Experiment No. 5

Half Wave Rectifier with and without Filter

1. OBJECTIVES

- ❖ To construct a half-wave rectifier circuit and analyze its output.
- ❖ To analyze the rectifier output using a capacitor in shunt as a filter.

2. COMPONENTS REQUIRED

- ❖ DSO1052B Digital Oscilloscope and Probes.
- ❖ Function Generator.
- ❖ Capacitor 1 μf.
- ❖ Bread Board.
- ❖ Connecting wires.
- ❖ Diode 1N4007.
- ❖ Digital Voltmeter (0 - 20V).
- ❖ Resistors 1kΩ, 100 kΩ.

3. THEORY

We have studied the operation and IV characteristics of a PN junction diode in the previous experiments. We have seen that the diode can conduct only when it is forward biased and blocks when it is reversed biased. A widely used application of this feature and diodes in general is in the conversion of an alternating voltage (AC) into a continuous voltage (DC). In other words, ***Rectification***.

A ***rectifier*** is an electronic device that converts AC voltage into DC voltage. In other words, it converts alternating current to direct current. A rectifier is used in almost all the electronic devices. Mostly it is used to convert the main voltage into DC voltage in the power supply section. By using DC voltage supply electronic devices work.

There are many possible ways to construct rectifier circuits using a diode or a group of diodes. The basic types of rectifier circuits are: • ***The Half Wave Rectifier*** • ***The Full Wave Rectifier***

Half Wave Rectifier

The easiest rectifier to understand is the half wave rectifier. A simple Half Wave Rectifier is nothing more than a single PN junction diode connected in series to the load resistor as shown in Figure 1.

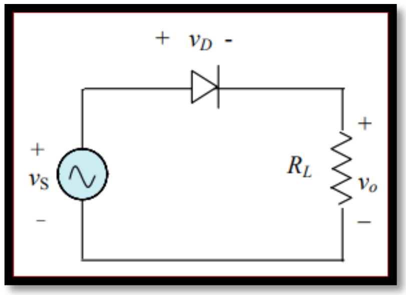

Fig. 1: Half-wave rectifier circuit.

Circuit operation

Let's look at the operation of this single diode rectifier when connected across an alternating voltage source **vs**. The supply voltage is given by:

$$v_s = V_m \sin \omega t$$

where ω (= 2πf = 2π/T) is the angular frequency in rad/s.

During the positive half-cycle of the input, the diode is forward biased and conducts. Current flows through the load and a voltage is developed across it. During the negative half-cycle, it is reverse bias and does not conduct. Therefore, in the negative half cycle of the supply, no current flows in the load resistor as no voltage appears across it. Thus the dc voltage across the load is sinusoidal for the first half cycle only and a pure a.c. input signal is converted into a unidirectional pulsating output signal. The waveforms for source voltage Vs and output voltage Vo are shown in Figure 2.

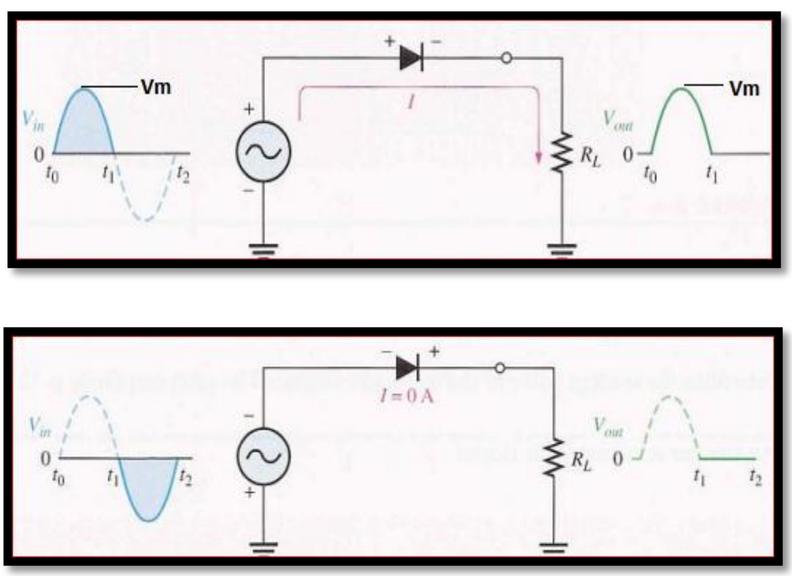

Fig. 2: Source and output voltages.

Average load voltage

If a DC voltmeter is connected to measure the output voltage of the half-wave rectifier (across the load resistance), the reading obtained would be the average load voltage V_{avg}, also called the DC output voltage.

$$\text{Average or mean value(dc value)} = \frac{\text{area under the curve}}{\text{length of base}}$$

$$V_{av} = \frac{\int_0^{\pi} V_m \sin(\theta)}{2\pi} = \frac{V_m}{2\pi}(-\cos(\theta))\Big|_0^{\pi} = \frac{2V_m}{2\pi} = \frac{V_m}{\pi} = .318V_m$$

The output voltage waveform and average voltage are shown in Figure 3.

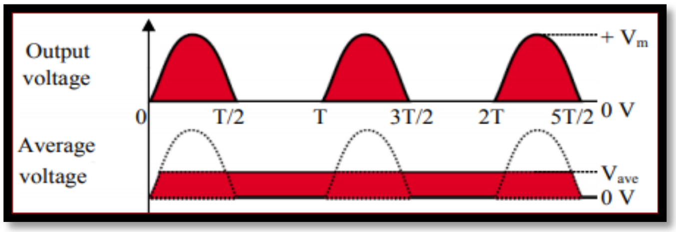

Fig. 3: Output voltage and average voltage for half-wave rectifier.

Root mean square (RMS) value of output load voltage V_{RMS}

The root mean square (RMS) value of output load voltage in a half wave rectifier is:

$$RMS\ Value = \sqrt{\left(\frac{1}{2\pi}\right)\int_0^{\pi}(Vm\sin\omega t)^2 d(\omega t) + \left(\frac{1}{2\pi}\right)\int_{\pi}^{2\pi} 0\, d\omega t}$$

$$= \sqrt{\left(\frac{Vm^2}{2\pi}\right)\int_0^{\pi}(\sin\omega t)^2 d(\omega t)}$$

$$= Vm\sqrt{\left(\frac{1}{4\pi}\right)\int_0^{\pi} 2(\sin\omega t)^2\, d(\omega t)}$$

$$= \left(\frac{Vm}{2}\right)\sqrt{\left(\frac{1}{\pi}\right)\int_0^{\pi}(1-\cos\omega t)\, d(\omega t)}$$

$$= \left(\frac{Vm}{2}\right)\sqrt{\left(\frac{1}{\pi}\right)\left[\int_0^{\pi} 1 d(\omega t) - \int_0^{\pi}\cos\omega t\, d(\omega t)\right]}$$

$$= \left(\frac{Vm}{2}\right)\sqrt{\left(\frac{1}{\pi}\right)[\pi - 0)]}$$

$$= \frac{Vm}{2}$$

peak inverse voltage

peak inverse voltage is the maximum voltage that a diode can withstand in the reverse direction without breaking down or avalanching. If this voltage is exceeded the diode may be destroyed.

For the half wave rectifier, the value of PIV is: $\boldsymbol{PIV = V_m}$. The reasoning for this equation is that when the diode is reverse biased, there is no voltage across the load. Therefore, all of the secondary voltage (V_m) appears across the diode.

Ripple Factor of Half Wave Rectifier

The output of a rectifier consists of a d.c. component as well as an a.c. component which is also known as ripple. This a.c. component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output. Hence the smaller this component, the more effective is the rectifier.

The ratio of a.c. component to the d.c. component in the rectifier output is known as ripple factor. Therefore, ripple factor is very important in deciding the effectiveness of a rectifier. The smaller the ripple factor, the lesser the effective a.c. component and hence more effective is the rectifier.

$$r = \frac{V_{ac}(output)}{V_{dc}(output)} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}} = \sqrt{\frac{V_{rms}^2}{V_{dc}^2} - 1} = \sqrt{\left(\frac{0.5}{0.318}\right)^2 - 1} = 1.21$$

Hence it is clear that a.c. component exceeds the d.c. component in the output of a half wave rectifier .It results more pulsation in the output. So half wave rectifier is ineffective for conversion of a.c into d.c. Note that for us to construct a good rectifier, we want to keep the ripple factor as low as possible. This is why we use capacitors and inductors as filters to reduce the ripples in the circuit.

Half-wave Rectifier with Capacitor Filter

The capacitor is the most basic filter type and is the most commonly used. The half-wave rectifier for power supply application is shown below. A capacitor filter is connected in parallel with the load.

Circuit operation

The operation of this circuit during positive half cycle of the source voltage is shown in figure 4. During the positive half cycle, diode D will conduct, and the capacitor charges rapidly. As the input starts to go negative, D turns off, and the capacitor will slowly discharge through the load (figure 5).

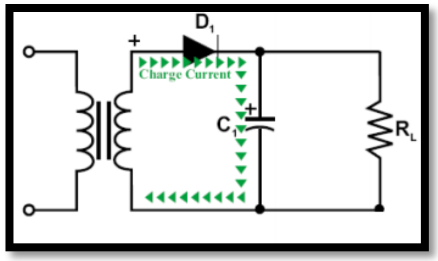

Fig. 4: Half wave rectifier with capacitor filter – positive half cycle.

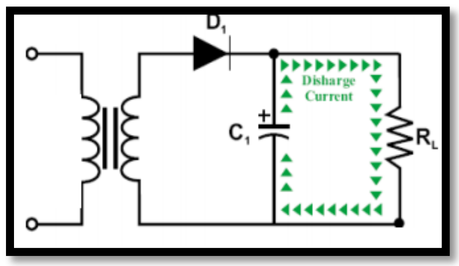

Fig. 5: Half wave rectifier with capacitor filter – negative half cycle.

The working of the capacitor can be understood in the following manner using figure 6. For the first quarter of the positive cycle of the input voltage, the capacitor will charge up to the supply maximum voltage Vm. For the second quarter of the positive cycle, the diode will become reverse bias because of the cathode at a higher potential than the anode. So, for the rest of the cycle, the capacitor will provide current to the load and discharge until the supply voltage becomes more than that of capacitor voltage. As the input voltage increased from the capacitor voltage the capacitor will again start charging and the chain will remain. The discharging time of the capacitor depends upon the RC time constant.

In the filtering action, the capacitor charges quickly and discharge slowly because of load resistance. That cause a change in voltage across the capacitor, which is undesirable and called ripple voltage.

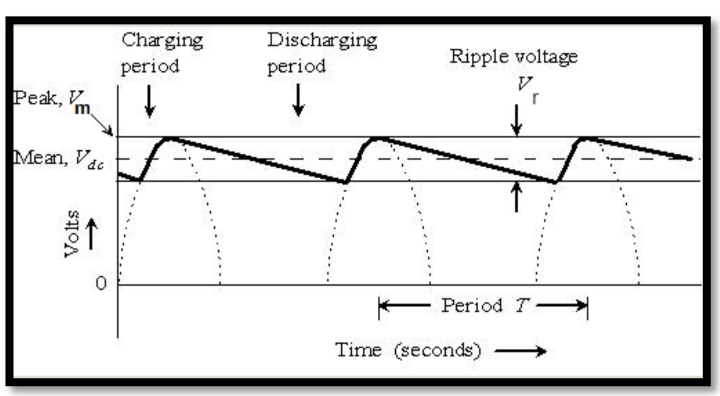

Fig. 6:Output voltage waveform of half-wave rectifier with capacitor filter.

The ripple factor can be significantly reduced using a filter capacitor. For a half wave rectifier with filter capacitor, ripple factor is given by,

$$\boldsymbol{r} = \frac{\mathbf{1}}{\mathbf{2}\sqrt{\mathbf{3}}\,\boldsymbol{f}\boldsymbol{R_L}\boldsymbol{C}}$$

Where f is the frequency of pulsating DC which in this case is same as that of AC mains.

Also,

$$\boldsymbol{V_{dc}} = \boldsymbol{V_m} - \frac{\boldsymbol{V_r}}{\mathbf{2}}$$

$$\boldsymbol{V_r} = \frac{\boldsymbol{V_m}}{\mathbf{2}\sqrt{\mathbf{3}}\,\boldsymbol{f}\boldsymbol{R_L}\boldsymbol{C}}$$

4. PROCEDURE

❖ **Without Filter**

1- Configure the half-wave rectifier circuit as shown in Figure 1 and apply an AC voltage of $\boldsymbol{V_{pp}}$ = 10V .
2- Use channel 1 of the oscilloscope to measure the peak-to-peak value of the input signal .
3- **Transfer the graph into a sheet of graph paper. Each axis should be labeled and appropriate units indicated**.
4- Determine the amplitude (peak value) and the frequency f of the input voltage .
5- Use the second oscilloscope channel to measure the output voltage and enter this into the same sheet of graph paper.
6- Determine the amplitude (peak value) and the frequency $\boldsymbol{f}$ of the output voltage .
7- Measure the input a.c. voltage and the output a.c. and d.c. voltages using multimeter for at least 2 values of load resistor (Be careful to choose proper settings of multimeter for ac and dc measurement).
8- Multiply the $\boldsymbol{V_{ac}}$ at the input by √2? to get the peak value and calculate $\boldsymbol{V_{dc}}$ Using the formula $\boldsymbol{Vdc = Vm/\pi}$. Compare this value with the measured $\boldsymbol{V_{dc}}$ at the output.
9- Calculate the ripple factor.

Table (I): Data and results for Half wave rectifier with no filter,, R=1 $k\Omega$

<table>
<tr><td colspan="4" align="center">R=1 $k\Omega$</td></tr>
<tr><td colspan="2" align="center">Input</td><td colspan="2" align="center">output</td></tr>
<tr><td>V_{pp}</td><td></td><td>V_m(measured from CRO)</td><td></td></tr>
<tr><td>V_m</td><td></td><td>V_m(calculated)</td><td></td></tr>
<tr><td>V_{ac}(measured using voltmeter)</td><td></td><td>V_m%</td><td></td></tr>
<tr><td>V_{ac}(calculated)</td><td></td><td>V_{dc}(measured using voltmeter)</td><td></td></tr>
<tr><td>V_{ac}%</td><td></td><td>V_{dc}(calculated)</td><td></td></tr>
<tr><td>Frequency f</td><td></td><td>V_{dc}%</td><td></td></tr>
<tr><td colspan="2" rowspan="4"></td><td>V_{ac}(measured using voltmeter)</td><td></td></tr>
<tr><td>V_{ac}(calculated)</td><td></td></tr>
<tr><td>V_{ac}%</td><td></td></tr>
<tr><td>Frequency f</td><td></td></tr>
<tr><td colspan="4" align="center">Ripple factor(measured and calculated)</td></tr>
</table>

- **With Filter**

Connect the capacitor across the output for each load resistor as shown in figure 4 and measure the output a.c. and d.c. voltages once again and calculate the ripple factor. (If time permits you could also use different values of capacitors and study the output)

Table (2): Data and result for Half wave rectifier with filter,, R=1 $k\Omega$,, C=1 μF

output	
V_m(measured from CRO)	
V_m(calculated)	
V_m%	
V_{dc}(measured using voltmeter)	
V_{dc}(measured from CRO)	
V_{dc}(calculated)	
V_{dc}%	
V_r(measured from CRO)	
V_r(calculated)	
V_r%	
Ripple factor	

Table (3): Data and result for Half wave rectifier with filter,, R=100 $k\Omega$,, C=1 µF.

output	
V_m(measured from CRO)	
V_m(calculated)	
V_m%	
V_{dc}(measured using voltmeter)	
V_{dc}(measured from CRO)	
V_{dc}(calculated)	
V_{dc}%	
V_r(measured from CRO)	
V_r(calculated)	
V_r%	
Ripple factor	