Rectifiers

Theory

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.

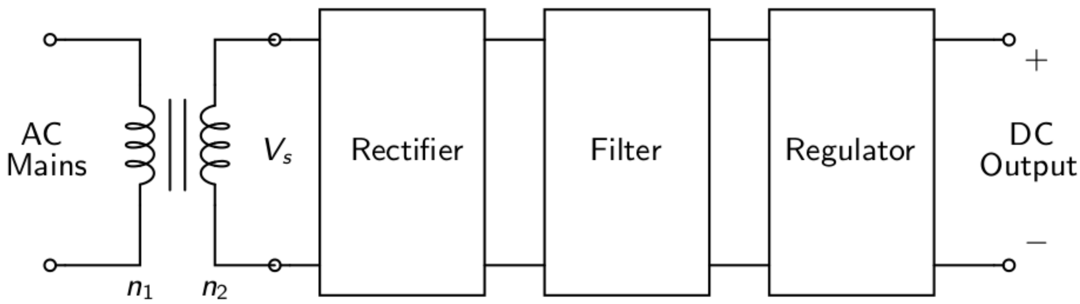

Figure 1: A typical DC power supply

The transformer is used to step down the AC mains voltage (230V, 50 Hz) to desired voltage level by controlling the turns ratio $n_2 : n_1$. The secondary voltage, v_S is 230. 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 to 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. The transformer has not been shown to make it simple.

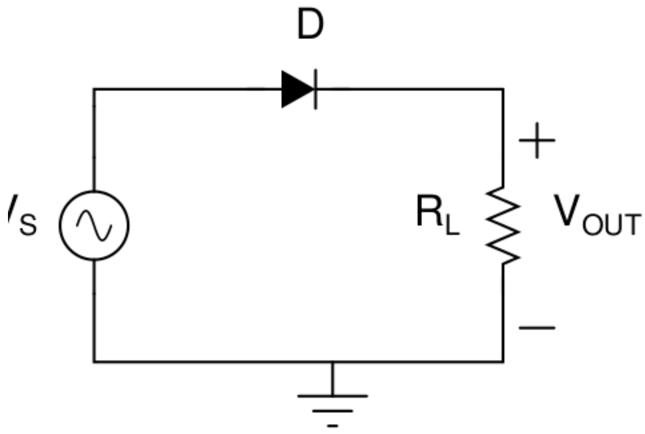

Figure 2: Half Wave Rectifier

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

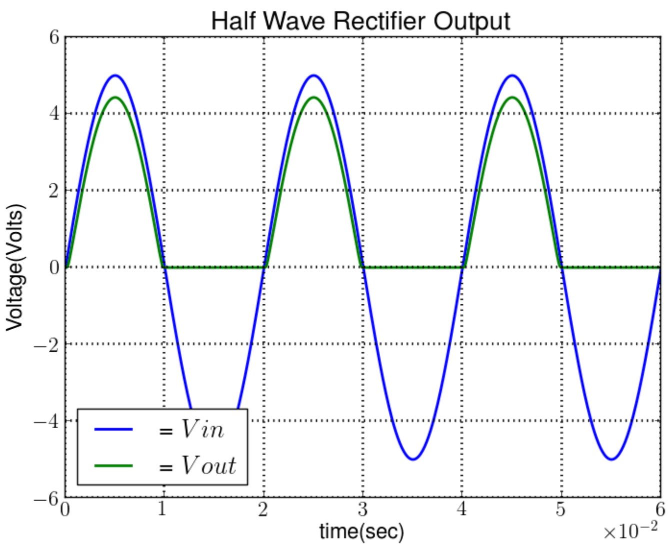

Figure 3: Half Wave Rectifier Waveform

The output voltage is pulsating DC which has a significant AC component and a 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 capacitor filter across the output terminals as shown in Fig. 4.

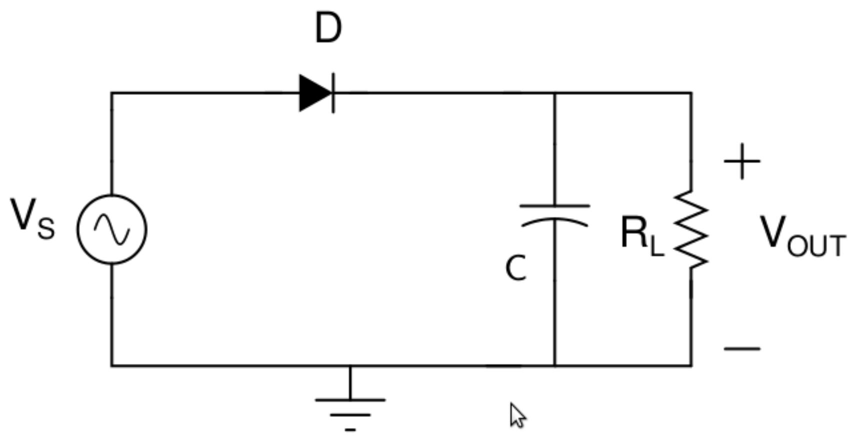

Figure 4: Half Wave Rectifier with Capacitive Filter

During the positive half cycle as v_S increases, the diode D conducts allowing the capacitor to charge to the peak voltage of the sinusoid. At 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 C (which is the voltage at the cathode of the diode) becomes less than v_S which is a rising sinusoid. The diode then gets forward biased and starts conducting till the peak is reached and this cycle continues. Refer Fig. 8. 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 of a Half Wave Rectifier

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) V_{RRMS} in the output current to the DC component of the output current

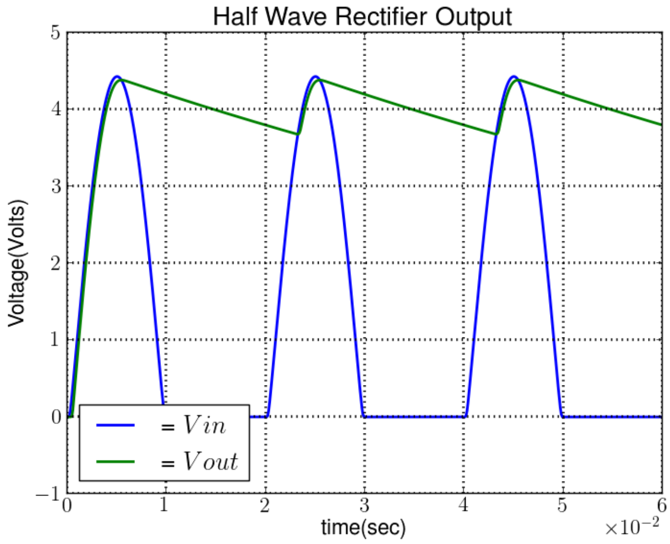

Figure 5: Half Wave Rectifier Waveform

V_{DC}.

$$\gamma = \frac{V_{RRMS}}{V_{DC}} \tag{1}$$

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

$$V_{RRMS} = \sqrt{V_{RMS}^2 - V_{DC}^2} \tag{2}$$

where V_{RRMS} is the again the RMS value at the rectified output and V_{RMS} is the RMS value of the input signal. For half wave rectifier,

$$V_{RMS} = \frac{V_M}{\sqrt{2}} \tag{3}$$

$$V_{DC} = \frac{V_M}{\pi} \tag{4}$$

where V_M is the peak value of v_S. Substituting Eqn. 3 and Eqn. 4 in Eqn. 2 we get

$$\gamma = 1.21 \tag{5}$$

The ripple factor can be significantly reduced using a filter capacitor. The ripple factor is given by Eqn. 6

$$\gamma = \frac{1}{2\sqrt{3} f R_L C} \tag{6}$$

where f is the frequency of signal v_S

Full Wave Rectifier with Center Tapped Transformer

The circuit consists of a center tapped transformer, followed by the rectifier formed by two diodes D_1 and D_2, and finally the load R_L 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.

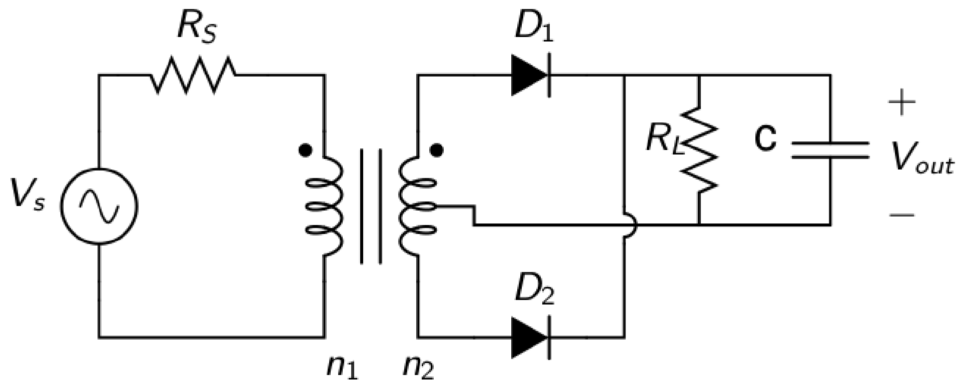

Figure 6: Full Wave Rectifier with Center Tapped Transformer and Capacitive Filter

Assume that the capacitor is not connected initially. Due to the center tap transformer, during the positive half cycle of the input v_S, D_1 will be forward biased and D_2 will be reverse biased. This results in the current flowing from D_1 to R_L. In negative half cycle, D_2 gets forward biased and D_1 reverse biased making the current flow from D_2 to R_L. Thus, in both the half cycles the current through R_L flows in the same direction resulting in pulsating DC across R_L.

Now consider the full wave rectifier with capacitor filter as shown in Fig. 6. During the positive half cycle, capacitor C will charge to the peak of the input waveform while the load R_L is being supplied current through D_1. When the input starts to go below its peak value, the voltage across C will cause D_1 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_L and C.

During the negative half cycle, diode D_2 will initially be reverse biased due to voltage across C. When the voltage at the input exceeds the voltage across C, D_2 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 D_2 will be reverse biased. The next positive cycle is similar to the previous negative cycle with diode D_1 being forward biased when the input voltage crosses the voltage across C. Capacitor C ensures that the voltage across load R_L remains close to the peak of the input voltage provided the value of R_L is sufficiently large.

Bridge Rectifier

Fig. 7 shows the circuit of diode bridge rectifier. The circuit uses four diodes D_1, D_2, D_3 and D_4 connected in the form of bridge.

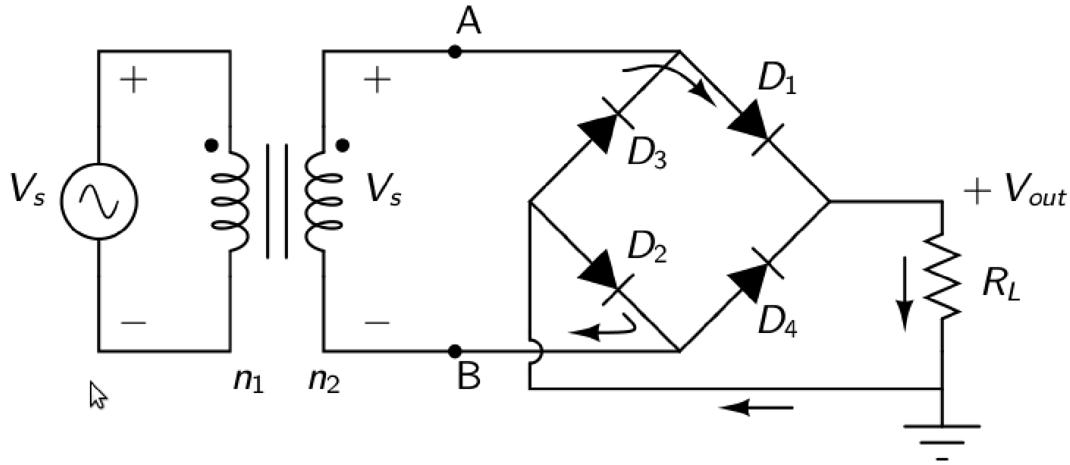

Figure 7: Full Wave Bridge Rectifier

During the positive cycle of v_S, point A is positive with respect to B causing diode D_1 and D_2 to forward bias and D_3 and D_4 to get reversed biased. This results in the current to flow from A, through D_1-R_L-D_2-B-A.

During negative cycle, the polarities change. Now point B is positive with respect to A causing diodes D_3 and D_4 to conduct and D_1 and D_2 to reverse bias. The resulting current then flows from B through D_4-R-D_3-A-B. In both the cycles, the current through the load resistor R_L flows in the same direction ensuring the pulsating DC across R_L 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 previous section. Fig. **??** shows the input output waveforms.

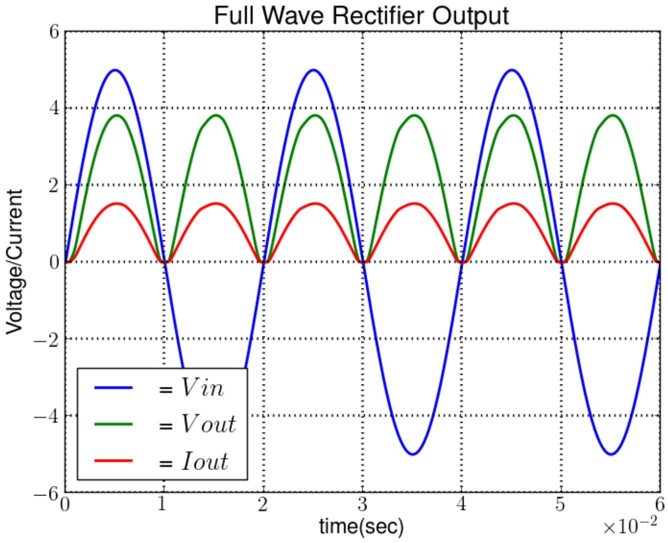

Figure 8: Full Wave Rectifier Waveform

Ripple Factor of a Full Wave Rectifier

The ripple factor is given by Eqn. 7

$$\gamma = \frac{V_{RRMS}}{V_{DC}} \tag{7}$$

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

$$V_{RRMS} = \sqrt{V_{RMS}^2 - V_{DC}^2} \tag{8}$$

where V_{RRMS} is the again the RMS value at the rectified output and V_{RMS} is the RMS value of the input signal. For full wave rectifier,

$$V_{RMS} = \frac{V_M}{\sqrt{2}} \tag{9}$$

$$V_{DC} = \frac{2V_M}{\pi} \tag{10}$$

where V_M is the peak value of v_S. Substituting Eqn. 9 and Eqn. 10 in Eqn. 8 we get

$$\gamma = 0.483 \tag{11}$$

This is a significant improvement in the ripple factor compared to that of a Half wave rectifier ($\gamma = 1.21$). 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.

The ripple factor for full wave rectifier with capacitor filter is given by Eqn. 12

$$\gamma = \frac{1}{4\sqrt{3} f R_L C} \tag{12}$$

where f is the frequency of signal v_S