Basics of Electronics Engineering
CSE-2 sem

Topic- Rectifiers and clippers

Introduction

⁂ A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction, a process known as rectification.

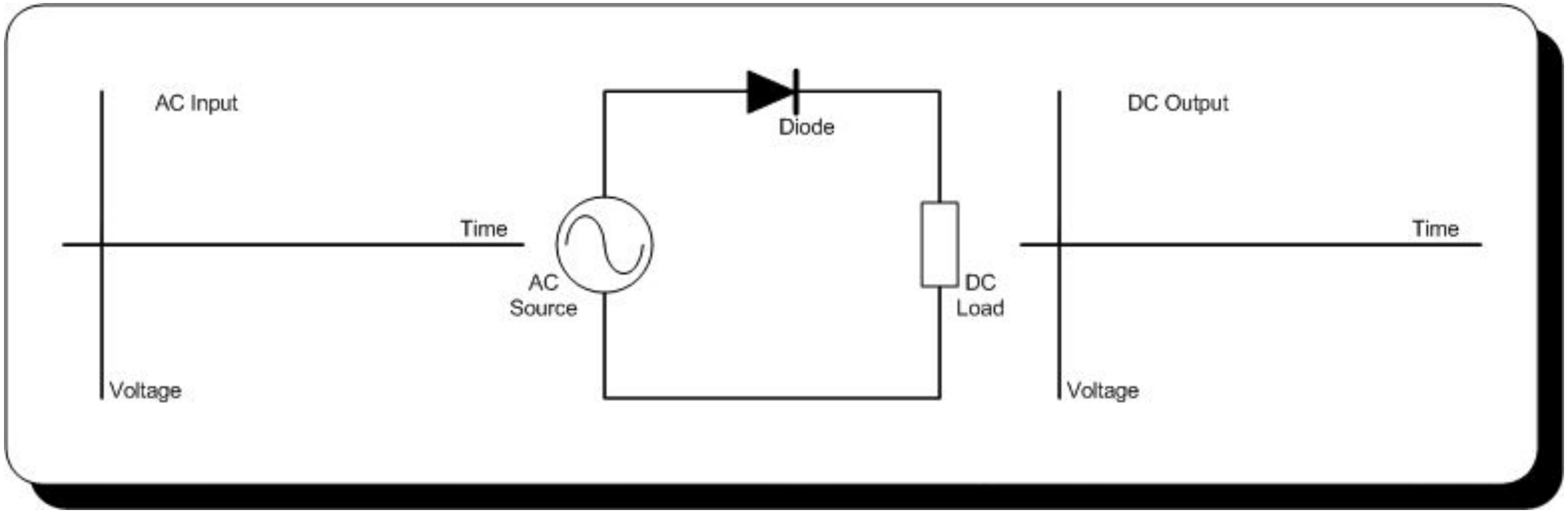
Types of Rectifiers

- Half wave Rectifier
- Centre tapped Rectifier
- Bridge Rectifier

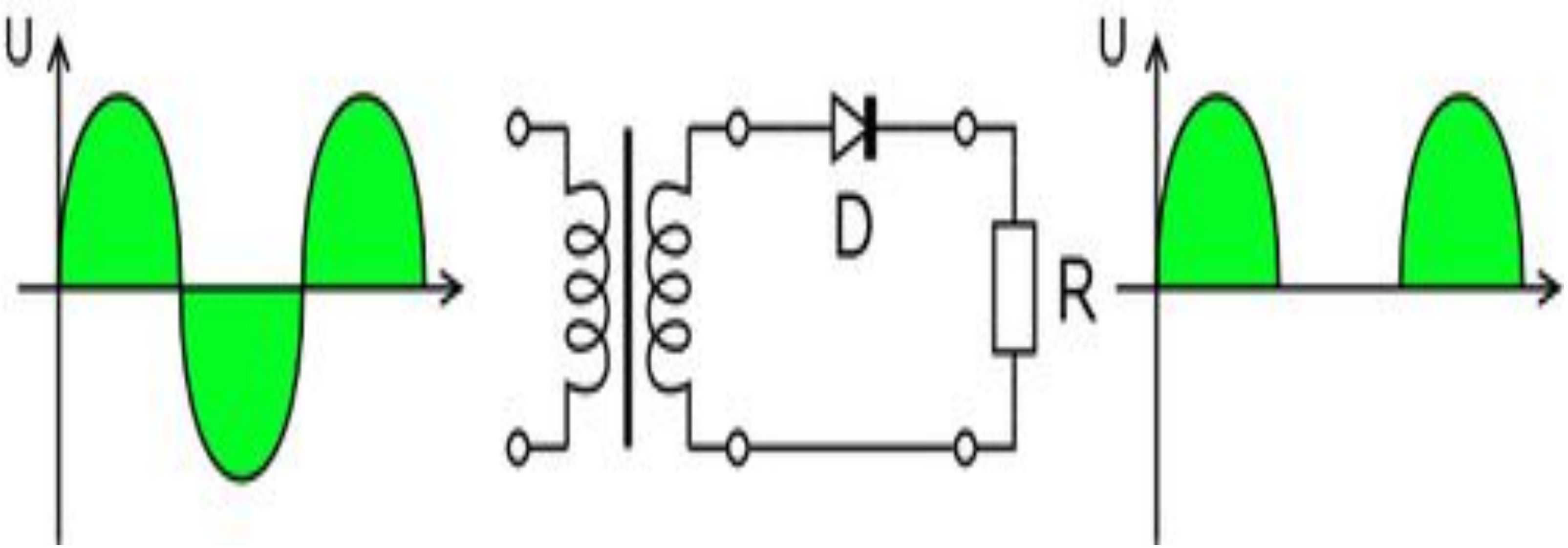
Half wave rectifier

- 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 very inefficient if used for power transfer.

Half wave rectifier working animation

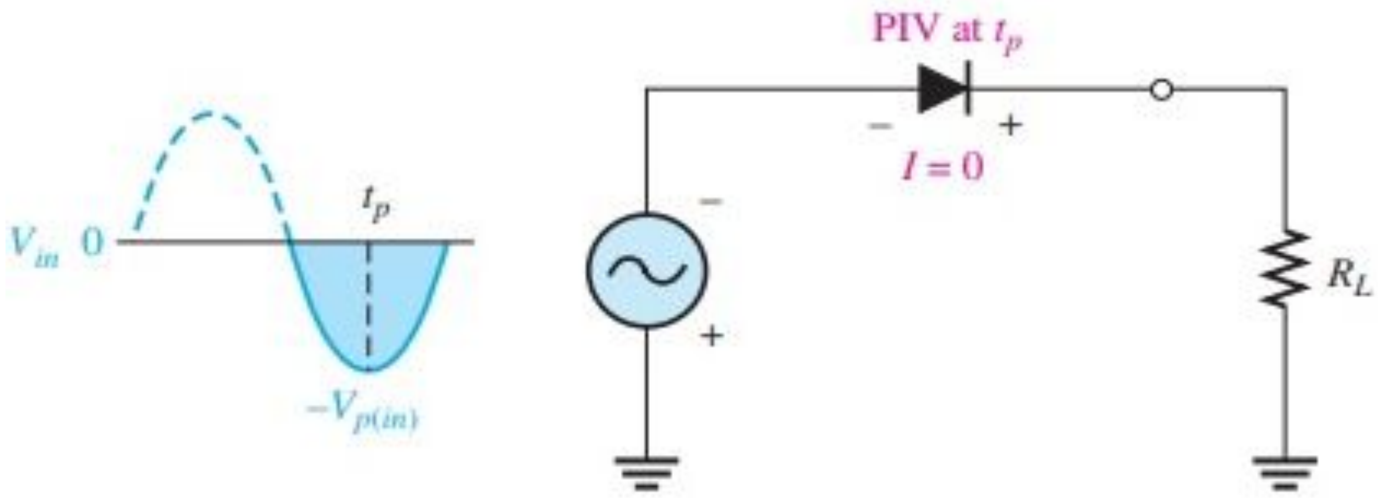


Half wave rectification



Peak Inverse Voltage

Peak Inverse Voltage (PIV) is the maximum voltage that the diode can withstand during reverse bias condition. If a voltage is applied more than the PIV, the diode will be destroyed.



The PIV occurs at the peak of each half-cycle of the input voltage when the diode is reverse-biased. In this circuit, the PIV occurs at the peak of each negative half-cycle

Half Wave Rectifier Calculations

For a half wave rectifier, we have

$$I_d = \begin{cases} I_m \sin\omega t & \text{for } 0 < \omega t < \pi \\ 0 & \text{for } \pi < \omega t < 2\pi \end{cases}$$

DC value of current(**I_{dc}**):
From the image(3), it is seen that the output current is not steady but contains fluctuations despite of being a DC current. The average value of this fluctuating DC current can be calculated as follows:

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} I_d \, d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} i_d \, d(\omega t) + \int_{\pi}^{2\pi} i_d \, d(\omega t)\right]$$

$$= \frac{1}{2\pi}\int_0^{\pi} i_d \, d(\omega t)$$

$[\because$ id=0 in the range π to $2\pi]$

$$= \left(\frac{1}{2\pi}\right)\int_0^{\pi} I_m \sin\omega t \; d(\omega t)$$

$$= \frac{I_m}{2\pi}\left[-\cos(\omega t)\right]_0^{\pi}$$

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

Half Wave Rectifier Calculations

RMS value of output current(I_{rms}):

$$I_{rms}=\sqrt{\frac{1}{2\pi}\int_{0}^{2\pi} i_d^2\, d(\omega t)}$$

$$=\sqrt{\frac{1}{2\pi}\left[\int_{0}^{\pi} i_d^2\, d(\omega t)+\int_{\pi}^{2\pi} i_d^2\, d(\omega t)\right]}$$

$$=\sqrt{\frac{1}{2\pi}\int_{0}^{\pi} i_d^2\, d(\omega t)}$$

$$=\sqrt{\frac{1}{2\pi}\int_{0}^{\pi} I_m^2 \sin^2\omega t\, d(\omega t)}$$

$$=\sqrt{\frac{I_m^2}{2\pi}\left[\frac{\omega t}{2}-\frac{\sin 2\omega t}{4}\right]_0^{\pi}}$$

[$\because$ id=0 in the range π to 2π]

$$=\sqrt{\frac{I_m^2}{2\pi}\frac{\pi}{2}}$$

$$=\sqrt{\frac{I_m^2}{4}}$$

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

Efficiency of Half wave Rectifier

Efficiency of a half wave rectifier(η):

$$\eta = \frac{\text{Output DC power}}{\text{Input AC power}} \text{ x } 100\%$$

$$\text{Input AC power } P_{iac} = \frac{1}{2\pi}\int_0^{2\pi}(\text{instantaneous power})\, d(\omega t)$$

$$P_{iac} = \frac{1}{2\pi}\int_0^{2\pi} e \text{ x } i_d\, d(\omega t)$$

$$= \frac{1}{2\pi}\int_0^{2\pi} i_d(R_f + R_L) \text{ x } i_d\, d(\omega t)$$

$$= \frac{R_f + R_L}{2\pi}\int_0^{2\pi} i_d^2\, d(\omega t)$$

$$= (R_f + R_L) I_{rms}^2$$

$$\therefore P_{iac} = \frac{(R_f + R_L) I_m^2}{4}$$

Efficiency of Half wave Rectifier contd.

Output DC power $P_{odc} = I_{dc}^2 R_L$

$$P_{odc} = \frac{I_m^2 R_L}{\pi^2}$$

$$\therefore \text{Rectifier efficiency } \eta = \frac{P_{odc}}{P_{iac}} \times 100\%$$

$$= \frac{I_m^2 R_L}{\pi^2} \times \frac{4}{(R_f + R_L) I_m^2} \times 100\%$$

$$= \frac{40.6\ R_L}{R_f + R_L} \%$$

If $R_f << R_L$, $\eta = 40.6\%$

Half Wave Rectifier Calculations

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Ripple factor(**r**):
At the output of half wave rectifier, periodically varying components are still present even though we have achieved a unidirectional current. Filters are used in the rectifier to reduce the varying components. A measure of the varying component is given by the ripple factor as follows:

$$r = \frac{I'_{rms}}{I_{dc}} = \frac{E'_{rms}}{E_{dc}}$$

where I'_{rms} and E'_{rms} represent the RMS value of ripple current and voltage respectively.

$$r = \frac{I'_{rms}}{I_{dc}}$$

$$= \sqrt{\frac{(I^2_{rms} - I^2_{dc})}{I^2_{dc}}}$$

$$= \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

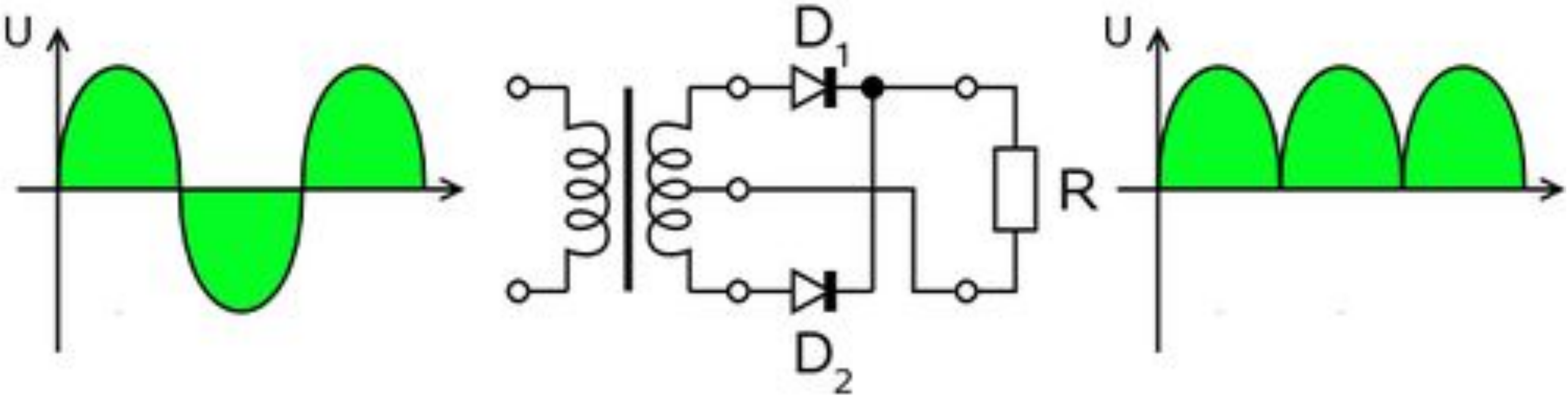
$$= \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1}$$

$$\therefore r = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1}$$

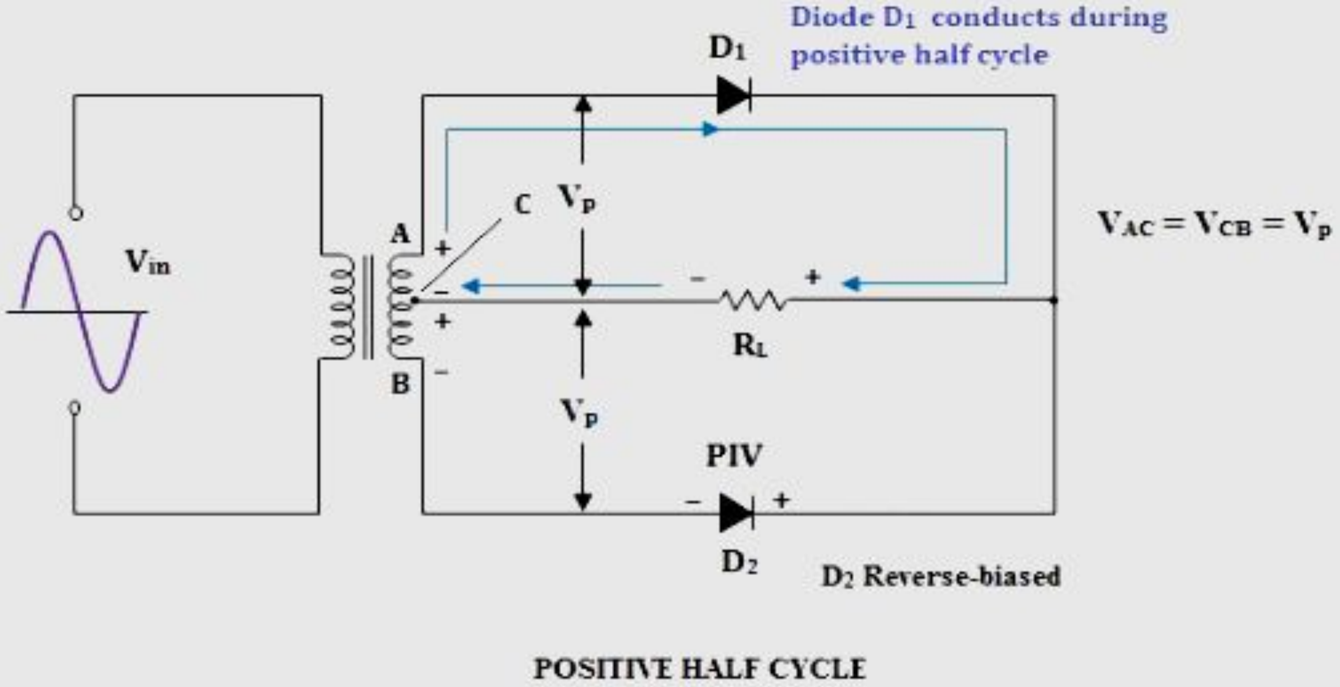
$$\therefore r = 1.21$$

Centre Tapped Full wave rectifier

⁂ For single-phase AC, if the transformer is center-tapped, then two diodes back-to-back (i.e. anodes-to-anode or cathode-to-cathode) can form a full-wave rectifier.



PIV of Centre Tapped Rectifier



The maximum reverse voltage appearing across will be 2*Vp. Where Vp is the amplitude of input signal.

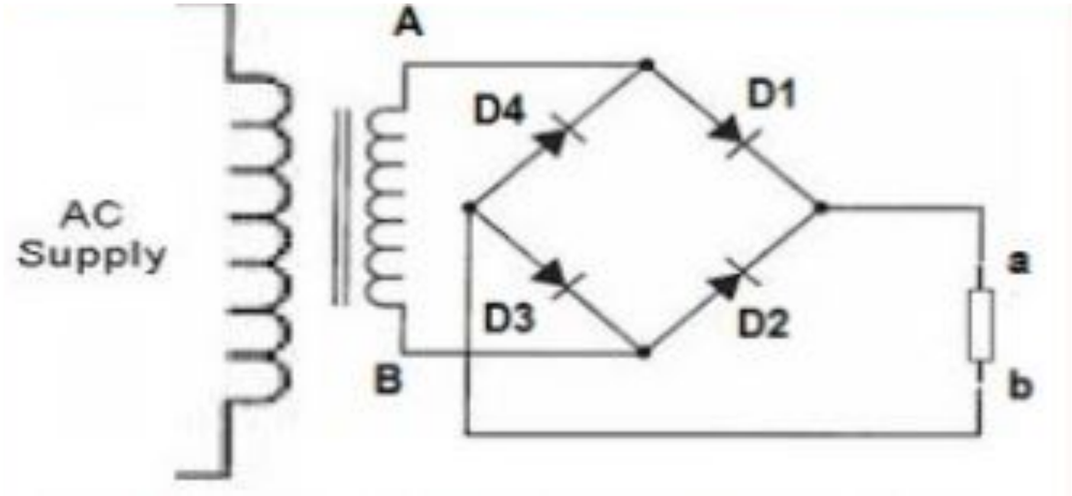
So the diode that is used in a center-tapped full wave rectifier should have a PIV of atleast twice the peak voltage of input sine wave. Otherwise diode breakdown will happen and current will flow through the reverse biased diode. And the circuit is not a rectifier anymore.

Bridge Rectifier

- A bridge rectifier is an alternating current (AC) to direct current (DC) convertor.
- It rectifies mains AC input to DC output.
- Bridge rectifiers are widely used in power supplies.
- It requires four diodes instead of two, but avoids the need for a centre-tapped transformer.

Bridge Rectifier

- It consist of four diodes D1, D2, D3, D4 and step down transformer with load connected resistance.
- The AC voltage is first applied to primary of the transformer which is step down with the step down transformer and applied to the secondary of the transformer.

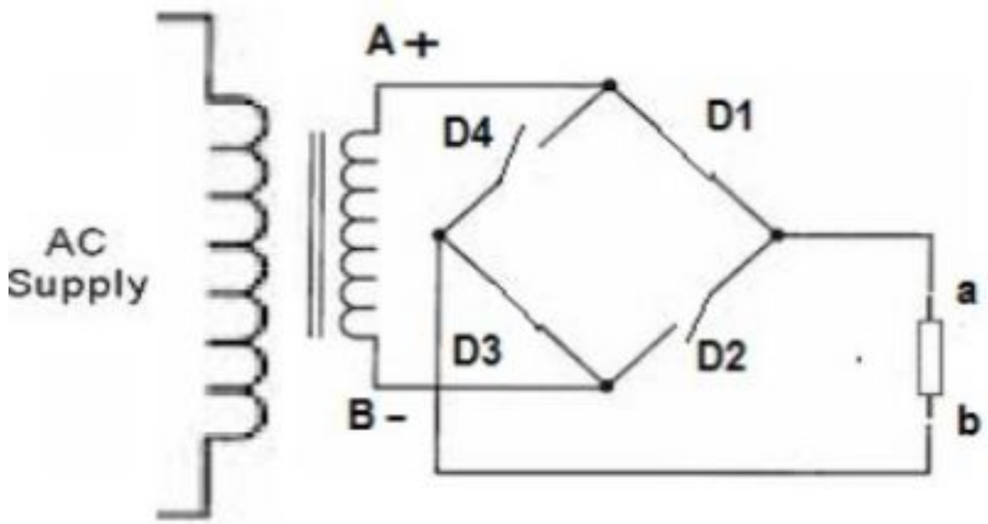


Bridge rectifier

Bridge Rectifier

<u>During positive half cycle of applied voltage:</u>

Point A becomes at positive potential (+) whereas point B will be at negative potential (-). So diode D1 and D3 becomes forward bias and behave like a closed switch whereas diode D2 and D4 becomes in reverse bias and behaves like an open switch.

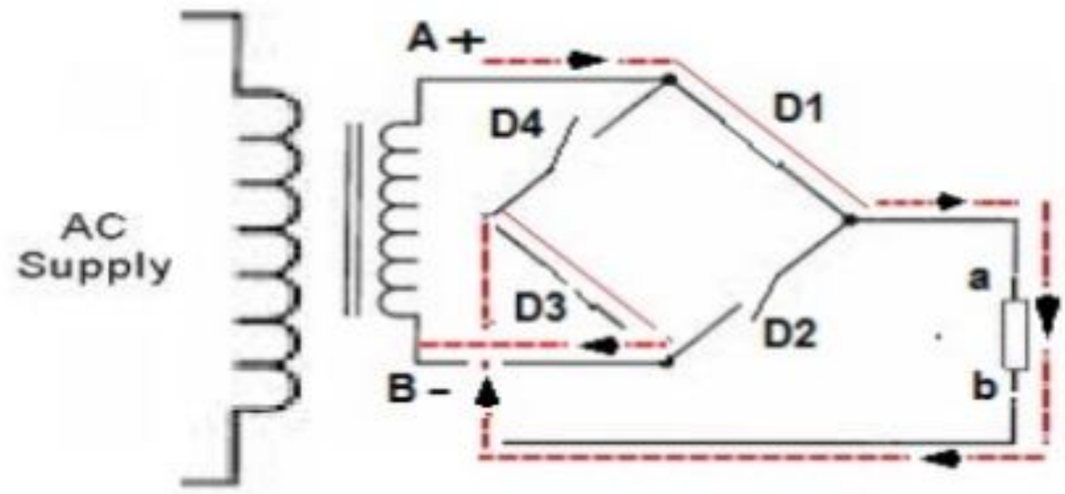


Equivalent circuit of bridge rectifier during positive half cycle

Bridge Rectifier

So current will start to flow from point A through diode D1 to the point B through load resistance RL to point b through diode D3 and finally reaches to point B.

In this way the direction of current through load resistance RL is from small a to small b.



Shows the current direction through load resistance RL: A-D1-a-RL-b-D3-B

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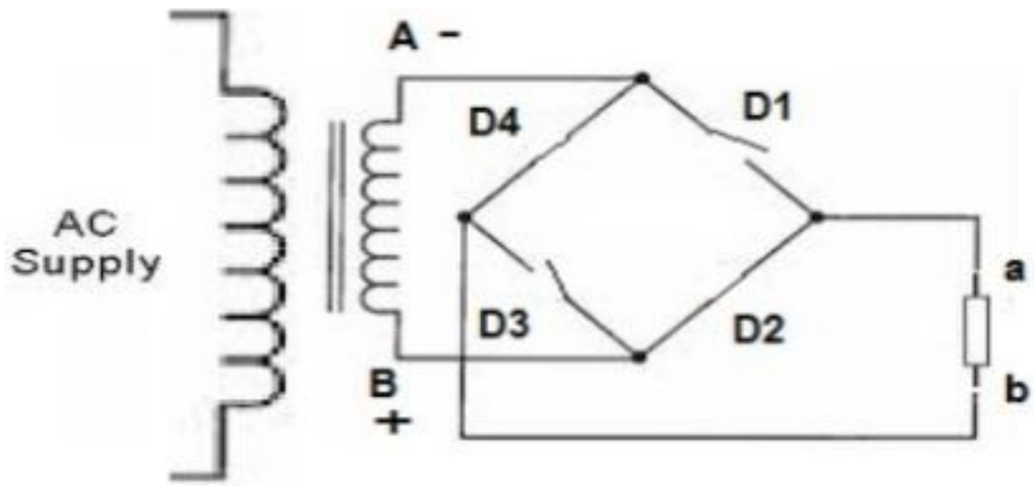
During negative half cycle:

Point A will be at negative potential (-) whereas point B will be at positive potential.

So diode D1 and D3 comes in reverse bias and behaves like an open switch whereas diode D2 and D4 comes in forward bias and behaves like closed switch.



Equivalent circuit of bridge rectifier during negative half cycle

Bridge Rectifier

So during negative half cycle, current will start to flow from point B through diode D2 to the point a through load resistance RL to point b to diode D4 and finally reaches to point A.

In this way the direction of current through load resistance RL is from small a to small b

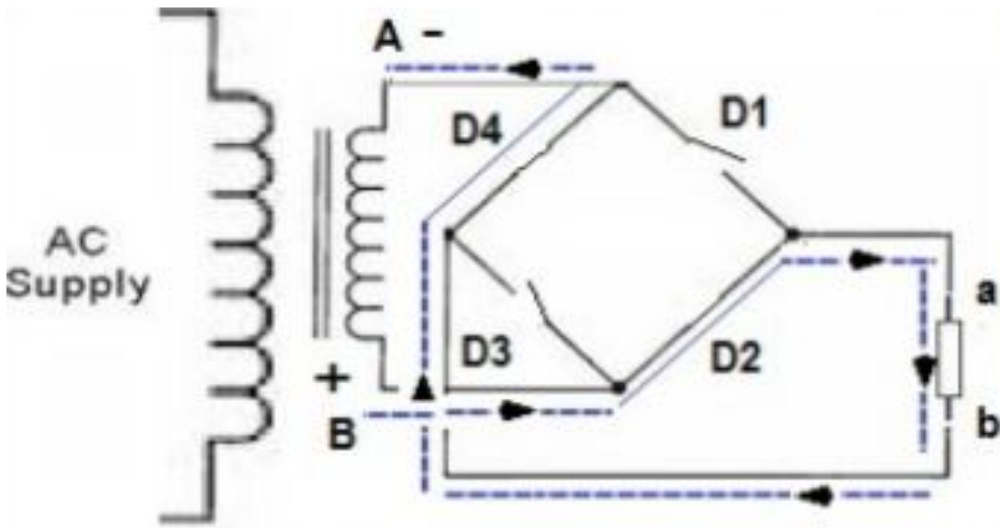
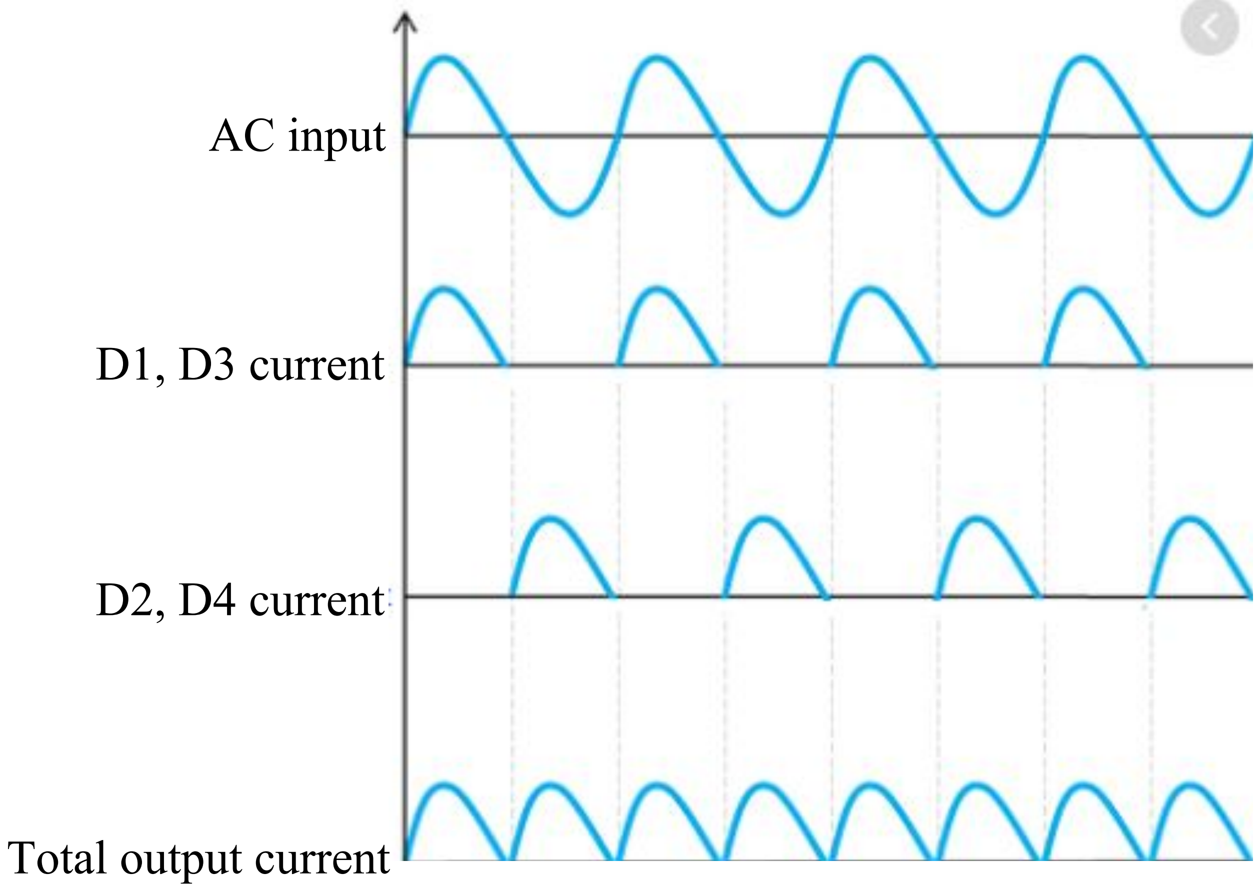


Fig Shows the current direction through load resistance RL: B-D2-a-RL-b-D4-A

Bridge Rectifier Waveforms

In this way, Bridge rectifier convert both cycles of an AC voltage into DC.



PIV Bridge Rectifier

PIV (Peak inverse Voltage): At any instant when the transformer secondary voltage attains positive peak value Vmax, diodes D1 and D3 will be forward biased (conducting) and the diodes D2 and D4 will be reverse biased (non conducting). If we consider ideal diodes in bridge, the forward biased diodes D1 and D3 will have zero resistance. This means voltage drop across the conducting diodes will be zero. This will result in the entire transformer secondary voltage being developed across load resistance RL.

Thus **PIV of a bridge rectifier = Vmax (max of secondary voltage)**

Full Wave Rectifier Calculations

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2. Ripple factor

$$K_f = \frac{I_{rms}}{I_{av}} = \frac{\mathrm{I_{max}}/\sqrt{2}}{2\,I_{\max}/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

$$\gamma = \sqrt{K_f^2 - 1} = \sqrt{(1.11)^2 - 1} = 0.482$$

3. Efficiency

$P_{dc} = I^2_{dc}\, R_L = (2I_{max}/\pi)^2 R_L = (4/\pi^2)\, I^2_{MAX} R_L$

AC power input to the transformer, P_{ac} = Power dissipated in diode junction + Power dissipated in load resistance R_L

$= I^2_{rms}\, R_F + I^2_{rms}\, R_L = \{I^2_{MAX}/2\}[R_F + R_L]$

So, Rectification Efficiency, $\eta = P_{dc}/P_{ac} = \{(4/\pi^2)\, I^2_{MAX} R_L\}/\{I^2_{MAX}/2\}[R_F + R_L]$

$= \{0.812/(1 + R_F/R_L)\}$

In case of bridge rectifier, $\eta = \{0.812/(1 + 2R_F/R_L)\}$

$\eta \times 100 = 81.2\%$

Comparison of different Rectifiers

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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}	$2f_{in}$	$2f_{in}$
6	Peak inverse voltage	V_m	$2V_m$	V_m

Diode Clippers

The clipper which removes the positive half cycle of the input voltage is called positive clipper.

Positive series clipper circuit:

- When the input is positive, diode D is reverse biased and so the output remains at zero i.e., positive half cycle is clipped off.
- During the negative half cycle of the input, the diode is forward biased and so the negative half cycle appears across the output.

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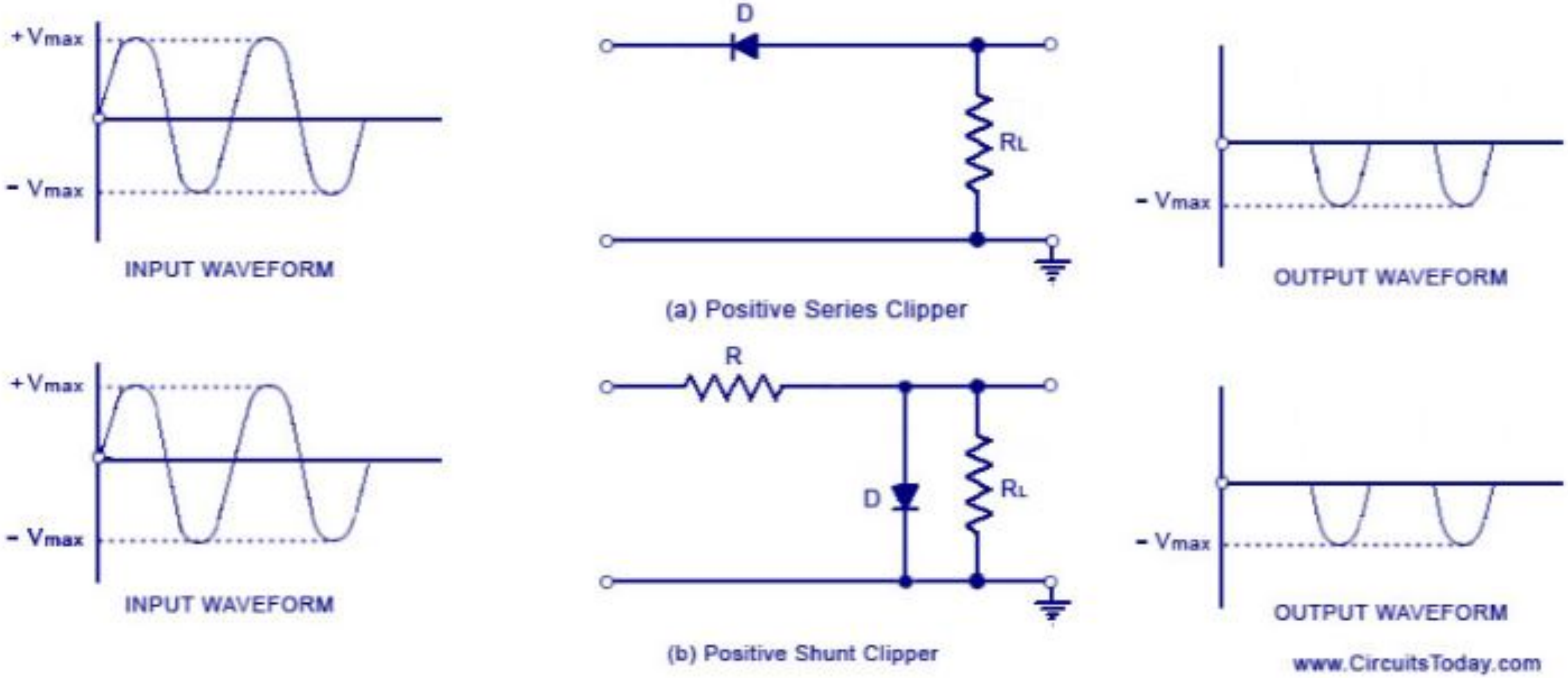
Positive shunt clipper circuit:

- When the input is positive, diode D is forward biased and conducts heavily (i.e., diode acts as a closed switch). So the voltage drop across the diode is zero. Thus output voltage during positive half cycle is zero.
- During the negative half cycles of the input signal voltage, the diode is reverse biased and behaves as an open switch.

Positive Clippers

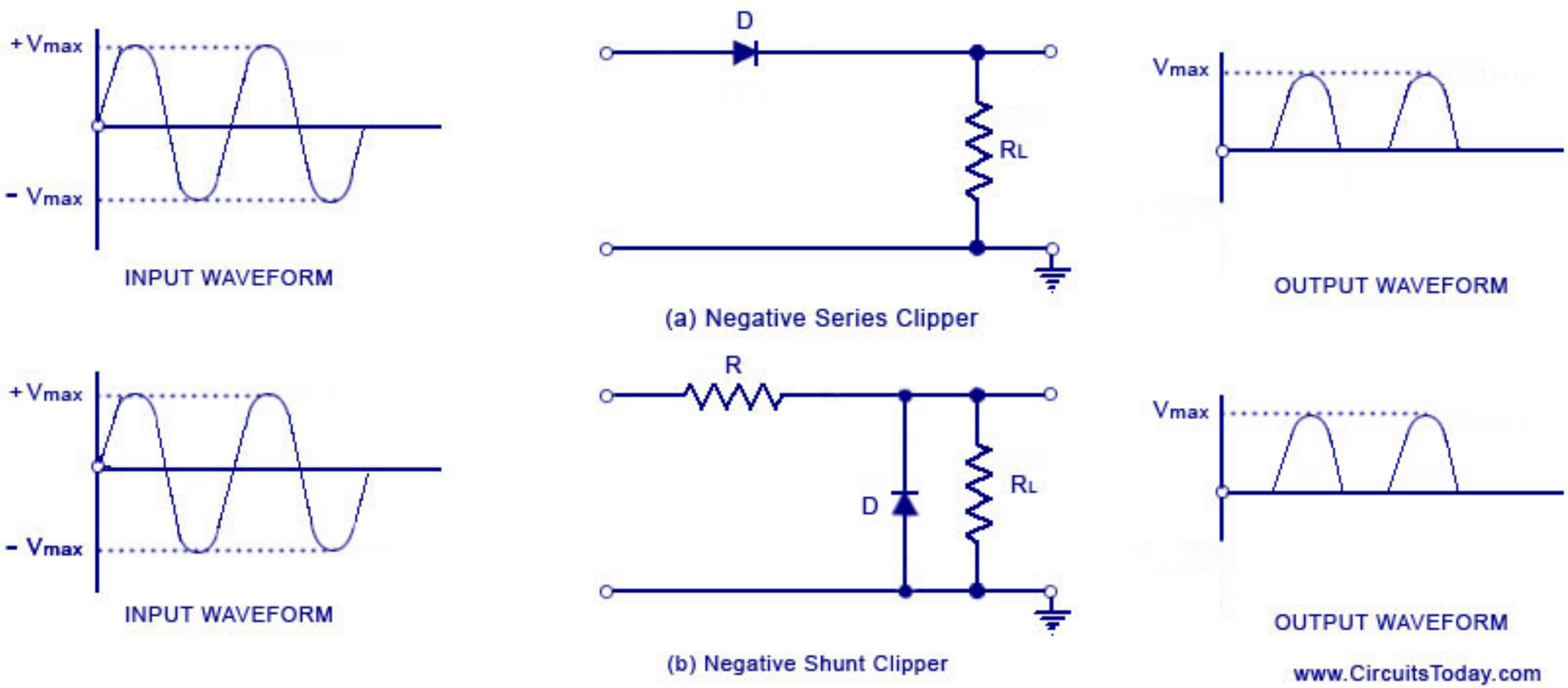
Positive clipper circuit:



Negative Clippers

If the diode is connected with reversed polarity, the circuits will become for a negative series clipper and negative shunt clipper.

The negative clipper is one which removes all the negative half cycles of the input voltage.



Numericals

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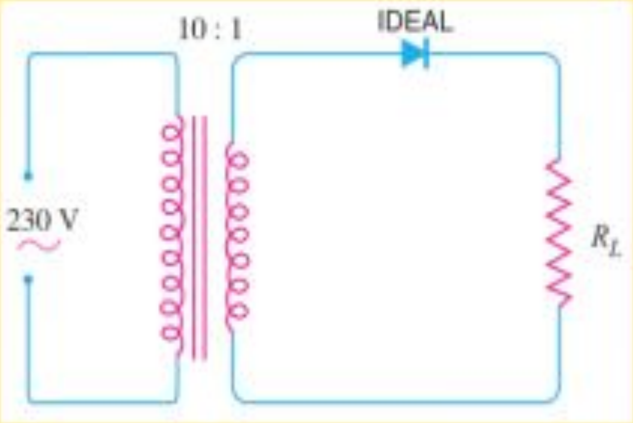
Example 1

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 = 230 V

$\therefore$ Max primary voltage $V_{pm} = \sqrt{2} \times 230 = 325.3$ V

$\therefore$ Max secondary voltage $V_{sm} = V_{pm} \times (N_2/N_1) = 325.3 \times (1/10) = 32.53$ V

Numericals

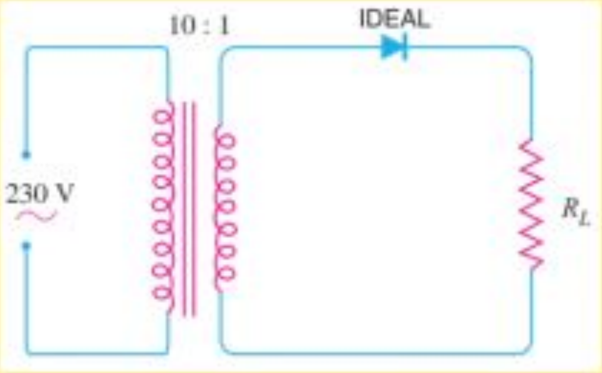
(i) the output dc voltage

$$I_{d.c.} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L$$

$$= \frac{V_{sm}}{\pi}$$

$$= \frac{32.53}{\pi} = 10.36\ \text{V}$$



(ii) the peak inverse voltage.

- The maximum secondary voltage appears across the diode.
- ∴ Peak inverse voltage V_{sm} = **32.53 V**

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Example 2

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

Diode resistance, $r_f = 25\ \Omega$

Load resistance, $R_L = 800\ \Omega$

Let V_m be the maximum value of ac voltage required.

$$\therefore V_{dc} = I_{dc} \times R_L$$

$$V_{dc} = \frac{I_m}{\pi} \times R_L$$

$$\left[\because I_m = \frac{V_m}{r_f + R_L}\right]$$

$$V_{dc} = \frac{V_m}{\pi(r_f + R_L)} \times R_L$$

$$50 = \frac{V_m}{\pi(25 + 800)} \times 800$$

$$V_m = \frac{\pi \times 825 \times 50}{800} = 162\text{ V}$$

Hence, ac voltage of maximum value 162 V is required.