Diode Applications

Rectifier Circuits

One of the most important applications of diodes is in the design of rectifier (AC to DC) circuits. A diode rectifier forms an essential building block of the dc power supplies required to power electronic equipment. A block diagram of such a power supply is shown in Fig. 4.20.

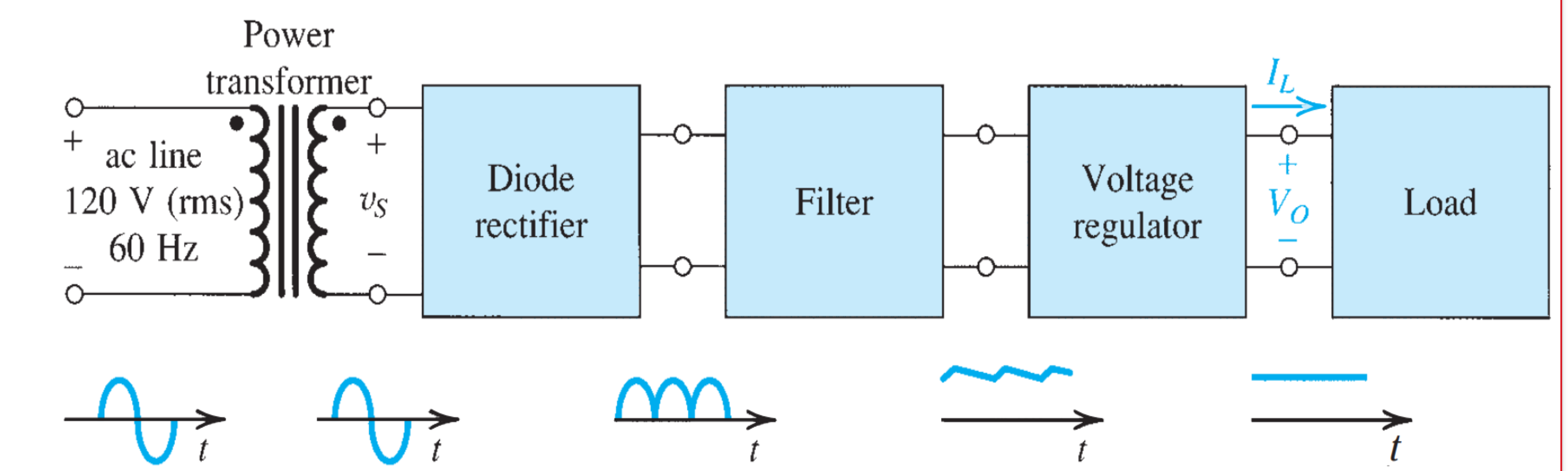


Figure 4.20 Block diagram of a dc power supply.

Diode Applications

The Half-Wave Rectifier

The half-wave rectifier utilizes alternate half-cycles of the input sinusoid. Figure 4.21(a) shows the circuit of a half-wave rectifier. Figure 4.21(b) shows the output voltage obtained when the input v_S is a sinusoid.

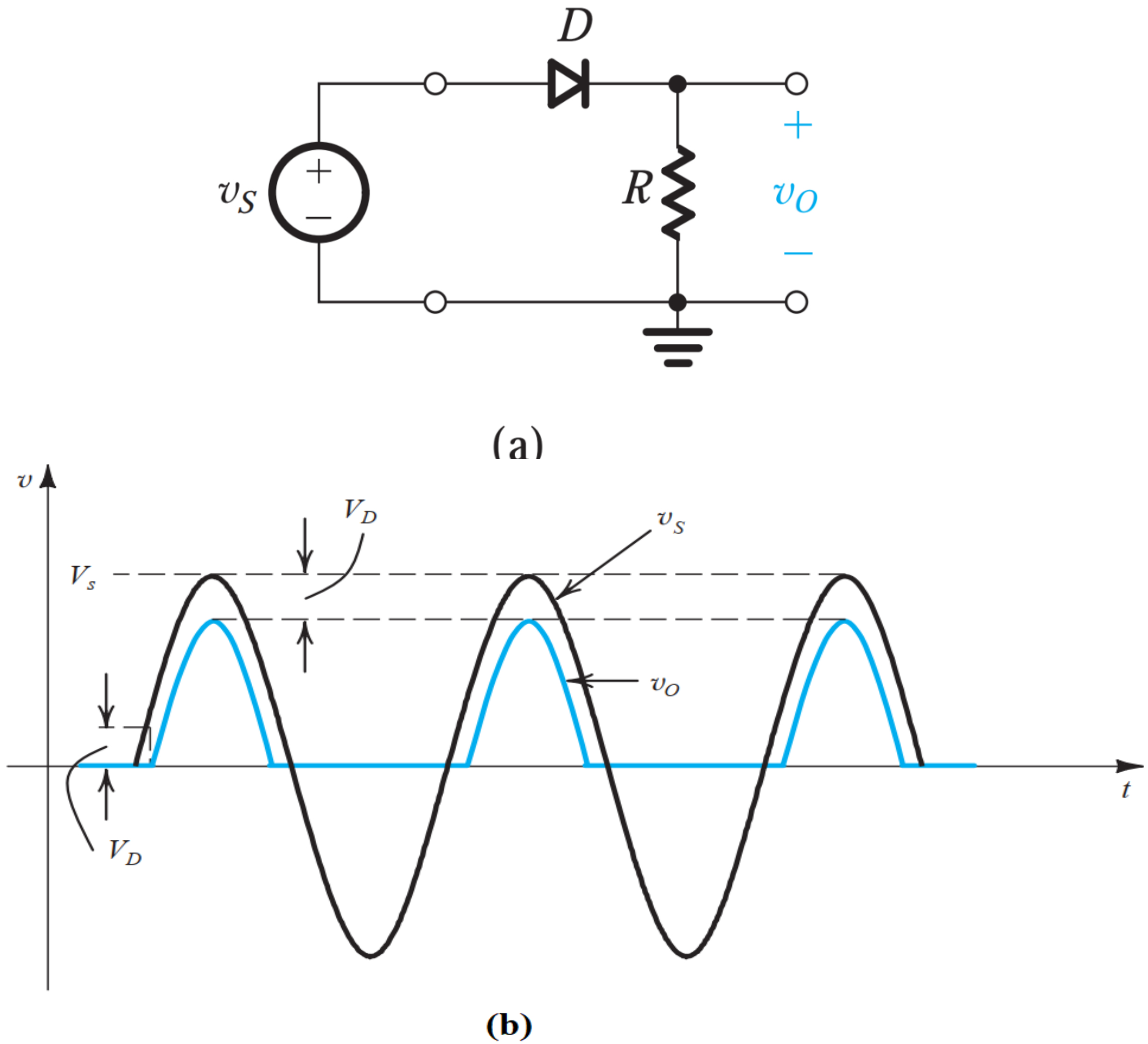


Figure 4.21 **(a)** Half-wave rectifier. **(b)** Input and output waveforms.

Diode Applications

The Full-Wave Rectifier

The full-wave rectifier utilizes both halves of the input sinusoid. To provide a unipolar output, it inverts the negative halves of the sine wave. One possible implementation is shown in Fig. 4.22(a). Here the transformer secondary winding is **center-tapped** to provide two equal voltages v_S across the two halves of the secondary winding with the polarities indicated.

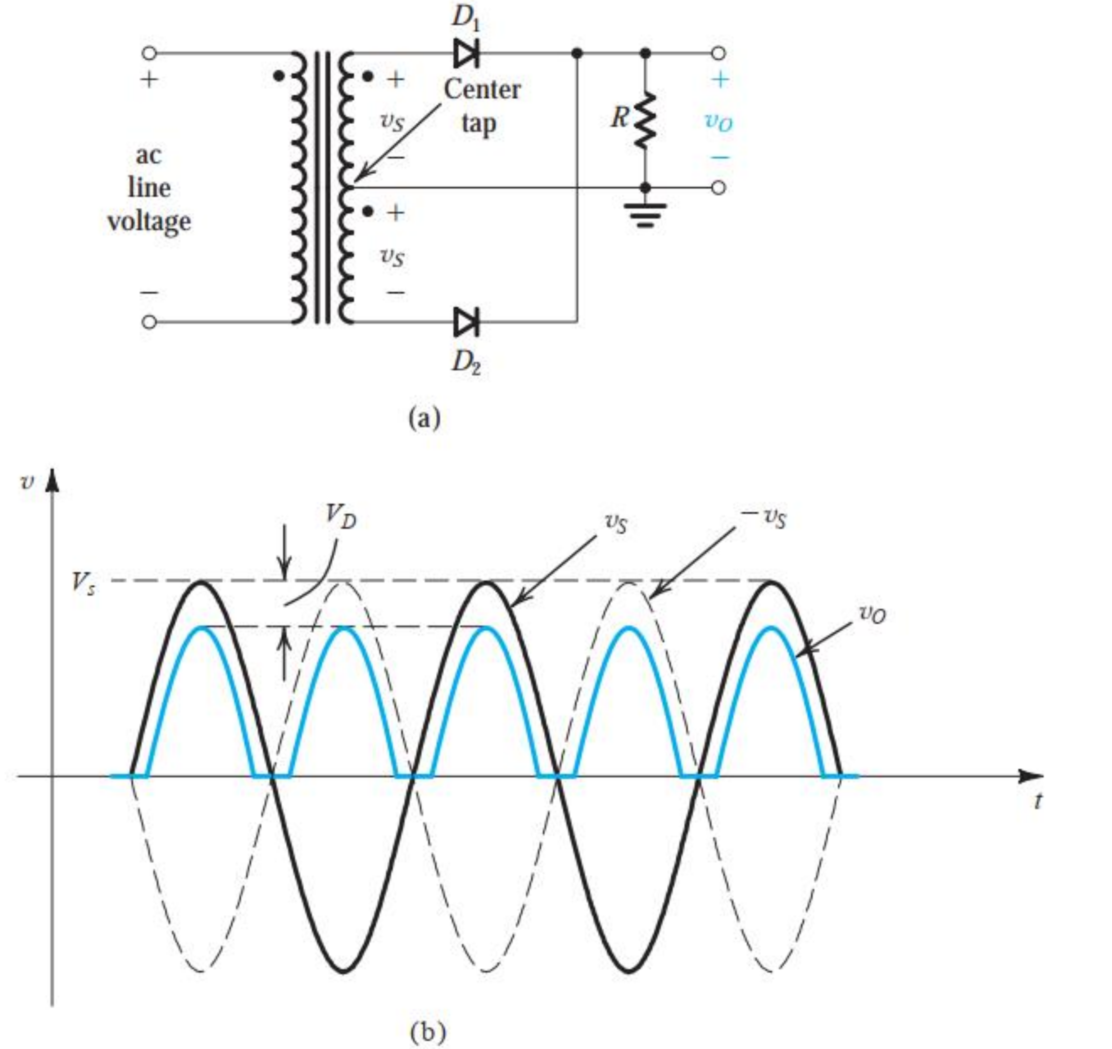


Figure 4.22 Full-wave rectifier utilizing a transformer with a center-tapped secondary winding: **(a)** circuit; **(b)** input and output waveforms.

Diode Applications

The Center-Tapped rectifier circuit operates as follows:

Note that when the input line voltage (feeding the primary) is positive, both of the signals labeled v_S will be positive. In this case D_1 will conduct and D_2 will be reverse biased. The current through D_1 will flow through R and back to the center tap of the secondary. The circuit then behaves like a half-wave rectifier.

Now, during the negative half-cycle of the ac line voltage, both of the voltages labeled v_S will be negative. Thus D_1 will be cut off while D_2 will conduct. The current conducted by D_2 will flow through R and back to the center tap. It follows that during the negative half-cycles while D_2 conducts, the circuit behaves again as a half-wave rectifier. The important point, however, is that the current through R always flows in the same direction, and thus v_O will be unipolar, as indicated in Fig. 4.22(b).

Diode Applications

The Bridge Rectifier

An alternative application of the full-wave rectifier is shown in Fig. 4.23(a). This circuit, known as the **bridge rectifier** because of the similarity with the Wheatstone bridge, does not require a center-tapped transformer, a distinct advantage over the center-tapped rectifier circuit of Fig. 4.22. The bridge rectifier, requires four diodes as compared to two in the previous circuit. This is not much of a disadvantage, because diodes are inexpensive.

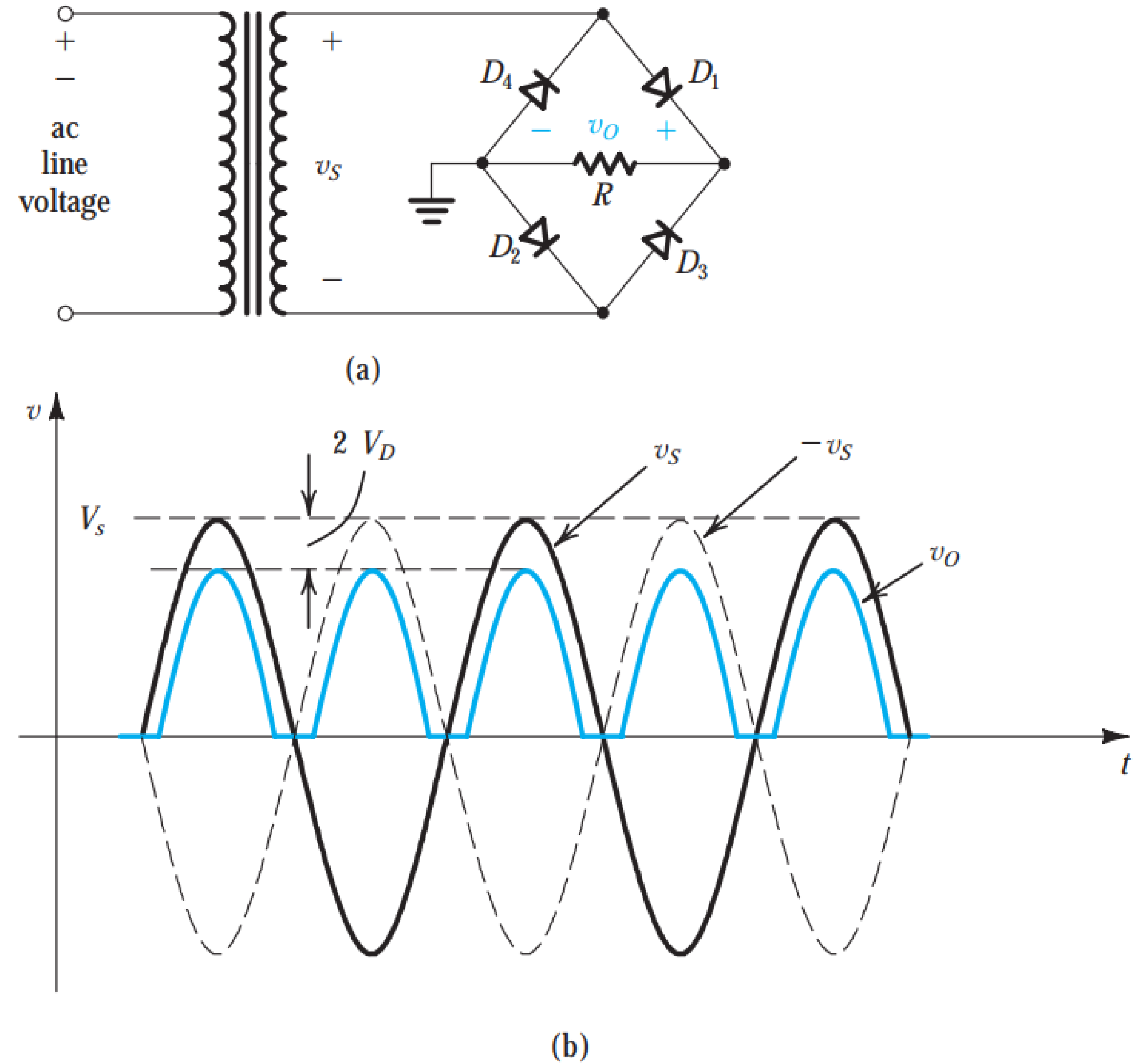


Figure 4.23 The bridge rectifier: **(a)** circuit; **(b)** input and output waveforms.

Diode Applications

The bridge rectifier circuit operates as follows:

During the positive half-cycles of the input voltage, v_S is positive, and thus current is conducted through diode D_1, resistor R, and diode D_2. Meanwhile, diodes D_3 and D_4 will be reverse biased. Observe that there are two diodes in series in the conduction path, and thus v_O will be lower than v_S by two diode drops (compared to center-tapped). This is somewhat of a disadvantage of the bridge rectifier.

Next, consider the situation during the negative half-cycles of the input voltage. The secondary voltage v_S will be negative, and thus $-v_S$ will be positive, forcing current through D_3, R, and D_4. Meanwhile, diodes D_1 and D_2 will be reverse biased. The important point to note, though, is that during both half-cycles, current flows through R in the same direction (from right to left), and thus v_O will always be positive, as indicated in Fig. 4.23(b).

Diode Rectifier

The average value of Half wave rectifier circuit

$$V_o = \frac{1}{T}\int_0^T v(t)dt$$

$$= \frac{1}{2\pi}\int_0^{2\pi} V_m\, sin\theta\; d\theta$$

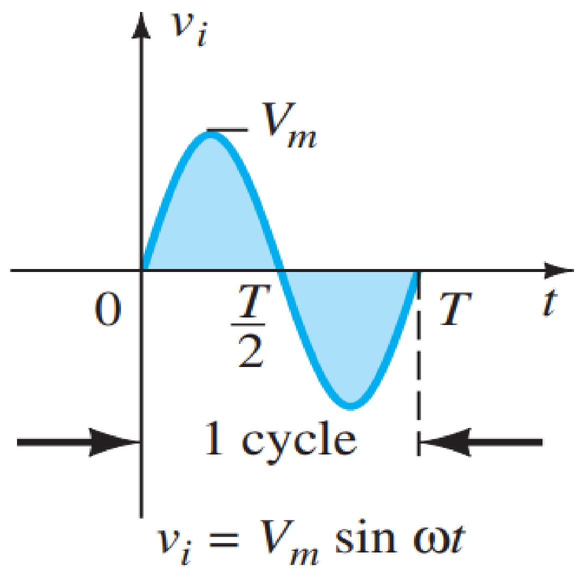
$$= \frac{V_m}{2\pi}[\int_0^{\pi} sin\theta\; d\theta + \int_{\pi}^{2\pi} sin\theta\; d\theta]$$

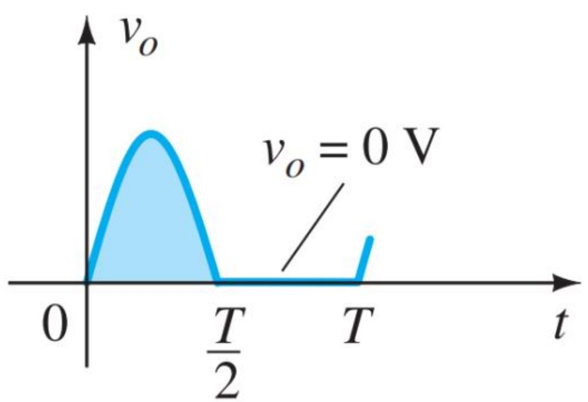
$$= \frac{V_m}{2\pi}[-cos\theta]_0^{\pi}$$

$$= -\frac{V_m}{2\pi}[-1-1] = \frac{V_m}{2\pi}[2]$$

$$\therefore \boldsymbol{V_0 = \frac{V_m}{\pi}}$$

Similarly, $\boldsymbol{I_0 = \frac{I_m}{\pi}}$





Diode Rectifier

The R.M.S value of Half wave rectifier circuit,

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T \{v(t)\}^2 dt} \quad = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_m^2\, sin^2\theta d\theta}$$

$$= \sqrt{\frac{V_m^2}{2\pi}[\int_0^{\pi} sin^2\theta d\theta + \int_{\pi}^{2\pi} sin^2\theta d\theta]}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{\pi} sin^2\theta d\theta} \quad = \sqrt{\frac{V_m^2}{4\pi}\int_0^{\pi} 2sin^2\theta d\theta}$$

$$= \sqrt{\frac{V_m^2}{4\pi}\int_0^{\pi}(1 - cos2\theta) d\theta} \quad = \sqrt{\frac{V_m^2}{4\pi}\{\int_0^{\pi}(1) d\theta - \int_0^{\pi}(cos2\theta) d\theta\}}$$

$$= \sqrt{\left(\frac{Vm^2}{4\pi} \times [\theta]_0^{\pi}\right)} \quad = \sqrt{\left(\frac{Vm^2}{4\pi} \times \pi\right)} \quad = \sqrt{\left(\frac{Vm^2}{4}\right)}$$

$$\boldsymbol{V_{rms} = \frac{V_m}{2}}$$

Similarly, $\boldsymbol{I_{rms} = \frac{I_m}{2}}$

Diode Rectifier

The average value of Full wave rectifier circuit

$$V_o = \frac{1}{2\pi}\int_0^{2\pi} v(t)dt$$

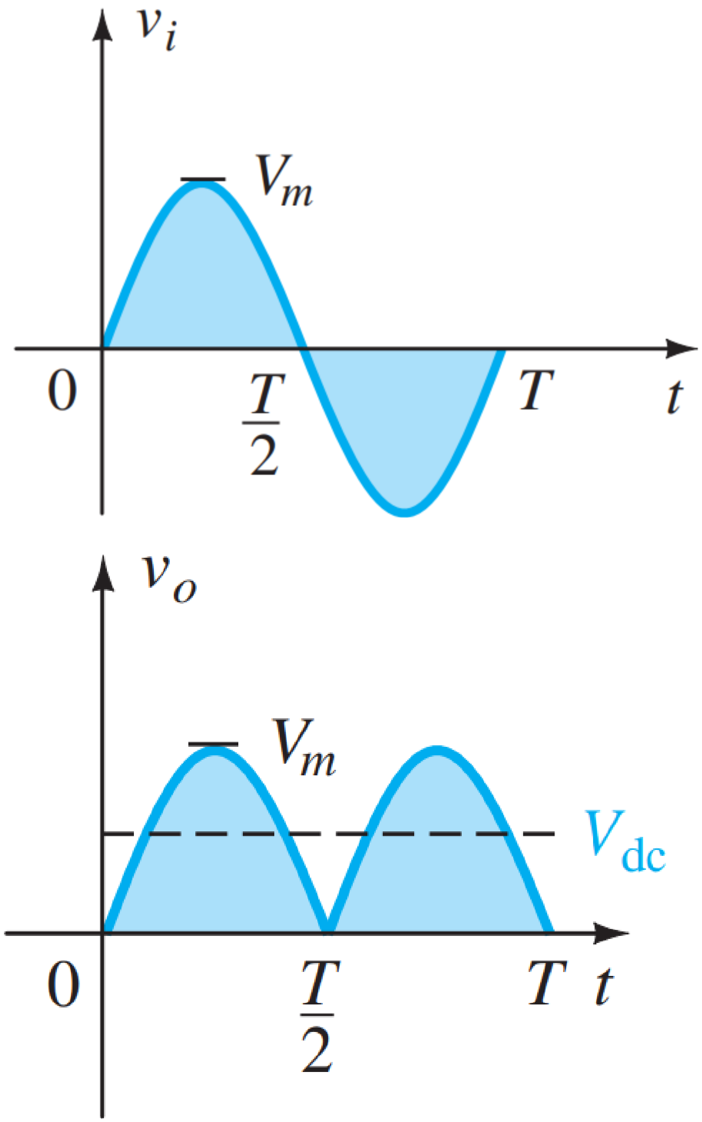
$$= \frac{1}{2\pi}[\int_0^{\pi} V_m sin\theta\ d\theta + \int_{\pi}^{2\pi} V_m sin\theta\ d\theta]$$

$$= \frac{1}{\pi}\int_0^{\pi} V_m sin\theta\ d\theta \quad = \frac{V_m}{\pi}[-cos\theta]_0^{\pi}$$

$$= -\frac{V_m}{\pi}[-1-1]$$

$$\boldsymbol{V_o = \frac{2V_m}{\pi}}$$

Similarly, $\boldsymbol{I_o = \frac{2I_m}{\pi}}$



Diode Rectifier

The RMS value of full wave rectifier circuit,

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi}\{v(t)\}^2 d\theta}$$

$$= \sqrt{\frac{1}{\pi}\int_0^{\pi} V_m^2\, sin^2\theta d\theta}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{\pi} 2sin^2\theta d\theta}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\int_0^{\pi}(1 - cos2\theta)d\theta}$$

$$= \sqrt{\frac{V_m^2}{2\pi}\left[\left(\theta - \frac{sin2\theta}{2}\right)\right]_0^{\pi}} \quad = \sqrt{\frac{V_m^2}{2\pi}\times\pi}$$

$$\therefore \boldsymbol{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

Similarly, $\boldsymbol{I_{rms} = \frac{I_m}{\sqrt{2}}}$

Diode Rectifier

Efficiency of Half wave rectifier

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{dc}}{P_{ac}} = \frac{P_{avg}}{P_{rms}}$$

$$P_{dc} = I_o^2 \times R = \left(\frac{I_m}{\pi}\right)^2 \times R_L$$

$$Since\ I_0 = \frac{I_m}{\pi}$$

$$P_{ac} = I_{rms}^2 \times R = \left(\frac{I_m}{2}\right)^2 \times \left(R_L + r_f\right) \cong \left(\frac{I_m}{2}\right)^2 \times R_L$$

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

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{\left(\frac{I_m}{\pi}\right)^2 \times R_L}{\left(\frac{I_m}{2}\right)^2 \times R_L} = \frac{4}{\pi^2} = 0.405 = \mathbf{40.5}\%$$

Diode Rectifier

Efficiency of Full wave rectifier

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{dc}}{P_{ac}} = \frac{P_{avg}}{P_{rms}}$$

$$P_{dc} = I_o^2 \times R = \left(\frac{2I_m}{\pi}\right)^2 \times R_L$$

$$Since\ I_0 = \frac{2I_m}{\pi}$$

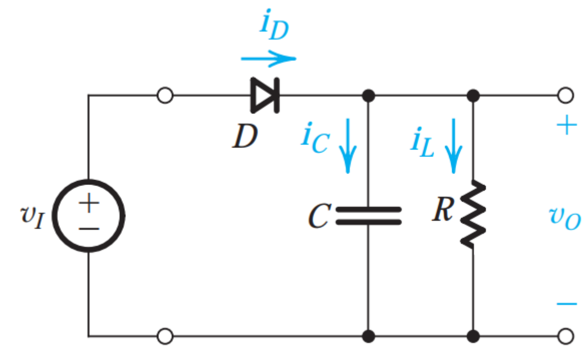
$$P_{ac} = I_{rms}^2 \times R = \left(\frac{I_m}{\sqrt{2}}\right)^2 \times \left(R_L + 2r_f\right) \cong \left(\frac{I_m}{2}\right)^2 \times R_L$$

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

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 \times R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 \times R_L} = \frac{8}{\pi^2} = 0.81 = \mathbf{81}\%$$

Diode Rectifier

Rectifier with a Filter Capacitor



At the end of the discharge interval, which lasts for almost the entire period T,

$$v_O = V_p - V_r \,,$$

where V_r is the peak-to-peak ripple voltage.

The output dc voltage (V_O) can be obtained by taking the average values of v_O,

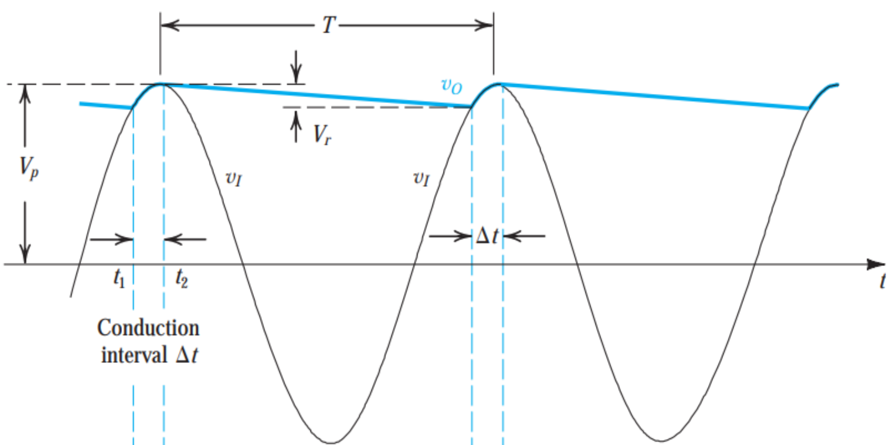
$$V_o = V_p - \frac{1}{2}V_r$$

During the diode-off interval, v_O can be expressed as

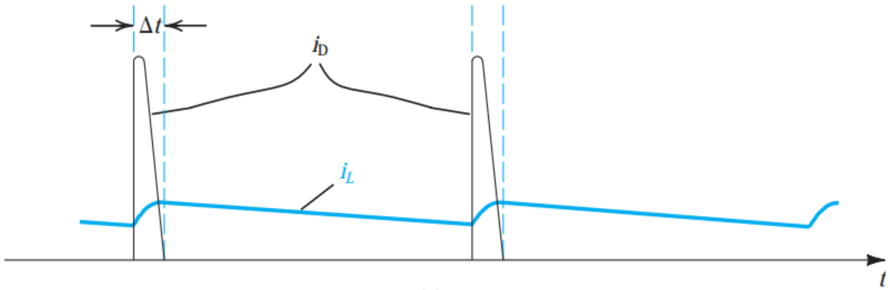
$$v_o = V_p e^{-t/CR}$$

At the end of the discharge interval we have

$$V_p - V_r \cong V_p e^{-T/CR}$$



(b)



(c)

Diode Rectifier

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Now, since CR >>T, we can use the approximation $e^{-T/CR} \cong 1 - \frac{T}{CR}$ to obtain

$$V_p - V_r \cong V_p(1 - \frac{T}{CR})$$

$$V_p - V_r \cong V_p - V_p \frac{T}{CR}$$

$$V_r \cong V_p \frac{T}{CR}$$

$$\therefore \boldsymbol{V_r} \cong \frac{\boldsymbol{V_p}}{\boldsymbol{fCR}}$$

Assuming that diode conduction ceases almost at the peak of v_P , we can determine the conduction interval Δt from

$$V_p \cos(\omega \Delta t) = V_p - V_r$$

Diode Rectifier

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Since $(\omega\Delta t)$ is a small angle, we can employ the approximation

$$\cos(\omega\Delta t) = 1 - \frac{1}{2}(\omega\Delta t)^2$$

$$\therefore V_p \left(1 - \frac{1}{2}(\omega\Delta t)^2\right) = V_p - V_r$$

$$\Rightarrow V_p - \frac{1}{2}V_p(\omega\Delta t)^2 = V_p - V_r$$

$$\Rightarrow \frac{1}{2}V_p(\omega\Delta t)^2 = V_r$$

$$\Rightarrow V_p(\omega\Delta t)^2 = 2V_r$$

$$\Rightarrow (\omega\Delta t) = \sqrt{\frac{2V_r}{V_P}}$$

$$\Rightarrow \boldsymbol{\Delta t = \frac{1}{\omega}\sqrt{\frac{2V_r}{V_P}}}$$