# Chapter Four
# Diode Applications

## 4.1: Introduction (Overview)

In Chapter 3, you learned that a semiconductor diode is a device with a single *pn* junction. The importance of the diode in electronic circuits cannot be overemphasized. Its ability to conduct current in one direction while blocking current in the other direction is essential to the operation of many types of circuits. One circuit in particular is the ***AC rectifier***, which will be covered in this chapter. Other important applications are circuits such as ***Diode limiters***, ***Diode clampers***, and ***Diode voltage multipliers***.

## Chapter Outline:

- Half-Wave Rectifiers
- Full-Wave Rectifiers
- Power Supply Filters and Regulators
- Diode Limiting and Clamping Circuits
- Voltage Multipliers
- System Application

## 4.2: Rectifier

- **Rectifier is an electrical device that converts alternating current (AC) to direct current (DC)**, a process known as **rectification**.
- **Rectifiers** have many uses including as components of power supplies and as amplitude modulation detectors (envelope detectors) of radio signals.
- **Rectifiers** are most commonly made using solid state diodes but other types of components can be used when very high voltages or currents are involved.
- When only a single diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is simply one of usage.
- The term rectifier describes a diode that is being used to convert AC to DC. Most rectifier circuits contain a number of diodes in a specific arrangement to more efficiently convert AC power to DC power than is possible with only a single diode. This will be addressed next.

## 4.2.1: Half Wave Rectifier

In **half wave rectification**, **either the positive or negative half of the AC wave is passed, while the other half is blocked**.
Because only one-half of the input waveform reaches the output, it is only 50% efficient if used for power transfer. Half-wave rectification can be achieved with a single diode in a single-phase supply as shown in this figure.

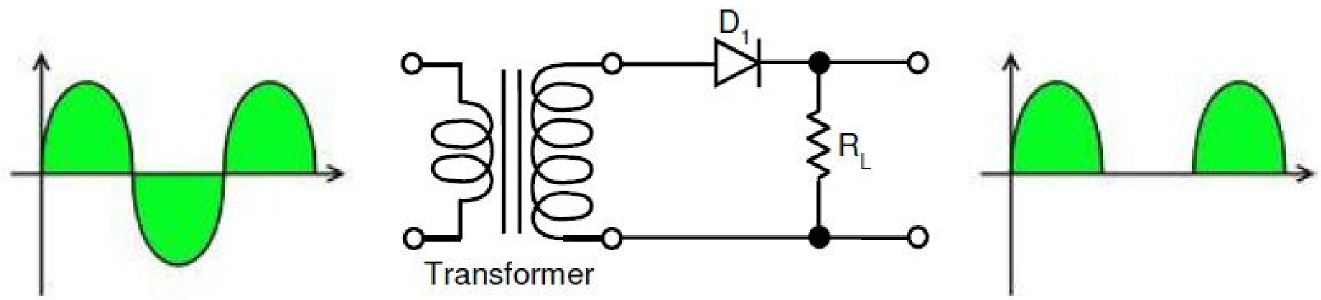
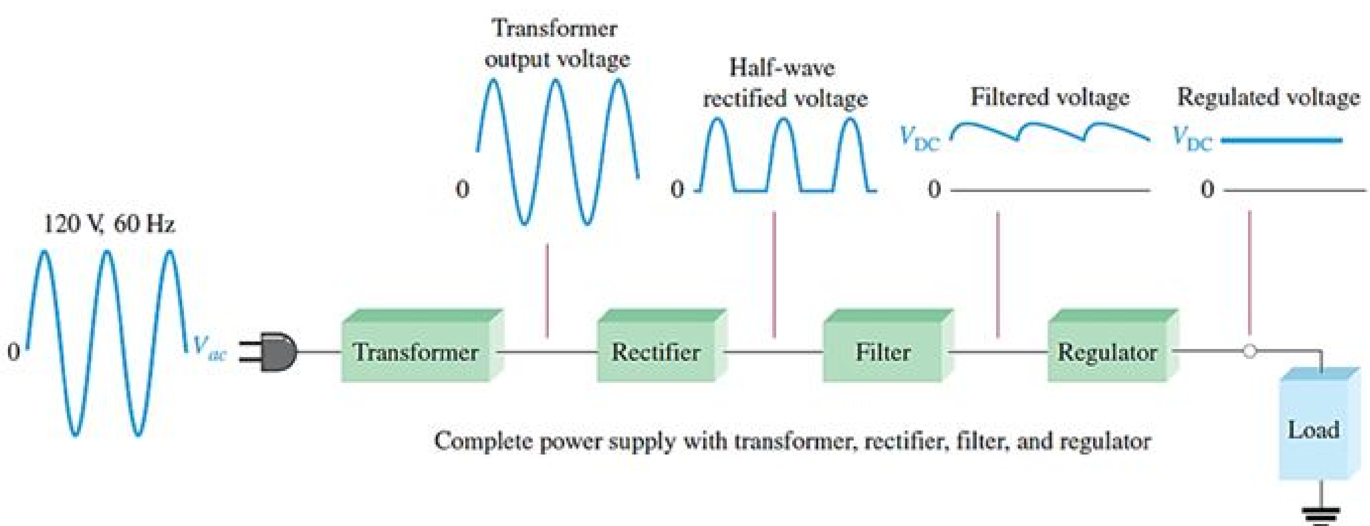



**Figure (1): Half wave rectification circuit.**

**NOTE**:




Assuming the diode to have a **small forward resistance ($r$)**, and **infinite reverse resistance**, **the diode current or load current** can be expressed as:

$$i = I_m \sin wt = \frac{V_m}{r + R_L} \sin wt \qquad 0 < wt < \pi \quad \dots (1)$$

$$i = 0 \qquad \pi < wt < 2\pi \quad \dots (2)$$

Where $I_m$ and $V_m$ represent the **maximum values of current and voltage** respectively.

Using a Fourier series expansion, the current given by eq. (1) in the interval ($0 < wt < 2\pi$) can be expressed as:

$$i = \frac{I_m}{\pi} + \frac{I_m}{2}\sin wt - \frac{2I_m}{3\pi}cos2wt - \frac{2I_m}{15\pi}cos4wt, \quad 0 < wt < 2\pi \quad \ldots (3)$$

The term ($\frac{I_m}{\pi}$) in eq. (3) represents the **average or DC value of $i$** in the interval ($0 < wt < 2\pi$). Thus, we have:

$$I_{dc} = \frac{I_m}{\pi} = \frac{V_m}{\pi(r + R_L)} \quad \ldots (4)$$

**Prove it! (Review in CH 4 at Advanced Electricity and Magnetism)**

Apparently, the output current $i$ is a mixture of a Dc component and AC components of various frequencies (harmonics). The DC component in series with $R_L$.

The corresponding **DC voltage or rectified output across $R_L$** is:

$$V_{dc} = I_{dc}\,R_L = \frac{I_m}{\pi}R_L = \frac{V_m}{\pi}\left(\frac{R_L}{r + R_L}\right) \quad \ldots (5)$$

The **DC power ($P_{dc}$)**, delivered to the load is:

$$P_{dc} = I_{dc}^2\,R_L = \frac{I_m^2}{\pi^2}R_L = \frac{V_m^2}{\pi^2(r + R_L)^2}R_L \quad \ldots (6)$$

The second and higher order term in the series equation (3) cause dissipation of power in $R_L$ , decrease the power efficiency and create a ripple in the output voltage.

To determine the power efficiency, we calculate the **root mean square value ($I_{rms}$) of the total load current**. From the definition of $I_{rms}$, we have:

$$I_{rms} = \sqrt{\frac{\int_0^{\pi} i^2\,dwt}{2\pi - 0}} \quad \ldots (7)$$

Using eq. (1), it gives:

$$I_{rms} = \frac{I_m}{2} \quad \ldots (8)$$

**Prove it! (Review in CH 4 at Advanced Electricity and Magnetism)**

The **AC input power** is given by:

$$P_{ac} = I_{rms}^2(r + R_L) = \frac{I_m^2}{4}(r + R_L) \quad \ldots (9)$$

The **power conversion efficiency ($\eta$)** is defined as:

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100\,\% \quad \ldots (10)$$

Using equation (6) and (9) in (10), we obtain:

$$\eta_{HW} = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}(r + R_L)} \times 100\% \frac{4}{\pi^2}\left(\frac{R_L}{r + R_L}\right) 100\% = \left(\frac{40.6}{1 + \frac{r}{R_L}}\right) \% \quad \dots (11)$$

For an ideal diode , $r = 0$:

$$\eta_{HW} = 40.6\,\%$$

This is the **theoretical efficiency** of **a single-phase half-wave rectifier**.

## Peak Inverse Voltage (PIV):

Since the diode has very small forward resistance, the voltage appearing across the diode during the positive half-cycle of the AC input is very small. However, during the negative half-cycle, since the output voltage across load is negligible, almost whole of the secondary voltage appears across the diode in accordance with the Kirchoffs law. The maximum reverse voltage appearing across the diode is called the **peak inverse voltage (PIV)** and may produce **breakdown** in the diode. To avoid this, the PIV rating of the diode must be greater than the peak inverse voltage.

$$V_{m(out)} = V_{m(sec)} - V_B \;\; OR \;\; V_{m(sec)} = \left(\frac{N_2}{N_1}\right) \times V_{m(\text{pri})} \dots (12)$$

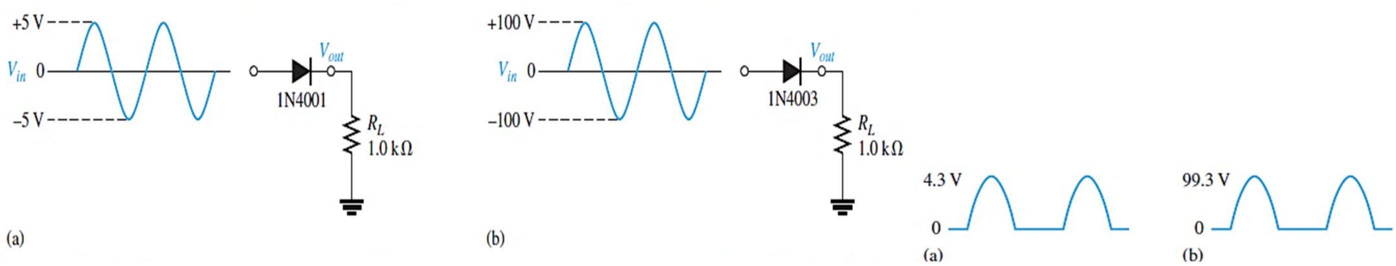
$$\boldsymbol{PIV = V_{m(\text{sec})}\,(V_{m(in)}) \dots (13)}$$

**NOTE**:

- Whenever the AC input becomes negative at the diode's anode, the diode blocks current flow. → output voltage becomes zero.
- The Diode introduces a 0.7V **drop** so output peak is 0.7V smaller than the input peak; $V_{AVG} = \frac{V_{m(out)}}{\pi}$.

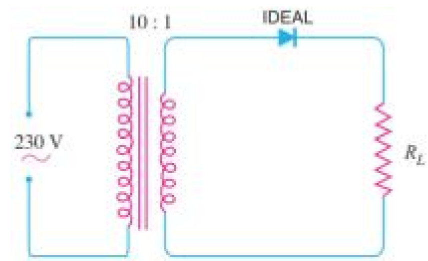
**Example 4.1:** Draw the output voltages of each rectifier for the indicated input voltages, as shown in this Figure. The 1N4003 are specific rectifier diodes.

**Solution:**




$V_{m(out)} = V_{m(in)} - 0.7 = 5 - 0.7 = 4.3\,V$ and $V_{m(out)} = V_{m(in)} - 0.7 = 100 - 0.7 = 99.3\,V$

**Example 4.2:** An ac supply of 230 V is applied to a half-wave rectifier circuit through a transformer of turn ratio 10:1. Assume the diode to be ideal. Find (i) the output $dc$ voltage (ii) the peak inverse voltage.




**Solution:**

Primary to secondary turns is $N_1/N_2 = 10$

rms of the primary voltage: $V_{(pri)} = 230$ V

∴ Max primary voltage: $V_{m(pri)} = \sqrt{2}V_{(pri)} = \sqrt{2} \times 230 = 325.3$ V

∴ Max secondary voltage: $V_{m(sec)} = V_{m(pri)} \times (N_2/N_1) = 325.3 \times \frac{1}{10} = 32.53$ V

(i) the output $dc$ voltage:

$$V_{dc} = I_{dc}R_L = \frac{I_m}{\pi}R_L = \frac{V_{m(sec)}}{\pi}\left(\frac{R_L}{r + R_L}\right) = \frac{32.53}{\pi}\left(\frac{R_L}{0 + R_L}\right) = 10.36\ V$$

(ii) the peak inverse voltage:

$$PIV = V_{m(sec)} = 32.53\ \text{V}$$

**Example 4.3:** A half-wave rectifier is used to supply 50V $dc$ to a resistive load of 800 Ω. The diode has a resistance of 25 Ω. Calculate $ac$ voltage required.

**Solution:**

Output dc voltage, $V_{dc} = 50\ V$ , Load resistance, $R_L = 800\ \Omega$ , Diode resistance, $r = 25\ \Omega$

$$V_{dc} = I_{dc}R_L = \frac{I_m}{\pi}R_L = \frac{1}{\pi}\left(\frac{V_m}{r + R_L}\right)R_L$$

$$50 = \frac{1}{\pi}\left(\frac{V_m}{25 + 800}\right) \times 800 \rightarrow V_m = \frac{50\pi \times 825}{800} = 162\ V$$

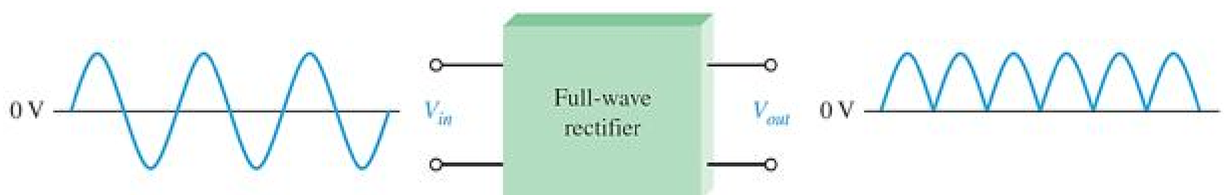
$$V_{rms} = \frac{V_m}{2} = \frac{162}{2} = 81\ V$$

## 4.2.2: Full Wave Rectifier

Although half-wave rectifiers have some applications, the full-wave rectifier is the most commonly used type in DC power supplies. Here, you will use what you learned about half-wave rectification and expand it to full-wave rectifiers. You will learn about two types of full-wave rectifiers which are:

- **Center-tapped**, and
- **Bridge**.

A **full-wave rectifier** allows unidirectional (one-way) current through the load during the entire **360$^{0}$** of the input cycle, whereas a **half-wave rectifier** allows current through the load only during **one-half** of the cycle. The result of full-wave rectification is an **output voltage with a frequency twice the input frequency and that pulsates every half-cycle of the input**, as shown in Figure below.




The output frequency is twice the input frequency.

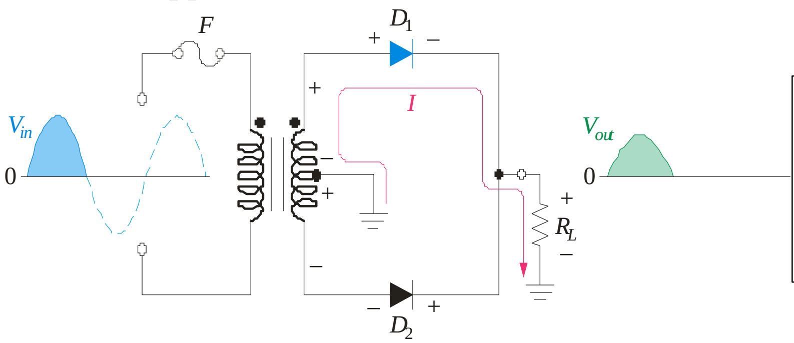
The number of positive alternations that make up **the full-wave rectified voltage is twice that of the half-wave voltage for the same time interval**. The average value, which is the value measured on a $dc$ voltmeter, **for a full-wave rectified sinusoidal voltage is twice that of the half-wave**, as shown in the following formula: $\boldsymbol{V_{AVG} = \frac{2V_{m(out)}}{\pi} = 0.637V_m}$

$\boldsymbol{V_{AVG}}$ is approximately 63.7% of $V_p$ for a full-wave rectified voltage.

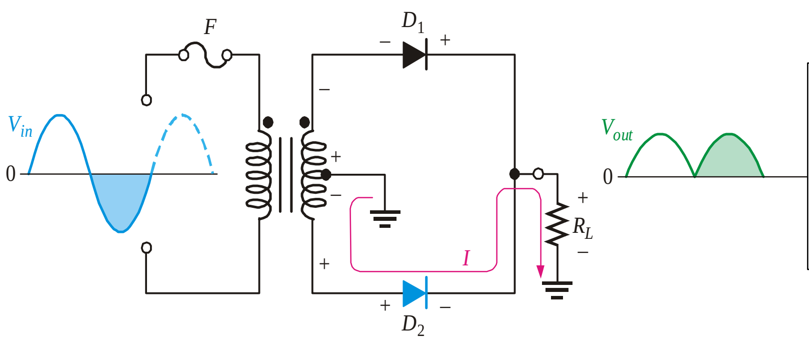
## 4.2.2.1: The Center-Tapped Full Wave Rectifiers

A Center-tap full-wave rectifier does not block negative cycle in the input voltage, rather it transforms them into positive cycle at the output.

A center-tapped transformer is used with two diodes that conduct on alternating half-cycles.




During the **positive half-cycle**, the upper diode is forward-biased and the lower diode is reverse-biased.




During the **negative half-cycle**, the lower diode is forward-biased and the upper diode is reverse-biased.

## The Center-Tapped Full Wave Rectifiers Calculation:

In the full wave rectifier circuit, the **diode $D_1$** conducts during the **positive half cycle** of the AC signal and the **diode $D_2$** conducts during the **negative half**. The output current through the load always flows in the same direction but is pulsating. The wave forms of the individual diode currents and the total output current through load are shown before.

Assuming each diode to have small forward resistance and infinite reverse resistance, the currents $i_1$ and $i_2$ can be expressed as:

$$i_1 = I_m \sin wt = \frac{V_m}{r + R_L} \sin wt \,,\; i_2 = 0 \qquad 0 < wt < \pi \quad \ldots (14)$$

$$i_1 = 0,\; i_2 = -I_m \sin wt = \frac{V_m}{r + R_L} \sin wt \qquad \pi < wt < 2\pi \quad \ldots (15)$$

**Note** that the current $i_1$ and $i_2$, in fact, flow in **opposite directions**, but the load is so connected that each pass through it in the **same direction**.

Using the Fourier series expansion as given by equation (3), the total current resulting from the expressions (14) and (15) can be:

$$i = \frac{2I_m}{\pi} - \frac{4I_m}{\pi}\left(\frac{1}{3}\cos 2wt + \frac{1}{15}\cos 4wt + \frac{1}{35}\cos 6wt + \cdots\right) \quad \dots (16)$$

The lowest frequency AC component has a frequency **twice** the input signal frequency. The **average or DC value of the current** is:

$$I_{dc} = \frac{2\,I_m}{\pi} = \frac{2\,V_m}{\pi(r + R_L)} \quad \dots (17)$$

**Prove it! (Review in CH 4 at Advanced Electricity and Magnetism)**

The desired rectifier is thus:

$$V_{dc} = I_{dc}\,R_L = \frac{2\,I_m}{\pi}R_L = \frac{2\,V_m}{\pi}\left(\frac{R_L}{r + R_L}\right) \quad \dots (18)$$

Which is **twice** the output of the half wave rectifier see equation (5).

And the **power output across the load ($P_{dc}$)** is:

$$P_{dc} = I_{dc}^2\,R_L = \frac{4\,I_m^2}{\pi^2}R_L = \frac{4\,V_m^2}{\pi^2(r + R_L)^2}R_L \quad \dots (19)$$

The **$I_{rms}$ value of the total load current** is calculated as:

$$I_{rms} = \sqrt{\frac{\int_0^{2\pi} i^2\,dwt}{2\pi - 0}} = \sqrt{\frac{\int_0^{\pi} I_m^2 \sin^2 wt\,dwt + \int_{\pi}^{2\pi} I_m^2 \sin^2 wt\,dwt}{2\pi - 0}} = \frac{I_m}{\sqrt{2}} \quad \dots (20)$$

**Prove it! (Review in CH 4 at Advanced Electricity and Magnetism)**

The **AC input power** is given by:

$$P_{ac} = I_{rms}^2(r + R_L) = \frac{I_m^2}{2}(r + R_L) \quad \dots (21)$$

Thus, the **power rectification efficiency ($\eta$)** becomes:

$$\eta_{FW} = \frac{P_{dc}}{P_{ac}} \times 100\,\% = \frac{\frac{4I_m^2}{\pi^2}R_L}{\frac{I_m^2}{2}(r + R_L)} \times 100\% \frac{8}{\pi^2}\left(\frac{R_L}{r + R_L}\right)100\% = \left(\frac{81.2}{1 + \frac{r}{R_L}}\right)\% \quad \dots (22)$$

For an ideal diode , $r = 0$:

$$\eta_{FW} = 81.2\,\%$$

This is the **theoretical maximum efficiency** of **a single-phase full wave rectifier**. It is **double** the efficiency of a half wave rectifier

# Peak Inverse Voltage (PIV):

In a full wave rectifier, when one of the diodes is conducting, the other one is non-conducting. Consider the case when the voltage between either end of the secondary and the central point is maximum, i.e. $V_m$ , and $D_1$ is conducting. Neglecting the forward resistance of the diode, the voltage appearing across $R_L$ is $V_m$. the voltage across $D_2$ is, therefore, $2\,V_m$ irrespective of the nature of the load. Hence the PIV across each diode is twice the maximum secondary voltage measured from either end to the central point.

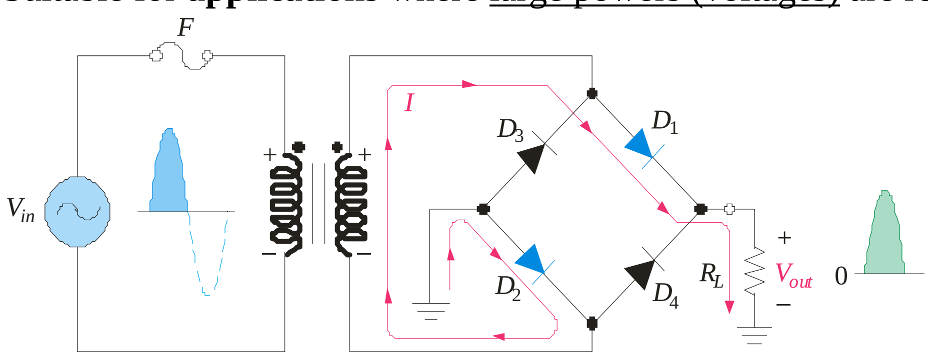
$$V_{(out)} = \frac{V_{(sec)}}{2} - V_b;\ V_{m(sec)} = 2V_{m(out)} + 2V_b \quad \dots (23)$$

$$PIV = 2V_{m(out)} + V_b = \boldsymbol{V_{m(sec)} - V_b} \quad \dots (24)$$

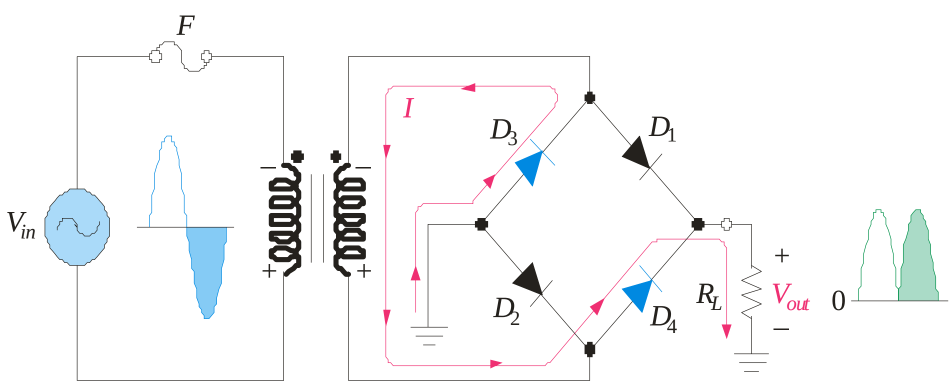
## 4.2.2.2: Full Wave Bridge Rectifier

The Bridge Full-Wave rectifier uses four diodes connected across the entire secondary as shown.

Suitable for **applications** where large powers (voltages) are required.




Conduction path for the **positive** half-cycle.




Conduction path for the **negative** half-cycle.

- It is a full wave rectifier that employs four identical diodes forming a **bridge-type** arrangement as shown before.

- During the positive half of the $AC$ cycle, **$D_1$ and $D_2$ are forward-biased and conduct**, while diodes $D_3$ and $D_4$ are reverse-biased and do not conduct. The direction of the current is indicated by solid arrows.

- During the negative half cycle, the **diodes $D_3$ and $D_4$ conduct** and the current flows in a direction indicated by dotted arrows. Thus, in both half cycles, the **current flows through the load**.

- The bridge rectifier needs a **smaller transformer** compared with the center tap rectifier for the same DC output. This is because in the bridge rectifier the full secondary voltage is used for rectification in both the input half cycles.

- The **transformer** with center taping is not needed. However, the **current rating of the bridge secondary** should be about **40 percent greater than** that for the center tap secondary.

## Peak Inverse Voltage (PIV):

- $V_{dc} = \frac{2\,V_m}{\pi} - 2V_b$ (If these diode drops are taken into account)
- $V_{m(out)} = V_{m(sec)} - 2V_b \; (= V_{m(sec)})$ ... (25)
- $PIV = V_{m(out)} + V_b \; (= V_{m(out)})$ ... (26)

## Summary of Rectifier Circuits

| Rectifier | Ideal $V_{DC}$ | Realistic $V_{DC}$ |
|---|---|---|
| Half Wave Rectifier | $V_{DC} = 0.318V_m$ | $V_{DC} = 0.318V_m - 0.7$ |
| Bridge Rectifier | $V_{DC} = 0.636V_m$ | $V_{DC} = 0.636V_m - 2(0.7\text{ V})$ |
| Center-Tapped Transformer Rectifier | $V_{DC} = 0.636V_m$ | $V_{DC} = 0.636V_m - 0.7\text{ V}$ |

$V_m$ = peak of the AC voltage.

**Example 4.4:** A full-wave rectifier uses two diodes; the internal resistance of each diode may be assumed constant at 20 Ω. The transformer rms secondary voltage from center tap to each end of secondary is 50 V and load resistance is 980 Ω. Find: (i) the average load current, (ii) the rms value of load current.

**Solution:**

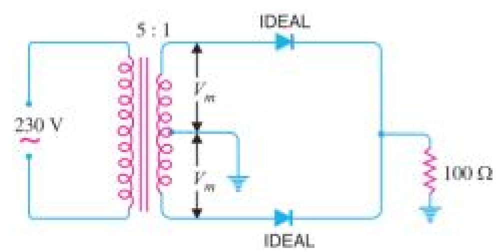
Max. ac voltage: $V_m = V_{rms} \times \sqrt{2} = 50 \times \sqrt{2} = 70.7\,V$

Max. load current: $I_m = \frac{V_m}{r+R_L} = \frac{70.7}{20+980} = 70.7\,mA$

(i) average load current: $I_{dc} = \frac{2I_m}{\pi} = \frac{2\times 70.7}{\pi} = 45\,mA$

(ii) RMS value of load current is: $I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}} = 50\,mA$

**Example 4.5:** In the center-tap circuit shown, the diodes are assumed to be ideal i.e., having zero internal resistance. Find: (i) dc output voltage (ii) peak inverse voltage.



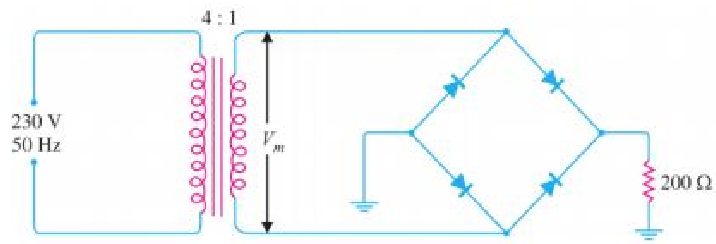

**Solution:**

- Primary to secondary turns is $N_1 / N_2 = 5$
- rms of the primary voltage: $V_{(pri)} = 230$ V
- ∴ Max primary voltage: $V_{m(pri)} = \sqrt{2}V_{(pri)} = \sqrt{2} \times 230 = 325.3$ V
- ∴ Max secondary voltage: $V_{m(sec)} = V_{m(pri)} \times (N_2 / N_1) = 325.3 \times \frac{1}{5} = 65$ V
- rms of the secondary voltage; $V_{(sec)} = \frac{V_{m(sec)}}{\sqrt{2}} = \frac{65}{\sqrt{2}} = 46\,V$
- Maximum voltage across **half** secondary winding is: $V_{m(out)} = \frac{V_{m(sec)}}{2} = \frac{65}{2} = 32.5\,V$
- Average output voltage: $V_{AVG} = \frac{2\,V_{m(out)}}{\pi} = \frac{2\times 32.5}{\pi} = 20.7\,V$

(i) $dc$ output voltage: $V_{dc} = V_{AVG} = 20.7\,V$

(ii) peak inverse voltage: $PIV = V_{p(sec)} = 2V_{p(out)} = 65\,V$

**Example 4.6:** In the bridge type circuit shown, the diodes are assumed to be ideal. Assume primary to secondary turns to be 4. Find: (i) $dc$ output voltage (ii) peak inverse voltage (iii) output frequency.




**Solution:**

- Primary to secondary turns is $N_1 / N_2 = 4$
- rms of the primary voltage: $V_{(pri)} = 230$ V
- ∴ Max primary voltage: $V_{m(pri)} = \sqrt{2}V_{(pri)} = \sqrt{2} \times 230 = 325.3$ V
- ∴ Max secondary voltage: $V_{m(sec)} = V_{m(pri)} \times (N_2 / N_1) = 325.3 \times \frac{1}{4} = 81.3$ V $= V_{m(out)}$
- rms of the secondary voltage; $V_{(sec)} = \frac{V_{m(sec)}}{\sqrt{2}} = \frac{81.3}{\sqrt{2}} = 57.5\ V$
- Average output voltage; $V_{AVG} = \frac{2\ V_{m(sec)}}{\pi} = \frac{2 \times 81.3}{\pi} = 52\ V$

Average current; $I_{dc} = \frac{2V_{m(out)}}{\pi R_L} = 0.26\text{A}$

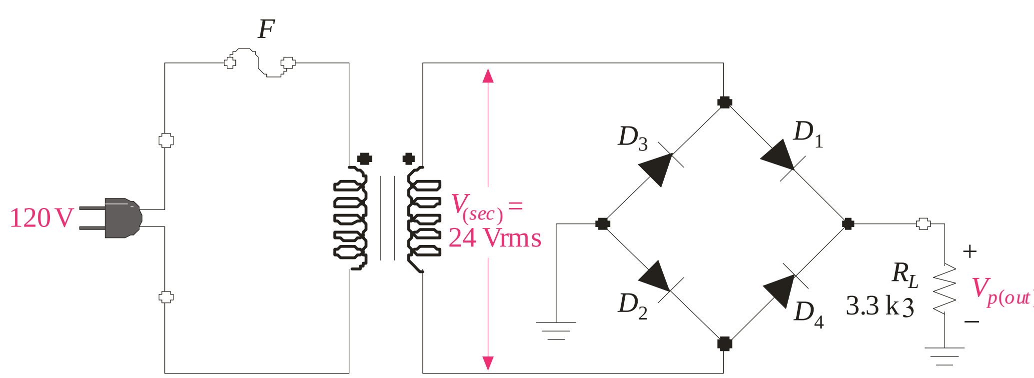
(i) $dc$ output voltage: $V_{dc} = V_{AVG} = 52\ V$

(ii) peak inverse voltage: $PIV = V_{m(out)} = 81.3\ V$

(iii) output frequency:

$$f_{out} = 2\, f_{in} = 2 \times 50 = 100\ Hz$$

**Example 4.7:** Determine the peak output voltage and current in the 3.3 KW load resistor if $V_{sec} = 24\ V_{rms}$. Use the practical diode model.




**Solution:**

The peak output voltage is: $V_{m(sec)} = \sqrt{2}\, V_{rms} = \sqrt{2} \times 24 = 33.9\ V$

$PIV = V_{p\ (out)} = V_{m(sec)} - 2V_b = 33.9 - 2(0.7) = 32.5\ V$

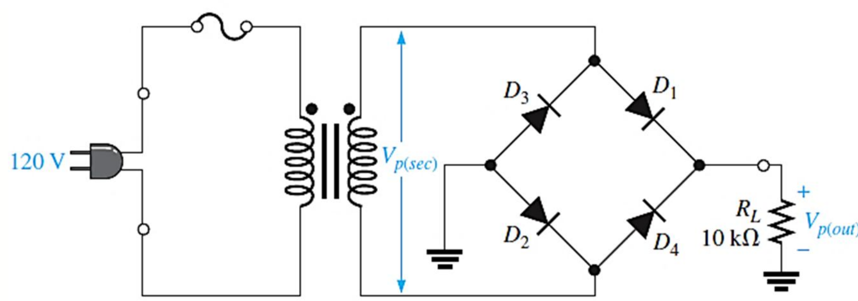
Applying Ohm's law; $I_{p\ (out)} = \frac{V_{p\ (out)}}{R_L} = \frac{32.5}{3.3 \times 10^3} = 9.8\ mA.$

**Example 4.8:** A full wave rectifier uses an applied voltage of $200\,sin\,(314t)$ to center tap with a load of $1k\Omega$. The forward resistance of each diode is $100\Omega$. Find $I_{dc}$, $I_{rms}$ in the load, and total load power $P_{ac}$, DC power delivered to the load $P_{dc}$.

**Solution:**

- $V_i = 200\,si\,n(314t) \rightarrow V_m = 200\,V$
- $I_m = \frac{V_m}{r_f+R_L} = \frac{200}{100+1000} = 181.8\,mA$
- $I_{dc} = \frac{2I_m}{\pi} = \frac{2\times181.8}{\pi} = 115.7\,mA$
- $I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{181.8}{\sqrt{2}} = 128.6\,mA$
- $P_{ac} = I_{rms}^2\,R_L = 16.5\,w$
- $P_{dc} = I_{dc}^2R_L = 13.4\,w$
- **IF** $\eta = \frac{P_{dc}}{P_{ac}} = \frac{13.4}{16.5} = 0.812$

**Example 4.8:** Determine the peak output voltage for the bridge rectifier in this Figure. Assuming the practical model, what **PIV** rating is required for the diodes? The transformer is specified to have a **12 V rms** secondary voltage for the standard **120 V** across the primary.




**Solution:**

The peak output voltage (taking into account the two diode drops) is:

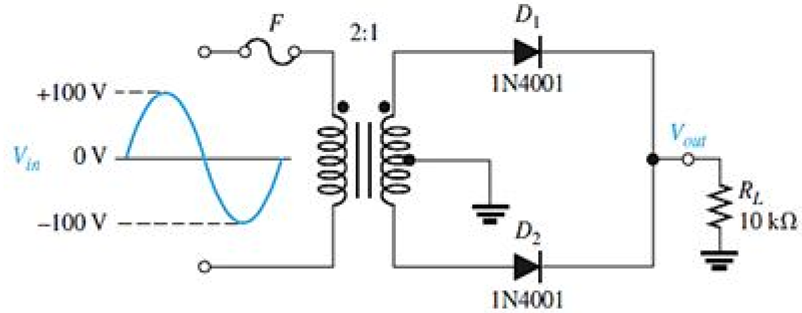
$$V_{m(\text{sec})} = \sqrt{2}\,V_{rms} = 1.414 \times 12 = 17\,V$$

$$V_{m(\text{out})} = V_{m(\text{sec})} - 1.4 = 17 - 1.4 = 15.6\,V$$

The PIV rating for each diode is:

$$PIV = V_{m(\text{out})} + 0.7 = 15.6 + 0.7 = 16.3\,V$$

**Example 4.9:** (a) Show the voltage waveforms across each half of the secondary winding and across $R_L$ when a 100 V peak sine wave is applied to the primary winding in this Figure.
(b) What minimum **PIV** rating must the diodes have?




**Solution:**

(a) The transformer turns ratio $n = \frac{N_2}{N_1} = \frac{1}{2} = 0.5.$

The total peak secondary voltage is:

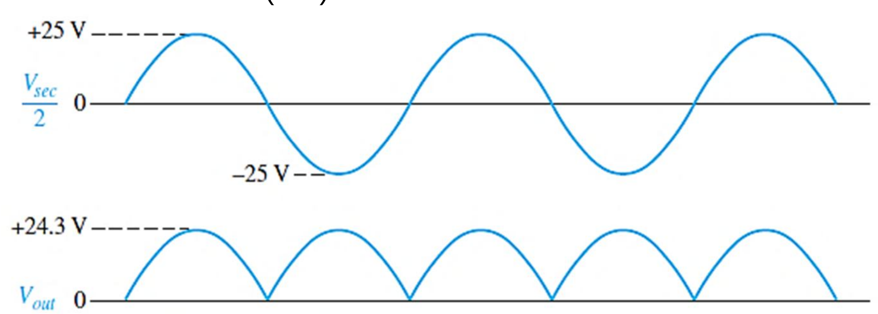
$$V_{m(\text{sec})} = n\,V_{m(\text{pri})} = 0.5 \times 100 = 50\,V$$

There is a 25 V peak across each half of the secondary with respect to ground. The output load voltage has a peak value of 25 V, less the 0.7 V drop across the diode. The waveforms are shown in Figure below.

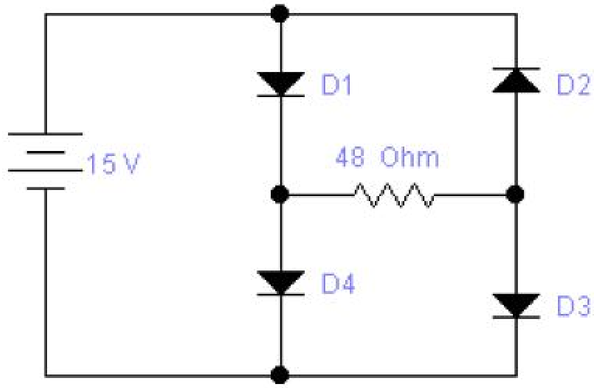
$$V_{m(\text{out})} = \frac{V_{m(\text{sec})}}{2} - 0.7 = \frac{50}{2} - 0.7 = 25 - 0.7 = 24.3\,V$$

(b) Each diode must have a minimum PIV rating of:

$$PIV = 2\,V_{m(\text{out})} + 0.7 = 2 \times 24.3 + 0.7 = 49.3\,V$$

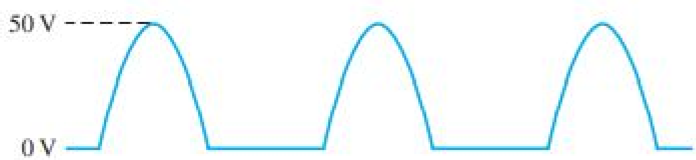


**H.W: Q1:** Calculate the current through 48Ω resistor in circuit below. Assuming the diodes to be Si and forward resistance of each diode is 1Ω.



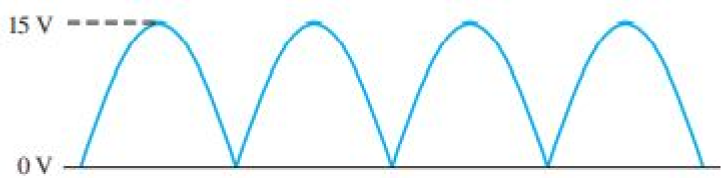

**Solution:**

**H.W: Q2:** What is the average value of the half-wave rectified voltage in this Figure?



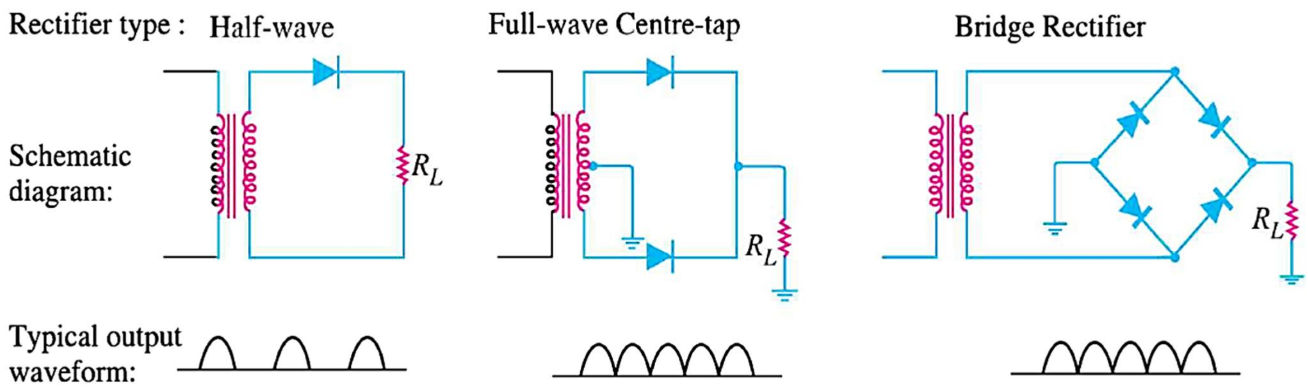

**Solution:** $V_{AVG} = \frac{V_m}{\pi} = \frac{50}{\pi} = 15.9\ V.$

**H.W: Q3:** Find the average value of the full-wave rectified voltage in this Figure?




**Solution:** $V_{AVG} = \frac{2\,V_m}{\pi} = \frac{2\times 15}{\pi} = 9.55\ V.$

## Comparison of Rectifiers:




| S. No. | Particulars | Half-wave | Centre-tap | Bridge type |
|---|---|---|---|---|
| 1 | No. of diodes | 1 | 2 | 4 |
| 2 | Transformer necessary | no | yes | no |
| 3 | Max. efficiency | 40.6% | 81.2% | 81.2% |
| 4 | Ripple factor | 1.21 | 0.48 | 0.48 |
| 5 | Output frequency | $f_{in}$ | $2 f_{in}$ | $2 f_{in}$ |
| 6 | Peak inverse voltage | $V_m$ | $2 V_m$ | $V_m$ |

# 4.3: Filter Circuits

As described earlier, the output of a **rectifier** contains **a number of ac components** in addition to the **dc component**.

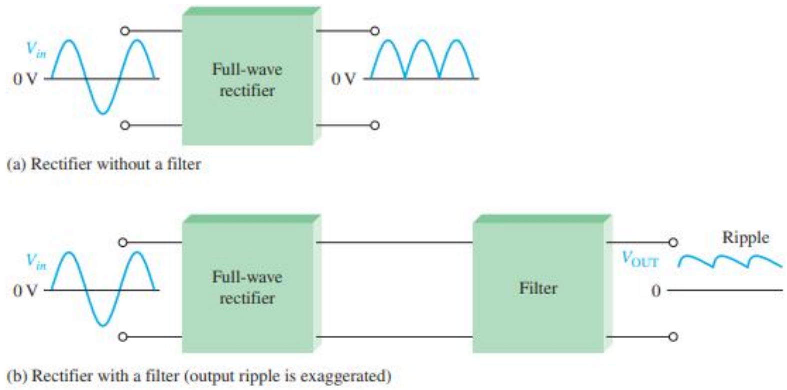



**Figure: Power supply filtering.**

To remove the A.C components (To minimize ripple in the rectifier output) or filter them out in a rectifier circuit, a filter circuit is used. A **filter circuit is a device to remove the A.C components of the rectified output, but allows the D.C components to reach the load**.
A filter circuit is in general a combination of inductor ($L$) and Capacitor ($C$) called $LC$ filter circuit.
A **capacitor** allows A.C only and **inductor** allows D.C only to pass.
So, a suitable $L$ and $C$ network can effectively filter out the A.C component from rectified wave.

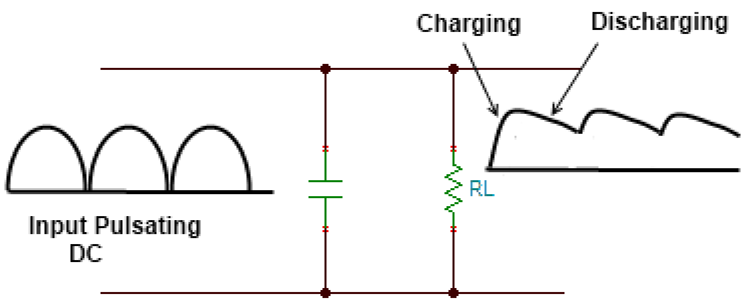
A filter circuit consists of passive circuit elements i.e., **inductors**, **capacitors**, **resistors** and **their combination**.
The filter action depends upon the electrical properties of passive circuit elements.
For example, an **inductor** allows the D.C to pass through it. But it blocks A.C.
On the other hand, a **capacitor** allows the A.C to pass through it. But it blocks the D.C.

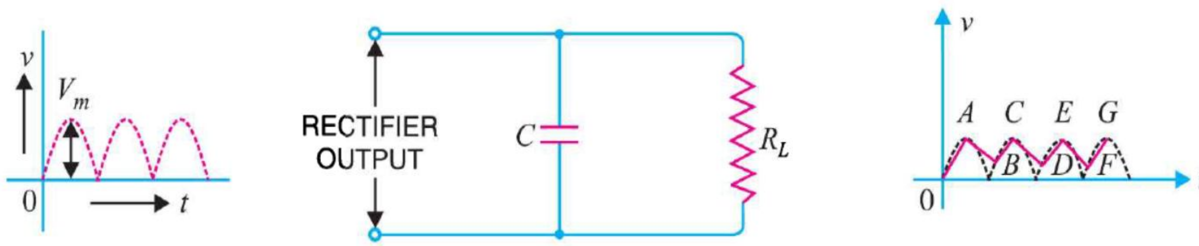
Some of the important filters are given below.
1. Capacitor Filter, 2. Inductor Filter, 3. LC Filter, and 4. π or CLC Filter

**NOTE**:
The **ac components** produce ripple in the rectifier output which is **unwanted**, and must be removed or minimized **before** connecting the rectifier to a load.

## 4.3.1: Capacitor Filter Circuits

A power supply filter ideally eliminates the fluctuations in the output voltage of a half-wave or full-wave rectifier and produces a constant-level *dc* voltage.



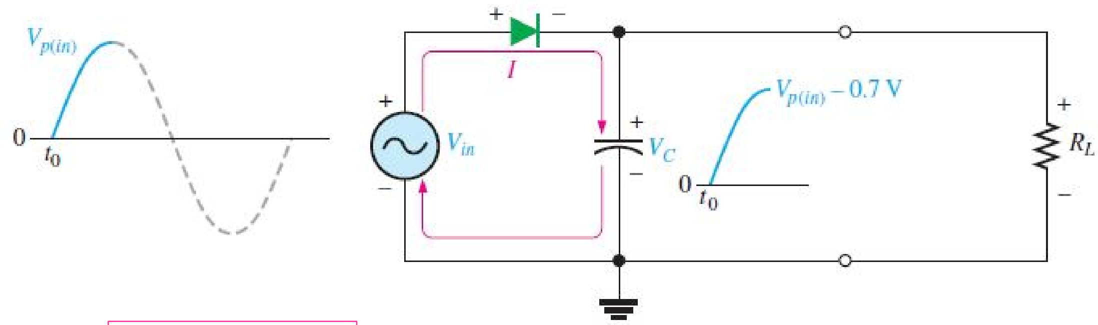

At point A the **capacitor is charged** to the peak value $V_m$. (See 3rd Fig.)

The rectifier voltage ($V_m$) starts to decrease. At this occurs, the **capacitor discharges** through the $R_L$, and the voltage across it decreases as shown by line AB (3rd Fig.).
The **voltage will decrease slightly** because immediately the next voltage peak comes and recharges the capacitor.
This process is **repeated** and the **output voltage waveform** becomes ABCDEFG.

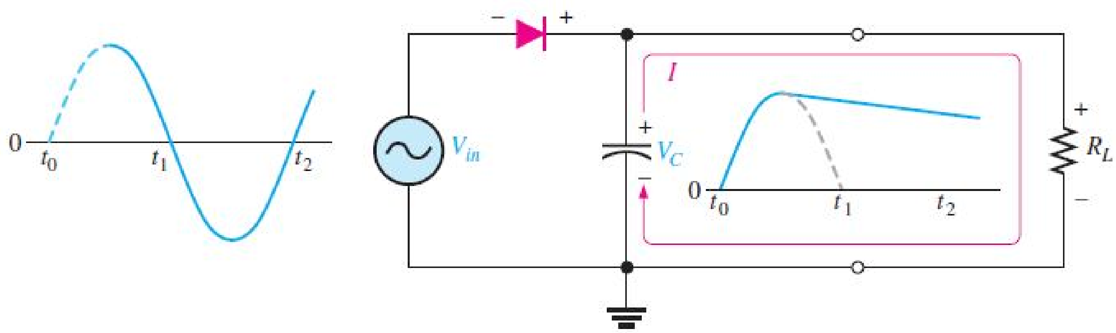
The **capacitor filter circuit** is **popular (famous)** because of its low cost, small size, little weight, and good characteristics.

Useful for load up to 50mA as in transistor radio battery eliminators.

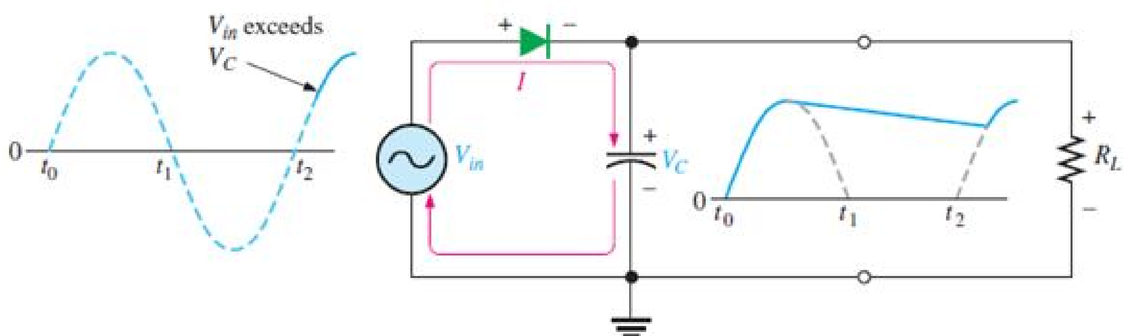
A half wave rectifier with capacitor filter is shown in the below figure.




(a) Initial charging of the capacitor (diode is forward-biased) happens only once when power is turned on.




(b) The capacitor discharges through $R_L$ after peak of positive alternation when the diode is reverse-biased. This discharging occurs during the portion of the input voltage indicated by the solid dark blue curve.




(c) The capacitor charges back to peak of input when the diode becomes forward-biased. This charging occurs during the portion of the input voltage indicated by the solid dark blue curve.

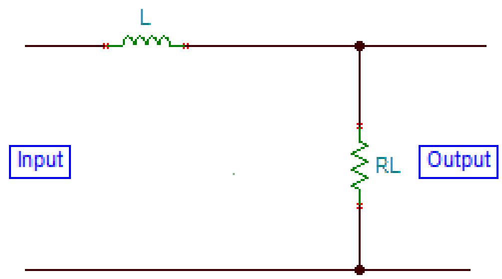
**Figure: Operation of a half-wave rectifier with a capacitor-input filter. The current indicates charging or discharging of the capacitor.**

NOTE:

- An AC/DC power supply <u>is built</u> using a **transformer** and a **half** or **full-wave** rectifier.
- The **transformer** <u>is used</u> to step down the voltage input.
- The **rectifier** <u>converts</u> AC to pulsed DC.
- A filter **capacitor** <u>is used</u> to smooth out the pulses.
- The **capacitor** <u>must be large enough</u> to store sufficient charge so as to provide a steady current supply to the load: $R_L C >> \frac{1}{f}$, where $f$ is rectified signal's frequency.

## 4.3.2: Inductor Filter Circuits

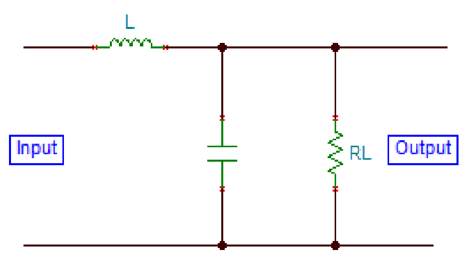
This type of filter is also called **choke filter**. The **Inductor Filter** consists of the **self-inductance $L$** which is inserted between the **rectifier** and the **load resistance $R_L$**.
The **rectifier** contains A.C components as well as D.C components.
When the output passes through the inductor, it offers a high resistance to the A.C component and no resistance to D.C components. Therefore, **A.C components** of the rectified output is blocked (is reduced after passing through an inductor or choke filter) and **only D.C components** reached at the load.




The **reactance of an inductor** ($X_L$) with is given by $X_L = wL = 2\pi f L$ where $w$ is the **angular frequency of the current**.

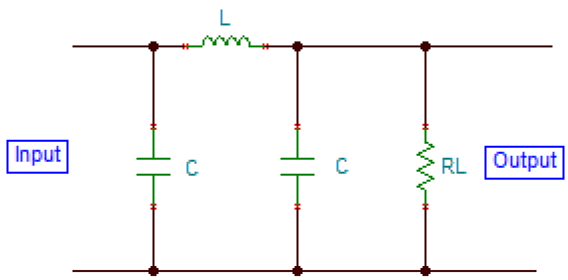
## 4.3.3: LC Filter (LC-Section) Circuits

In inductor filter, the **ripple factor** is directly proportional to the **load resistance** ($\gamma \propto R_L$).
In a capacitor filter, the **ripple factor** is varying inversely with the **load resistance** ($\gamma \propto \frac{1}{R_L}$).
Hence if we combine the inductor filter with the capacitor the **ripple factor** will become almost independent of the **load filter**. It is also known as **inductor input filter**, **choke input filter**, **L input** or **LC-section**.
In this circuit a choke is connected in series with the load. It offers **high resistances to the AC components** and **allows DC component to flow through the load**. The capacitor across the load is connected in parallel which filter out any **AC component flowing through the choke.**
In this way the reppls are rectified and a smooth DC is provided through the load.



# 4.3.4: CLC Or Pie Filter Circuits

It consists of **one inductor** and **two capacitors** connected across its each end.
The three components are arranged in shape of Greek letter **Pi**. It is also called **capacitor input Pi filter**.
The input capacitor $C_1$ is selected to offer **very low reactance** to the repel frequency hence major parts of filtering is done by $C_1$. Most of the remaining repels are removed by the combining action of L and $C_2$.
This circuit gives much **better filter** then LC filter. However, $C_1$ is still directly connected across the supply and would need high pulse of current if load current is large.
**This filter is used for the low current equipment's**.



# 4.4: Ripple Factor

The **ratio of rms value of ac compound to the *dc* compound in the rectifier output** is known as **ripple factor (γ)**, i.e.:

$$\gamma = \frac{\acute{I}_{rms}\ (effective\ or\ rms\ value\ of\ ac\ compound\ of\ the\ load\ current)}{I_{dc}\ (average\ or\ dc\ value\ of\ the\ load\ current)}\quad or\quad \gamma = \frac{\acute{V}_{rms}}{V_{dc}} \quad \ldots (27)$$

The relationship between rms value of the total load current $I_{rms}$, and the rms value of the AC components $\acute{I}_{rms}$, is given by:

$$I^2{}_{rms} = I^2{}_{dc} + \acute{I}^2{}_{rms} \rightarrow \acute{I}_{rms} = \sqrt{I^2{}_{rms} - I^2{}_{dc}}$$

$$\gamma = \frac{\acute{I}_{rms}}{I_{dc}} = \frac{\sqrt{I^2{}_{rms} - I^2{}_{dc}}}{\sqrt{I^2{}_{dc}}} =$$

$$\gamma = \sqrt{\frac{I^2{}_{rms}}{I^2{}_{dc}} - 1}\ \ OR\ \gamma = \sqrt{\frac{V^2{}_{rms}}{V^2{}_{dc}} - 1} \quad \ldots (28)$$

## 4.4.1: Ripple Factor of the Half-Wave Rectifier

The ripple factor of the half wave rectifier as given by equation (28) is:

$$\gamma = \sqrt{\left(\frac{\frac{I_m}{2}}{\frac{I_m}{\pi}}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21$$

This shows that the AC component outweighs the DC component in the output which means poor rectification. Thus a half wave rectifier is not suitable for AC to DC conversion. The circuit, however, acts as a basic building block to construct more complex and efficient circuits.

## 4.4.2: Ripple Factor of the Full-Wave Rectifier

The ripple factor of the full wave rectifier as given by equation (28) is:

$$\gamma = \sqrt{\frac{I^2{}_{rms}}{I^2{}_{dc}} - 1} = \sqrt{\left(\frac{\frac{I_m}{\sqrt{2}}}{\frac{2\,I_m}{\pi}}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = 0.48$$

This is considerably less than the corresponding value for half wave rectifier.
However, it is still too large to be fed to the electronic devices which require; $\gamma \leq 0.005$

## 4.4.3: Ripple Voltage

The variation in the capacitor voltage due to the charging and discharging is called the ripple voltage. Generally, ripple is undesirable; thus, the smaller the ripple, the better the filtering action, as illustrated in this Figure.

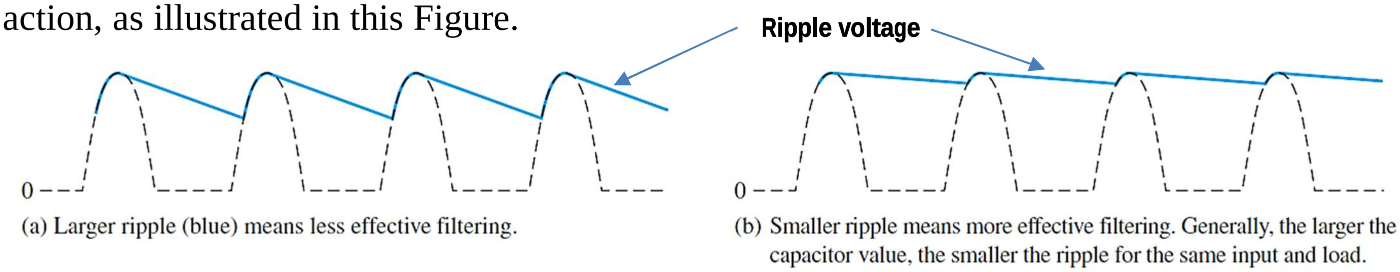



**Figure: Half-wave ripple voltage.**

For a given input frequency, the output frequency of a full-wave rectifier is twice that of a half-wave rectifier, as illustrated in this Figure.

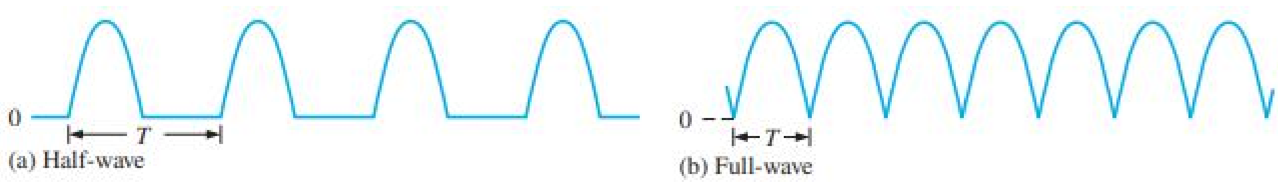



**Figure:** The **period** of a full-wave rectified voltage is <u>half</u> that of a half-wave rectified voltage. The **output frequency** of a full-wave rectifier is <u>twice</u> that of a half-wave rectifier.

This makes a full-wave rectifier <u>easier</u> to filter <u>because of the shorter time between peaks</u>. <u>When filtered</u>, the full-wave rectified voltage <u>has a smaller ripple than does</u> a half-wave voltage for the <u>same</u> load resistance and capacitor values. The capacitor **discharges less** during the shorter interval between full-wave pulses, as shown in this Figure.

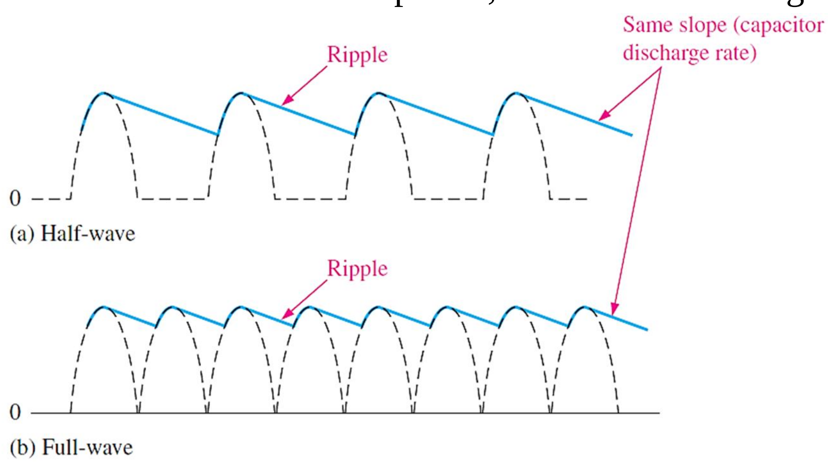



**Figure: Comparison of ripple voltages for half-wave and full-wave rectified voltages with the same filter capacitor and load and derived from the same sinusoidal input voltage.**

## 4.4.4: Ripple Factor with Capacitor Filter

The **ripple factor ($\gamma$)** is an indication of the effectiveness of the filter and is defined as:

$$\gamma = \frac{V_{r\,(pp)}}{V_{DC}} \quad \ldots (29)$$

where $V_{r\,(pp)}$ is the **peak-to-peak ripple voltage** and $V_{DC}$ is the ***dc* (average) value of the filter's output voltage**, as illustrated in this Figure.

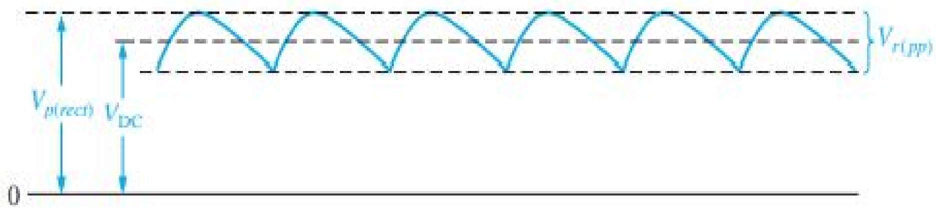



**Figure: $V_r$ and $V_{DC}$ Determine the Ripple Factor.**

The lower the ripple factor, the better the filter. The ripple factor can be lowered by **increasing the value of the filter capacitor** or **increasing the load resistance**.

For a full-wave rectifier with a capacitor-input filter, approximations for the **peak-to-peak ripple voltage** $\left(V_{r\,(pp)}\right)$, and the ***dc* value of the filter output voltage** $(V_{DC})$ are given in the following equations:

$$V_{r\,(pp)} \cong \left(\frac{1}{fR_LC}\right) V_{p\,(rect)} \quad \ldots (30)$$

$$V_{DC} \cong \left(1 - \frac{1}{2fR_LC}\right) V_{p\,(rect)} = V_{p\,(rect)} - \frac{V_{r\,(pp)}}{2} \quad \ldots (31)$$

The variable $V_{p\,(rect)}$ is the unfiltered peak rectified voltage.

Notice that if $R_L$ or $C$ increases, the ripple voltage decreases and the $dc$ voltage increases.

Note:

$$\gamma = \frac{\acute{V}_{rms}}{V_{dc}} = \frac{\frac{I_{dc}(2\pi - w(t_2 - t_1))}{2\sqrt{3}wC}}{I_{dc}R_L} = \frac{2\pi - w(t_2 - t_1)}{2\sqrt{3}wCR_L} \text{ ... (32) } For\ HWR$$

If $(t_2 - t_1) << \frac{2\pi}{w}$, $w(t_2 - t_1)$ is neglected. Then we obtain:

$$\gamma = \frac{2\pi}{2\sqrt{3}wCR_L} = \frac{1}{2\sqrt{3}fCR_L} \text{ ... (33) } For\ HWR$$

$$\gamma = \frac{\acute{V}_{rms}}{V_{dc}} = \frac{\frac{I_{dc}(\pi - w(t_2 - t_1))}{2\sqrt{3}wC}}{I_{dc}R_L} = \frac{\pi - w(t_2 - t_1)}{2\sqrt{3}wCR_L} \text{ ... (34) } For\ FWR$$

If $(t_2 - t_1) << \frac{\pi}{w}$, $w(t_2 - t_1)$ is neglected. Then we obtain:

$$\gamma = \frac{\pi}{2\sqrt{3}wCR_L} = \frac{1}{4\sqrt{3}fCR_L} \text{ ... (35) } For\ FWR$$

## 4.4.5: Ripple Factor with Inductor Filter

From equation (27), we have:

$$\gamma = \frac{\acute{I}_{rms}}{I_{dc}} = \frac{\frac{4V_m}{3\pi\sqrt{2}\sqrt{R_L^2 + 4w^2L^2}}}{\frac{2V_m}{\pi R_L}} = \frac{2R_L}{3\sqrt{2}\sqrt{R_L^2 + 4w^2L^2}} = \frac{2}{3\sqrt{2}\sqrt{1 + \frac{4w^2L^2}{R_L^2}}} \text{ ... (36)}$$

For $\frac{4w^2L^2}{R_L^2} >> 1$;

$$\gamma = \frac{R_L}{3\sqrt{2}\ wL} \text{ ... (37)}$$

## 4.4.6: Ripple Factor with LC Filter

$$\gamma = \frac{\acute{V}_{rms}}{V_{dc}} = \frac{V_2}{V_{dc}} = \frac{\frac{V_m}{3\pi\sqrt{2}\,w^2LC}}{\frac{2V_m}{\pi}} = \frac{1}{6\sqrt{2}\,w^2LC} \;\ldots (38)$$

At 50 Hz, we obtain;

$$\gamma = \frac{1.19}{LC} \;\ldots (39)$$

Where C is in microfarad and L is in henry.

## 4.4.7: Ripple Factor with Pie Filter

$$\gamma = \frac{\acute{V}_{rms}}{V_{dc}} = \frac{V_2}{V_{dc}} = \frac{\frac{\sqrt{2}I_{dc}X_cX_{c1}}{X_{L1}}}{V_{dc}} = \frac{\sqrt{2}X_cX_{c1}}{R_LX_{L1}} \;\ldots (40)$$

For the harmonic,

$$X_c = \frac{1}{2wC}, X_{c1} = \frac{1}{2wC_1}, X_{L1} = 2wL_1$$

Therefore, equation (40) becomes:

$$\gamma = \frac{1}{4\sqrt{2}w^3CC_1L_1R_L} \;\ldots (41)$$

At 50 Hz, we obtain;

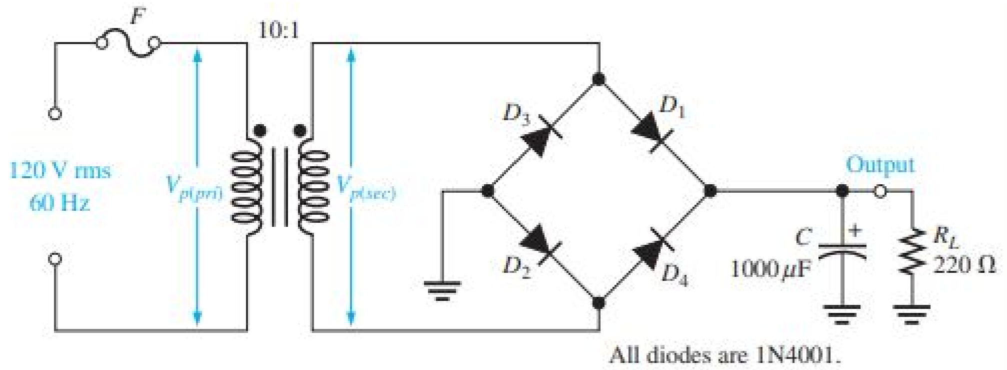
$$\gamma = \frac{5700}{CC_1L_1R_L} \;\ldots (42)$$

Where $\boldsymbol{C}$ and $\boldsymbol{C_1}$ are in microfarads, $\boldsymbol{L_1}$ is in henrys and $\boldsymbol{R_L}$ in ohms.

This expression shows that the ripple factor increases with decrease in load resistance.
If a $\pi$-section filter is followed by an LC-section filter with inductance $\boldsymbol{L_2}$ and capacitance $\boldsymbol{C_2}$, equation (40) may be extended to obtain the ripple. Thus we get:

$$\gamma = \frac{\sqrt{2}X_c}{R_L}\frac{X_{c1}}{X_{L1}}\frac{X_{c2}}{X_{L2}} \;\ldots (43)$$

**Example 4.10:** Determine the ripple factor for the filtered bridge rectifier with a load as indicated in this Figure.




**Solution:**

The transformer turns ratio $is\ n = \frac{N_2}{N_1} = 0.1.$

The peak primary voltage is: $V_{m(pri)} = \sqrt{2}\,V_{rms} = \sqrt{2} \times 120 = 170\,V$

The peak secondary voltage is: $V_{m(sec)} = \text{n}\,V_{m(pri)} = 0.1 \times 170 = 17\,V$

The unfiltered peak full-wave rectified voltage is:

$$V_{p(rect)} = V_{m(sec)} - 2V_b = 17 - 1.4 = 15.6\,V$$

The frequency of a full-wave rectified voltage is 120 Hz.

The approximate peak-to-peak ripple voltage at the output:

$$V_{r\,(pp)} \cong \left(\frac{1}{fR_LC}\right) V_{p\,(rect)} = \frac{1}{120 \times 220 \times 10^{-3}} \times 15.6 = 0.591\,V$$

The approximate dc value of the output voltage is determined as follows:

$$V_{dc} \cong \left(1 - \frac{1}{2fR_LC}\right) V_{p\,(rect)} = V_{p\,(rect)} - \frac{V_{r\,(pp)}}{2} = 15.6 - 0.3 = 15.3\,V$$

The resulting ripple factor is:

$$\gamma = \frac{V_{r\,(pp)}}{V_{dc}} = \frac{0.591}{15.3} = 0.039$$

The percent ripple is 3.9%.

# 4.5: Regulation

The change in DC output with DC load current is termed **regulation**. It is given by:

$$\textit{Line Regulation} = \frac{\Delta V_{OUT}}{\Delta V_{IN}} \times 100\% \quad \ldots (44)$$

$$\textit{Load Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% \quad \ldots (45)$$

Where $V_{NL}$ **is the output voltage at no load or the minimum load** and $V_{FL}$ **is the voltage at full load**.

For an ideal power supply, the **output voltage does not vary with load** (or DC load current) and **regulation is zero**.

## 4.5.1: Regulation of the Half-Wave Rectifier

The $dc$ output voltage across load is given by: $V_{dc} = I_{dc}R_L \rightarrow R_L = \frac{V_{dc}}{I_{dc}}$

Substituting the value of $R_L$ into equation (4), we obtain:

$$V_{dc} = \frac{V_m}{\pi} - I_{dc}r \quad \textbf{or} \quad V_{dc} = \frac{V_m}{\pi} - V_b \ \ldots (46)$$

This equation shows that $I_{dc}$ **equals zero (no load)**, the $dc$ **output voltage is maximum** and is equal to $V_{dc} = \frac{V_m}{\pi}$. Also, $V_{dc}$ decreases linearly with increase in $I_{dc}$ or load.

The larger value of the diode forward resistance ($r$), decreases the $dc$ output for a given load. Strictly speaking, the **resistance of transformer secondary** should also be added to $r$ while computing the regulation.

## 4.5.2: Regulation of the Full-Wave Rectifier

The $dc$ output voltage across load is given by: $V_{dc} = I_{dc}R_L \rightarrow R_L = \frac{V_{dc}}{I_{dc}}$

Substituting the value of $R_L$ into equation (20), we obtain:

$$V_{dc} = \frac{2\,V_m}{\pi} - I_{dc}r \quad \textbf{or} \quad V_{dc} = \frac{2\,V_m}{\pi} - V_b \quad \textbf{or} \quad V_{dc} = 0.9\,V_{rms} \ \ldots (47)$$

As in the case of half wave rectifier, the $DC$ voltage output decreases with increases in load or the forward resistance of either diode.

**H.W: Q4:** A certain 7805 regulator has a measured no-load output voltage of 5.18 V and a full-load output of 5.15 V. What is the load regulation expressed as a percentage.

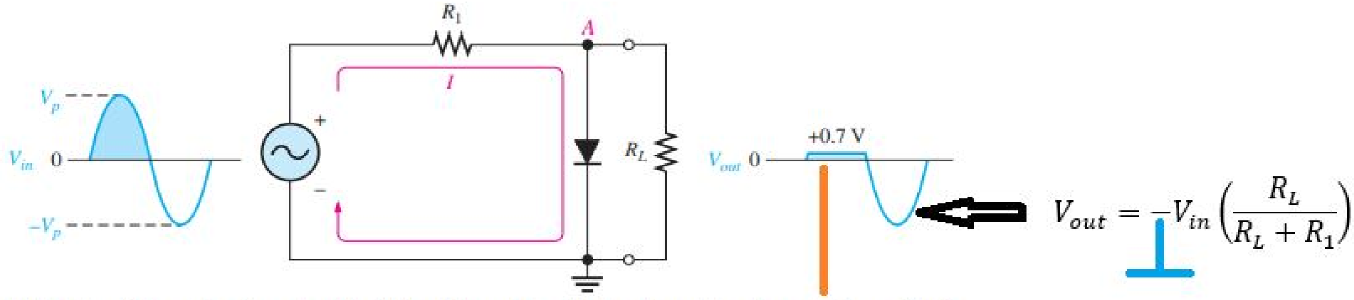
**Solution:** $\textit{Load regulation} = \frac{V_{NL}-V_{FL}}{V_{FL}} \times 100\% = \frac{5.18-5.15}{5.15} \times 100\% = 0.58\,\%$.

## 4.6: Diode Limiters (Clipper)

A clipper **is a type of diode network that has the ability to "clip off" a portion of the input signal without distorting the remaining part of the alternating waveform**.

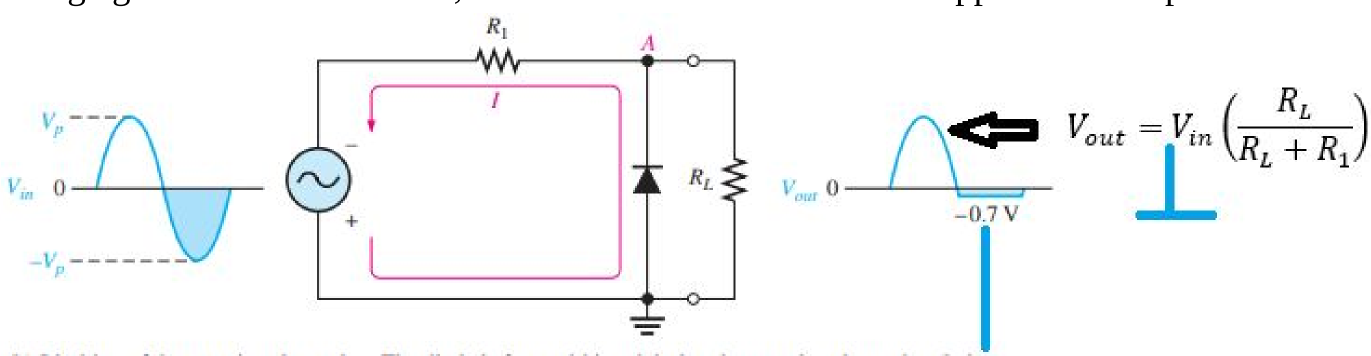
The **half-wave rectifier** is an example of the simplest form of a diode clipper — one resistor and a diode.

Depending on the orientation (direction) of the diode, the **positive or negative region of the input signal is "clipped" off**.




(a) Limiting of the positive alternation. The diode is forward-biased during the positive alternation (above 0.7 V) and reverse-biased during the negative alternation.

Figure (a) shows a diode limiter (also called clipper) that limits or clips the positive part of the input voltage. As the input voltage goes positive, the diode becomes forward biased and conducts current. Because the cathode is at ground potential (0 V), the anode cannot exceed 0.7V (assuming silicon). So, point A is limited to +0.7V when the input voltage exceeds this value. When the input voltage goes back below 0.7 V, the diode is reverse biased and appears as an open.




(b) Limiting of the negative alternation. The diode is forward-biased during the negative alternation (below −0.7 V) and reverse-biased during the positive alternation.

If the diode is turned around, as in Figure (b), the negative part of the input voltage is clipped off. When the diode is forward-biased during the negative part of the input voltage, point A is held at $-0.7\ V$ by the diode drop. When the input voltage goes above $-0.7\ V$, the diode is no longer forward-biased, and a voltage appears across $R_L$ proportional to the input voltage.

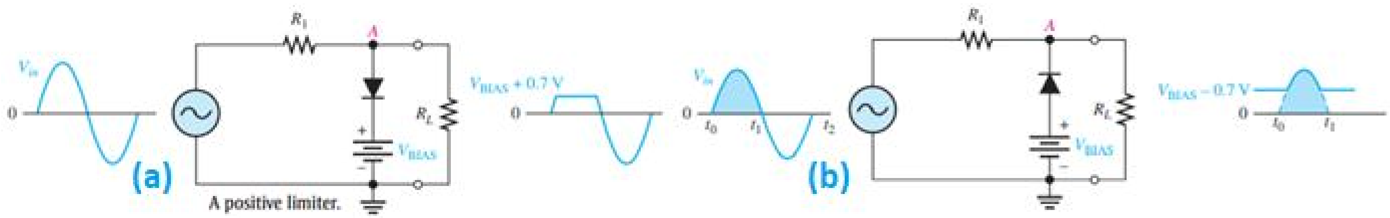
The magnitude of output voltage by the voltage divider formed by $R_1$ and the load resistor $R_L$, as follows:

$$V_{out} = V_{in}\left(\frac{R_L}{R_L + R_1}\right)$$

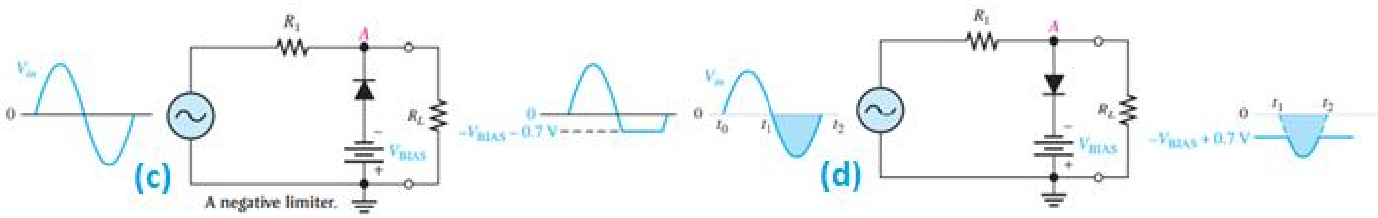
If $R_1$ is small compared to $R_L$ then $V_{out} = V_{in}$.

## 4.7: Biased Limiters

The level to which an ac voltage is limited can be adjusted by adding a bias voltage, $V_{BIAS}$, in series with the diode, as shown in Figure (a). The voltage at point A must equal $V_{BIAS} + 0.7\ V$ before the diode will become forward-biased and conduct. Once the diode begins to conduct, the voltage at point A is limited to $V_{BIAS} + 0.7\ V$ V so that all input voltage above this level is clipped off.



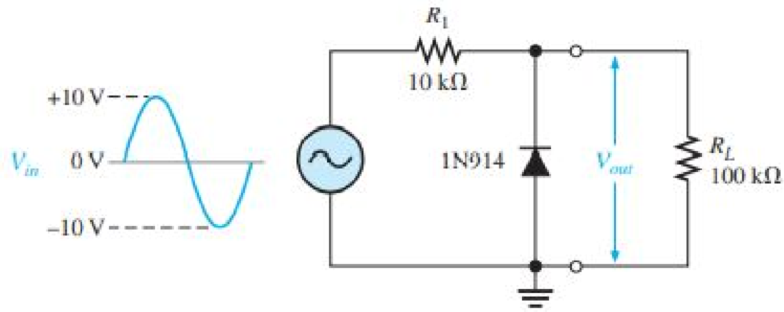

To limit a voltage to a specified negative level, the diode and bias voltage must be connected as in Figure (c). In this case, the voltage at point A must go below $-V_{BIAS} - 0.7\ V$ V to forward-bias the diode and initiate limiting action as shown.




By turning the diode around, the positive limiter can be modified to limit the output voltage to the portion of the input voltage waveform above $V_{BIAS} - 0.7\ V$ as shown by the output waveform in Figure (b). Similarly, the negative limiter can be modified to limit the output voltage to the portion of the input voltage waveform below $-V_{BIAS} + 0.7\ V$, as shown by the output waveform in Figure (d).

**NOTE**: What was the first sign? Therefore, you will be putting the same sign.

**Example 4.11:** What would you expect to see on an oscilloscope connected across $R_L$ in the limiter circuit shown below.

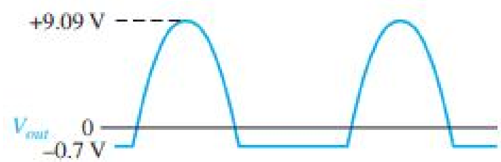



**Solution:**

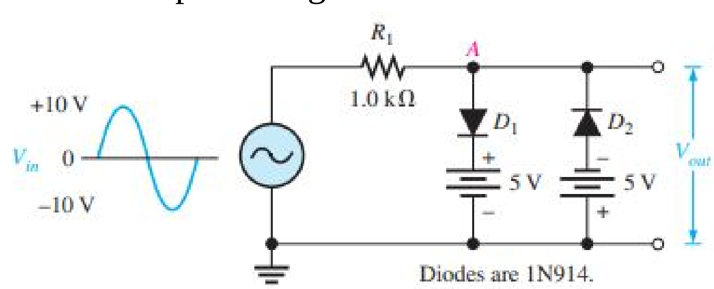
The diode is forward-biased and conducts when the input voltage goes below $-0.7\ V$.

For the negative limiter, the peak output voltage across $R_L$ by the following equation:

$$V_{out} = V_{in}\left(\frac{R_L}{R_L + R_1}\right) = 10\left(\frac{1000}{1000 + 100}\right) = 9.09\ V$$




**Example 4.12:** Figure shown below shows a circuit combining a positive limiter with a negative limiter Determine the output voltage waveform.

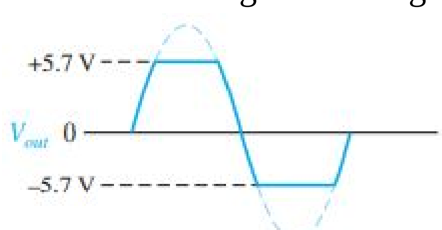



**Solution:**

When the voltage at point A reaches $V_{BIAS} + 0.7 = 5 + 0.7 = 5.7\ V$. diode $D_1$ conducts and limits the waveform to $+5.7\ V$.

Diode D2 does not conduct until the voltage reaches $-V_{BIAS} - 0.7 = -5 - 0.7 = -5.7\ V$.

Therefore, positive voltages above $+5.7\ V$ and negative voltages below $-5.7\ V$ are clipped off.

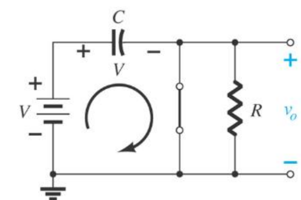


# 4.8: Diode Clampers (DC Restorers)

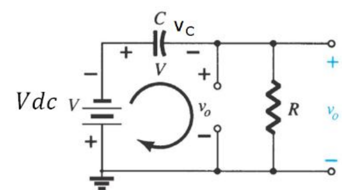
**Clampers** are sometimes known as **DC restorers**.

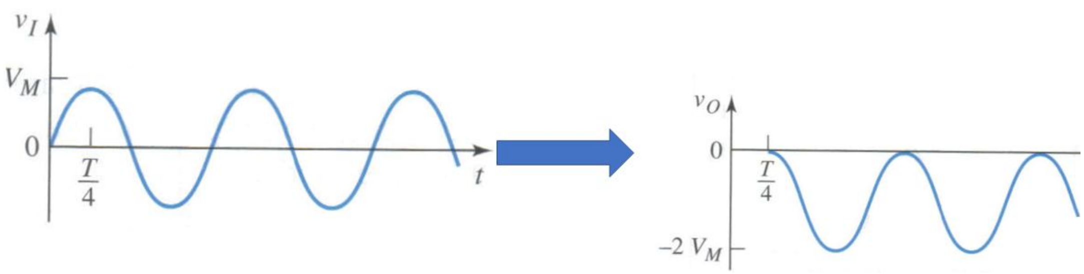
A **clamper is a network constructed of a diode, a resistor, and a capacitor that shifts a waveform to a different DC level <u>without changing</u> the appearance of the applied signal**.

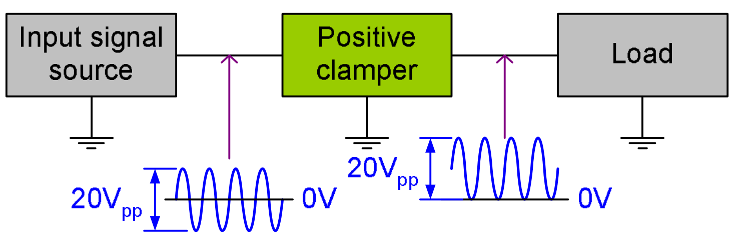
Operation at forward biased, the diode is short circuited (i.e., "on" state). The voltage will be $V_o = 0$ since the current is shorted thru diode and the capacitor is charged up to a voltage V.

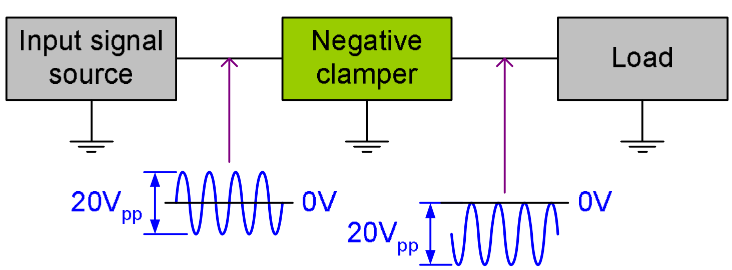



During reverse biased, the diode is open circuited (i.e., "off" state). The voltage will be $V_o = 0$ since the current is shorted thru diode.
The voltage across R will be: $V_{dc} + V_c = -V + (-V) = -2V$




OR A **clamper adds a dc level to an ac voltage**.

Figures (a) and (b) show a diode clamper that inserts a **positive dc level** in the output waveform. The operation of this circuit can be seen by considering the first negative half-cycle of the input voltage.

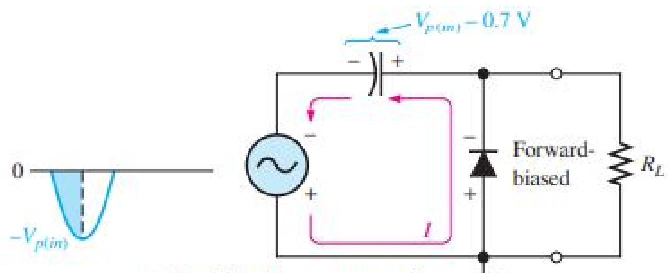
When the input voltage initially goes negative, **the diode is forward biased**, allowing the **capacitor to charge to near the peak of the input $+(V_{p\,(in)} - 0.7\,V)$**, as shown in Figure (a). **Just after the negative peak, the diode is reverse-biased**.

This is because the cathode is held near $V_{p\,(in)} - 0.7\,V$ by the charge on the capacitor.

The **capacitor** can only discharge through the **high resistance of $R_L$**. So, from the peak of one negative half-cycle to the next, the **capacitor discharges very little**.

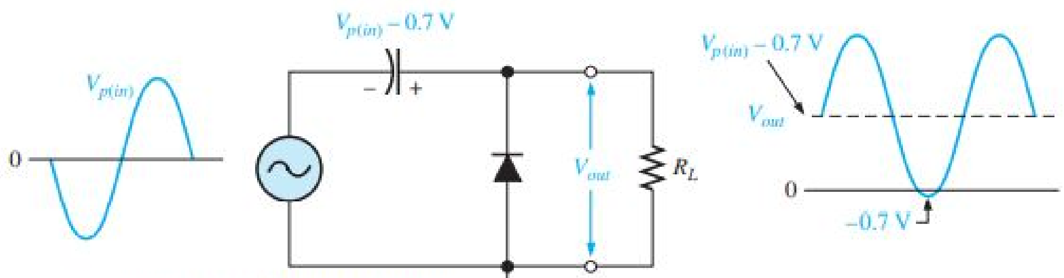
The **amount that is discharged**, of course, depends on the **value of $R_L$**.

**For good clamping action**, the **time constant ($\tau$ = RC = $\frac{1}{2\pi f_c}$)** (where $f_c$ is the cutoff frequency) should be at least **ten times the period** of the input frequency.



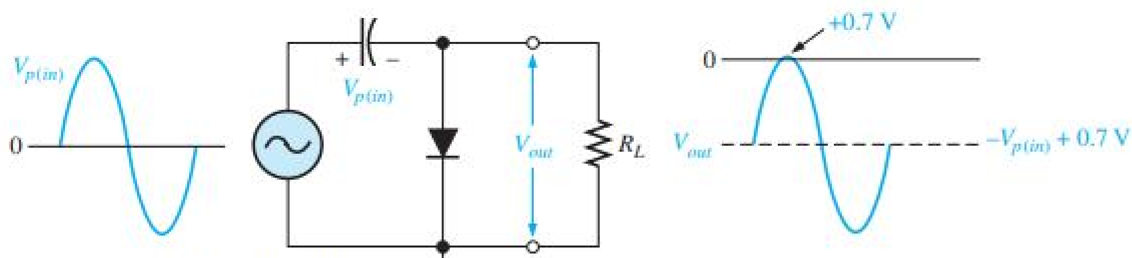
(a) Positive clamper operation.

The net effect of the clamping action is that the capacitor retains a charge approximately equal to the peak value of the input less the diode drops ($V_{DC} = +(V_{p\,(in)} - 0.7)$). The capacitor voltage acts essentially as a battery in series with the input voltage. The **dc voltage of the capacitor** adds to the input voltage by superposition, as in Figure (b).



(b) Positive clamper operation.

If the diode is turned around. A negative dc voltage is added to the input voltage to produce the output voltage as shown in Figure (c). $V_{DC} = -(V_{p\,(in)} - 0.7)$

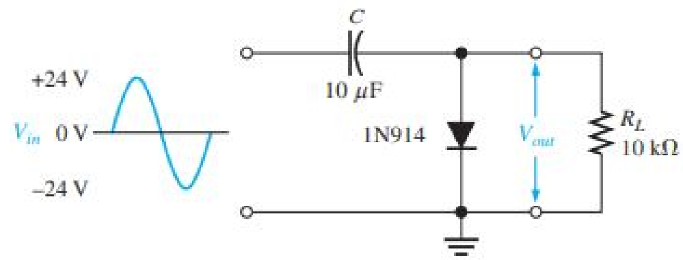


(c) Negative clamper.

# Clamper Application:

A clamping circuit is often used in television receivers as a dc restorer. The incoming composite video signal is normally processed through capacitively coupled amplifiers that eliminate the dc component. Thus, losing the black and white reference levels and the blanking level. Before being applied to the picture tube. These reference levels must be restored.

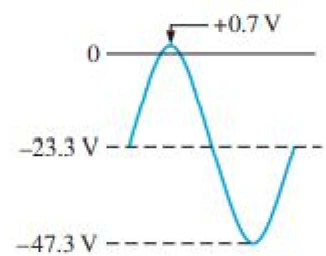
**Example 4.13:** What is the output voltage that you would expect to observe across $R_L$ in the clamping circuit of the circuit below. Assume that $RC$ is large enough to prevent significant capacitor discharge.



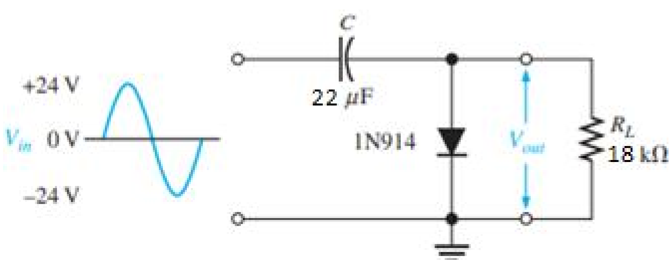

**Solution:** Ideally. a negative dc value equal to the input peak less the diode drop is inserted by the clamping circuit.

$$V_{DC} = -(V_{p\ (in)} - 0.7) = -(24 - 0.7) = -23.3\ V$$

Actually, the capacitor will discharge slightly between peaks, and, as a result, the output voltage will have an average value of slightly less than that calculated above. The output waveform goes to approximately +0.7 V.




**H.W: Q5**: What is the output voltage that you would observe across $R_L$ in Figure for $C = 22\mu f$ and $R_L = 18\ k\Omega$?



# 4.9: Voltage Multipliers

**Voltage multipliers use clamping action to increase peak rectified voltages without the necessity of increasing the transformer's voltage rating**.
Multiplication factors of two, three, and four are common.
Voltage multipliers are used in high-voltage, low-current applications such as TV receivers.

## 4.9.1: Voltage Doubler

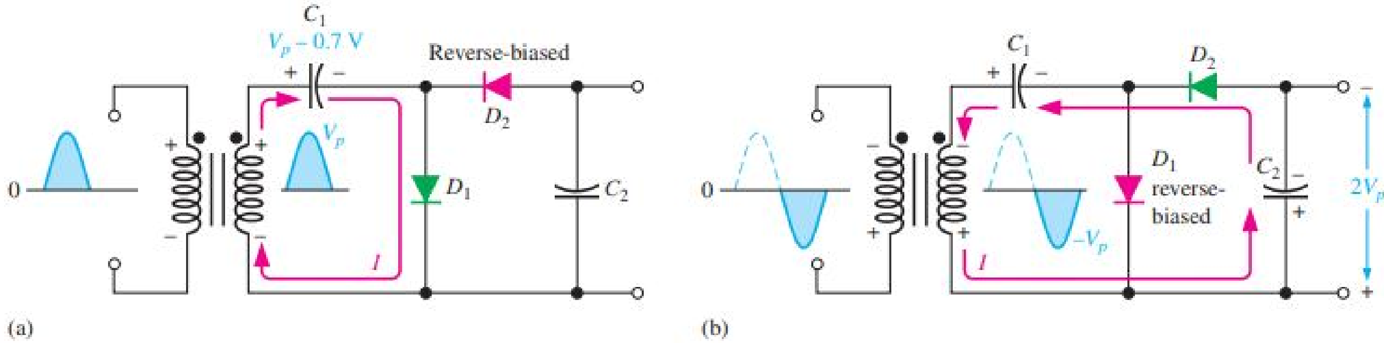
A **voltage Doubler is a voltage multiplier with a multiplication factor of two**.

**Half-Wave Voltage Doubler**:
A half-wave voltage Doubler is shown in this Figure.
During the positive half-cycle of the secondary voltage, diode $D_1$ is forward-biased and $D_2$ is reverse-biased.
Capacitor **$C_1$** is charged to the peak of the secondary voltage ($V_p$) less the diode drops with the polarity shown in part (a).
During the negative half-cycle, diode $D_2$ is forward-biased and $D_1$ is reverse-biased, as shown in part (b).
Since $C_1$ can't discharge, the peak voltage on $C_1$ adds to the secondary voltage to charge $C_2$ to approximately $2V_p$.
Applying Kirchhoff's law around the loop as shown in part (b), the voltage across $C_2$ is:

$$V_{C1} - V_{C2} + V_p = 0$$

$$V_{C2} = V_{C1} + V_p$$

Neglecting the diode drop of $D_2$; $V_{C1} = V_p$.
Therefore; $V_{C2} = V_p + V_p = 2V_p$




Half-wave voltage doubler operation. $V_p$ is the peak secondary voltage.

Under a no-load condition, $C_2$ remains charged to approximately $2V_p$ If a load resistance is connected across the output, $C_2$ discharges slightly through the load on the next positive half-cycle and is again recharged to $2V_p$ on the following negative half-cycle.

The resulting output is a half-wave, capacitor-filtered voltage.

The peak inverse voltage ($\boldsymbol{PIV}$) across each diode is $2V_p$.

If the diode were reversed, the output voltage across $C_2$ would have the opposite polarity.

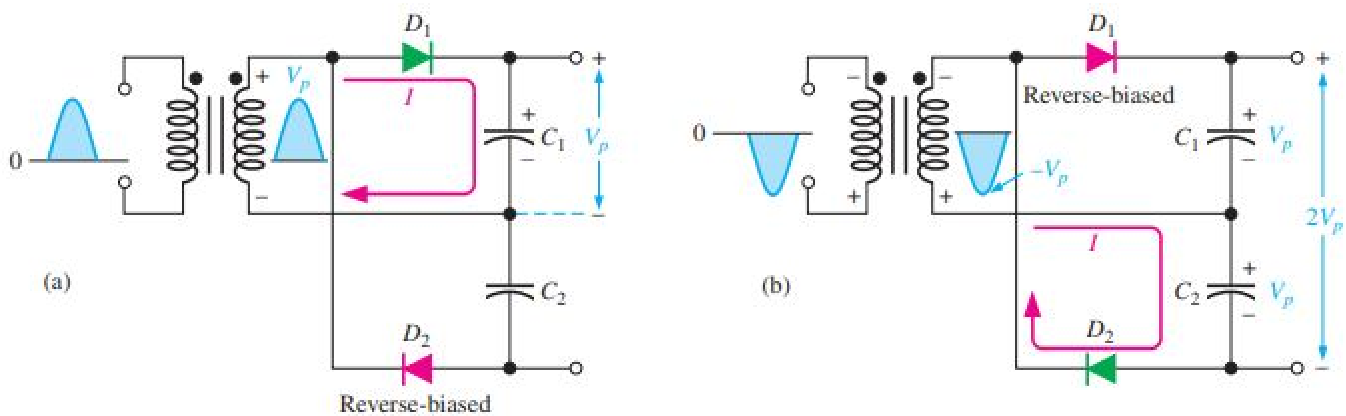
## **Full-Wave Voltage Doubler**:

A full-wave Doubler is shown in this Figure.

When the secondary voltage is positive, $D_1$ is forward-biased and **$C_1$** charges to approximately $V_p$, as shown in part (a).

During the negative half-cycle, $D_2$ is forward-biased and **$C_2$** charges to approximately $V_p$, as shown in part (b).

The output voltage $(2V_p)$, is taken across the two capacitors in series.



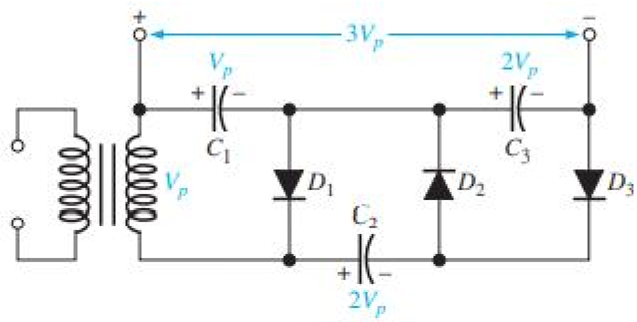

Full-wave voltage doubler operation.

## 4.9.2: Voltage Tripler

The addition of another diode-capacitor section to the half-wave voltage Doubler creates a **voltage Tripler**, as shown in this Figure.

The operation is as follows: On the positive half-cycle of the secondary voltage, **$C_1$** charges to $V_p$ through $D_1$. During the negative half-cycle, **$C_2$** charges to $2V_p$ through $D_2$, as described for the Doubler. During the next positive half-cycle, **$C_3$** charges to $2V_p$ through $D_3$.

The Tripler output is taken across $C_1$ and $C_3$, as shown in the figure.



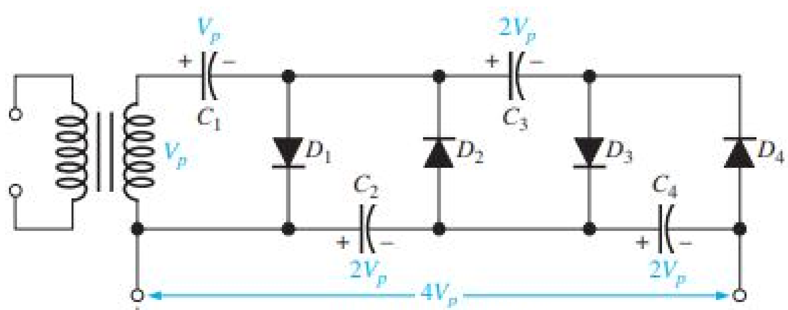
Voltage tripler.

## 4.9.2: Voltage Quadrupler

The addition of still another diode-capacitor section, as shown in this Figure, produces an output four times the peak secondary voltage.

$C_4$ charges to $2V_p$ through $D_4$ on a negative half-cycle. The $4V_p$ output is taken across $C_2$ and $C_4$, as shown.

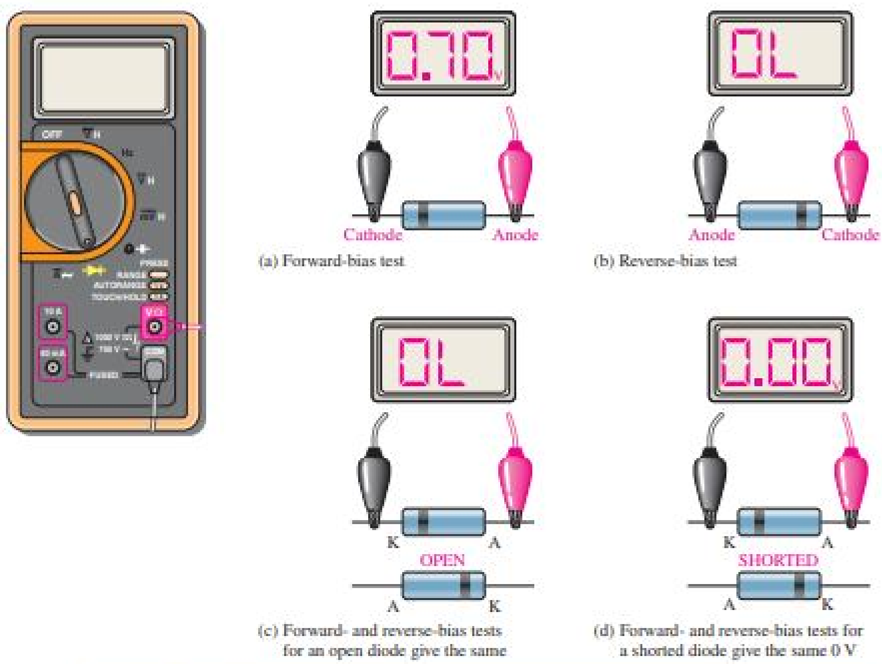
In both the Tripler and Quadrupler circuits, the **PIV of each diode is $2V_p$**.



Voltage quadrupler.

# 9.10: Testing a Diode

A multimeter can be used as a fast and simple way to check a diode out of the circuit.
A good diode will show an extremely high resistance (ideally an open) with reverse bias and a very low resistance with forward bias. A defective open diode will show an extremely high resistance (or open) for both forward and reverse bias. A defective shorted or resistive diode will show zero or a low resistance for both forward and reverse bias. An open diode is the most common type of failure.




Testing a diode out-of-circuit with a DMM.

**NOTE**:
You must see on pages from 78 to 84 in Electronic Devices Conventional (9th Edition-Floyd).

**H.W: Q6**: **Answers can be found at** https://quizlet.com/429026817/thomas-floyd-mcq-flash-cards/

1. The average value of a half-wave rectified voltage with a peak value of 200 V is
   (a) 63.7 V (b) 127.2 V (c) 141 V (d) 0 V
2. When a 60 Hz sinusoidal voltage is applied to the input of a half-wave rectifier, the output frequency is
   (a) 120 Hz (b) 30 Hz (c) 60 Hz (d) 0 Hz
3. The peak value of the input to a half-wave rectifier is 10 V. The approximate peak value of the output is
   (a) 10 V (b) 3.18 V (c) 10.7 V (d) 9.3 V
4. The peak value of the input to a half-wave rectifier is 10 V, the diode must be able to withstand a reverse voltage of
   (a) 10 V (b) 5 V (c) 20 V (d) 3.18 V
5. The average value of a full-wave rectified voltage with a peak value of 75 V is
   (a) 53 V (b) 47.8 V (c) 37.5 V (d) 23.9 V
6. When a 60 Hz sinusoidal voltage is applied to the input of a full-wave rectifier, the output frequency is
   (a) 120 Hz (b) 60 Hz (c) 240 Hz (d) 0 Hz
7. The total secondary voltage in a center-tapped full-wave rectifier is 125 V rms. Neglecting the diode drop, the rms output voltage is
   (a) 125 V (b) 177 V (c) 100 V (d) 62.5 V
8. When the peak output voltage is 100 V, the PIV for each diode in a center-tapped full-wave rectifier is (neglecting the diode drop)
   (a) 100 V (b) 200 V (c) 141 V (d) 50 V
9. When the rms output voltage of a bridge full-wave rectifier is 20 V, the peak inverse voltage across the diodes is (neglecting the diode drop)
   (a) 20 V (b) 40 V (c) 28.3 V (d) 56.6 V
10. The ideal dc output voltage of a capacitor-input filter is equal to
    (a) the peak value of the rectified voltage
    (b) the average value of the rectified voltage
    (c) the rms value of the rectified voltage
11. A certain power-supply filter produces an output with a ripple of 100 mV peak-to-peak and a dc value of 20 V. The ripple factor is
    (a) 0.05 (b) 0.005 (c) 0.00005 (d) 0.02

12. A 60 V peak full-wave rectified voltage is applied to a capacitor-input filter. If $f = 120\,Hz$, $R_L = 10\,k\Omega$, and $C = 10\,\mu F$, the ripple voltage is

(a) 0.6 V (b) 6 mV (c) 5.0 V (d) 2.88 V

13. If the load resistance of a capacitor-filtered full-wave rectifier is reduced, the ripple voltage

(a) increases (b) decreases (c) is not affected (d) has a different frequency

14. Line regulation is determined by

(a) load current
(b) Zener current and load current
(c) changes in load resistance and output voltage
(d) changes in output voltage and input voltage

15. Load regulation is determined by

(a) changes in load current and input voltage
(b) changes in load current and output voltage
(c) changes in load resistance and input voltage
(d) changes in Zener current and load current

16. A 10 V peak-to-peak sinusoidal voltage is applied across a silicon diode and series resistor. The maximum voltage across the diode is

(a) 9.3 V (b) 5 V (c) 0.7 V (d) 10 V (e) 4.3 V

17. In a certain biased limiter, the bias voltage is 5 V and the input is a 10 V peak sine wave. If the positive terminal of the bias voltage is connected to the cathode of the diode, the maximum voltage at the anode is

(a) 10 V (b) 5 V (c) 5.7 V (d) 0.7 V

18. In a certain positive clamper circuit, a 120 V rms sine wave is applied to the input. The dc value of the output is

(a) 119.3 V (b) 169 V (c) 60 V (d) 75.6 V

19. The input of a voltage Doubler is 120 V rms. The peak-to-peak output is approximately

(a) 240 V (b) 60 V (c) 167 V (d) 339 V

20. If the input voltage to a voltage Tripler has a rms value of 12 V, the dc output voltage is approximately

(a) 36 V (b) 50.9 V (c) 33.9 V (d) 32.4 V

21. When a silicon diode is working properly in forward bias, a DMM in the diode test position will indicate

(a) 0 V (b) OL (c) approximately 0.7 V (d) approximately 0.3 V

22. When a silicon diode is open, a DMM will generally indicate

(a) 0 V (b) OL (c) approximately 0.7 V (d) approximately 0.3 V