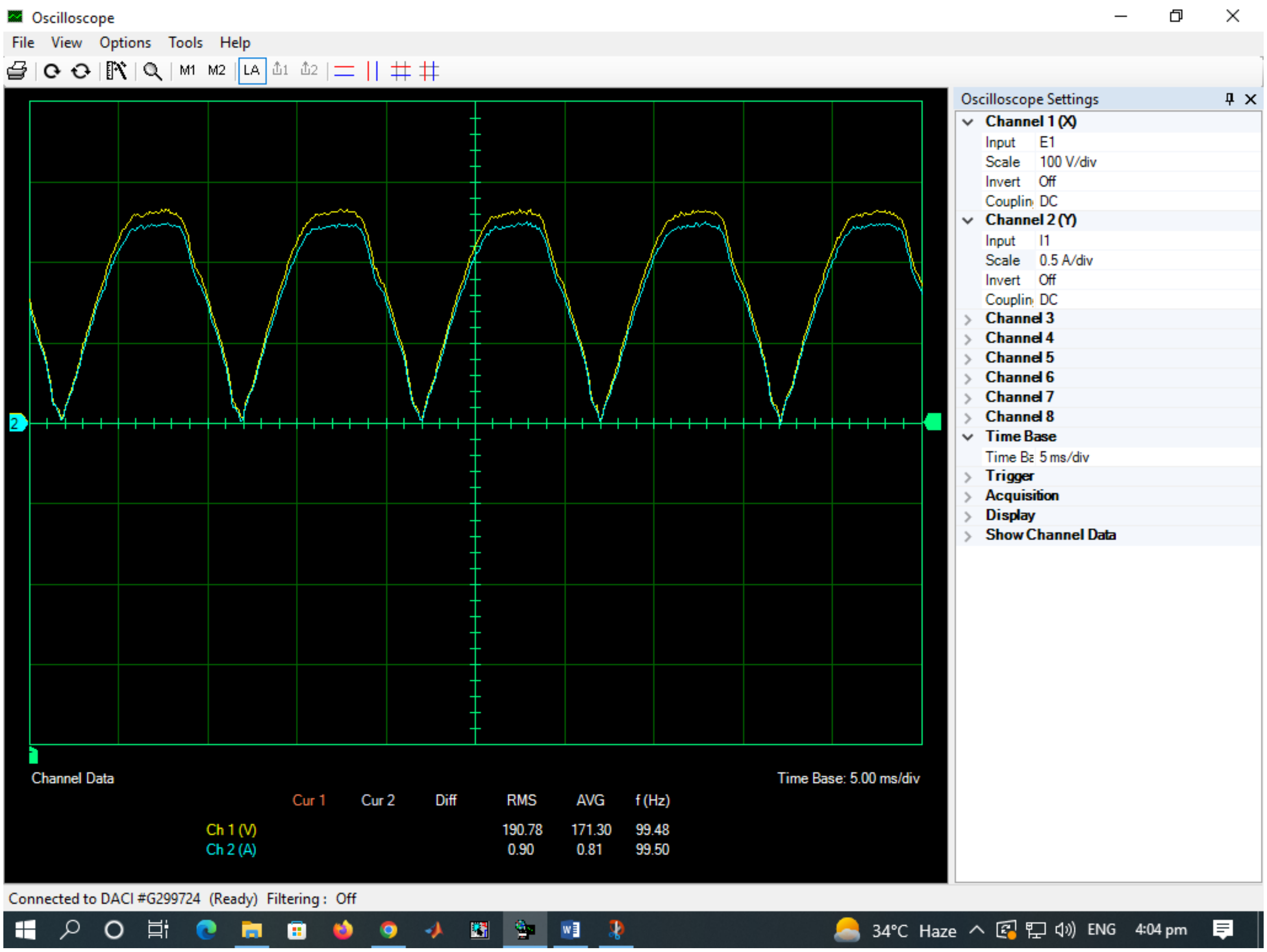
Table 3: Measurements for bridge rectifier circuit

Load Z_1	Output Voltage E_1 dc	Output Current I_1 dc	Output Power $P_o = E_1 \times I_1$	Conduction Angle
	V	A	W	degrees
(a) Resistive	190	0.904	172.2	Refer to graph
(b) Inductive	190.2	0.901	171.4	Refer to graph

Inductive Load:



Resistive load



5.4.2. With the power off, change the load in the circuit to the inductive load, $Z_{1\ (b)}$. Repeat the procedure steps necessary to complete Table 3 and Figure 14.

5.4.3. **What is the effect of the inductive load on the operation of the circuit?**

The current varies slowly and is not in phase with voltage.

5.4.4. **Compare the following characteristics of a single-phase bridge rectifier to those of a single phase half-wave rectifier.**

Diode Conduction angle:

Ripple Frequency:

Average output voltage and power:

	Half Wave Rectifier	Full wave Rectifier
Diode Conduction angle:	180◦	360◦
Ripple Frequency	50 Hz	100 Hz
Average output voltage	135 V	190 V
Average output power	52 W	172 W

Diode Conduction angle:
The diode conduction angle increases, almost doubles in single-phase bridge rectifier as compared to that of single-phase half wave rectifier
Ripple Frequency:
The ripple frequency almost doubles in single-phase bridge rectifier as compared to that of single-phase half wave rectifier or the input voltage
Average output voltage and power:
The output voltage for single-phase bridge rectifier is almost same to that of voltage input. As compared to single-phase half wave rectifier, whose output was about 40% of that of input. We also see that its power output was also half to that single-phase bridge rectifier.

On the power supply, set the voltage control knob to 0 then set the main power switch to O (OFF).

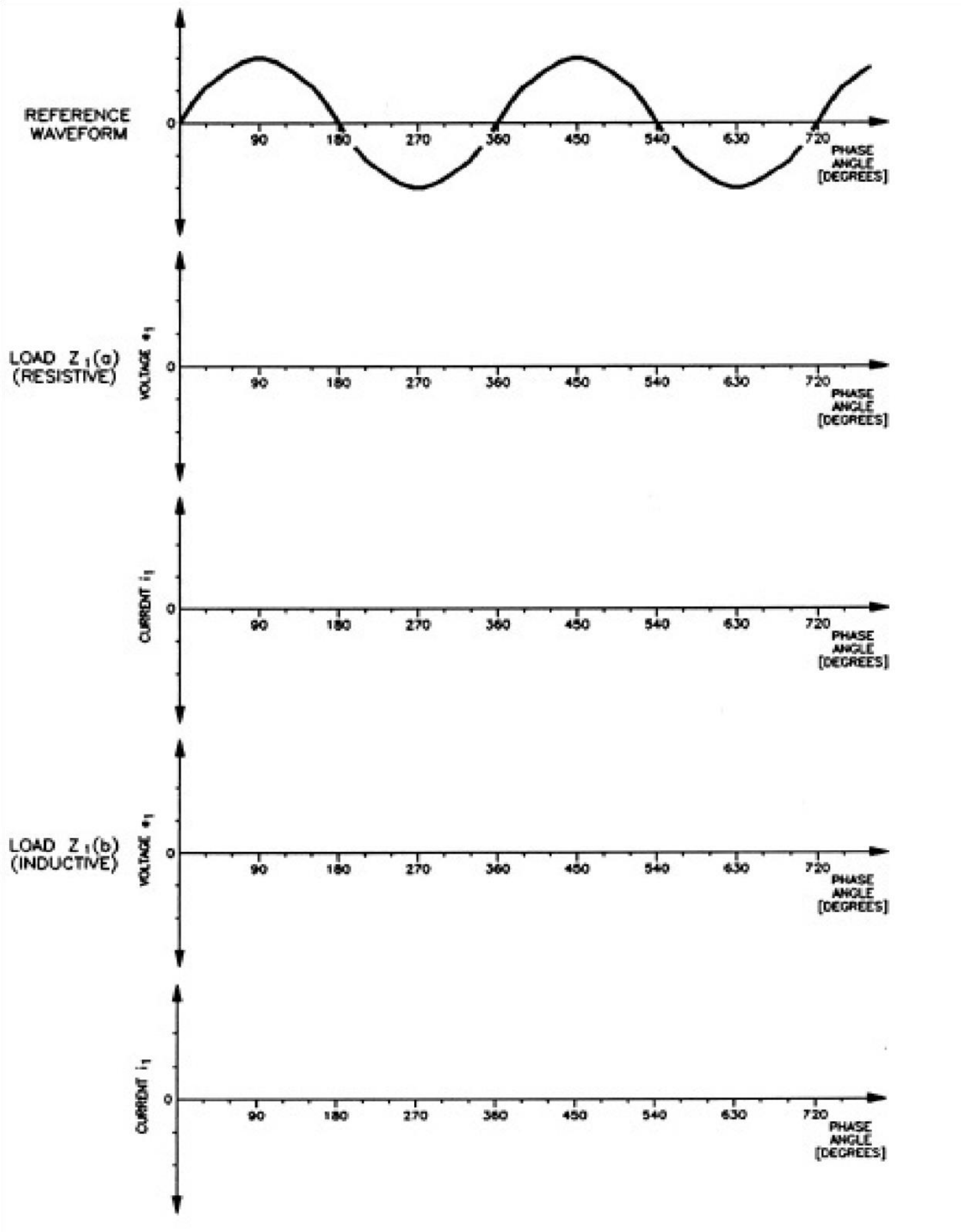


Figure 14: Voltage and current waveforms for a full-wave bridge rectifier.

Conclusion:

1. Diodes allow current to pass in one direction only. This is apparentin the characteristic curve of the diode.
2. We observed the operation of a half-wave rectifying circuit. We saw the effect of the type of load on the conduction angle, and use of a free-wheeling diode.
3. We observed the operation of full wave rectifier