Rectifier Circuits

Introduction

We have studied the operation and I/V characteristics of a PN junction diode in the previous experiment. We have seen that the diode can conduct only when it is forward biased and blocks when it is reversed biased. This property of diode makes it an essential component of DC power supplies which are used to power electronic systems and circuits. The block diagram of a typical DC power supply is shown in Fig.1.

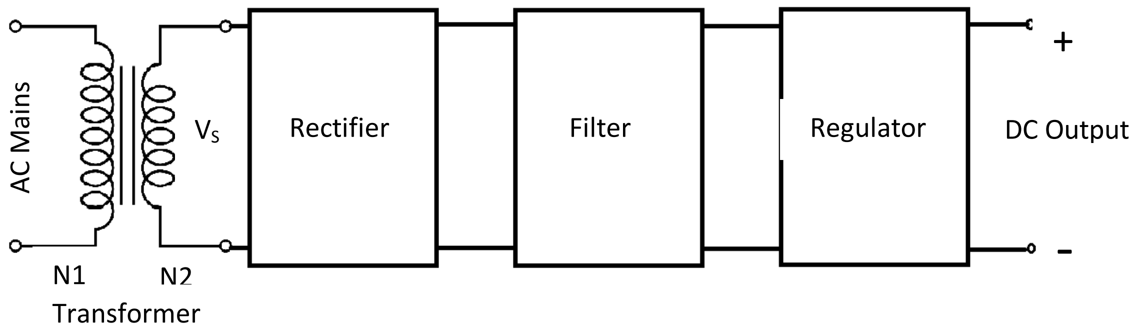


Figure 1: A typical DC power supply

The transformer is used to step down the AC mains voltage (230V, 50 Hz) to desired voltage level by controlling the turns ratio N2:N1. The secondary voltage, V_s is 230(N2/N1). The transformer also provides electrical isolation to the electronic system from AC mains.

The rectifier converts the AC voltage to pulsating DC, which is smoothened by filter circuit. The output voltage of the power supply is expected remain constant against variations in the load current or variations in input voltage. This is accomplished by using a suitable voltage regulator.

In this experiment, we will study three different types of rectifiers with capacitor filter.

Half Wave Rectifier:

This is the simplest rectifier that uses a single diode and a load resistor. Fig. 2 shows the circuit diagram for a half wave rectifier.

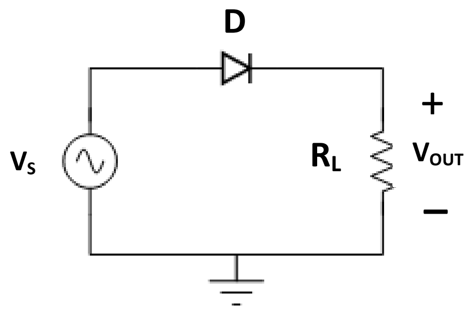
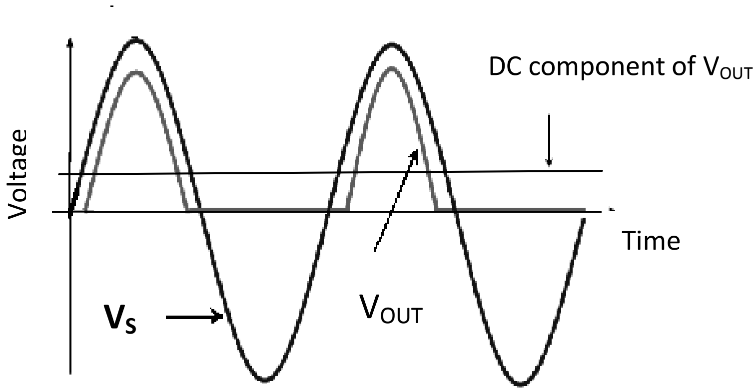
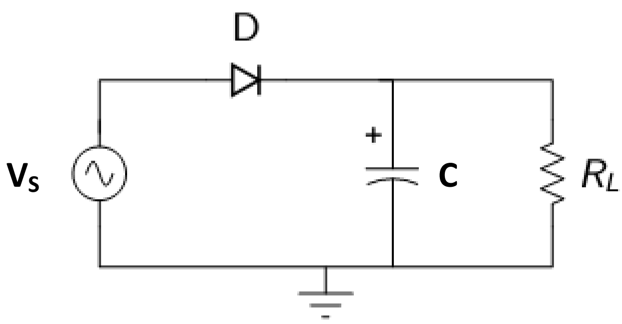


Figure 2: Half Wave Rectifier

The diode is forward biased during each positive half cycle causing current to flow in the circuit. These current results in voltage V_{OUT} across the resistor R_L. The waveform of V_{OUT} with respect to V_S is shown in Fig.3.



The output voltage is pulsating DC which has a significant AC component and DC component which is the average value of V_{OUT}. This kind of voltage is not suitable as a DC supply. A simple way to make the output voltage smooth is to connect a filter capacitor across the output terminals.



During positive half cycle as V_s increases, the diode D conducts allowing the capacitor to charge to peak voltage of the sinusoid. After the peak, the voltage V_s starts decreasing making the anode of the diode at lesser voltage than cathode as the capacitor C holds the voltage at cathode at the peak voltage. This reverse biases the diode D and the capacitor C starts discharging through R_L till the voltage across (which is the voltage at the cathode) it becomes less than Vs which is rising sinusoid. The diode then gets forward biased and starts conducting till the peak are reached and this cycle continues. The charging and discharging of the capacitor causes **ripple voltage** in the output. Larger capacitor (and /or R_L) results in slower discharge and "flat" output giving rise to less ripple content.

Ripple factor: Ripple factor is a measure of effectiveness of a rectifier circuit. It is defined as the ratio of RMS value of the AC component (ripple component) I_{rrms} in the output waveform to the DC component V_{DC} in the output waveform.

$$r = \frac{I_{rrms}}{I_{DC}}$$

We can measure the value of RMS component of overall output waveform from which we can estimate the value of I_{rrms}.

We get,

$$I_{rrms} = \sqrt{I_{rms}{}^2 - I_{DC}{}^2}$$

For half wave rectifier,

$$I_{rms} = \frac{I_m}{2}$$

$$I_{DC} = \frac{I_m}{\pi}$$

This leads to ripple factor r =1.21 for half wave rectifier.

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

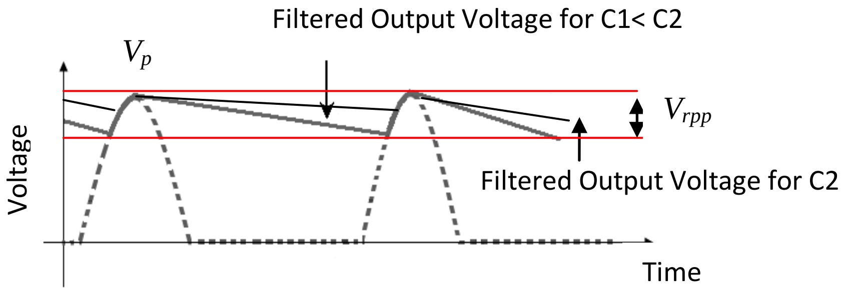
$$r = \frac{1}{2\sqrt{3}fR_L C}$$

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

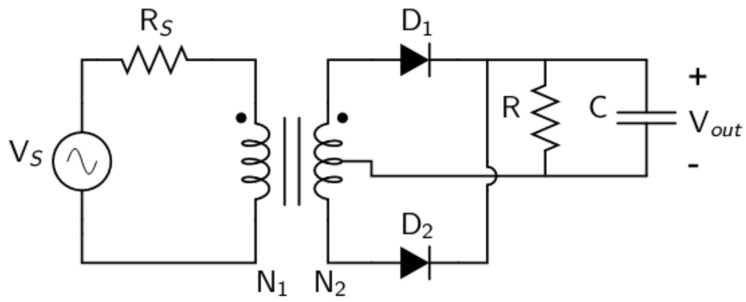
The value of ripple factor can also be estimated from the waveform of the output voltage.

$$r = \frac{V_{rpp}/2\sqrt{3}}{V_p - 0.5V_{rpp}}$$

Where V_p is the peak value of the output voltage and V_{rpp} is peak to peak value of the ripple voltage.

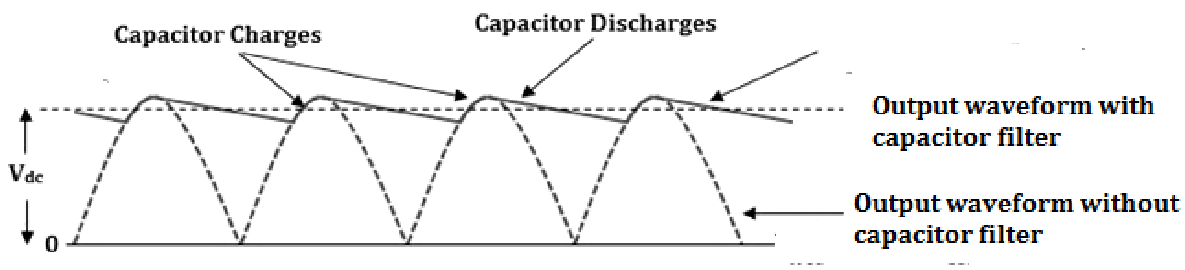


Full wave rectifier with centretapped transformer



The circuit consists of a center-tapped transformer, followed by the rectifier formed by two diodes D_1 and D2, and finally the load R with a capacitor filter C. The circuit is designed such that the current through the load is always in the same direction during both the half cycles.

Assume that the capacitor is not connected initially. Due to the center tap rectifier, during the positive half cycle of the input V_s, A is positive with respect to B, hence diode D1 will be forward biased and D2 will be reverse biased. This results in the current flowing from A-D1-R-B-A. In negative half cycle, C is positive with respect to B. This makes C positive with respect to B causing diode D2 to get forward biased making the current flow from C-D2-R-B-C. Thus in both the half cycles the current through R flows in the same direction resulting in pulsating DC across R.



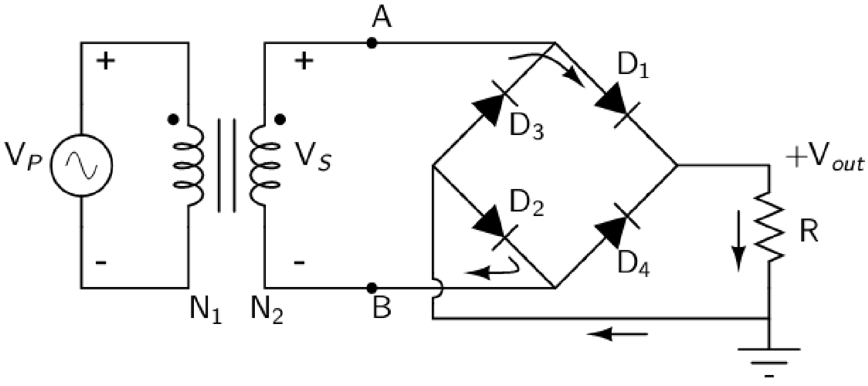
With capacitor filter

During the positive half cycle, capacitor C will charge to the peak of the input waveform while the load R is being supplied current through D1. When the input starts to go below its peak value, the voltage across C will cause D1 to be reverse biased, thus disconnecting the rectifier from the load. The capacitor will then provide the necessary current for the load. The rate of potential drop across C will be based on the values of R & C.

During the negative half cycle, diode D2 will initially be reverse biased due to voltage across C. When the voltage at the input crosses the dropping voltage across C, D2 will be forward biased. Now the load is supplied current by the input while simultaneously charging C. This continues till the negative peak of the input waveform, after which D2 will be reverse biased. The next positive cycle is similar to the previous negative cycle with diode D1 being forward biased when the input voltage crosses the voltage across C. Capacitor C ensures that the voltage across load R remains close to the peak of the input voltage.

Bridge Rectifier

Fig. 1 shows the circuit of diode bridge rectifier. The circuit uses four diodes D1, D2, D3 and D4 connected in the form of bridge.

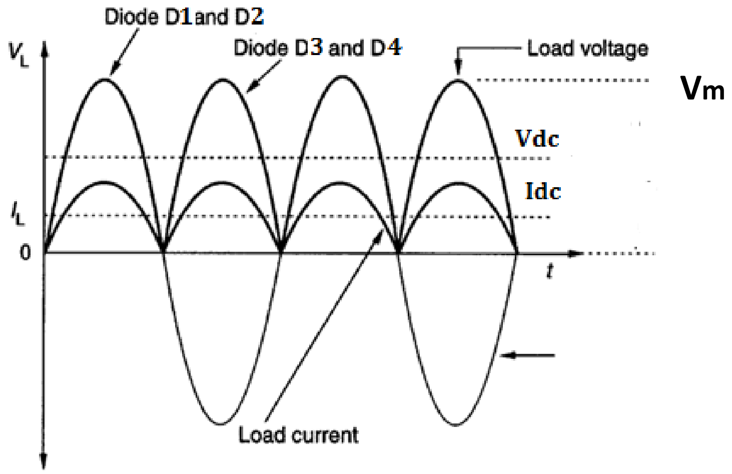


During the positive cycle of *Vs*, point A is positive with respect to B causing diode D1 and D2 to forward bias and D3 and D4 to get reversed biased. This results in the current to flow from A, through D1, R, D2, B to A.

During negative cycle, the polarities change. Now point B is positive with respect to A causing diodes D3 and D4 to conduct and D1 and D2 to reverse bias. The resulting current then flows from B through D4, R, D3, A to B. In both the cycles, the current through the load resistor R flows in the same direction ensuring the pulsating DC across R in both the half cycles of the input voltage. Hence, this is a full wave rectifier.

The output voltage can be smoothened by connecting a suitable capacitor across the load resistor as explained in section B.

Fig 2 shows the input output waveforms.



The ripple factor of full wave rectifier (both centre tapped and bridge rectifier)

The ripple factor is given by,

$$r = \frac{V_{rrms}}{V_{DC}} \qquad (1)$$

where V_{rrms} is RMS value of AC component(ripple) in the rectifier output and VDC is the DC component (average value) of the rectified output.

$$V_{rrms} = \sqrt{V_{rms}{}^2 - V_{DC}{}^2} \qquad (2)$$

where V_{rms} is the RMS value of the rectified output.

For full wave rectifier,

$$V_{rms} = \frac{V_m}{\sqrt{2}} \text{ and } V_{DC} = \frac{2V_m}{\pi} \qquad (3)$$

where, V_m is peak value of the voltage V_s. Substituting these values in (2) we get.

$$r = 0.483 \qquad (4)$$

This is a significant improvement in the ripple factor compared to that of a Half wave rectifier (r=1.21). However, this pulsating DC is not useful to power electronic circuits as it still has a large AC component. The output can be made smooth by using capacitor filter as described in Half Wave rectifier. Try to analyse the circuit in Fig. 3 and the waveforms in Fig 4.

The ripple factor for full wave rectifier with capacitor filter is given by.

$$r = \frac{1}{4\sqrt{3}\, f R_L C}$$

where f is the frequency of the signal V_s