Half-Wave Rectifier Circuit With and Without Filter

Gayatri P
2nd year, Integrated M.Sc. Physics
Roll No.: 2211185

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A rectifier circuit is used to convert AC current into DC current. In this experiment, we will construct a half-wave rectifier circuit and analyze its output. Additionally, we will also attach a capacitor in shunt to the circuit as a filter and analyse its output. This will demonstrate the need for filters in rectification circuits.

I. INTRODUCTION

The process of conversion of Alternating current into Direct current is known as rectification. For this, Diodes — which only allow unidirectional flow of current — are used. In this experiment, we are making a half-wave rectifier.

II. THEORY

In a a Half-wave rectifier, during the positive half-cycle of the AC input, the diode is forward biased and current flows through the load and a voltage is developed across it. During the negative half-cycle, it is reverse biased and does not conduct. Therefore, 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.

We can represent the input AC voltage by

$$V(t) = V_{\max} \sin(\omega t)$$

Since the diode conducts only in one half-cycle (0-π), the DC component in the output will be the time average of $V(t)$ from 0 to $T/2$, $\langle V(t) \rangle$ which comes out to be $V_{\max}/\pi$, where $V_{\max}$ is the peak value of the voltage.

$$V_{\text{dc}} = \langle V(t) \rangle = \frac{V_{\max}}{\pi} = 0.318 V_{\max} \tag{1}$$

The RMS of voltage would be,

$$V_{\text{rms}} = \langle V^2(t) \rangle = \frac{V_{\max}}{2} \tag{2}$$

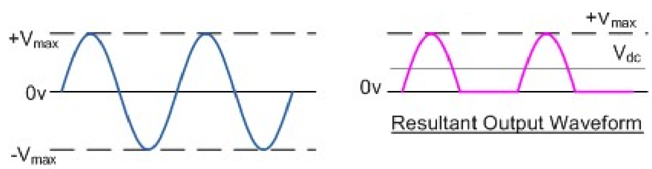


FIG. 1: Half-wave rectifier input and output waveforms

A. Ripple Factor

As the voltage across the load resistor is only present during the positive half of the cycle, the average DC voltage measured is very low.This variation on the rectified waveform is called *Ripple* and is an undesirable feature. The ripple factor is a measure of purity of the d.c. output of a rectifier and is defined as:

$$r = \frac{V_{\text{ac}}}{V_{\text{dc}}} \tag{3}$$

Where V_{ac} and V_{ac} are the AC and DC components of the output wavform respectively. Since $V_{\text{rms}}^2 = V_{\text{ac}}^2 + V_{\text{dc}}^2$,

$$\begin{aligned} r &= \sqrt{\frac{V_{\text{rms}}^2 - V_{\text{dc}}^2}{V_{\text{dc}}^2}} \\ &= \sqrt{\frac{V_{\text{rms}}^2}{V_{\text{dc}}^2} - 1} = \sqrt{\frac{0.5}{0.318} - 1} \\ &= 1.21 \end{aligned}$$

B. Rectification Efficiency

Rectification efficiency (η), is a measure of the percentage of total AC power input converted to useful DC power output.

$$\begin{aligned} \eta &= \frac{V_{\text{dc}} I_{\text{dc}}}{V_{\text{ac}} I_{\text{ac}}} = \frac{I_{\text{dc}}^2 R}{I_{\text{ac}}^2 / (r_d + R)} \\ &= \frac{(0.318 V_{\max})^2}{(0.5 V_{\max})^2 \left(1 + \frac{r_d}{R}\right)} = \frac{0.405}{\left(1 + \frac{r_d}{R}\right)} \end{aligned}$$

where r_d is the forward resistance of the diode. Under ideal conditions ($r_d \approx 0$), the rectification efficiency for a half-wave rectifier is 40.5%.

C. Filters

The output of a rectifier gives a pulsating DC signal because of presence of some AC components whose frequency is equal to that of the AC supply frequency. To remove any voltage variations or ripples, and smoothen the output, Filter circuits are used. Various filter circuits are available such as shunt capacitor, series inductor, choke input LC filter and π-filter etc. Here we use a simple shunt capacitor filter circuit. Since a capacitor is open to DC and offers low impedance path to AC current, putting a capacitor across the output will make the DC component to pass through the load resulting in smaller ripple voltage.

1. *Working Principle*

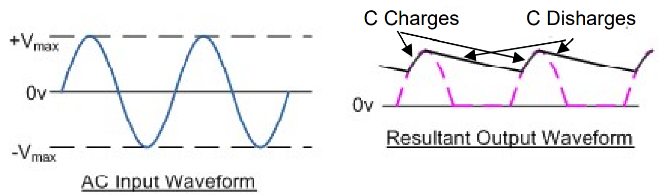


FIG. 2: Half-wave rectifier with a capacitor filter — input and output waveforms

When the rectifier output voltage is increasing, the capacitor gets charged to its peak voltage V_m. Just past that, the rectifier output voltage starts to fall. As the source voltage decreases below V_m , the capacitor will try to send the current back to diode making it reverse biased. Thus the diode separates/disconnects the source from the load and hence the capacitor will discharge through the load until the source voltage becomes more than the capacitor voltage. The diode again starts conducting and the capacitor is again charged to the peak value V_m and the process continues.

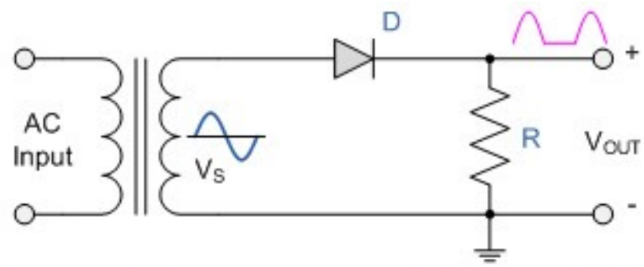
The decay is seen is the exponential decay of any capacitor is charging through a load resistor. The extent to which the capacitor voltage drops depends on the capacitance and the amount of current drawn by the load — these two factors effectively form the RC time constant for voltage decay. A proper combination of large capacitance and small load resistance can give out a steady output.

III. EXPERIMENTAL SETUP

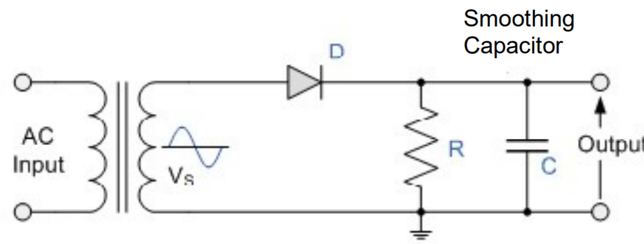
A. Components Used

1. Step-down transformer
2. Junction diode
3. Load resistors
4. Electolytic capacitors
5. Oscilloscope
6. Multimeters
7. Breadboard
8. Connecting wires

B. Circuit Diagram



(a) Without a filter



(b) With a capacitor filter

FIG. 3: Circuit diagrams for the Half-wave rectifier circuits

IV. RESULTS

The output wave-forms as seen on the oscilloscope for different values of loads and capacitance are shown here in Figs 5 to 9.

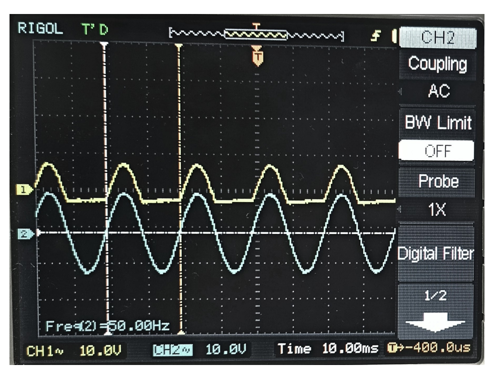


FIG. 4: Half wave rectifier without a filter at $R = 2.2k\Omega$

FIG. 5: Half wave rectifier with a filter at $R = 1.5k\Omega$ and $C = 10.71\mu F$

FIG. 6: Half wave rectifier with a filter at $R = 1.0k\Omega$ and $C = 28.83\mu F$

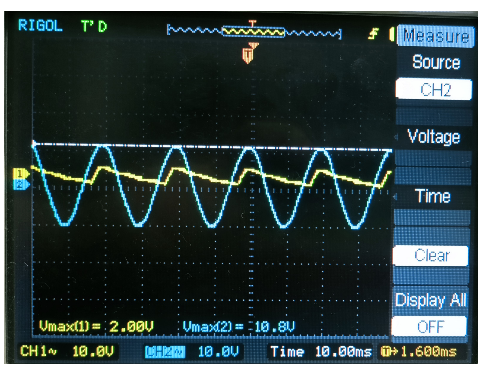


FIG. 7: Half wave rectifier with a filter at $R = 1.5k\Omega$ and $C = 23.50\mu F$

FIG. 8: Half wave rectifier with a filter at $R = 2.2k\Omega$ and $C = 23.50\mu F$

V. CONCLUSION

For the half-wave rectifier circuit without the filter, we can see that the ripple factor and rectification efficiency stays around the same for different loads with an average value,

$$r = 1.23$$
$$\eta = 32.85\%$$

where r is close to the theoretically calculated value and the rectification efficiency is less than the ideal value, as predictable.

For the half-wave rectifier circuit with the filter, we can see that for a particular capacitance, r is inversely proportional to the load resistance. Similarly, for a particular load resistance, r is inversely proportional to capacitance. The lowest r measured is 0.073.

Since we are ideally aiming for the lowest ripple factor in the output signal (i.e. maximise the DC component), we can conclude that a proper combination of significantly large values of RC will give us a steady output signal.

VI. PRECAUTIONS

1. The transformer must be handled carefully.
2. Switch on the circuit only after verifying the connections to be proper.
3. Visualise the output on the oscilloscope to make sure the rectification is happening before taking readings.
4. Do not change the resistor or the capacitor while the circuit is switched on.

[1] SPS. Lab manual. *Website*, 2023. `https://www.niser.ac.in/sps/sites/default/files/2-b-half%20wave%20rectifier.pdf`.