University of Calcutta
Semester 4
PHYSICS
paperPHS-A-CC-4-10-TH (OLD SYLLABUS)
DIODE AS A RECTIFIER, C-FILTER

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WHAT IS RECTIFICATION MEANS??

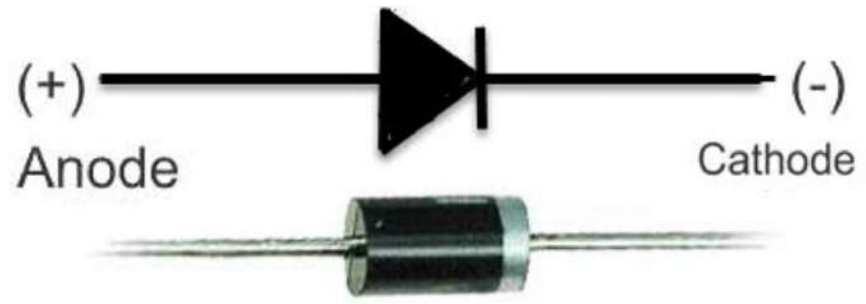
Rectification is the process of converting bidirectional current flow to unidirectional current flow. The process is of vital importance in many areas of circuit design, including radio communication and AC to DC power conversion.

WHY DIODE IS CHOSEN AS A RECTIFIER

Since, a diode can only conduct current one way

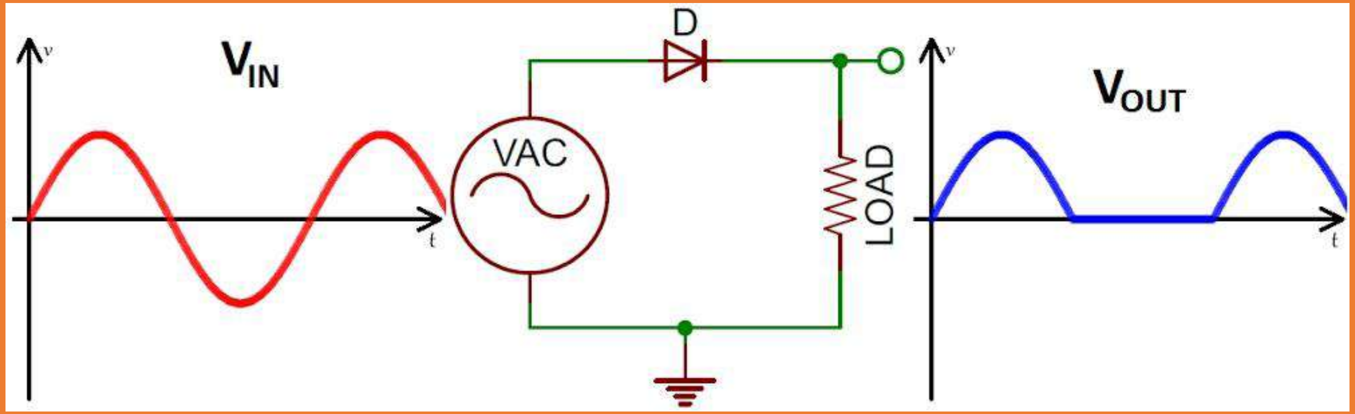
Symbol of a Diode

The symbol of a rectifier diode symbol is shown below, the arrowhead points in the direction of conventional current flow.

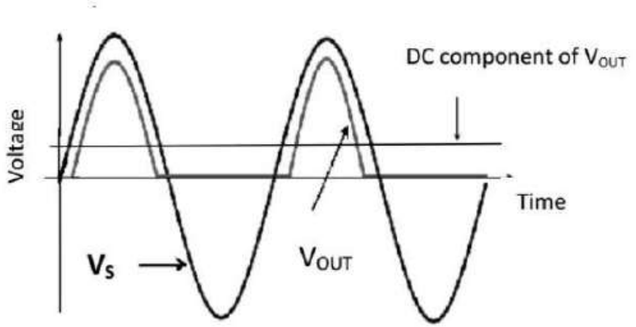


Rectifier Diode Symbol

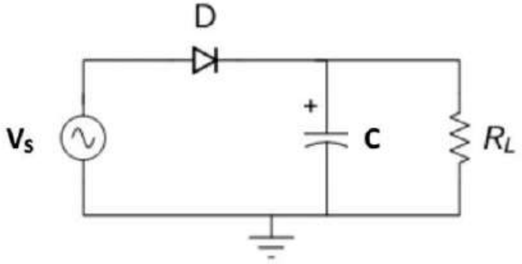
DIODE AS HALF WAVE RECTIFIER



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



The output voltage is pulsating DC which has a significant AC component and DC component which is the average value of V_{OUT}. This kind of voltage is not suitable as a DC supply. A simple way to make the output voltage smooth is to connect a filter capacitor across the output terminals.



During positive half cycle as V_s increases, the diode D conducts allowing the capacitor to charge to peak voltage of the sinusoid. After the peak, the voltage V_s starts decreasing making the anode of the diode at lesser voltage than cathode as the capacitor C holds the voltage at cathode at the peak voltage. This reverse biases the diode D and the capacitor C starts discharging through R_L till the voltage across (which is the voltage at the cathode) it becomes less than Vs which is rising sinusoid. The diode then gets forward biased and starts conducting till the peak are reached and this cycle continues. The charging and discharging of the capacitor causes **ripple voltage** in the output. Larger capacitor (and /or R_L) results in slower discharge and "flat" output giving rise to less ripple content.

WHAT IS RIPPLE FACTOR??

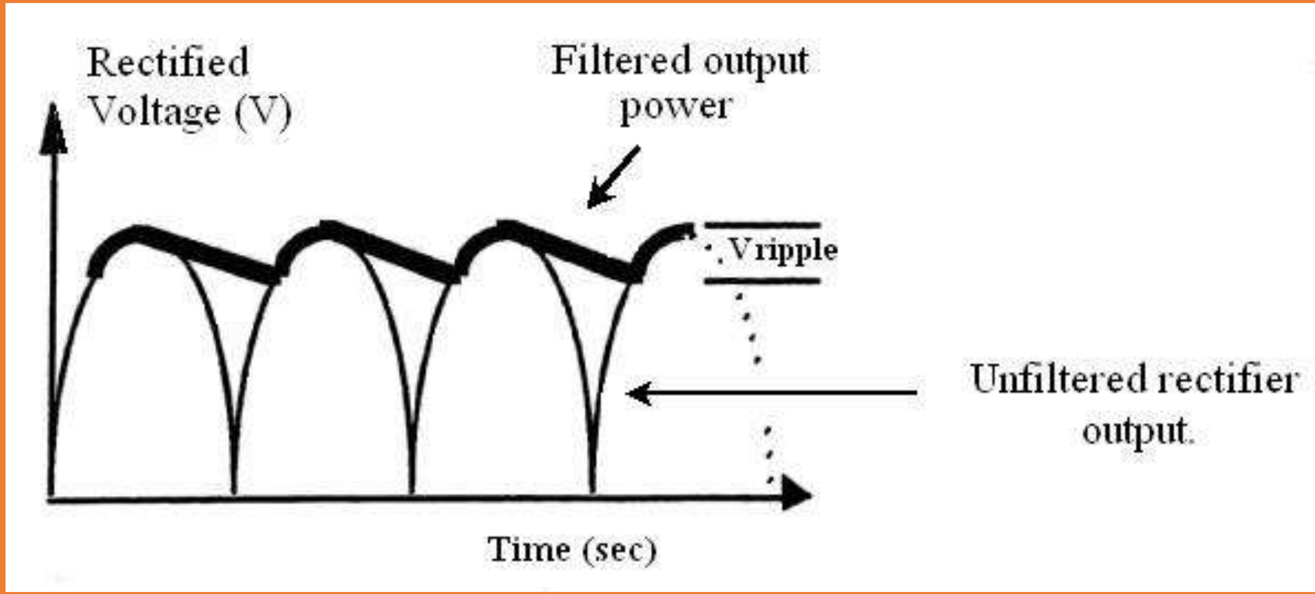
Ripple Factor

Measure of purity of the dc output of a rectifier

Defined as the ratio of ac component of the output wave to the dc component in the wave

$$\text{Ripple factor} \quad \gamma = \frac{\text{R.M.S. value of a.c. component of output}}{\text{Average or d.c. component of output}}$$

$$\text{Ripple factor} = \frac{I_{ac}}{I_{DC}}$$



Ripple factor: Ripple factor is a measure of effectiveness of a rectifier circuit. It is defined as the ratio of RMS value of the AC component (ripple component) I_{rrms} in the output waveform to the DC component V_{DC} in the output waveform.

$$r = \frac{I_{rrms}}{I_{DC}}$$

We can measure the value of RMS component of overall output waveform from which we can estimate the value of I_{rrms}.

We get,

$$I_{rrms} = \sqrt{I_{rms}^2 - I_{DC}^2}$$

For half wave rectifier,

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

$$I_{DC} = \frac{I_m}{\pi}$$

This leads to ripple factor r =1.21 for half wave rectifier.

The ripple factor can be significantly reduced using a filter capacitor.
For a half wave rectifier with filter capacitor, ripple factor is given by,

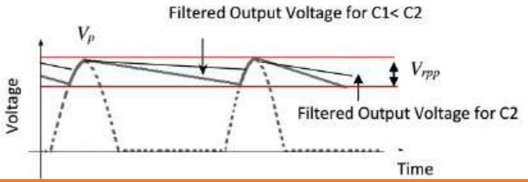
$$r = \frac{1}{2\sqrt{3} f R_L C}$$

Where *f is* the frequency of pulsating DC which in this case is same as that of AC mains.

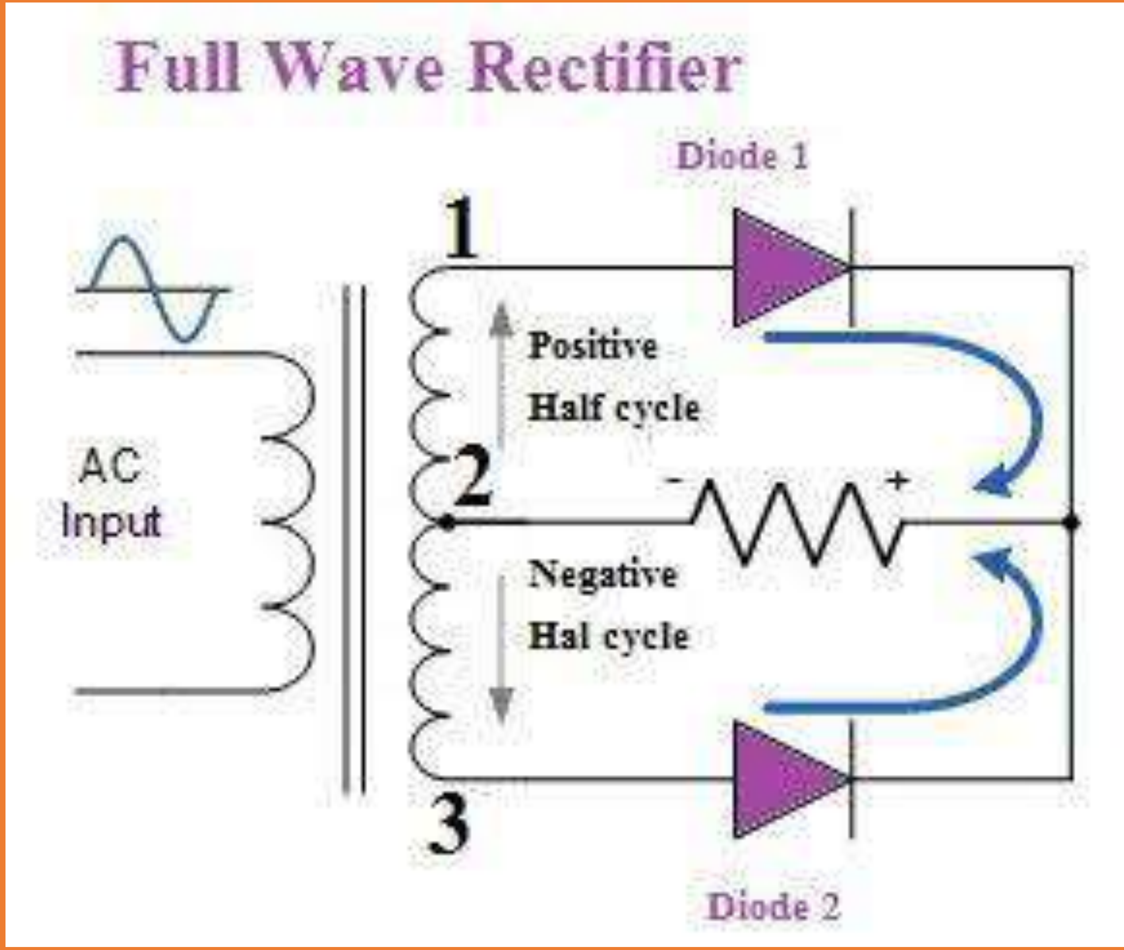
The value of ripple factor can also be estimated from the waveform of the output voltage.

$$r = \frac{V_{rpp}/2\sqrt{3}}{V_p - 0.5V_{rpp}}$$

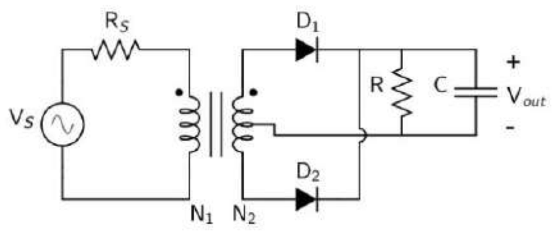
Where V_p is the peak value of the output voltage and V_{rpp} is peak to peak value of the ripple voltage.



DIODE AS A FULL WAVE RECTIFIER

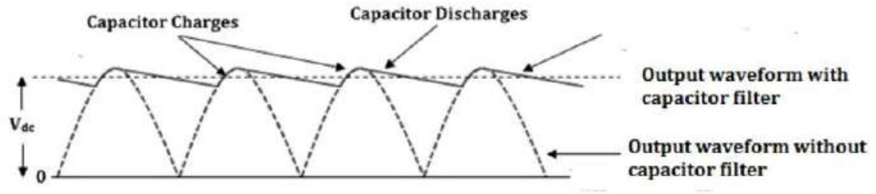


Full wave rectifier with centretapped transformer



The circuit consists of a center-tapped transformer, followed by the rectifier formed by two diodes D1 and D2, and finally the load R with a capacitor filter C. The circuit is designed such that the current through the load is always in the same direction during both the half cycles.

Assume that the capacitor is not connected initially. Due to the center tap rectifier, during the positive half cycle of the input V_s, A is positive with respect to B, hence diode D1 will be forward biased and D2 will be reverse biased. This results in the current flowing from A-D1-R-B-A. In negative half cycle, C is positive with respect to B. This makes C positive with respect to B causing diode D2 to get forward biased making the current flow from C-D2-R-B-C. Thus in both the half cycles the current through R flows in the same direction resulting in pulsating DC across R.

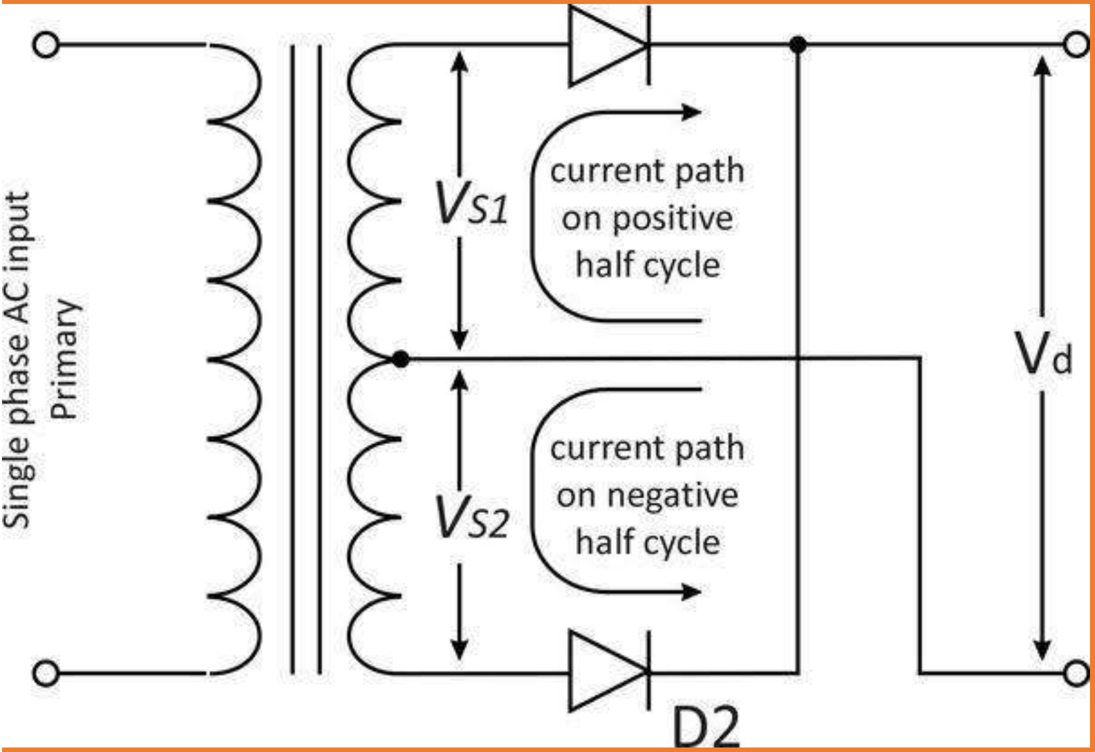


With capacitor filter

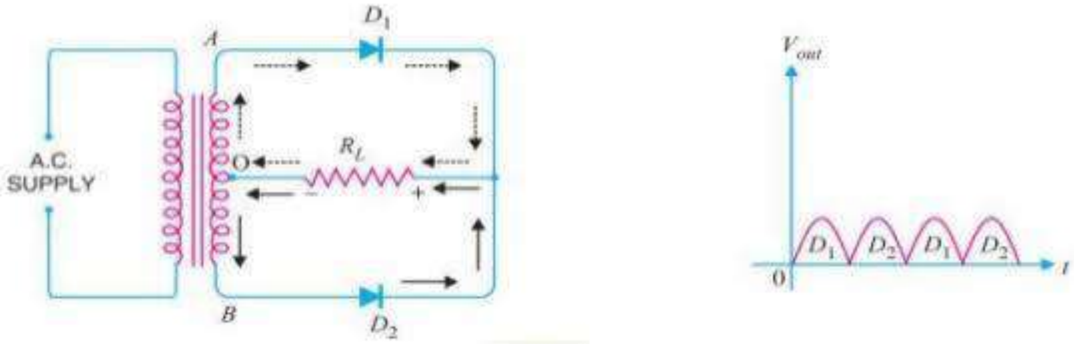
During the positive half cycle, capacitor C will charge to the peak of the input waveform while the load R is being supplied current through D1. When the input starts to go below its peak value, the voltage across C will cause D1 to be reverse biased, thus disconnecting the rectifier from the load. The capacitor will then provide the necessary current for the load. The rate of potential drop across C will be based on the values of R & C.

During the negative half cycle, diode D2 will initially be reverse biased due to voltage across C. When the voltage at the input crosses the dropping voltage across C, D2 will be forward biased. Now the load is supplied current by the input while simultaneously charging C. This continues till the negative peak of the input waveform, after which D2 will be reverse biased. The next positive cycle is similar to the previous negative cycle with diode D1 being forward biased when the input voltage crosses the voltage across C. Capacitor C ensures that the voltage across load R remains close to the peak of the input voltage.

CLEAR YOUR IDEAS MORE

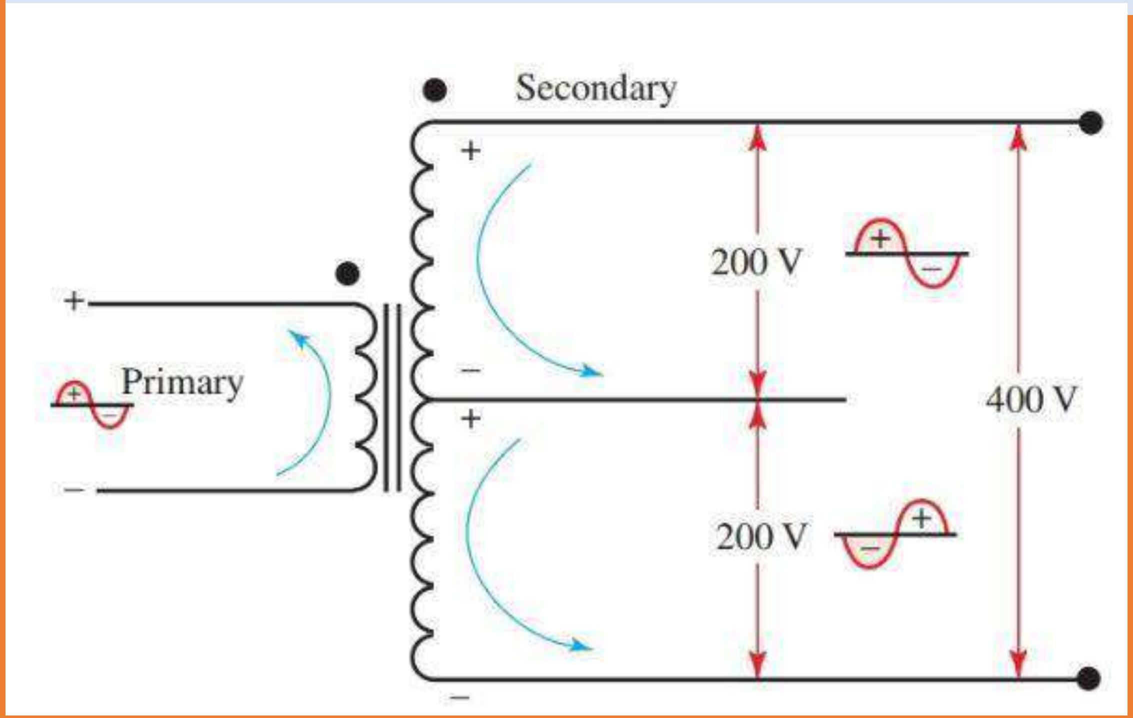


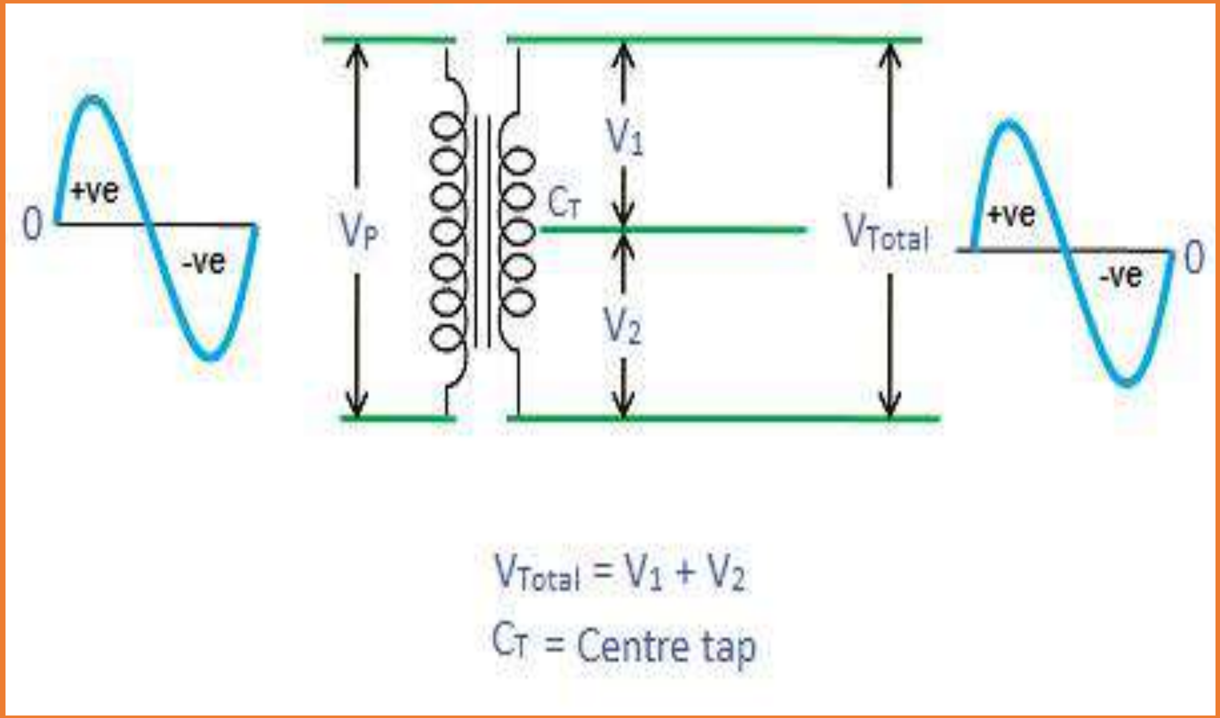
Centre Tap Full Wave Rectifier



- Circuit has two diodes D1 , D2 and a centre tap transformer.
- During positive half cycle Diode D1 conducts and during negative half cycle Diode D2 conducts.
- It can be seen that current through load RL is in the same direction for both cycle.

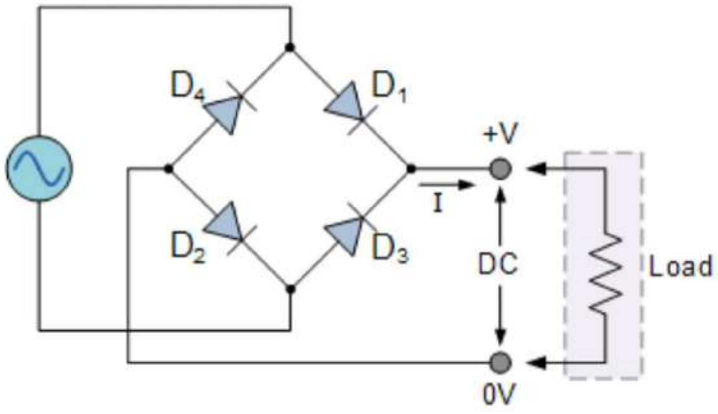
BASIC IDEA OF CENTRE TAPPED TRANSFORMER





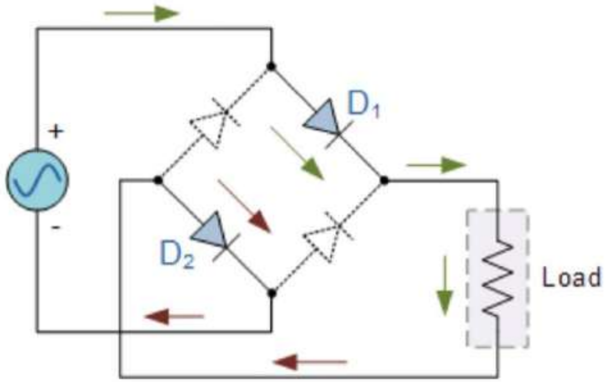
BRIDGE RECTIFIER: BASIC KNOWLEDGE

The Diode Bridge Rectifier



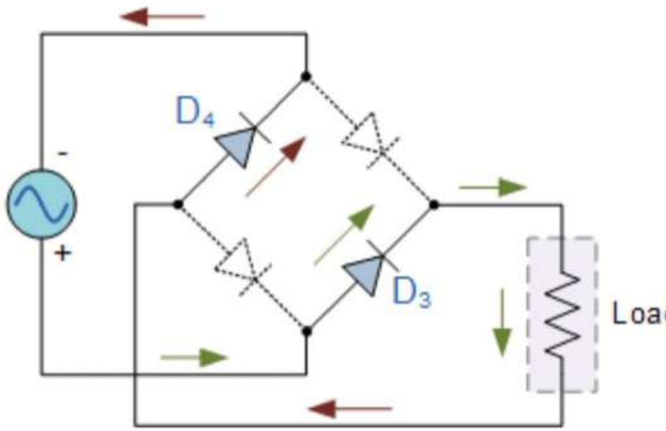
The four diodes labelled D_1 to D_4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.

The Positive Half-cycle



During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before.

The Negative Half-cycle



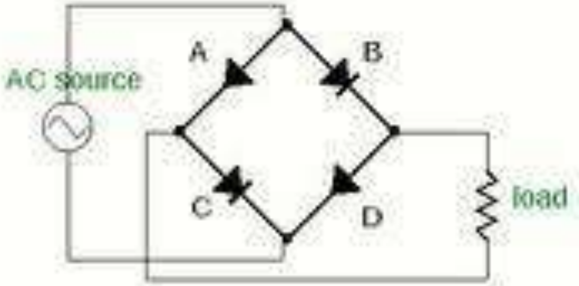
As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional the same as for the previous two diode full-wave rectifier, therefore the average DC voltage across the load is $0.637V_{max}$.

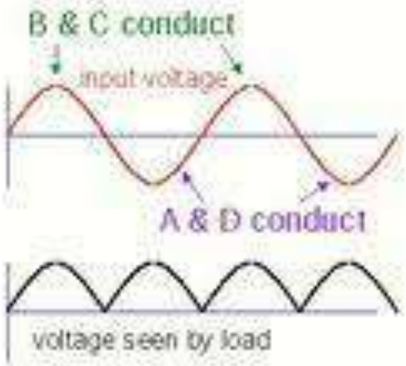
https://youtu.be/JG3asbRqHDs

DIODE AS BRIDGE RECTIFIER

Doing Better: Full-wave Diode Bridge

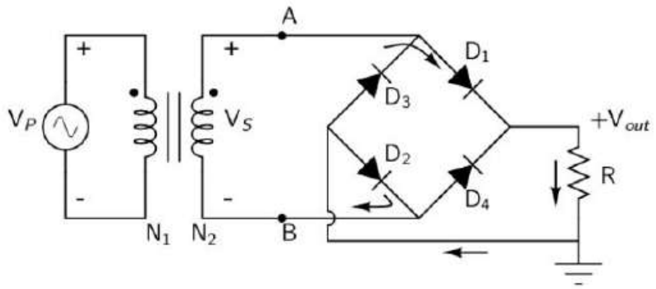
- The diode in the rectifying circuit simply prevented the negative swing of voltage from conducting
  - but this wastes half the available cycle
  - also very irregular (bumpy): far from a "good" DC source
- By using four diodes, you can recover the negative swing:





Bridge Rectifier

Fig. 1 shows the circuit of diode bridge rectifier. The circuit uses four diodes D1, D2, D3 and D4 connected in the form of bridge.

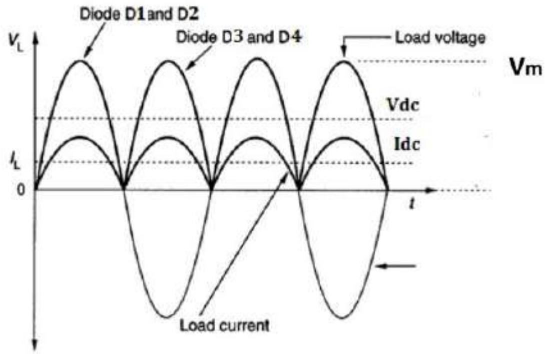


During the positive cycle of *Vs*, point A is positive with respect to B causing diode D1 and D2 to forward bias and D3 and D4 to get reversed biased. This results in the current to flow from A, through D1, R, D2, B to A.

During negative cycle, the polarities change. Now point B is positive with respect to A causing diodes D3 and D4 to conduct and D1 and D2 to reverse bias. The resulting current then flows from B through D4, R, D3, A to B. In both the cycles, the current through the load resistor R flows in the same direction ensuring the pulsating DC across R in both the half cycles of the input voltage. Hence, this is a full wave rectifier.

The output voltage can be smoothened by connecting a suitable capacitor across the load resistor as explained in section B.

Fig 2 shows the input output waveforms.



EXPRESSION OF RIPPLE FACTOR IN CASE OF FULL WAVE REFICITION

The ripple factor of full wave rectifier (both centre tapped and bridge rectifier)

The ripple factor is given by,

$$r = \frac{V_{rrms}}{V_{DC}} \qquad (1)$$

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

$$V_{rrms} = \sqrt{V_{rms}{}^2 - V_{DC}{}^2} \qquad (2)$$

where V_{rms} is the RMS value of the rectified output.

For full wave rectifier,

$$V_{rms} = \frac{V_m}{\sqrt{2}} \text{ and } V_{DC} = \frac{2V_m}{\pi} \qquad (3)$$

where, V_m is peak value of the voltage V_s. Substituting these values in (2) we get.

$$r = 0.483 \qquad (4)$$

This is a significant improvement in the ripple factor compared to that of a Half wave rectifier (r=1.21). However, this pulsating DC is not useful to power electronic circuits as it still has a large AC component. The output can be made smooth by using capacitor filter as described in Half Wave rectifier. Try to analyse the circuit in Fig. 3 and the waveforms in Fig 4.

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

$$r = \frac{1}{4\sqrt{3} f R_L C}$$

where f is the frequency of the signal V_s

RECTIFICATION EFFICIENCY: HALF WAVE RECTICATION

Efficiency of the Half-wave Rectifier

Rectifier efficiency is defined as the ratio of DC power to the applied input AC power.

Rectifier efficiency, η = DC output power/input AC power

$I_{dc} = I_m / \pi$

The DC output power is given by:

$P_{dc} = I^2_{dc} \times R_L = (I_m / \pi)^2 \times R_L$

The AC input power is given by:

$P_{ac} = I^2_{rms}(r_f + R_L)$, where r_f is diode resistance.

For a half-wave rectified wave:

$I_{rms} = I_m / 2$

Therefore, $P_{ac} = (I_m/2)^2 \times (r_f + R_L)$

Thus rectifier efficiency, η = DC output power/AC input power

$= [(I_m/\pi)^2 x R_L] / [(I_m/2)^2 x (r_f+R_L)]$

$= 0.406 R_L / (r_f + R_L)$

$= 0.406 / (1 + r_f/R_L)$

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

Therefore, maximum rectifier efficiency = 40.6%. This means only 40.6% of the input AC power is converted into DC power.

Rectifier Efficiency (η)

Tells us the percentage of total input ac power that is converted into useful dc output power.

$$\eta = \frac{\text{D.C. output power}}{\text{A.C. input power}} = \frac{P_{DC}}{P_{AC}}$$

$$\eta = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}[R_f + R_L + R_s]} = \frac{(4/\pi^2)R_L}{(R_f + R_L + R_s)} \qquad \eta = 40.6\ \%$$

Under best conditions (no diode loss) only 40.6% of the ac input power is converted into dc power.

The rest remains as the ac power in the load

Half Wave Rectifier Efficiency

Efficiency, h is the ratio of the dc output power to ac input power

Thus $\eta = \frac{dc\,output power}{ac\,input power} = \frac{P_{dc}}{P_{ac}}$

$$\frac{V_{dc}^2/R_L}{V_{rms}^2/R_L} = \frac{[V_m/\pi]^2}{[V_m/2]^2} = 4/\pi^2 = 0.406 = 40.6\%$$

RECTIFICATION EFFICIENCY: FULL WAVE RECTICATION

$I_{dc} = 2\, I_m / \pi = 2\, V_m / \pi R_L$

$I_{rms} = I_m / \sqrt{2} = 0.707\, I_m$

Rectifier Efficiency, $\eta = P_{dc} / P_{ac}$

$= I^2_{dc} R_L / I^2_{rms} (r_f + R_L)$

$= 0.812 / [1 + (r_f / R_L)]$

= 81.2% if the diode resistance r_f is negligible as compare to R_L.

Rectifier Efficiency (η)

$$\eta = \frac{P_{DC}\ \text{output}}{P_{AC}\ \text{input}}$$

$$\eta = \frac{\frac{4}{\pi^2} I_m^2 R_L}{\frac{I_m^2 (R_f + R_s + R_L)}{2}}$$

$$\eta = \frac{8\, R_L}{\pi^2 (R_f + R_s + R_L)}$$

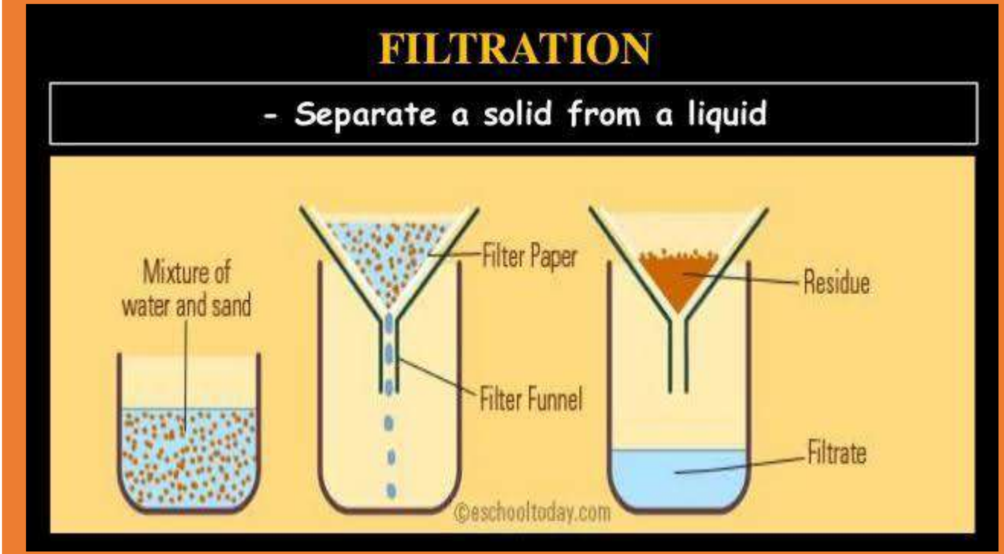
But if $R_f + R_s << R_L$, neglecting it from denominator

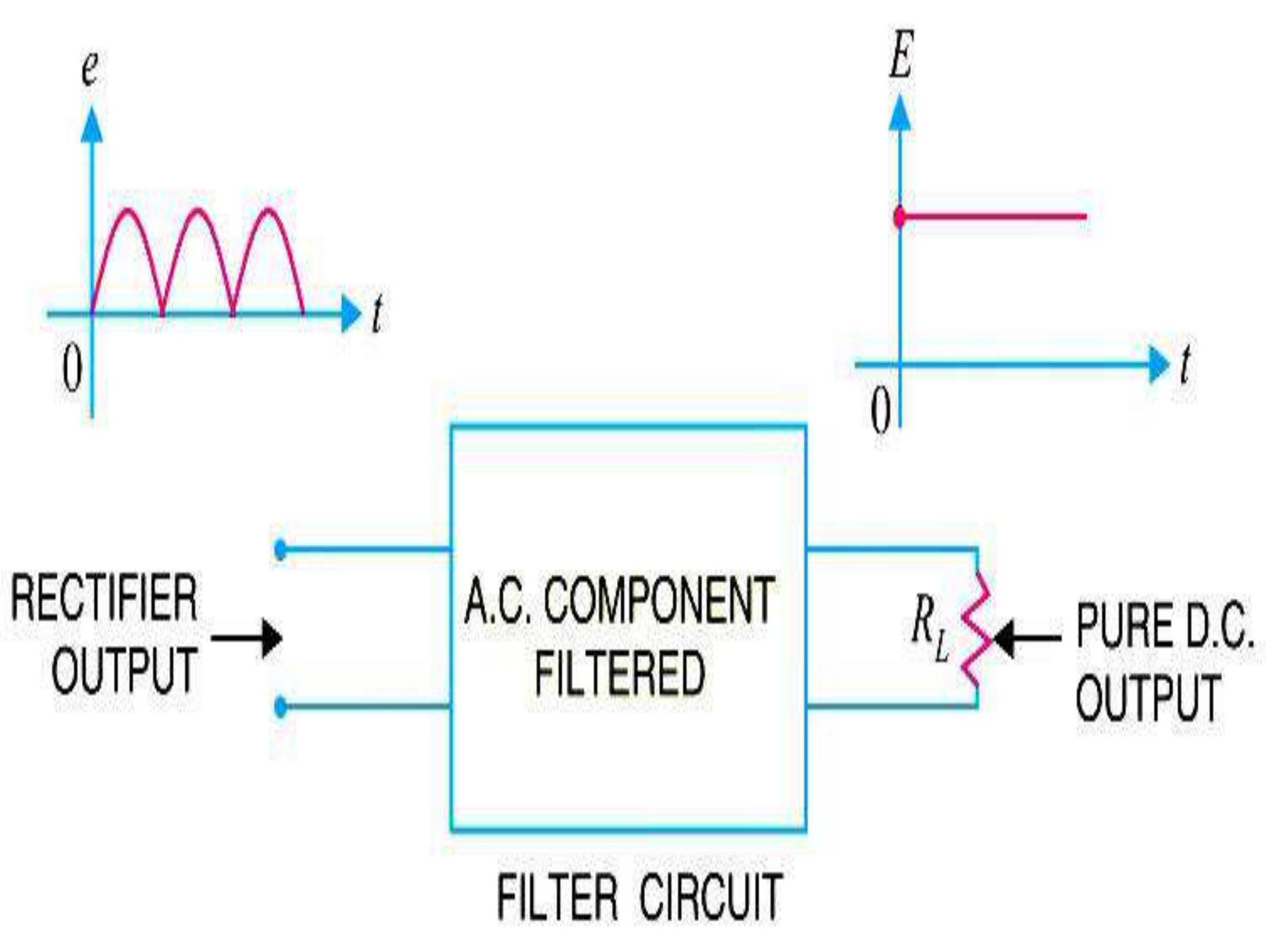
$$\eta = \frac{8\, R_L}{\pi^2 (R_L)} = \frac{8}{\pi^2}$$

$$\%\ \eta_{max} = \frac{8}{\pi^2} \times 100 = 81.2\ \%$$

The efficiency of the center tap full-wave rectifier is twice the value of the half-wave rectifier.

WHAT IS FILTRATION?





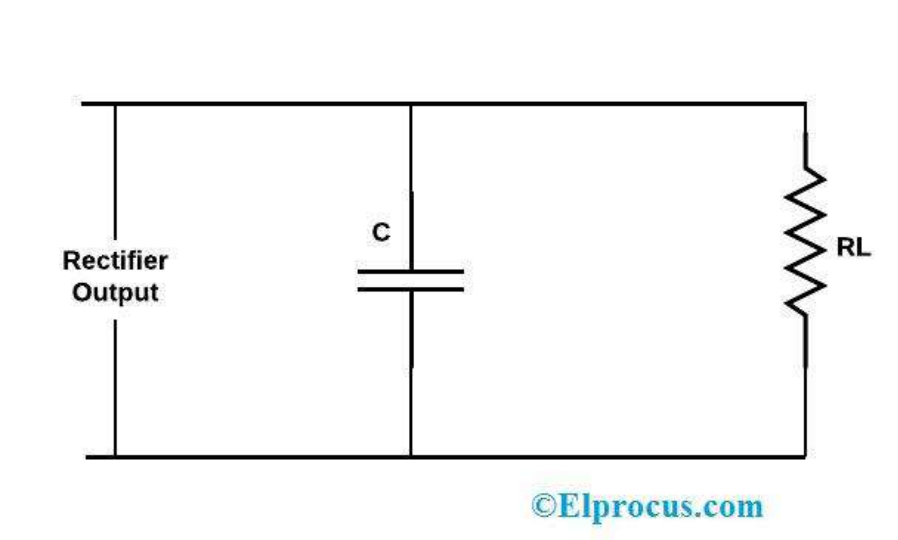
C-FILTER

C -filter is a circuit in which a capacitor is connected in parallel after the rectifier.

When a rectifier converts a.c. into d.c. all the a.c. components are not removed. To remove all the a.c. ripples we use c-filter.

This filter circuit is very simple because only a capacitor is connected in parallel after a rectifier. And we can obtain smooth d.c. spply.

This filter circuit is very cheap and easy in construction.



WHY CAPACITOR IS USED AS A FILTER IN RECTIFICATION

In power supplies, capacitors are used to smooth (filter) the pulsating DC output after rectification so that a nearly constant DC voltage is supplied to the load. The pulsating output of the rectifiers has an average DC value and an AC portion that is called ripple voltage. Filter capacitors reduce the amount of ripple voltage to a level that is acceptable. It should be noted that resistors and inductors can be combined with the capacitors to form filter networks. Here we will concentrate on capacitive filters only. In a filter circuit the capacitor is charged to the peak of the rectified input voltage during the positive portion of the input. When the input goes negative, the capacitor begins to discharge into the load. The rate of discharge is determined by the RC time constant formed by the capacitor and the load's resistance. See *Timing* paper for explanation of RC time constants.

The capacitance value needed to supply the power supplies output current (I) with the specified amount of ripple current (Vrms) with full wave rectification is:

$$C = \frac{I}{Vrms \times 4f} \qquad \text{Where } Vrms = \frac{V(p\text{-}p)}{2} \text{ for } f = 60\text{Hz}$$

$$C = \frac{2.4\, I}{Vrms} \qquad I = \text{ DC Load current of power supply in milliamps}$$

A more general formula is:

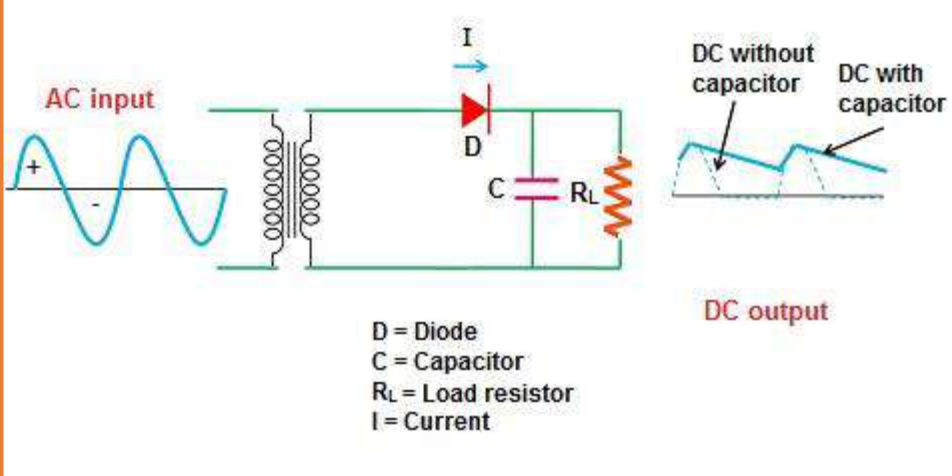
$$C \sim \frac{I \times Vdc}{VrmsVm\ 4} \qquad \text{Where } Vdc = \frac{Vm - V_{p\text{-}p}}{2}$$

Vm = max. voltage of input waveform

$V_{p\text{-}p}$ = peak to peak ripple voltage

https://youtu.be/R4oejVfW4ps

HOW C-FILTER WORKS : HALF WAVE RECTIFICATION



Half wave rectifier with capacitor filter

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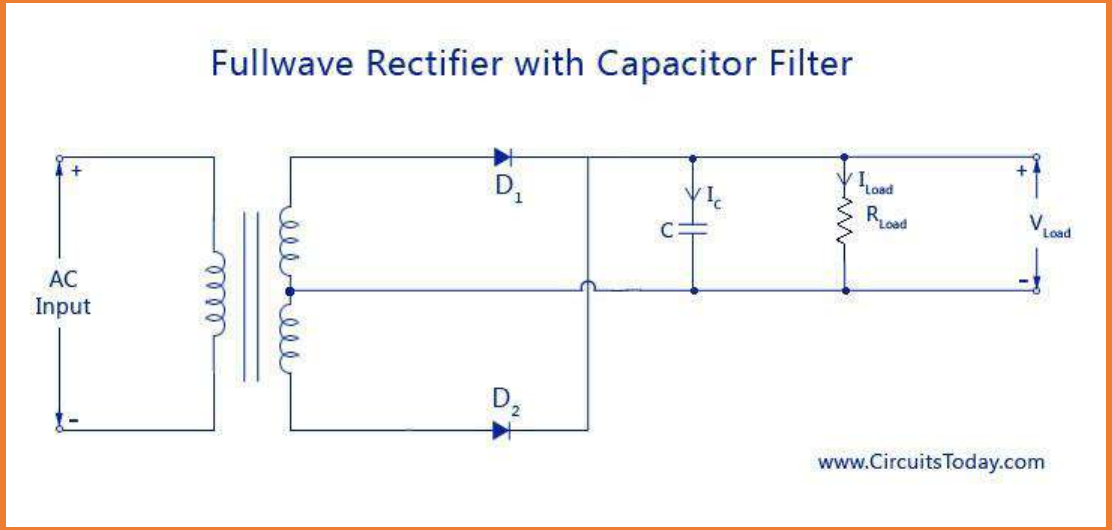
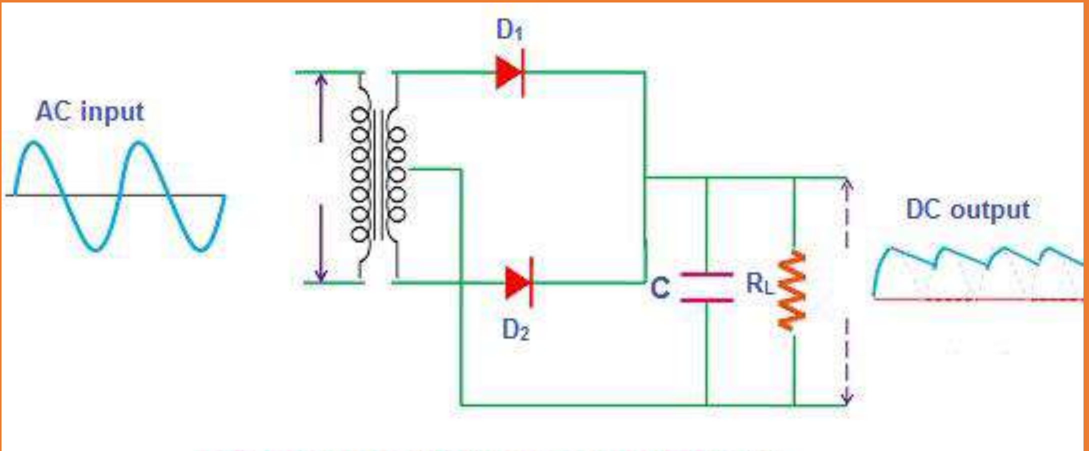
HOW C-FILTER WORKS : FULL WAVE RECTIFICATION





Full wave rectifier with capacitor filter

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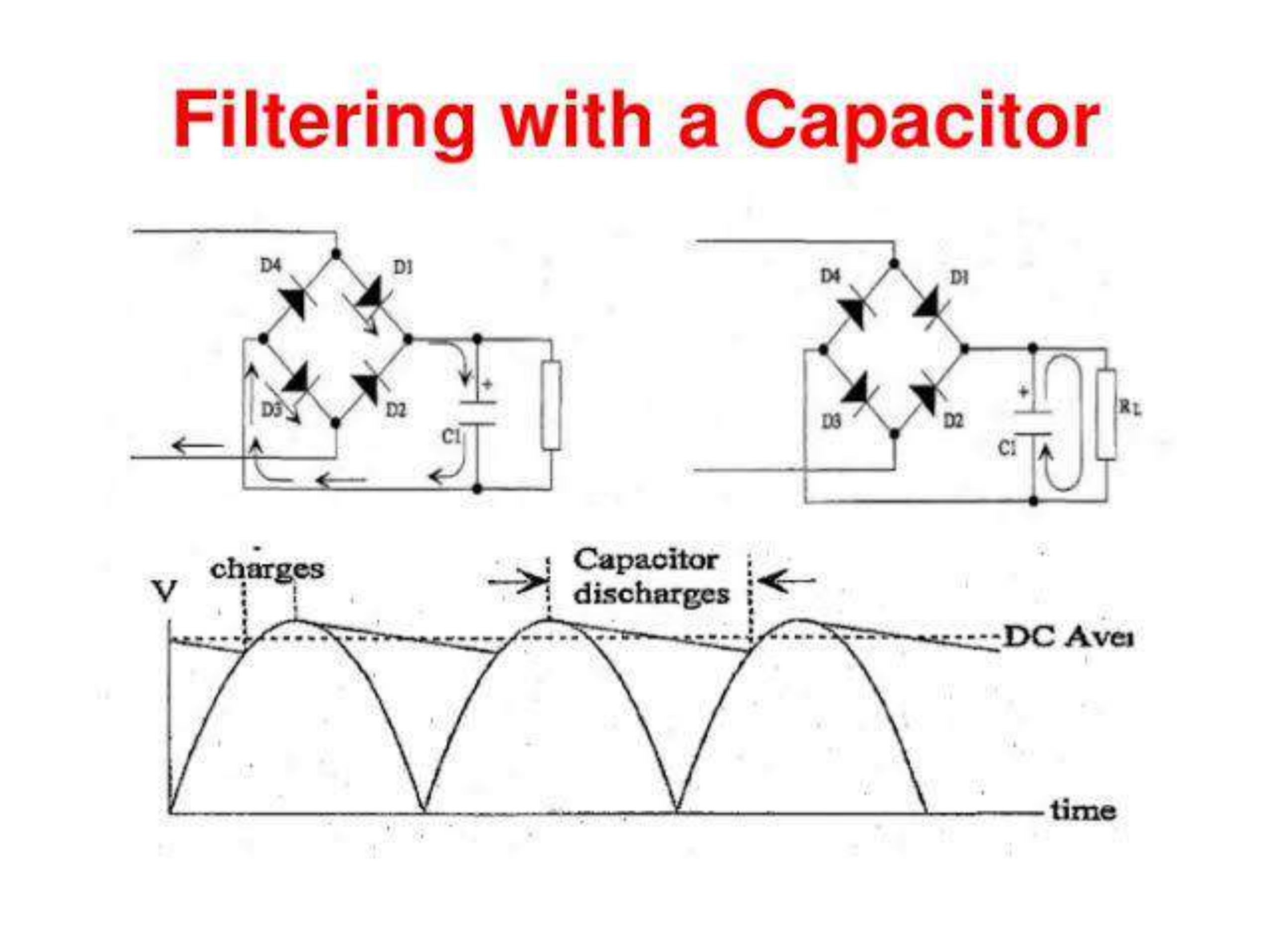
C-FILTER: BRIDGE RECTIFIER



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