Experiment No.3

Diode Applications 1

Rectifier Circuit

Object

The purpose of this experiment is to demonstrate the operation of three different diode rectifier circuits which are the half-wave rectifier, center-tapped full-wave rectifier, and the bridge full-wave rectifier. In addition to that, the operation of a capacitor filter connected to the output of the rectifier will also be demonstrated.

Required Parts and Equipment's

1. Digital Multimeters
2. Electronic Test Board (M50)
3. Step-down center-tapped transformer (220V/12Vr.m. s)
4. Dual-Channel Oscilloscope
5. General purpose Silicon Diodes [D_1,D_2,D_7,D_8]=1N4001, [D_3,D_4,D_5,D_6]=WL04
6. Resistors, $R_1 = 1K\Omega, R_2 = 2K\Omega$
7. Capacitors $C_1 = 470\mu F, 25V$, $C_2 = 2200\mu F, 25V$, $C_3 = C_4 = 470\mu F, 63V$
8. Leads and BNC Adaptors

Theory

The rectifier is circuit that converts the AC input voltage into a pulsed waveform having an average (or DC) value. This waveform can then be filtered to remove the unwanted variations. Rectifiers are widely used in power supplies which provide the DC voltage necessary for electronic circuits. The three basic rectifier circuits are the half-wave, the center-tapped full wave, and the full-wave bridge rectifier circuits. The most important parameters for choosing diodes for these circuits are the maximum forward current, and the peak inverse voltage rating (PIV) of the diode. The peak inverse voltage is the maximum voltage the diode can withstand when it is reverse-biased. The amount of reverse voltage that appears across a diode depends on the type of circuit in which it is connected.

Some characteristics of the three rectifiers circuits will be investigated in this experiment.

- **Half-Wave Rectifier**

Figure 1 shows a schematic diagram of a transformer coupled half-wave rectifier circuit. The transformer is useful in electrically isolating the diode rectifier circuit from the 220V AC source, and also is used to step-down the input line voltage into a suitable value according to the turn's ratio.

The transformer's turns ratio is defined by:

$$n = \frac{V_{pr(r.m.s)}}{V_{s(r.m.s)}}$$

Where $V_{pr(r.m.s)}$ is the r.m.s value of the transformer primary winding voltage, and $V_{s(r.m.s)}$ is the r.m.s value of the transformer secondary winding voltage. In the circuit of Fig.1, $V_{pr(r.m.s)}$= 220V.

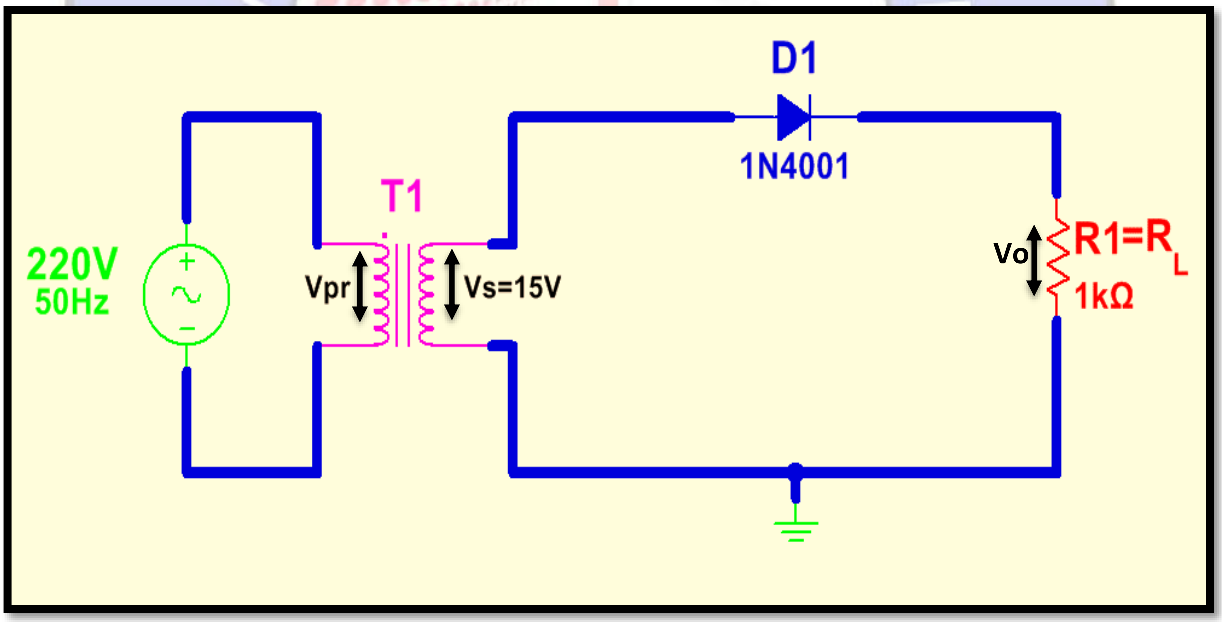

Figure 1: Half-Wave Rectifier with Transformer-Coupled Input Voltage

The peak value of the secondary winding voltage V_{sp} is related to the r.m.s value by the relation:

$$V_{sp} = \sqrt{2}\, V_{s(r.m.s)}$$

When the sinusoidal voltage across the secondary winding of the transformer goes positive, the diode is forward-biased and conducts current through the load resistor R_L. Thus, the output voltage across R_L has the same shape as the positive half-cycle of the input voltage.

When the secondary winding voltage goes negative during the second half of its cycle, the diode is reverse-biased. There is no current in this case, so the voltage across the load resistor is 0V. The net result is that only the positive half-cycles of the AC input voltage on the secondary winding appear across the load as shown in Fig.2. Since the output does not change polarity, it is a pulsating DC voltage with frequency equals to that of the input AC voltage.

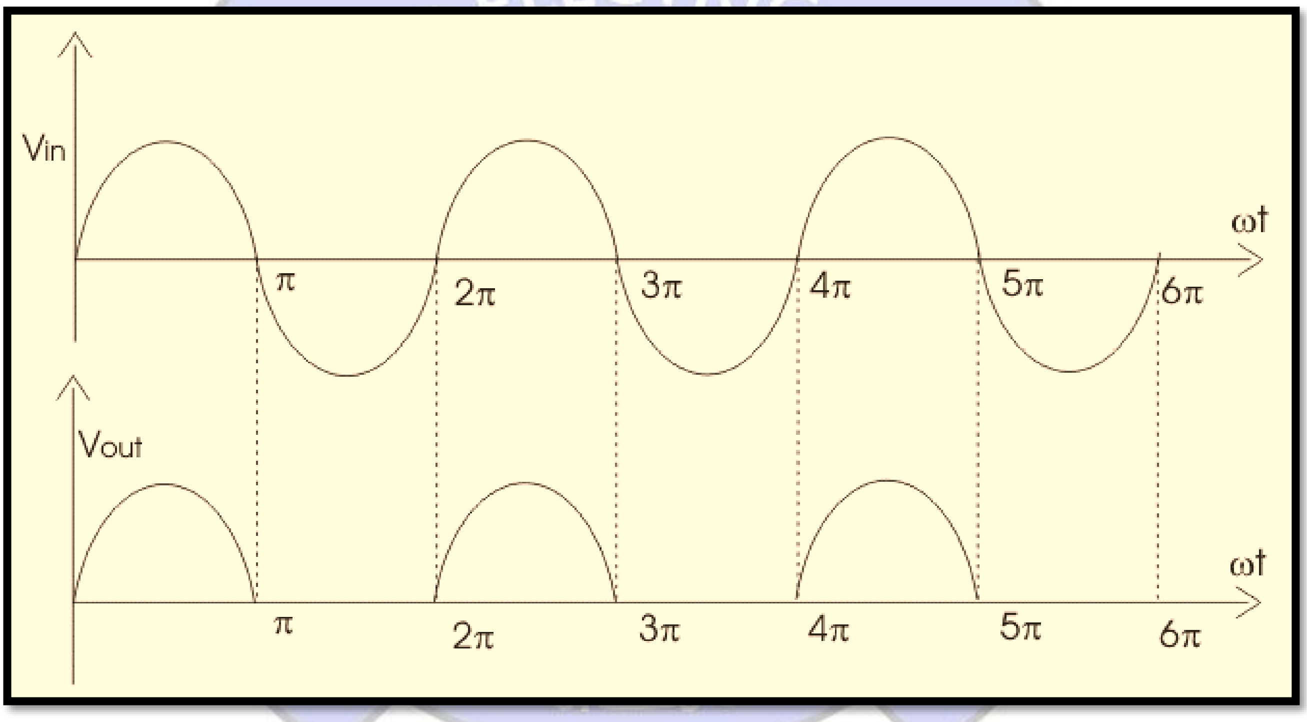

Figure 2: Waveforms of the Half-Wave Rectifier Circuit

When taking the voltage drop across the diode into account, the peak value of the output voltage is given by:

$$V_{op} = V_{sp} - 0.7$$

In equation (3), it was assumed that the voltage drop across the silicon diode is 0.7V when it conducts.

It can be verified that the average (or DC) value of the output voltage is given by:

$$V_{dc} = \frac{V_{op}}{\pi} = \frac{V_{sp} - 0.7}{\pi}$$

The peak inverse voltage (PIV) of the diode for this circuit equals the peak value of the secondary winding voltage:

$$PIV = V_{sp} = V_{op} + 0.7$$

- **Center-Tapped Full-Wave Rectifier**

The full-wave center-tapped rectifier uses two diodes connected to the secondary of a center tapped transformer as shown in Fig.3.

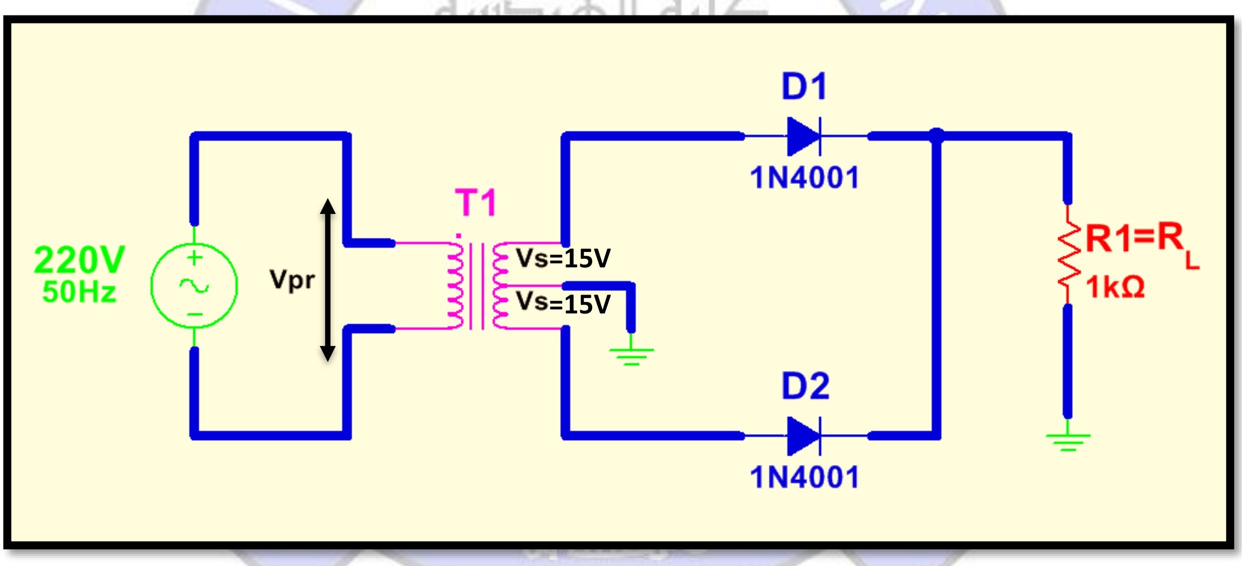

Figure 3: The Center-Tapped Full-Wave Rectifier Circuit

The Input voltage is coupled through the transformer to the center-tapped secondary. For the positive half cycle of the input signal, the polarities of the secondary winding voltages are shown in Fig.3. This makes the upper diode D_1conducting and the lower diode $D_2$to be reverse-biased. The current path is through $D_1$and the load resistor RL. For the negative half cycle of the input voltage, the voltage polarities on the secondary winding of the transformer will be reversed causing $D_2$to conduct, while reverse-biasing D_1. The current path is through $D_2$and R_L. Because the output current during both the positive and negative portions of the input cycle is in the same direction through the load, the output voltage developed across the load resistor is a full-wave rectified DC voltage as shown in Fig.4.

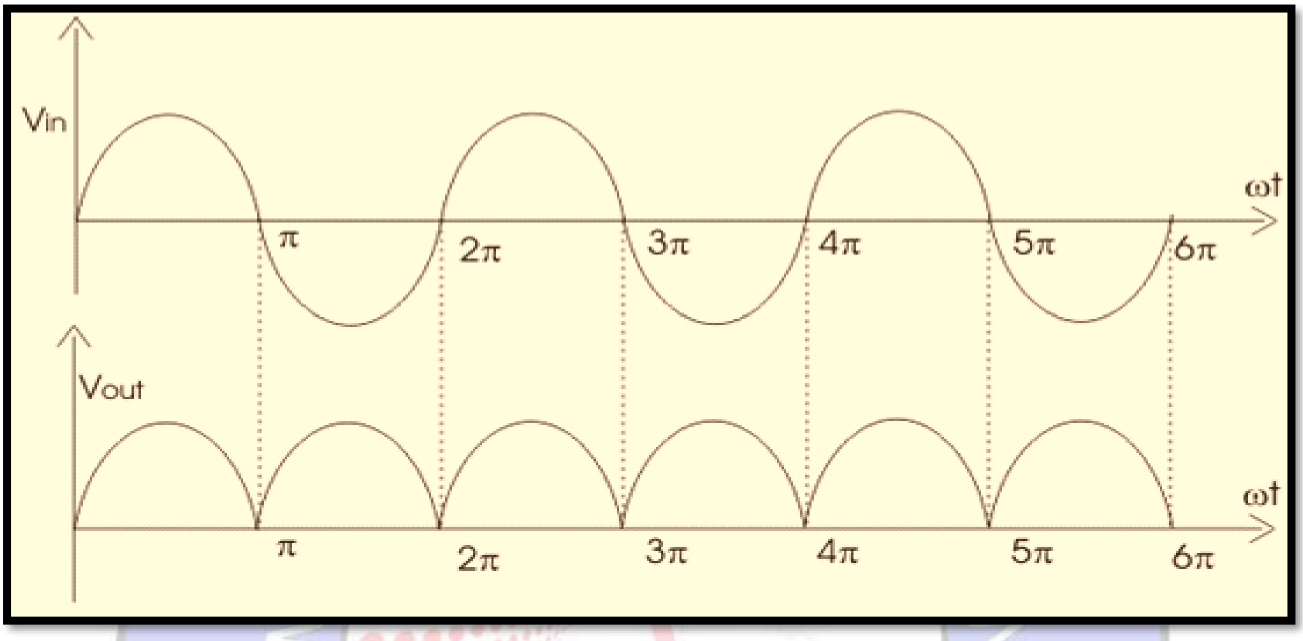

Figure 4: Waveforms of the Full-Wave Rectifier

The DC output voltage of the full-wave rectifier is given by:

$$V_{dc} = \frac{2V_{op}}{\pi} = \frac{2(V_{sp} - 0.7)}{\pi}$$

The peak inverse voltage (PIV) of each diode in this circuit is obtained as:

$$PIV = V_{sp} = V_{op} + 0.7$$

The frequency of the output voltage equals twice the line frequency as shown from the waveform of the output voltage.

- **Full-Wave Bridge Rectifier**

The full-wave bridge rectifier uses four diodes as shown in Fig.5. When the input cycle is positive, diodes $D_5$and $D_4$are forward biased and conduct current. A voltage is developed across R_L which looks like the positive half of the input cycle. During this time, diodes $D_3$and $D_6$are reverse-biased.

When the input cycle is negative, diodes D_3 and D_6 become forward-biased and conduct current in the same direction through R_L as during the positive half-cycle. During the negative half-cycle, D_4 and D_5 are reverse biased. A full-wave rectified output voltage appears across R_L as a result of this action.

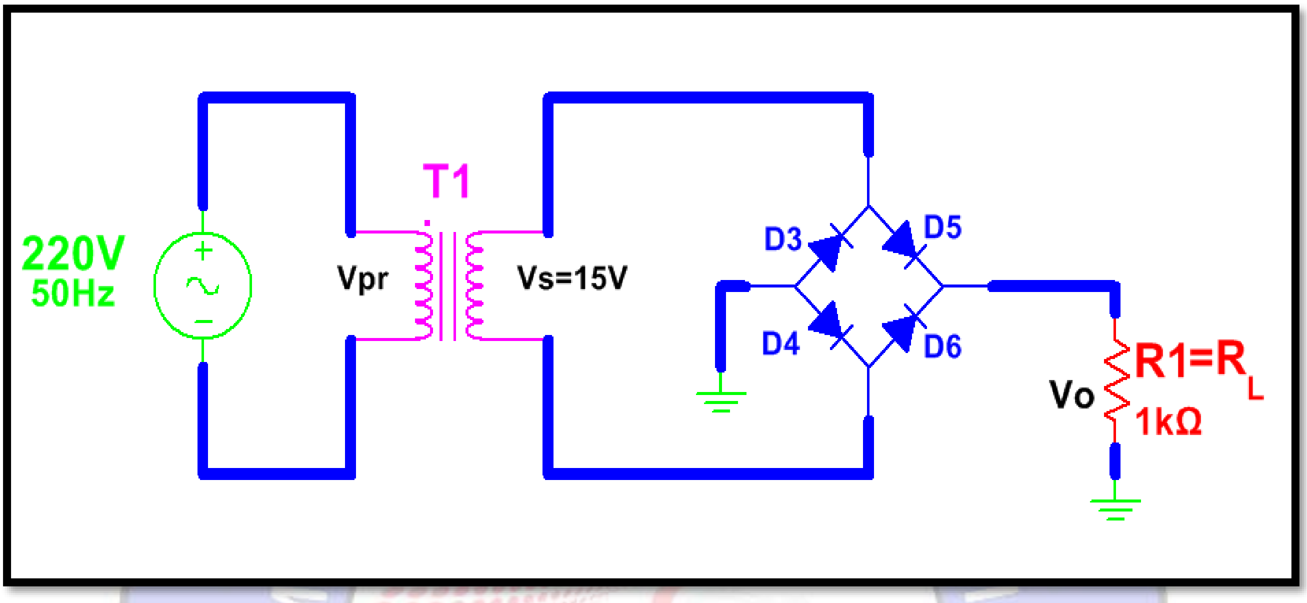

Figure 5: The Full-Wave Bridge Rectifier Circuit

In this circuit, two diodes are always in series with the load resistor during both the positive and negative half-cycles. If these diode drops are taken into account, the output peak voltage is:

$$V_{op} = V_{sp} - 1.4$$

The DC output voltage is given by:

$$V_{dc} = \frac{2V_{op}}{\pi} = \frac{2(V_{sp} - 1.4)}{\pi}$$

The peak inverse voltage of each diode in the circuit is given by:

$$PIV = V_{sp} - 0.7 = V_{op} + 0.7$$

- **Capacitor Filter**

As stated previously, the filter is used to reduce the ripples in the pulsating waveform of the rectifier. A half-wave rectifier with a capacitor filter is shown in Fig.6.

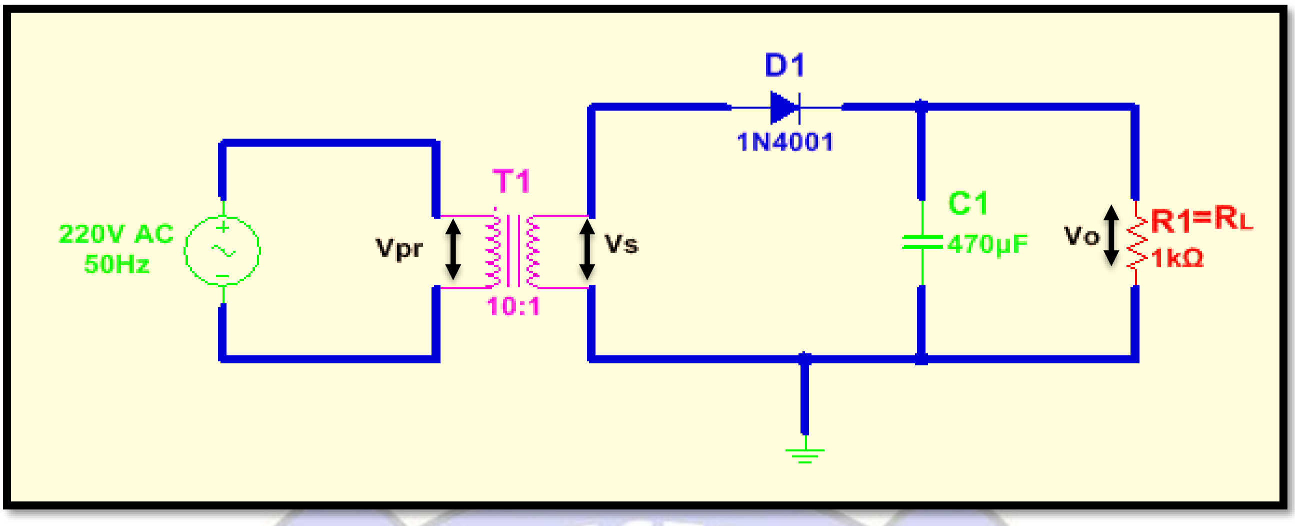

Figure 6: Half-Wave Rectifier with a Capacitor Filter

During the positive first quarter-cycle of the input signal, the diode is forward-biased, allowing the capacitor to charge to within 0.7V of the peak value of the secondary winding voltage. When the input begins to decrease below its peak, the capacitor retains its charge and the diode becomes reverse-biased because the cathode is more positive than the anode. During the remaining part of the cycle, the capacitor can discharge only through the load resistance at a rate determined by the $R_L C$ time constant, which is normally long compared to the period of the input signal. Figure 7 shows the output voltage of the filter circuit.

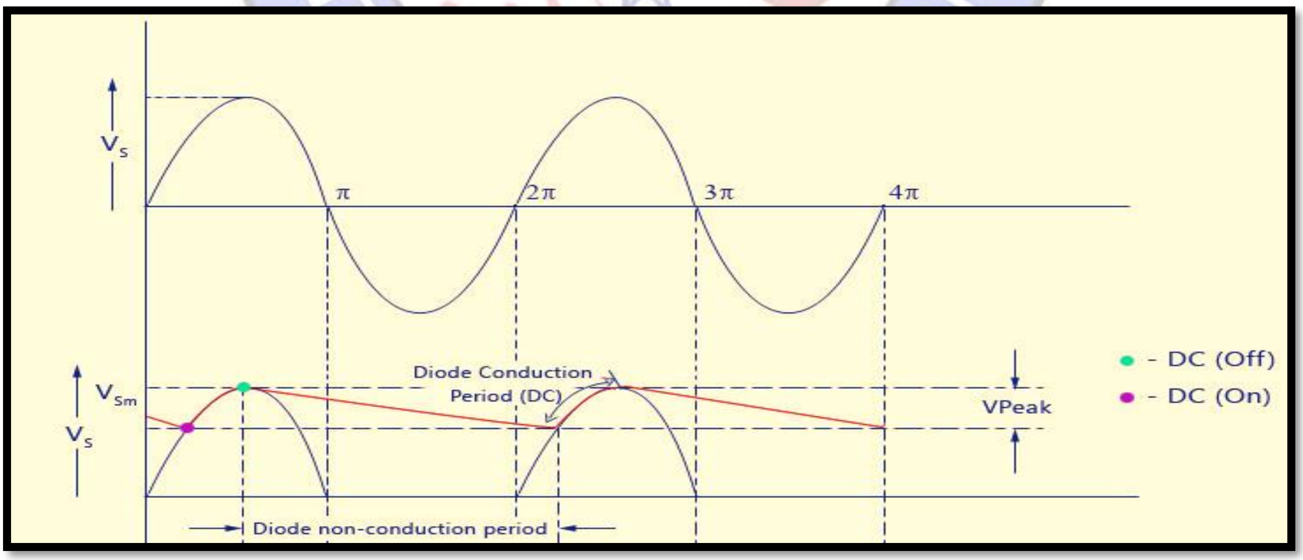

Figure 7: Output Waveform of the Capacitor Filter

Connected with the Half-Wave Rectifier

The variation in the capacitor voltage due to the charging and discharging is called the ripple voltage as illustrated in Fig.7. Generally, ripple is undesirable. Thus, the smaller the ripple, the better the filtering action.

For a half-wave rectified capacitor filter, the approximate value of the peak-to-peak ripple voltage is given by:

$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{op}$$

Where f is the frequency of the input signal, and V_{op} is the measured peak value of the output waveform.

The DC voltage of the output waveform can be approximated by:

$$V_{dc} = V_{op} - \left(\frac{V_{r(pp)}}{2}\right)$$

Or,

$$V_{dc} \cong \left(1 - \frac{1}{2fR_LC}\right)V_{op}$$

For the full-wave rectifier, the output frequency is twice that of the half-wave rectifier. This makes a full-wave rectifier easier to filter because of the shorter time between peaks. The peak-to-peak ripple voltage for the full-wave rectified capacitor filter is given by:

$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{op}$$

The DC voltage of the output waveform for the full-wave rectified capacitor filter can be approximated by:

$$V_{dc} \cong \left(1 - \frac{1}{4fR_LC}\right)V_{op}$$

The ripple factor is an indication of the effectiveness of the filter and is defined as:

$$r = \frac{V_{r(pp)}}{V_{dc}}$$

The lower the ripple factor, the better the filter. The ripple factor can be lowered by increasing the value of the filter capacitor or increasing the load resistance.

Procedure

1. Connect the half-wave rectifier circuit shown in Fig.8. Measure the DC output voltage, peak value of the secondary winding voltage, and the peak value of the output voltage as tabulated in Table 1. Sketch the output waveform.

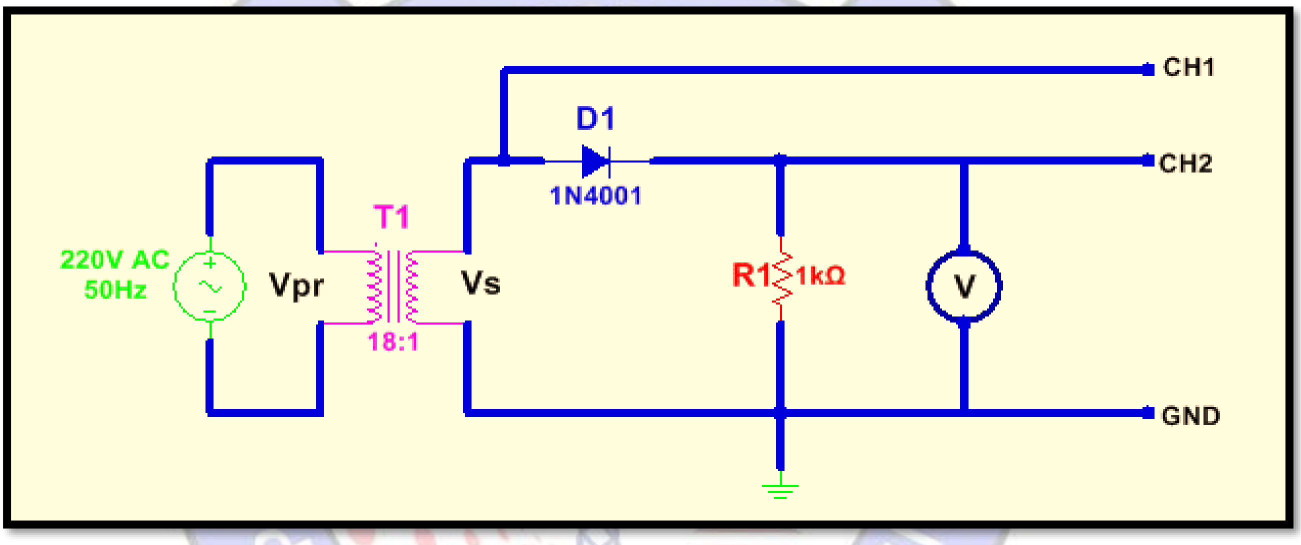

Figure 8: The Practical Half-Wave Rectifier Circuit

Quantity	Measured Value	Calculated Value
V_{sp}		
V_{op}		
V_{dc}		

Table 1: Recorded Data for the Half-wave Rectifier Circuit

2. Connect a capacitor filter at the output of the half-wave rectifier as shown in Fig.9, and measure the DC output voltage and peak-to-peak ripple voltage in the output.

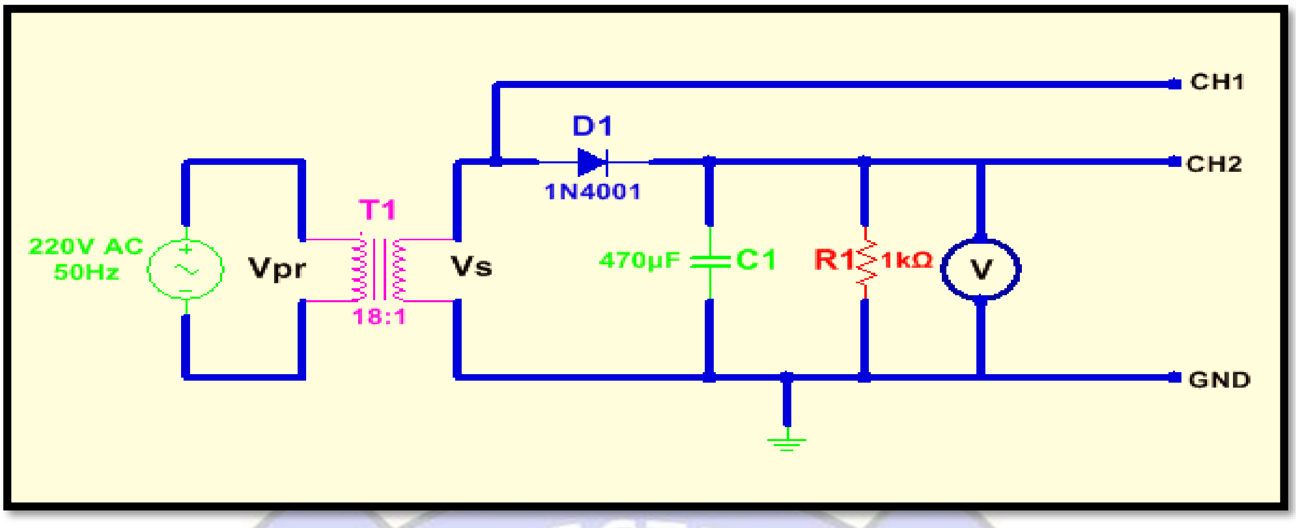

Figure 9: Practical Capacitor Filter Connected to the Half-Wave Rectifier

Quantity	Measured Value	Calculated Value
V_{dc}		
$V_{r(pp)}$		

3. Repeat step 2 after replacing the filter capacitor with another one of value 10µF.
4. Connect the full-wave center-tapped transformer rectifier circuit shown in Fig.10.Measure the DC output voltage, peak value of the secondary winding voltage, and the peak value of the output voltage as tabulated in Table 3. Sketch the output waveform in this case.

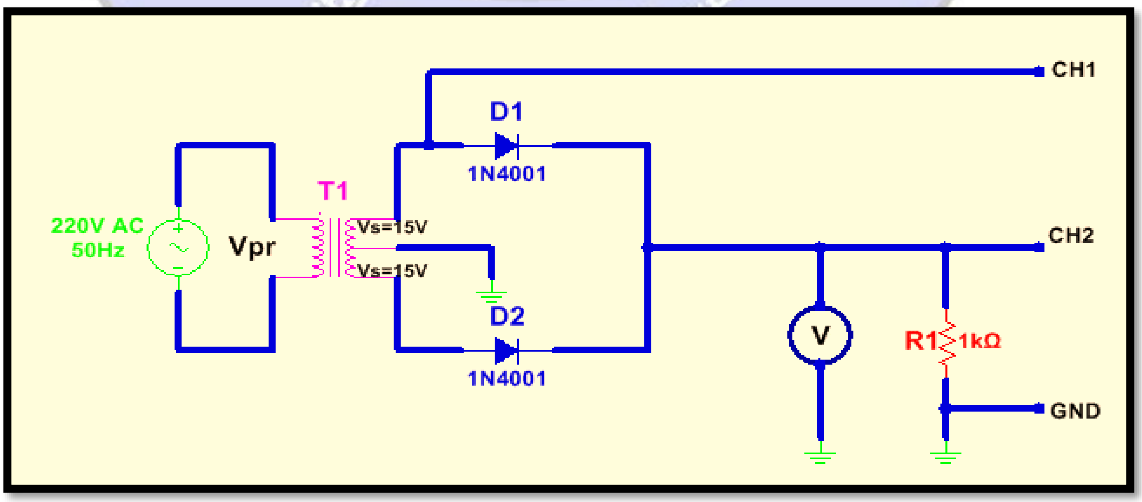

Figure 10: Practical Circuit for the Center-Tapped Full-Wave Rectifier

Quantity	Measured Value	Calculated Value
V_{sp}		
V_{op}		
V_{dc}		

Table 3: Recorded Data for the Center-Tapped Rectifier Circuit

5. Connect a capacitor filter at the output of the full-wave rectifier as shown in Fig.11, and measure the DC output voltage and peak-to-peak ripple voltage at the output.

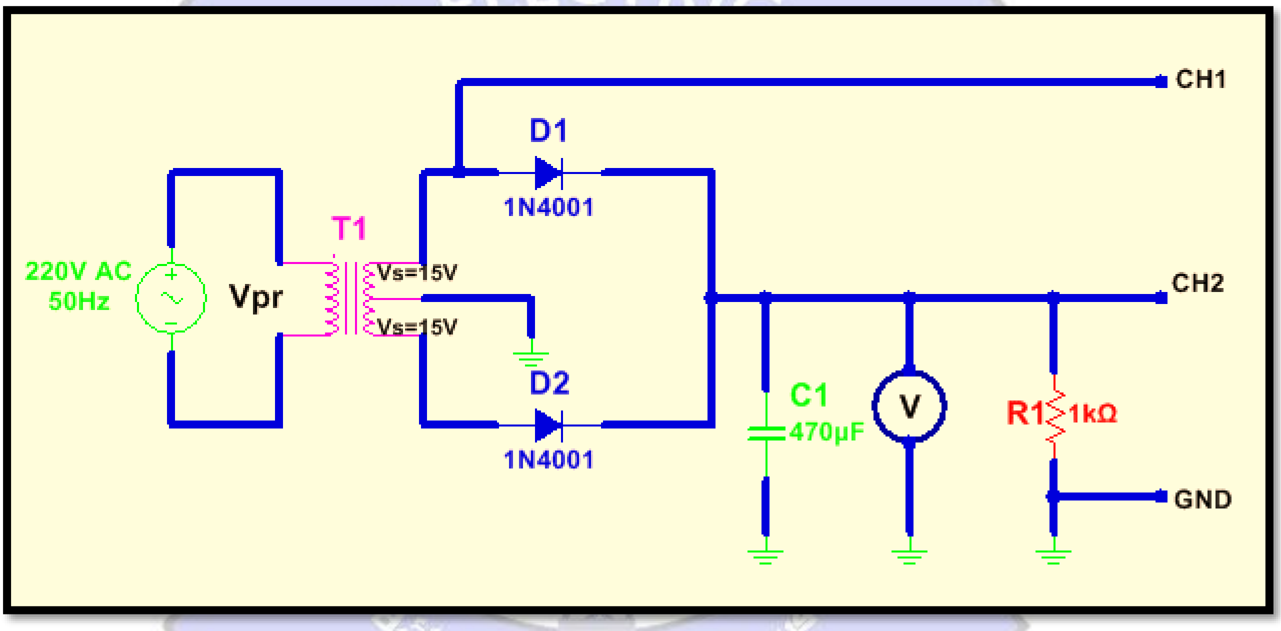

Figure 11: Practical Circuit for the Center-Tapped Full-Wave Rectifier with the Capacitor Filter

Quantity	Measured Value	Calculated Value
V_{dc}		
$V_{r(pp)}$		

6. Replace the filter capacitor with another one of value 10µF and repeat step 5.

7. Connect the full-wave bridge rectifier circuit shown in Fig.12. Measure the DC output voltage, and the peak value of the output voltage as tabulated in Table 5. Sketch the output waveform in this case. It should be noted that the secondary winding waveform in this case is similar to that of the center-tapped full-wave rectifier.

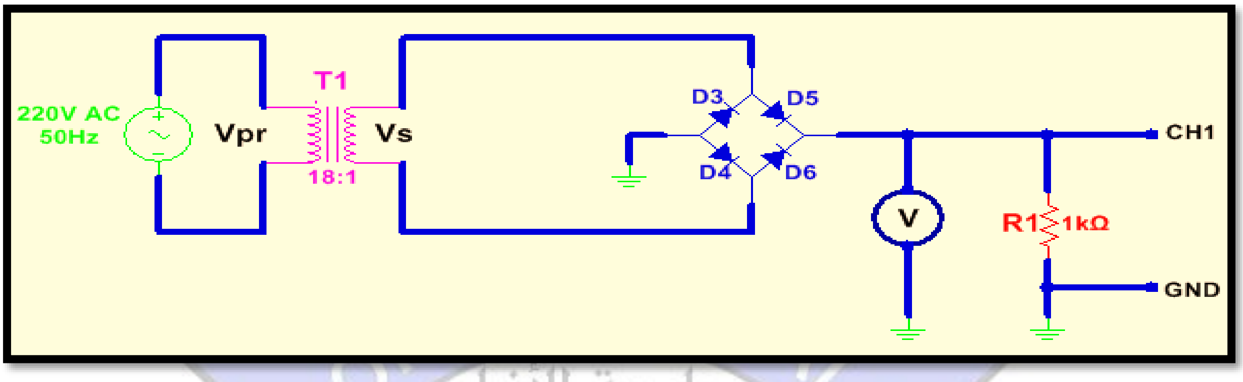

Figure 12: The Practical Full-Wave Bridge Rectifier Circuit

Quantity	Measured Value	Calculated Value
V_{op}		
V_{dc}		

Table 5: Recorded Data for the Full-Wave Bridge Rectifier Circuit

8. Connect a capacitor filter at the output of the full-wave bridge rectifier as shown in Fig.13, and measure the DC output voltage and peak-to-peak ripple voltage at the output.

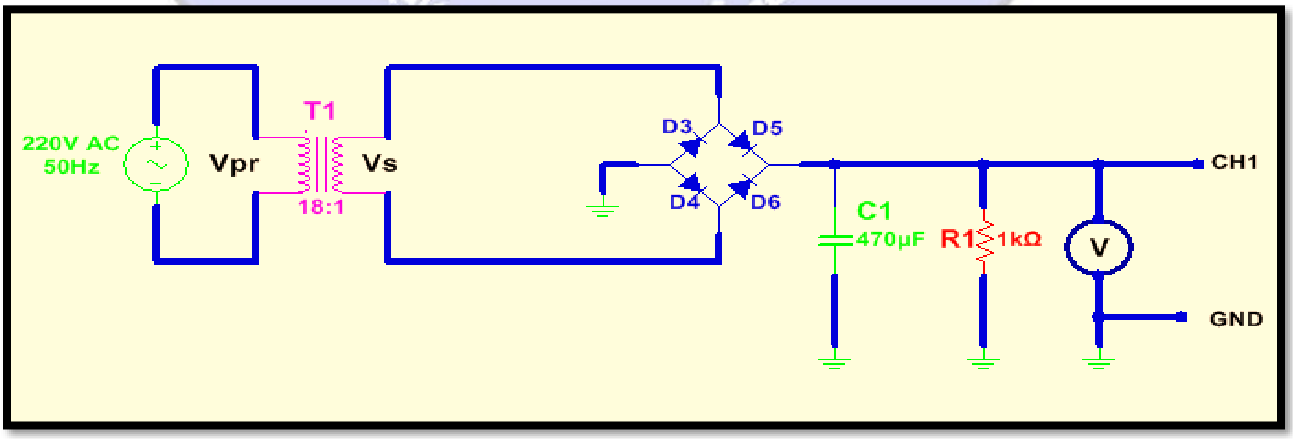

Figure 13: Practical Circuit for the Full-Wave Bridge Rectifier with the Capacitor Filter

Quantity	Measured Value	Calculated Value
V_{dc}		
$V_{r(pp)}$		

Table 6: Recorded Data for the Full-wave Bridge Rectifier and Filter Circuit

9. Replace the filter capacitor with another one of value 10μF and repeat step 8.

Calculations and Discussion

1. Calculate the theoretical output DC voltage of the half-wave rectifier circuit and compare it with measured value. For the capacitive filter, obtain the theoretical values of the DC output voltage and the ripple voltage and compare these values with the measured quantities. Determine also the practical and theoretical values of the ripple factor.
2. Calculate the theoretical output DC voltage of the center-tapped full-wave rectifier circuit and compare it with measured value. For the capacitive filter, obtain the theoretical values of the DC output voltage and the ripple voltage and compare these values with the measured quantities. Determine also the practical and theoretical values of the ripple factor.
3. Repeat the calculations for the full-wave bridge rectifier and filter circuit.
4. Determine the peak inverse voltage (PIV) on each diode in the three rectifier circuits.
5. If diode D4 in the bridge rectifier circuit of Figure 5 was removed or burned, explain the operation of the circuit in this case and sketch the predicted waveform of the output.
6. Explain the effect of increasing the filter capacitance on the output voltage in the halfwave rectifier and filter circuit.
7. Compare the DC output voltages of the three rectifier circuits. Which circuit has the highest output? On the other hand, which circuit has the lowest peak inverse voltage on each diode?

8. What value of filter capacitor is required to produce 1% ripple factor for a full-wave rectifier having a load resistance of 1.5kΩ? Assume that the peak value of the output voltage is 18V.