Electronic Circuits - Power Supplies

Any electronic device consists of a power supply unit which provides the required amount of AC or DC power supply to various sections of that electronic device.

Need for Power Supplies

There are many small sections present in the electronic devices such as Computer, Television, Cathode ray Oscilloscope etc. but all of those sections doesn't need 230V AC supply.

Instead one or more sections may need a 12v DC while some others may need a 30v DC. In order to provide the required dc voltages, the incoming 230v AC supply has to be converted into pure DC for the usage. The Power supply units serve the same purpose.

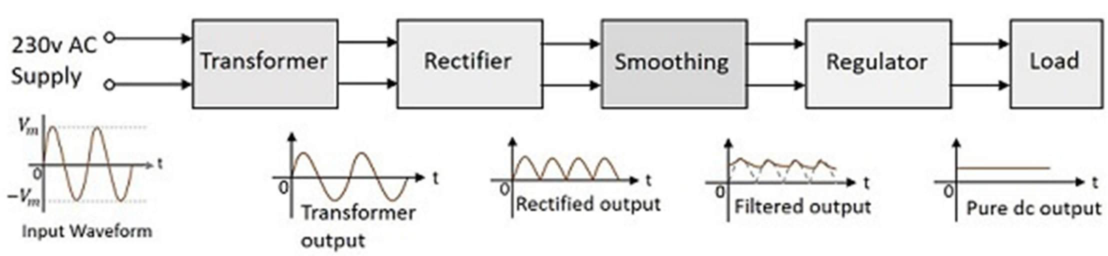
Parts of a Power supply

A typical Power supply unit consists of the following.

- Transformer − An input transformer for the stepping down of the 230v AC power supply.
- Rectifier − A Rectifier circuit to convert the AC components present in the signal to DC components.
- Smoothing − A filtering circuit to smoothen the variations present in the rectified output.
- Regulator − A voltage regulator circuit in order to control the voltage to a desired output level.
- Load − The load which uses the pure dc output from the regulated output.

Block Diagram of a Power Supply Unit

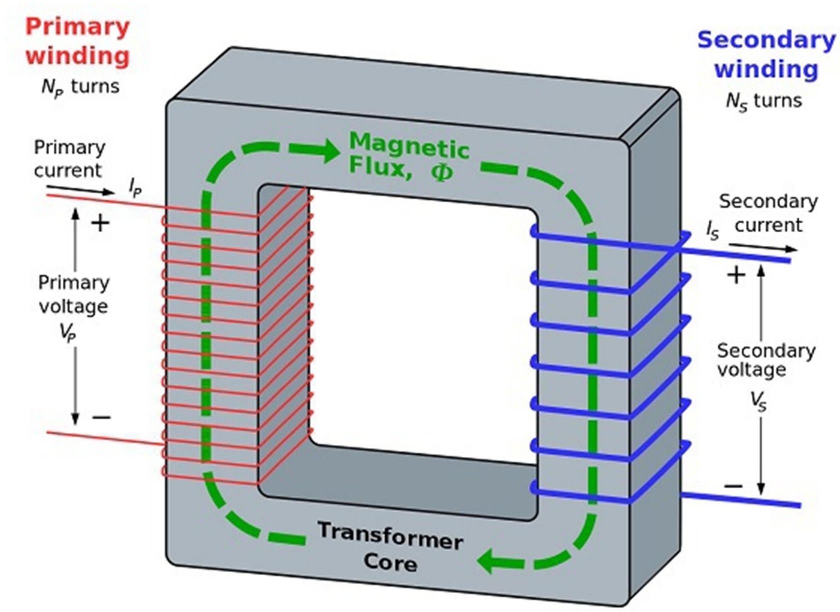
The block diagram of a Regulated Power supply unit is as shown below.



Transformer

A transformer has a primary coil to which input is given and a secondary coil from which the output is collected. Both of these coils are wound on a core material. Usually an insulator forms the Core of the transformer.

The following figure shows a practical transformer.

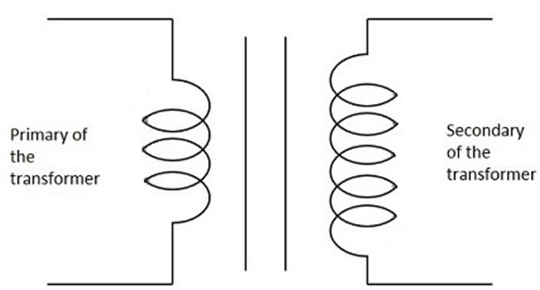


From the above figure, it is evident that a few notations are common. They are as follows −

- Np = Number of turns in the primary winding
- Ns = Number of turns in the secondary winding
- Ip = Current flowing in the primary of the transformer
- Is = Current flowing in the secondary of the transformer
- Vp = Voltage across the primary of the transformer
- Vs = Voltage across the secondary of the transformer
- ϕ = Magnetic flux present around the core of the transformer

Step-Up Transformer

When the secondary winding has more number of turns than the primary winding, then the transformer is said to be a Step-up transformer. Here the induced EMF is greater than the input signal.

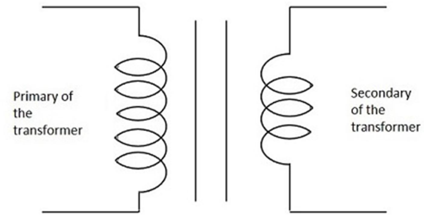


Step-up transformer

The figure below shows the symbol of a step-up transformer.

Step-Down Transformer

When the secondary winding has lesser number of turns than the primary winding, then the transformer is said to be a Step-down transformer. Here the induced EMF is lesser than the input signal.

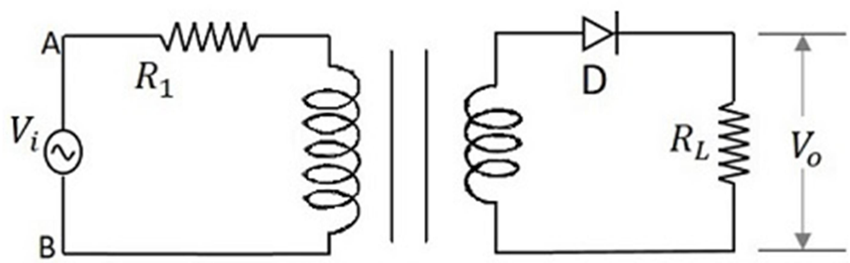


Step-down transformer

Half-Wave Rectifier

The name half-wave rectifier itself states that the **rectification** is done only for **half** of the cycle. The AC signal is given through an input transformer which steps up or down according to the usage. Mostly a step down transformer is used in rectifier circuits, so as to reduce the input voltage.

The input signal given to the transformer is passed through a PN junction diode which acts as a rectifier. This diode converts the AC voltage into pulsating dc for only the positive half cycles of the input. A load resistor is connected at the end of the circuit. The figure below shows the circuit of a half wave rectifier.



Step down Transformer

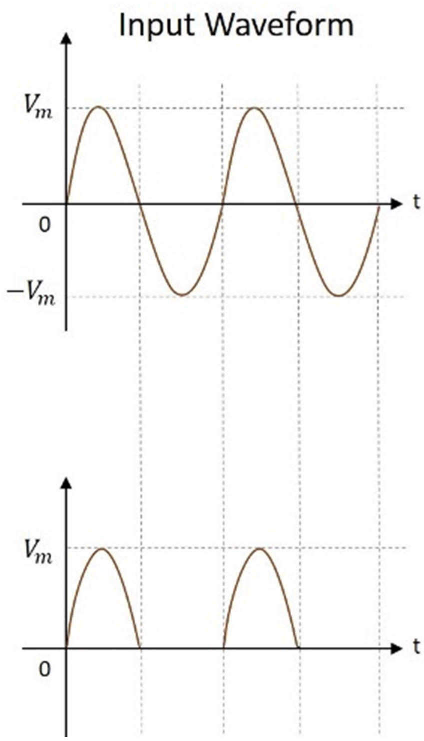
Working of a HWR

The input signal is given to the transformer which reduces the voltage levels. The output from the transformer is given to the diode which acts as a rectifier. This diode gets ON $conducts$ for positive half cycles of input signal. Hence a current flows in the circuit and there will be a voltage drop across the load resistor. The diode gets OFF $doesn't\ conduct$ for negative half cycles and hence the output for negative half cycles will be, i_D=0, and V_o=0.

Hence the output is present for positive half cycles of the input voltage only neglecting the reverse leakage current. This output will be pulsating which is taken across the load resistor.

Waveforms of a HWR

The input and output waveforms are as shown in the following figure.



Hence the output of a half wave rectifier is a pulsating dc. Let us try to analyze the above circuit by understanding few values which are obtained from the output of half wave rectifier.

Analysis of Half-Wave Rectifier

To analyze a half-wave rectifier circuit, let us consider the equation of input voltage.

$$v_i = V_m \sin \quad \omega t$$

V_m is the maximum value of supply voltage.

Let us assume that the diode is ideal.

- The resistance in the forward direction, i.e., in the ON state is Rf.
- The resistance in the reverse direction, i.e., in the OFF state is R_r.

The current **i** in the diode or the load resistor R_L is given by

$$i = I_m \sin \omega t \qquad for \quad 0 \le \omega t \le 2\pi$$

$$i = 0 \qquad for \quad \pi \le \omega t \le 2\pi$$

Where

$$I_m = V_m / R_f + R_L$$

d.c. power. The output current is pulsating direct current. Therefore, in order to find d.c. power, average current has to be found out.

$$*I_{av} = I_{dc} = \frac{1}{2\pi}\int_0^{\pi} i \, d\theta = \frac{1}{2\pi}\int_0^{\pi} \frac{V_m \sin\theta}{r_f + R_L} d\theta$$

$$= \frac{V_m}{2\pi(r_f + R_L)}\int_0^{\pi} \sin\theta \, d\theta = \frac{V_m}{2\pi(r_f + R_L)}[-\cos\theta]_0^{\pi}$$

$$= \frac{V_m}{2\pi(r_f + R_L)} \times 2 = \frac{V_m}{(r_f + R_L)} \times \frac{1}{\pi}$$

$$= {}^{**}\frac{I_m}{\pi} \qquad \left[\because I_m = \frac{V_m}{(r_f + R_L)}\right]$$

$$\therefore \quad \text{d.c. power, } P_{dc} = I_{dc}^2 \times R_L = \left(\frac{I_m}{\pi}\right)^2 \times R_L \qquad ...(i)$$

a.c. power input : The a.c. power input is given by :

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

For a half-wave rectified wave, $I_{rms} = I_m/2$

$$\therefore \quad P_{ac} = \left(\frac{I_m}{2}\right)^2 \times (r_f + R_L) \qquad ...(ii)$$

$$\therefore \quad \text{Rectifier efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{(I_m/\pi)^2 \times R_L}{(I_m/2)^2 (r_f + R_L)}$$

$$= \frac{0.406 R_L}{r_f + R_L} = \frac{0.406}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

$\therefore$ Max. rectifier efficiency = 40.6%

This shows that in half-wave rectification, a maximum of 40.6% of a.c. power is converted into d.c. power.

Full Wave Rectifiers

A Rectifier circuit that rectifies both the positive and negative half cycles can be termed as a full wave rectifier as it rectifies the complete cycle. The construction of a full wave rectifier can be made in two types. They are

- Center-tapped Full wave rectifier
- Bridge full wave rectifier

Both of them have their advantages and disadvantages.

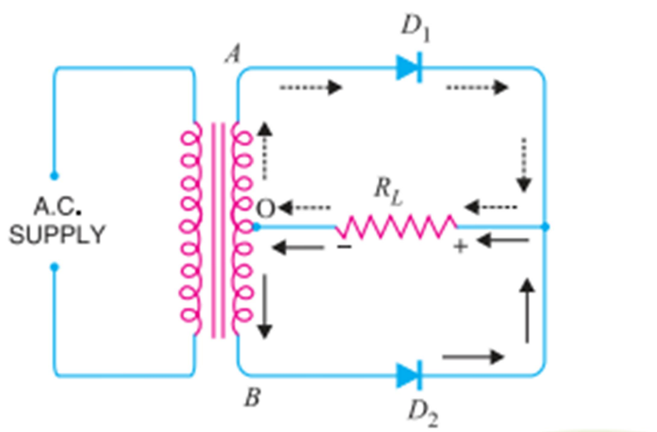
Center-tapped Full-Wave Rectifier

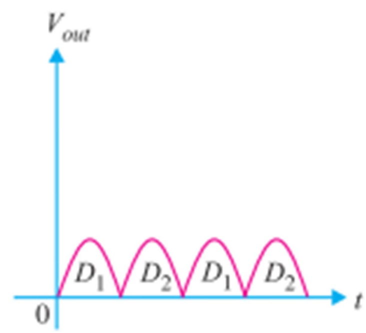
A rectifier circuit whose transformer secondary is tapped to get the desired output voltage, using two diodes alternatively, to rectify the complete cycle is called as a **Center-tapped Full wave rectifier circuit**. The transformer is center tapped here unlike the other cases.

The features of a center-tapping transformer are −

- The tapping is done by drawing a lead at the mid-point on the secondary winding. This winding is split into two equal halves by doing so.
- The voltage at the tapped mid-point is zero. This forms a neutral point.
- The center tapping provides two separate output voltages which are equal in magnitude but opposite in polarity to each other.
- A number of tapings can be drawn out to obtain different levels of voltages.

The center-tapped transformer with two rectifier diodes is used in the construction of a **Center-tapped full wave rectifier**. The circuit diagram of a center tapped full wave rectifier is as shown below.





Working of a CT- FWR

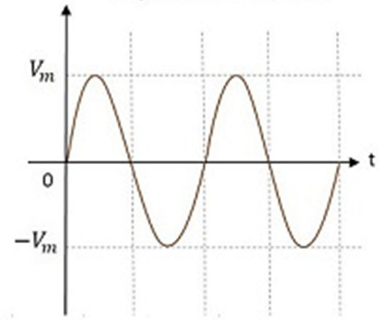
The working of a center-tapped full wave rectifier can be understood by the above figure. When the positive half cycle of the input voltage is applied, the point A at the transformer secondary becomes positive with respect to the point B. This makes the diode D1forward biased. Hence current i_1 flows through the load resistor.

When the negative half cycle of the input voltage is applied, the point A at the transformer secondary becomes negative with respect to the point B. This makes the diode $D2$ forward biased. Hence current i_2 flows through the load resistor.

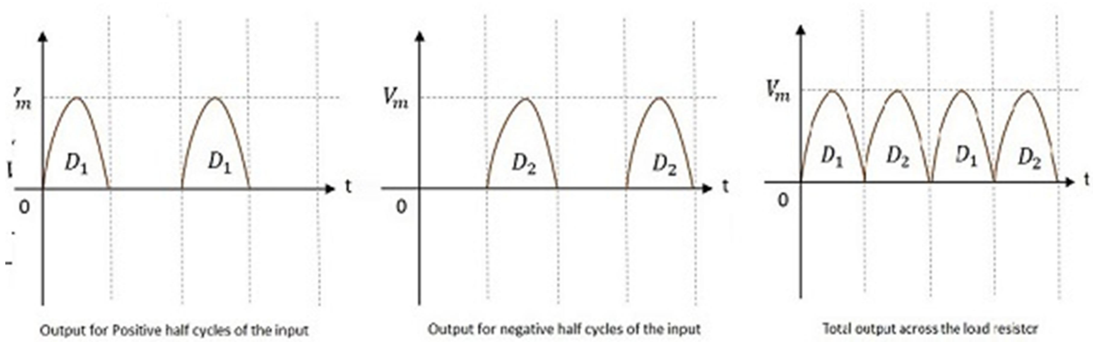
Waveforms

The input and output waveforms of the center-tapped full wave rectifier are as follows.

Input Waveform



Output Waveforms



From the above figure it is evident that the output is obtained for both the positive and negative half cycles. It is also observed that the output across the load resistor is in the **same direction** for both the half cycles.

Peak Inverse Voltage

As the maximum voltage across half secondary winding is V_m, the whole of the secondary voltage appears across the non-conducting diode. Hence the **peak inverse voltage** is twice the maximum voltage across the half-secondary winding, i.e.

$$PIV = 2V_m$$

Disadvantages

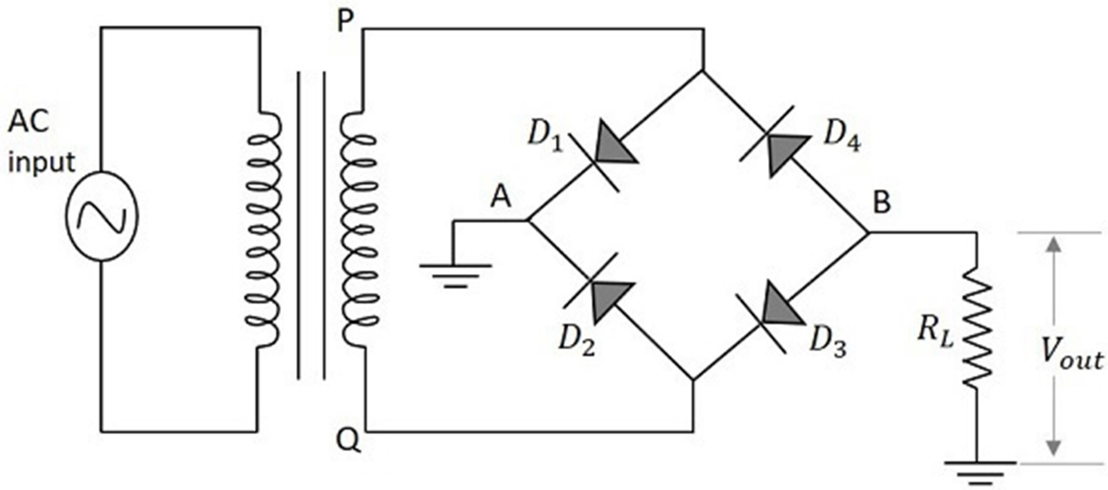
There are few disadvantages for a center-tapped full wave rectifier such as −

- Location of center-tapping is difficult
- The dc output voltage is small
- PIV of the diodes should be high

Bridge Full-Wave Rectifier

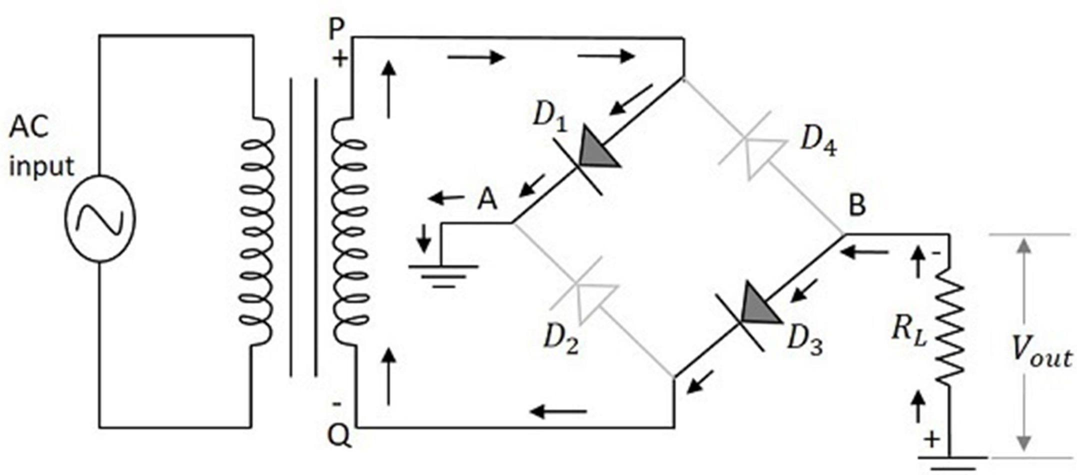
Full wave rectifier circuit which utilizes four diodes connected in bridge form so as not only to produce the output during the full cycle of input, but also to eliminate the disadvantages of the center-tapped full wave rectifier circuit.

There is no need of any center-tapping of the transformer in this circuit. Four diodes called $D1$, $D2$, $D3$ and $D4$ are used in constructing a bridge type network so that two of the diodes conduct for one half cycle and two conduct for the other half cycle of the input supply. The circuit of a bridge full wave rectifier is as shown in the following figure.



Working of a Bridge Full-Wave Rectifier

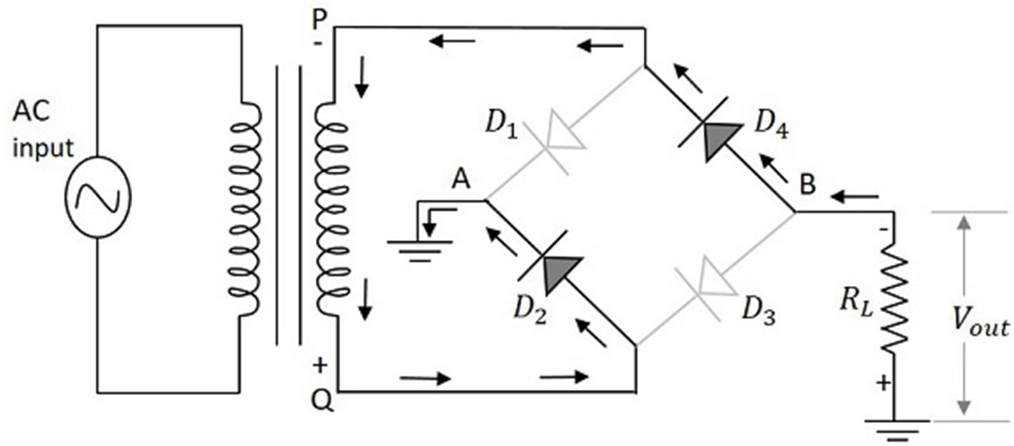
The full wave rectifier with four diodes connected in bridge circuit is employed to get a better full wave output response. When the positive half cycle of the input supply is given, point P becomes positive with respect to the point **Q**. This makes the diode $D1$ and $D3$ forward biased while $D2$ and $D4$ reverse biased. These two diodes will now be in series with the load resistor.



Hence the diodes $D1$ and $D3$ conduct during the positive half cycle of the input supply to produce the output along the load resistor. As two diodes work in order to produce the output, the voltage will be twice the output voltage of the center tapped full wave rectifier.

When the negative half cycle of the input supply is given, point P becomes negative with respect to the point **Q**. This makes the diode $D1$ and $D3$ reverse biased while $D2$ and $D4$ forward biased. These two diodes will now be in series with the load resistor.

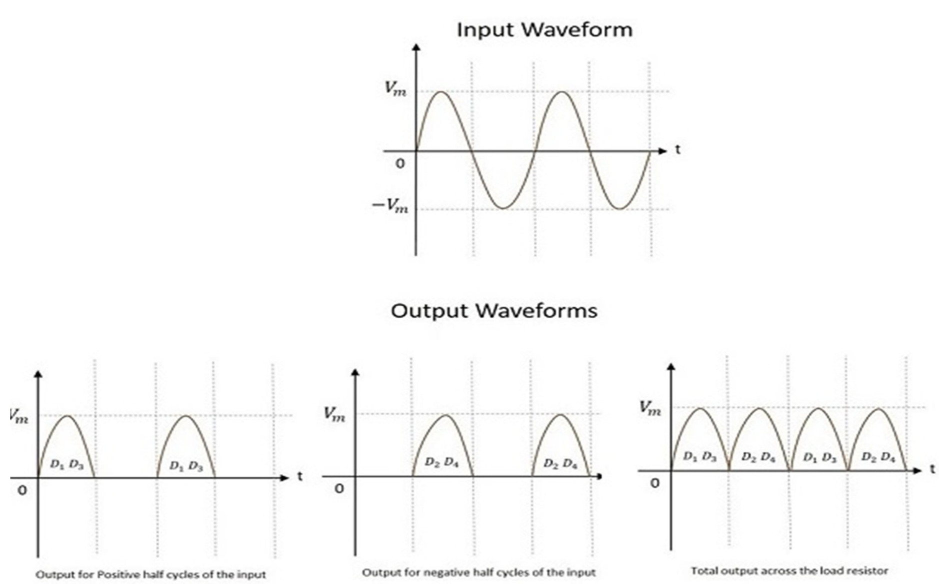
The following figure indicates this along with the conventional current flow in the circuit.



Hence the diodes $D2$ and $D4$ conduct during the negative half cycle of the input supply to produce the output along the load resistor. Here also two diodes work to produce the output voltage. The current flows in the same direction as during the positive half cycle of the input.

Waveforms of Bridge FWR

The input and output waveforms of the center-tapped full wave rectifier are as follows.



From the above figure, it is evident that the output is obtained for both the positive and negative half cycles. It is also observed that the output across the load resistor is in the **same direction** for both the half cycles.

Peak Inverse Voltage

Whenever two of the diodes are being in parallel to the secondary of the transformer, the maximum secondary voltage across the transformer appears at the non-conducting diodes which makes the PIV of the rectifier circuit. Hence the **peak inverse voltage** is the maximum voltage across the secondary winding, i.e.

$$PIV = V_m$$

Advantages

(*i*) The need for centre-tapped transformer is eliminated.

(*ii*) The output is twice that of the centre-tap circuit for the same secondary voltage.

(*iii*) The PIV is one-half that of the centre-tap circuit (for same d.c. output).

Disadvantages

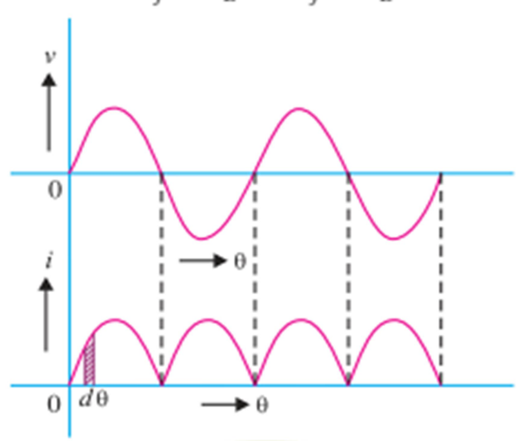
(i) It requires four diodes.

(ii) As during each half-cycle of a.c. input two diodes that conduct are in series, therefore, voltage drop in the internal resistance of the rectifying unit will be twice as great as in the centre tap circuit. This is objectionable when secondary voltage is small.

Efficiency of Full-Wave Rectifier

Figure shows the process of full-wave rectification. Let $v = V_m \sin\theta$ be the a.c. voltage to be rectified. Let r_f and R_L be the diode resistance and load resistance respectively. Obviously, the rectifier will conduct current through the load in the same direction for both half-cycles of input a.c. voltage. The instantaneous current i is given by :

$$i = \frac{v}{r_f + R_L} = \frac{V_m \sin\theta}{r_f + R_L}$$



d.c. output power. The output current is pulsating direct current. Therefore, in order to find the d.c. power, average current has to be found out. From the elementary knowledge of electrical engineering,

$$I_{dc} = \frac{2I_m}{\pi}$$

∴ d.c. power output, $P_{dc} = I_{dc}^2 \times R_L = \left(\frac{2I_m}{\pi}\right)^2 \times R_L$

a.c. input power. The a.c. input power is given by :

$$P_{ac} = I_{rms}^2 (r_f + R_L)$$

For a full-wave rectified wave, we have,

$$I_{rms} = I_m / \sqrt{2}$$

$$\therefore \quad P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)$$

∴ Full-wave rectification efficiency is

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(2I_m/\pi)^2 R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{(r_f + R_L)} = \frac{0.812\, R_L}{r_f + R_L} = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

∴ Maximum efficiency = 81.2%

This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice effective as a half-wave rectifier.

Ripple Factor

The output of a rectifier consists of a d.c. component and an a.c. component (also known as *ripple*). The a.c. component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output ; the smaller this component, the more effective is the rectifier.

The ratio of r.m.s. value of a.c. component to the d.c. component in the rectifier output is known as ripple factor *i.e.*

Ripple factor = r.m.s. value of a.c component / value of d.c. component

I_{ac} / I_{dc}

Therefore, ripple factor is very important in deciding the effectiveness of a rectifier. The smaller the ripple factor, the lesser the effective a.c. component and hence more effective is the rectifier.

Mathematical analysis: The output current of a rectifier contains d.c. as well as a.c. component. The undesired a.c. component has a frequency of 100 Hz (*i.e.* double the supply frequency 50 Hz) and is called the *ripple.* It is a fluctuation superimposed on the d.c. component**.**

By definition, the effective (*i.e.* r.m.s.) value of total load current is given by :

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

or

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

Dividing throughout by I_{dc}, we get,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2}$$

But I_{ac}/I_{dc} is the ripple factor.

$$\therefore \quad \text{Ripple factor} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

(*i*) For half-wave rectification. In half-wave rectification,

$$I_{rms} = I_m/2 \quad ; \quad I_{dc} = I_m/\pi$$

$$\therefore \quad \text{Ripple factor} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

It is clear that a.c. component exceeds the d.c. component in the output of a half-wave rectifier. This results in greater pulsations in the output. Therefore, half-wave rectifier is ineffective for conversion of a.c. into d.c.

(*ii*) For full-wave rectification. In full-wave rectification,

$$I_{rms} = \frac{I_m}{\sqrt{2}} \quad ; \quad I_{dc} = \frac{2\,I_m}{\pi}$$

$$\therefore \quad \text{Ripple factor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2\,I_m/\pi}\right)^2 - 1} = 0.48$$

$$i.e. \quad \frac{\text{effective a.c. component}}{\text{d.c. component}} = 0.48$$

This shows that in the output of a full-wave rectifier, the d.c. component is more than the a.c. component. Consequently, the pulsations in the output will be less than in half-wave rectifier. For this reason, full-wave rectification is invariably used for conversion of a.c. into d.c.

Half-Wave vs. Full-Wave Rectifier

Terms	**Half Wave Rectifier**	**Center Tapped FWR**	**Bridge FWR**
Number of Diodes	1	2	4
Transformer tapping	No	Yes	No
Peak Inverse Voltage	V_m	$2V_m$	V_m
Maximum Efficiency	40.6%	81.2%	81.2%
Average / dc current	I_m/π	$2I_m/\pi$	$2I_m/\pi$
DC voltage	V_m/π	$2V_m/\pi$	$2V_m/\pi$
RMS current	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
Ripple Factor	1.21	0.48	0.48
Output frequency	f_{in}	$2f_{in}$	$2f_{in}$

Filters

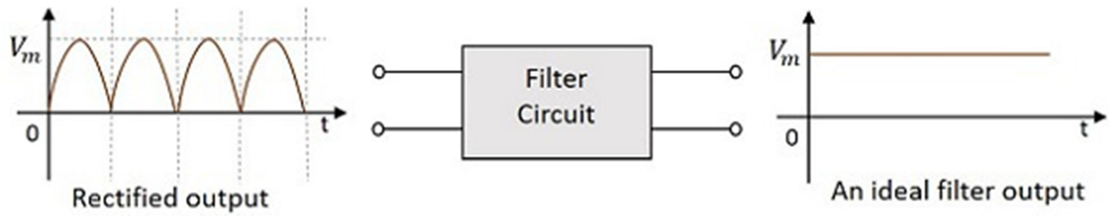
The power supply block diagram clearly explains that a filter circuit is needed after the rectifier circuit. A rectifier helps in converting a pulsating alternating current to direct current, which flows only in one direction. The outputs of all these rectifier circuits contain some ripple factor.

Need for Filters

The ripple in the signal denotes the presence of some AC component. This ac component has to be completely removed in order to get pure dc output. So, a circuit is needed that **smoothens** the rectified output into a pure dc signal.

A **filter circuit** is one which removes the ac component present in the rectified output and allows the dc component to reach the load.

The following figure shows the functionality of a filter circuit.

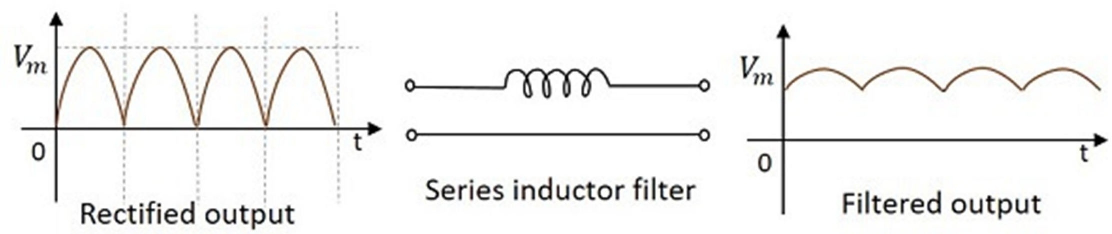


A filter circuit is constructed using two main components, inductor and capacitor.

- An inductor allows **dc** and blocks **ac**.
- A capacitor allows **ac** and blocks **dc**.

Series Inductor Filter

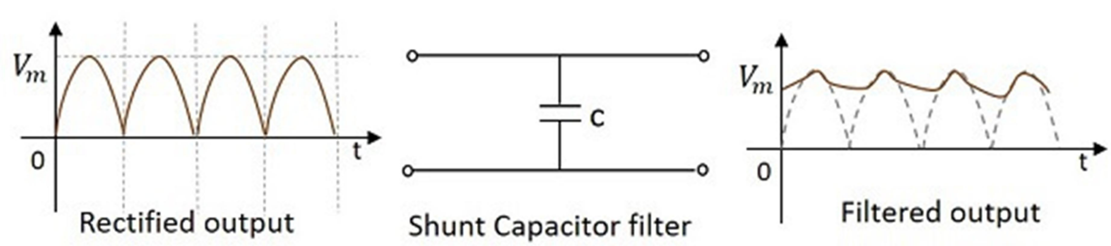
As an inductor allows dc and blocks ac, a filter called **Series Inductor Filter** can be constructed by connecting the inductor in series, between the rectifier and the load. The figure below shows the circuit of a series inductor filter.



The rectified output when passed through this filter, the inductor blocks the ac components that are present in the signal, in order to provide a pure dc. This is a simple primary filter.

Shunt Capacitor Filter

It consists of a capacitor *C* placed across the rectifier output in parallel with load R_L. The pulsating direct voltage of the rectifier is applied across the capacitor. As the rectifier voltage increases, it charges the capacitor and also supplies current to the load. At the end of quarter cycle, the capacitor is charged to the peak value V_m of the rectifier voltage. Now, the rectifier voltage starts to decrease. As this occurs, the capacitor discharges through the load and voltage across it (*i.e.* across parallel combination of *R*-*C*) decreases.

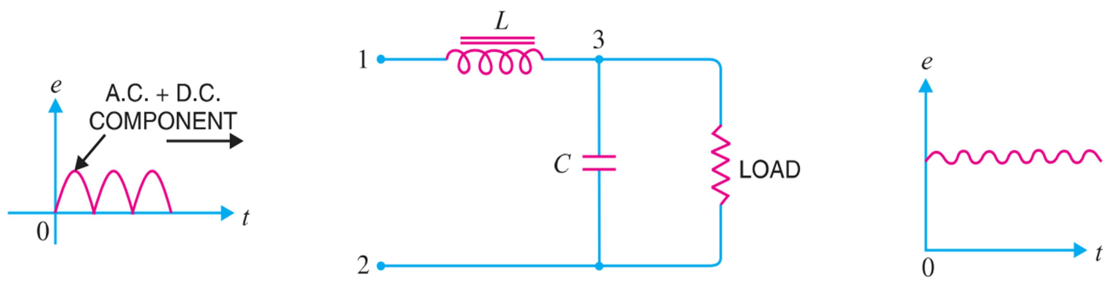


The voltage across load will decrease slightly because immediately the next voltage peak comes and recharges the capacitor. This process is repeated again and again. It may be seen that very little ripple is left in the output. Moreover, output voltage is higher as it remains substantially near the peak value of rectifier output voltage.

L-C Filter

It consists of a choke *L* connected in series with the rectifier output and a filter capacitor *C* across the load. Only a single filter section is shown, but several identical sections are often used to reduce the pulsations as effectively as possible.

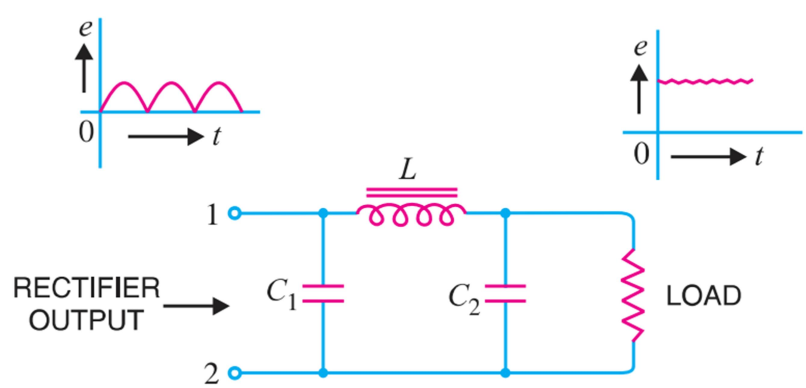
The pulsating output of the rectifier is applied across terminals 1 and 2 of the filter circuit. The pulsating output of rectifier contains a.c. and d.c. components. The choke offers high opposition to the passage of a.c. component but negligible opposition to the d.c. component. The result is that most of the a.c. component appears across the choke while whole of d.c. component passes through the choke on its way to load. This results in the reduced pulsations at terminal 3.



At terminal 3, the rectifier output contains d.c. component and the remaining part of a.c. component which has managed to pass through the choke. Now, the low reactance of filter capacitor bypasses the a.c. component but prevents the d.c. component to flow through it. Therefore, only d.c. component reaches the load. In this way, the filter circuit has filtered out the a.c. component from the rectifier output, allowing d.c. component to reach the load.

Π- Filter (*Pi filter*)

It consists of a filter capacitor C_1 connected across the rectifier output, a choke *L* in series and another filter capacitor C_2 connected across the load. Only one filter section is shown but several identical sections are often used to improve the smoothing action.



The pulsating output from the rectifier is applied across the input terminals of the filter. The filtering action of the three components *viz* C_1, L and C_2 of this filter is described below :

(a) The *filter capacitor* C_1 offers low reactance to a.c. component of rectifier output while it offers infinite reactance to the d.c. component. Therefore, capacitor C_1 bypasses an appreciable amount of a.c. component while the d.c. component continues its journey to the choke L.

(b) The *choke* L offers high reactance to the a.c. component but it offers almost zero reactance to the d.c. component. Therefore, it allows the d.c. component to flow through it, while the unbypassed a.c. component is blocked.

(c) The *filter capacitor* C_2 bypasses the a.c. component which the choke has failed to block. Therefore, only d.c. component appears across the load.

Regulators

The next and the last stage before load, in a power supply system is the Regulator part. A regulator is an important device when it comes to power electronics as it controls the power output.

Need for a Regulator

For a Power supply to produce a constant output voltage, irrespective of the input voltage variations or the load current variations, there is a need for a voltage regulator.

A **voltage regulator** is such a device that maintains constant output voltage, instead of any kind of fluctuations in the input voltage being applied or any variations in current, drawn by the load. The following image gives an idea of what a practical regulator looks like.

Types of Regulators

Regulators can be classified into different categories, depending upon their working and type of connection.

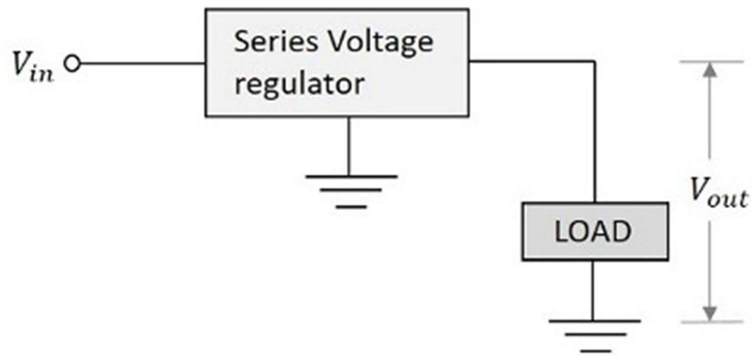
Depending upon the type of regulation, the regulators are mainly divided into two types namely, line and load regulators.

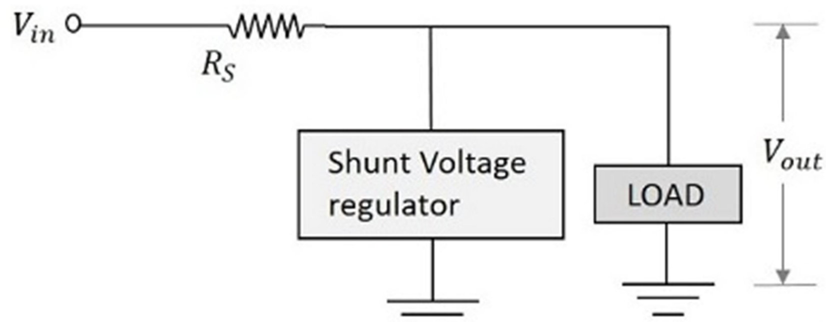
- **Line Regulator** − The regulator which regulates the output voltage to be constant, in spite of input line variations, it is called as **Line regulator**.
- **Load Regulator** − The regulator which regulates the output voltage to be constant, in spite of the variations in load at the output, it is called as **Load regulator**.

Depending upon the type of connection, there are two type of voltage regulators. They are

- Series voltage regulator
- Shunt voltage regulator

The arrangement of them in a circuit will be just as in the following figures.





Types of IC regulators

IC regulators can be of the following types –

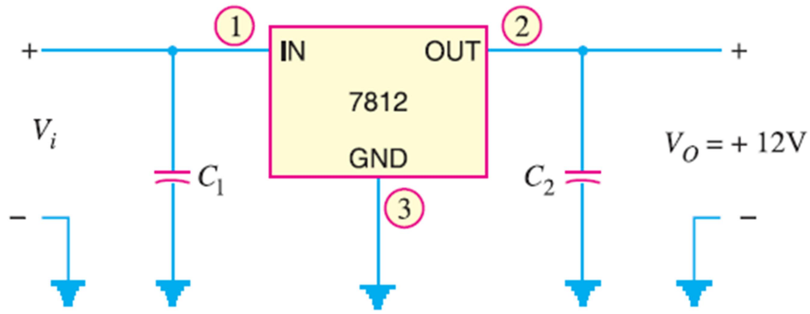
- Fixed Positive voltage regulators
- Fixed Negative voltage regulators
- Adjustable voltage regulators

Fixed Positive Voltage Regulator

This IC regulator provides a fixed positive output voltage. Although many types of IC regulators are available, the 7800 series of IC regulators is the most popular. The last two digits in the part number indicate the d.c. output voltage. For example [See Table below], the 7812 is a + 12V regulator whereas the 7805 is a + 5V regulator. Note that this series (7800 series) provides fixed regulated voltages from + 5 V to + 24V.

Type number	Output voltage
7805	+5.0 V
7806	+6.0 V
7808	+8.0 V
7809	+9.0 V
7812	+12.0 V
7815	+15.0 V
7818	+18.0 V
7824	+24.0 V

The 7800 series

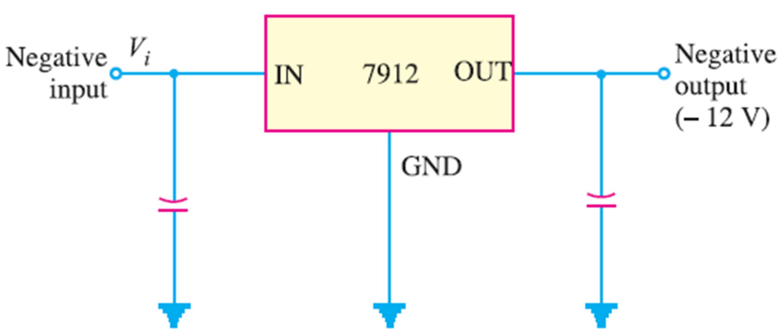


The figure above shows the circuit diagram of fixed positive voltage regulator . You can see how the 7812 IC is connected to provide a fixed d.c. output of + 12V. The unregulated input voltage Vi is connected to the IC's IN terminal and the IC's OUT terminal provides + 12V. Capacitors, although not always necessary, are sometimes used on the input and output. The output capacitor (C2) acts basically as a line filter to improve transient response. The input capacitor (C1) is used to prevent unwanted oscillations.

Fixed Negative Voltage Regulator

The output of these regulators is fixed to a specific value and the values are negative, which means the output voltage provided is negative voltage.

The most used series is 7900 series and the ICs will be like IC 7906, IC 7912 and IC 7915 etc. which provide -6v, -12v and -15v respectively as output voltages. The figure below shows the IC 7912 connected to provide a fixed 12v negative regulated output voltage.

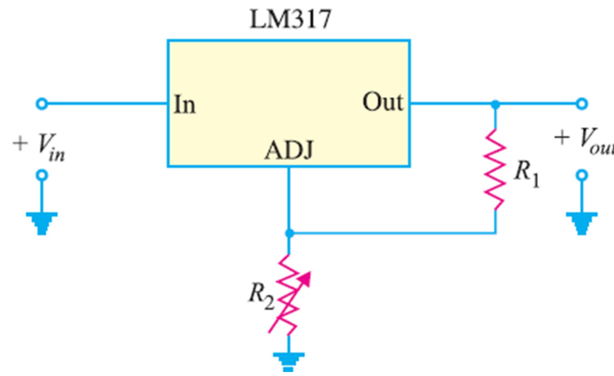


In the above figure, the input capacitor C1 is used to prevent unwanted oscillations and the output capacitor C2 acts as a line filter to improve transient response.

Adjustable Voltage Regulator

The adjustable voltage regulator can be adjusted to provide any d.c. output voltage that is within its two specified limits. The most popular three-terminal IC adjustable voltage regulator is the LM 317.

Circuit Diagram of Adjustable Voltage Regulator



The LM 317 is a three-terminal positive adjustable voltage regulator and can supply 1.5 A of load current over an adjustable output range of 1.25V to 37V. The figure above shows an unregulated power supply driving an LM 317 circuit. The data sheet of an LM 317 gives the following formula for the output voltage :

$$V_{out} = 1.25\left(\frac{R_2}{R_1} + 1\right)$$

This formula is valid from 1.25 V to 37V.