UNIT 2: POWER SUPPLIES

→ Power is the backbone of any electronic system and the power supply is what feeds the system.

→ This chapter gives an introduction to the Power supply circuits that we come across in our daily life.

→ 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, CRO etc. but all of those sections doesn't need 230V AC supply which we get from mains.

→ Instead one or more sections may need a 12V DC while some others may need a 30V DC.

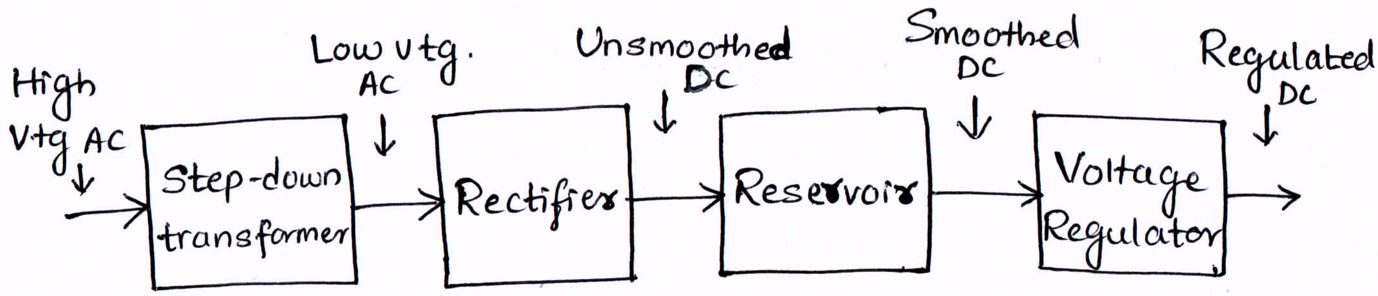
→ In order to provide the required dc voltages, the incoming 230V AC supply has to be converted into pure DC for the usage.

→ The power supply units serve the same purpose.

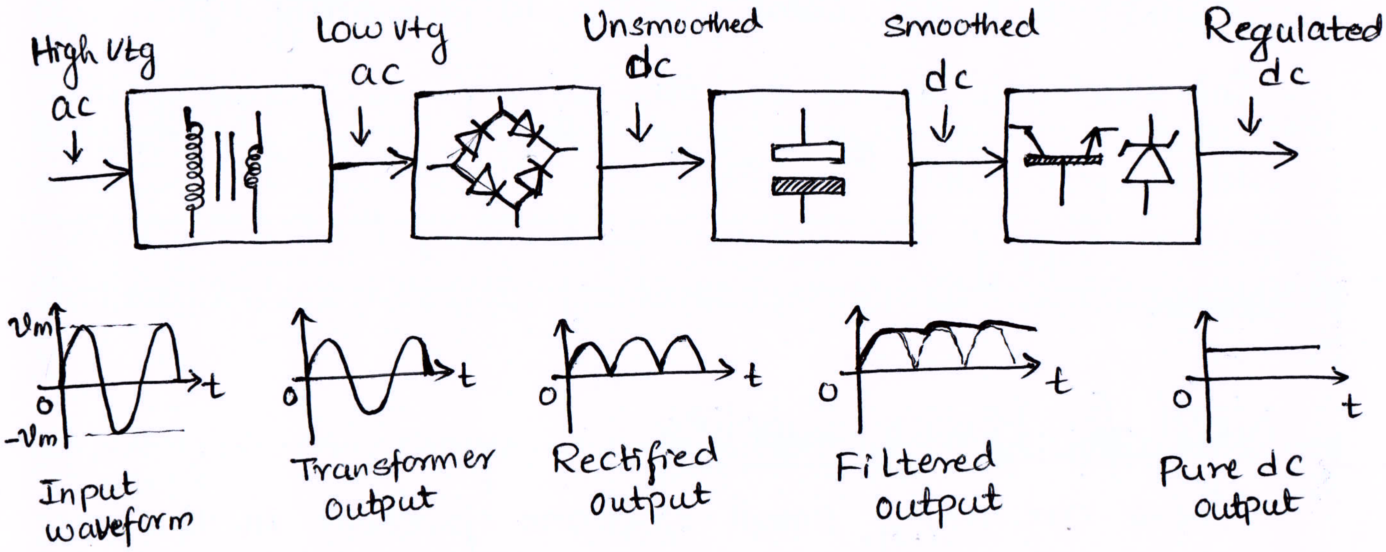
Parts of a Power Supply.

→ The block diagram of a d.c power supply is shown in fig. below.

→ It consists of step-down transformer, rectifier, reservoir and voltage regulator as shown.



Block diagram of a D.C power supply



Block diagram of a d.c power supply showing principle components.

→ From the above block diagrams, we can observe that transformer is present at the initial stage.

→ A transformer has a primary coil to which input is given and a secondary coil from which the output is collected.

→ In our power supply circuits, we use the step-down transformer (of appropriate turns ratio), as we need to lower the AC power to DC.

→ The output of this step-down transformer will be less in power and this will be given as the input to the next section, called Rectifier

→ Whenever there arises the need to convert an AC to DC power, a rectifier circuit comes for the rescue.

→ A simple PN junction diode acts as a rectifier.

→ The forward biasing and reverse biasing conditions of the diode makes the rectification.

→ The a.c output from the transformer secondary is then rectified using silicon rectifier diodes to produce an unsmoothed output (pulsating dc) as shown above in fig.

→ The pulsating dc output coming from rectifier element consists of unwanted ac component.

→ This ac component has to be completely removed in order to get pure dc. output.

→ So, the O/P of rectifier (pulsating dc) is then fed as input to next section i.e., Reservoir/Smoothing filter, which removes the ac component present in the rectified output and allows the dc component to reach the load.

→ The next and the last stage in power supply system is the Regulator part.

→ As we observe that the O/P of Reservoir/Smoothing filter is not pure dc.

→ In order to get purest form of dc O/P, we need to pass the pulsating dc O/P from filter ckt into the voltage regulator stage.

→ A voltage regulator is such a device that maintains constant output voltage, instead of any kind of fluctuations in the input voltage being applied.

Summary

→ The high voltage ac is fed to Stepdown transformer, which inturn gives low voltage ac.

→ The low voltage ac (o/p from transformer) is fed as input to next stage ie; Rectifier circuit. This will give the pulsating dc output which consists both ac and dc components.

→ Then the o/p of rectifier is fed as input to next stage i.e; Reservoir / smoothing filter (capacitor).

→ The capaciter helps to smooth out the voltage pulses produced by the rectifier.

→ Finally a stabilizing circuit (often based on Zener diode) provides a constant output voltage.

Rectifiers.

→ Rectification is the process of converting ac supply into pure dc Supply.

→ To perform this, we need a rectifier circuit.

→ A diode is used as a rectifying element to construct the rectifier circuit.

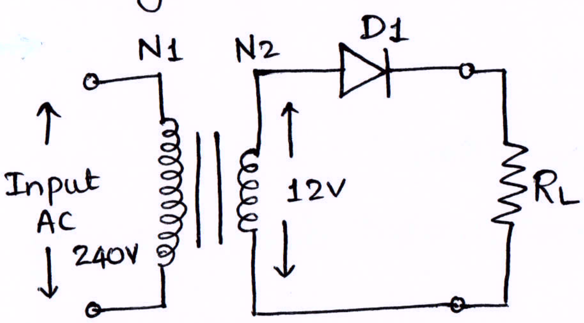
→ Depending on the o/p and no. of diodes usage, the rectifier circuits are classified into two main types.

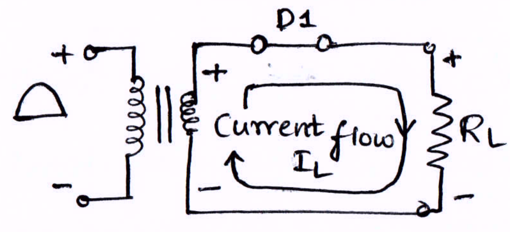
→ Half wave Rectifier and Full wave Rectifier.

→ Half wave rectifier ckt rectifies only one half cycle of the input supply whereas Full wave rectifier ckt rectifies both the half cycles of input supply.

Half Wave Rectifier (HWR).

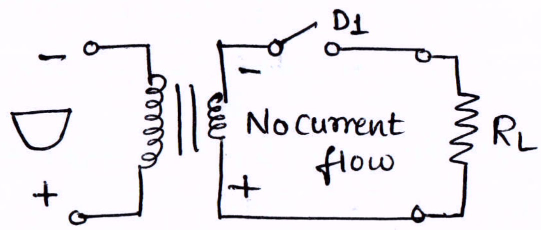
→ The name half-wave rectifier itself states that the rectification is done only for half (either positive or negative half) of the input supply cycle.



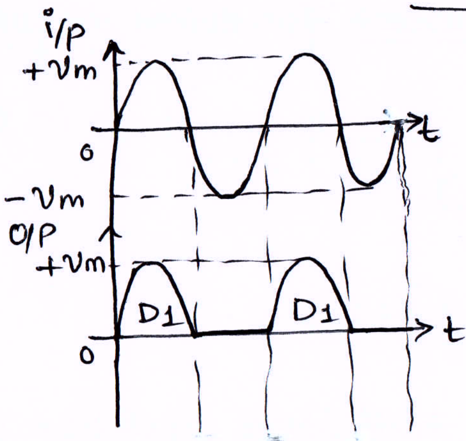


During +ve half cycle

N_1 = primary coil turns
N_2 = Secondary coil turns
R_L = Resistive load
D_1 = rectifying element (diode)



During −ve half cycle



Input and Output waveforms.

→ An alternating input voltage is applied via a transformer to a single diode connected in series with a load resistor R_L.

→ During the positive half cycle of the input, diode becomes forward biased and will effectively behave like a closed switch.

→ Current starts flowing in the direction shown above (from cathode to anode).

→ When diode is forward biased, the voltage drop across it is V_F and the output voltage is $\boxed{V_o = V_m - V_F}$.

$$\boxed{\begin{array}{l} V_o = V_m - 0 = V_m \\ V_o = V_m - 0.7 \end{array}}$$

← Ideal condition.

← Practical Condition (Si)

V_m = max. Secondary Vtg.

→ During negative half cycle of input, diode becomes reverse biased, causing the diode to act like an open switch as shown above.

→ No current flow in reverse biased diode condition.

→ $\boxed{\begin{array}{l} V_o = 0V \\ V_o = -I_R R_L \end{array}}$ ← Ideal Condition. ← Practical condition.

where I_R = very small reverse current due to minority charge carriers.
& R_L = very high resistance

→ From the i/p & o/p waveforms, we observe that diode D_1 conducts (ON) for every positive half cycle of i/p and doesn't conducts (OFF) for every negative half cycle of input.

→ The output will be pulsating which is taken across the load resistor (R_L).

Full Wave Rectifier (FWR)

→ Unfortunately, the half wave rectifier circuit is relatively inefficient as conduction takes place only on alternate half cycles.

→ A better rectifier arrangement would make use of both positive and negative half cycles.

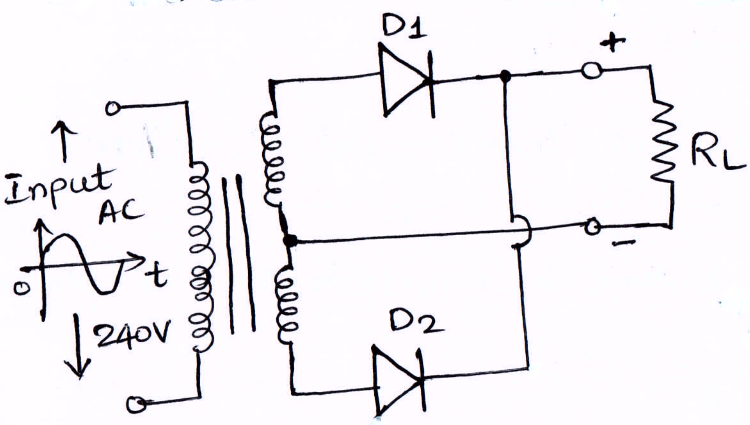
→ The full-wave rectifier circuits offer a considerable improvement over their half-wave rectifier counterparts.

→ There are two basic forms of FWR

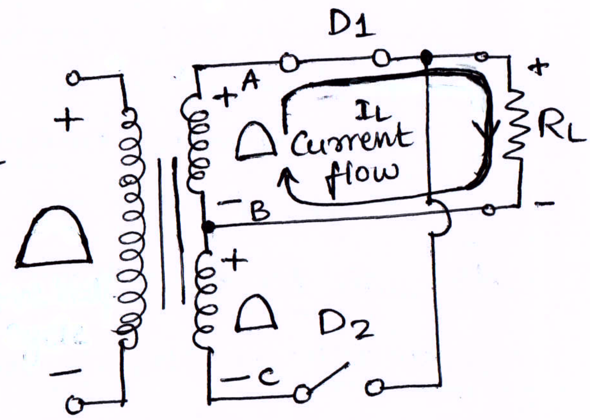
They are: (i) Centre Tapped / Biphase Rectifier
(ii) Bridge Rectifier.

(i) Centre Tapped / Bi-phase Rectifier.

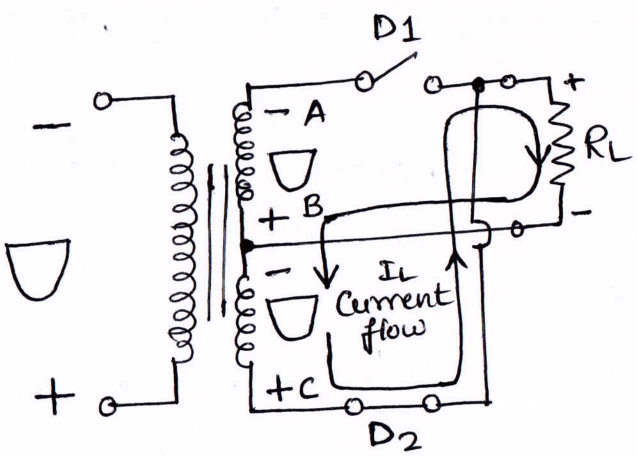
→ Centre tapped FWR uses two diodes.



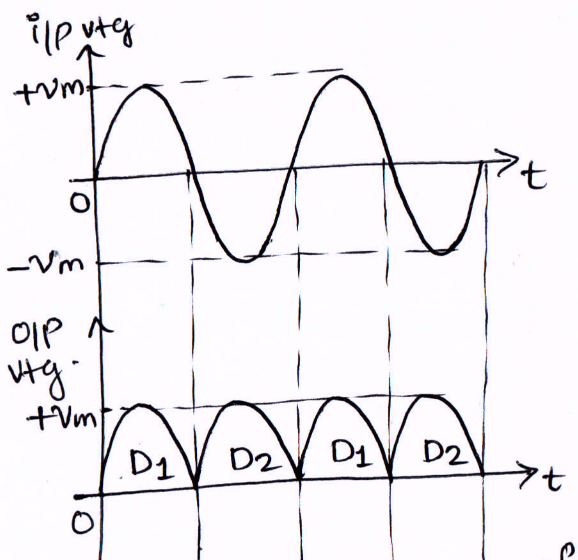
Bi-phase rectifier circuit



During +ve half cycle



During −ve half cycle



Input & Output waveforms

→ The circuit is essentially a combination of two half wave circuits.

→ The above fig. shows a simple bi-phase/centre tapped rectifier.

→ Mains voltage (240V) is applied to the primary of step-down transformer which has two identical secondary windings, each providing equal amount of voltage.

→ During positive half cycle of input voltage, point 'A' will be positive with respect to point 'B'.

→ Similarly point 'B' will be positive with respect to point 'C'

→ In this condition, diode D_1 conducts (ON) while D_2 will not conduct (OFF).

→ D_1 is forward biased, and load current (I_L) flows from the top of the transformer secondary through D_1, through R_L from top to bottom, and back to the transformer centre tap as shown in fig. above.

→ In this, the current is due to diode 'D_1'.

→ During negative half cycle of the input voltage, point 'C' will be positive with respect to point 'A'.

→ In this condition, diode D_2 will become forward biased and conducts (ON) while diode D_1 will become reverse biased and not conducts (OFF).

→ I_L flows from the bottom terminal of the transformer secondary through D_2, through R_L from top to bottom, and back to the transformer centre tap. as shown in fig.

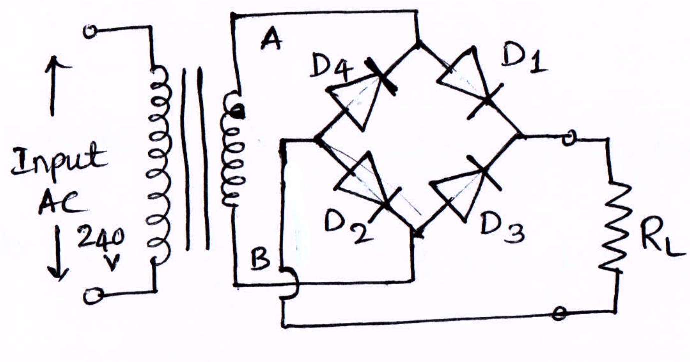
→ In this, the current is due to diode 'D_2'

→ From this we can observe that, every positive half cycles of input gets rectified by D_1 and every negative half cycles of input gets rectified by D_2.

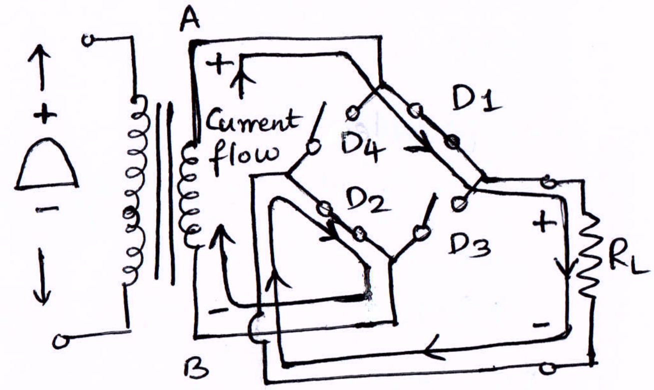
→ The result is that current is routed through the load in the same direction (top to bottom) for both half cycles operation, thus we get successive positive half cycles in the output as seen above.

→ The load current /o/p waveform is the sum of individual diode currents flowing in corresponding half cycles.

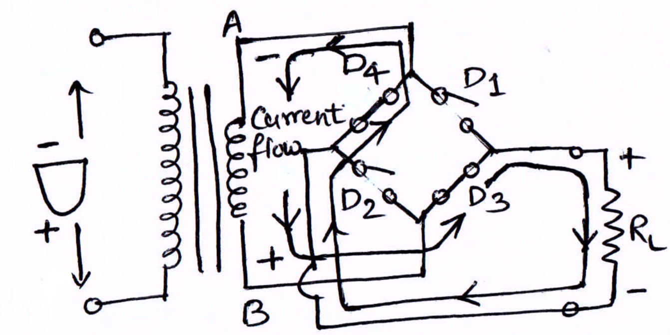
Bridge Rectifier.



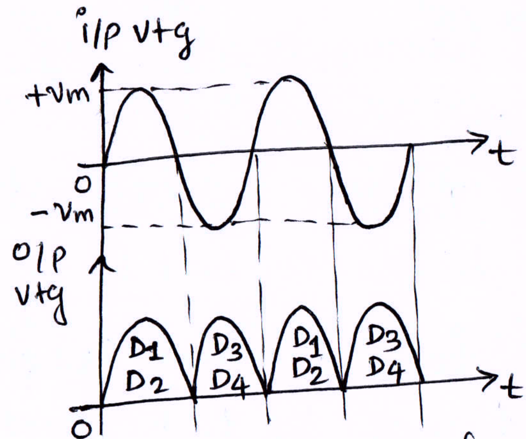
Full-wave Bridge Rectifier.



During +ve half cycle



During -ve half cycle



Input & Output Waveforms.

→ The centre-tapped transformer used in Bi-phase circuit, is usually more complex, expensive and requires more space than additional diodes.

→ So, a bridge rectifier is the circuit most frequently used for full wave rectification.

→ This avoids the need to have two seperate secondary windings.

→ The bridge rectifier circuit is essentially a FWR circuit, using 4 diodes, forming the 4 arms of an electrical bridge.

→ To one diagonal of the bridge, the ac voltage is applied through a transformer secondary, and the rectified dc voltage is taken from the other diagonal of the bridge as shown above.

→ The 4 diodes connected with their arrowhead symbols all pointing toward the positive output terminal of the circuit.

→ The fullwave bridge rectifier arrangement is as shown above.

→ Mains voltage is applied to the primary of a step-down transformer.

→ The secondary winding provides rms voltage as before.

→ During positive half cycle of input voltage, point 'A' will be positive with respect to point 'B'.

→ In this condition, diodes D_1 and D_2 conducts and diodes D_3 and D_4 not conducts.

→ The load current (I_L) flows from positive input terminal (A) through D_1 to R_L, and then through R_L and D_2 back to negative input terminal (B)

$(\underset{A}{+} \rightarrow D_1 \rightarrow R_L \rightarrow D_2 \rightarrow \underset{B}{-})$ current flow.

→ Note that, the direction of the load current through R_L is from top to bottom.

→ During this time, positive terminal of input is applied to cathode of D_4 and negative terminal of input is applied to anode of D_3. Hence D_4 and D_3 are reverse biased.

→ In this, the current is due to diodes D_1 and D_2.

→ During negative half cycle of input voltage, point 'B' will be positive with respect to point 'A'

→ In this condition, diodes D_3 and D_4 conducts (ON) and diodes D_1 and D_2 doesn't conducts (OFF).

→ The load current (I_L) flows from positive input terminal (B) through D_3 to R_L, and then through R_L and D_4 back to negative input terminal (A).

$$(\underset{B}{+} \rightarrow D_3 \rightarrow R_L \rightarrow D_4 \rightarrow \underset{A}{-}) \text{ Current flow.}$$

→ Note that, the direction of the load current through R_L is again from top to bottom.

→ During this time, positive terminal of input is applied to cathode of D_2 and negative terminal of input is applied to anode of D_1. Hence D_1 and D_3 are reverse biased.

→ In this, the current is due to diodes D_3 and D_4.

→ It is seen that during both half cycles of the input, the output terminal polarity is always positive at the top of R_L and negative at the bottom.

→ Both positive and negative half-cycles of the input are passed to the output.

→ The negative half cycles are inverted, so that the output is a continuous series of positive half cycles of sinusoidal voltages.

Capacitor Filter Circuit

→ The power supply block diagram clearly explains that a filter circuit is needed after the rectifier circuit.

→ Till now we have seen three different types of rectifier circuits.

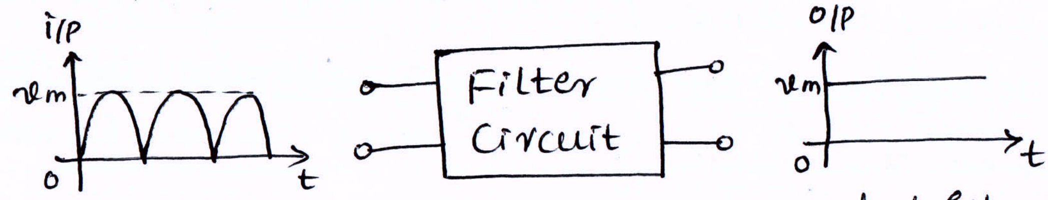
→ The outputs of all these rectifier circuits contains some ripple (ac component).

→ This ac component has to be completely removed in order to get pure dc output.

→ So, we need a circuit 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.



Rectified o/p.   An ideal filter o/p.

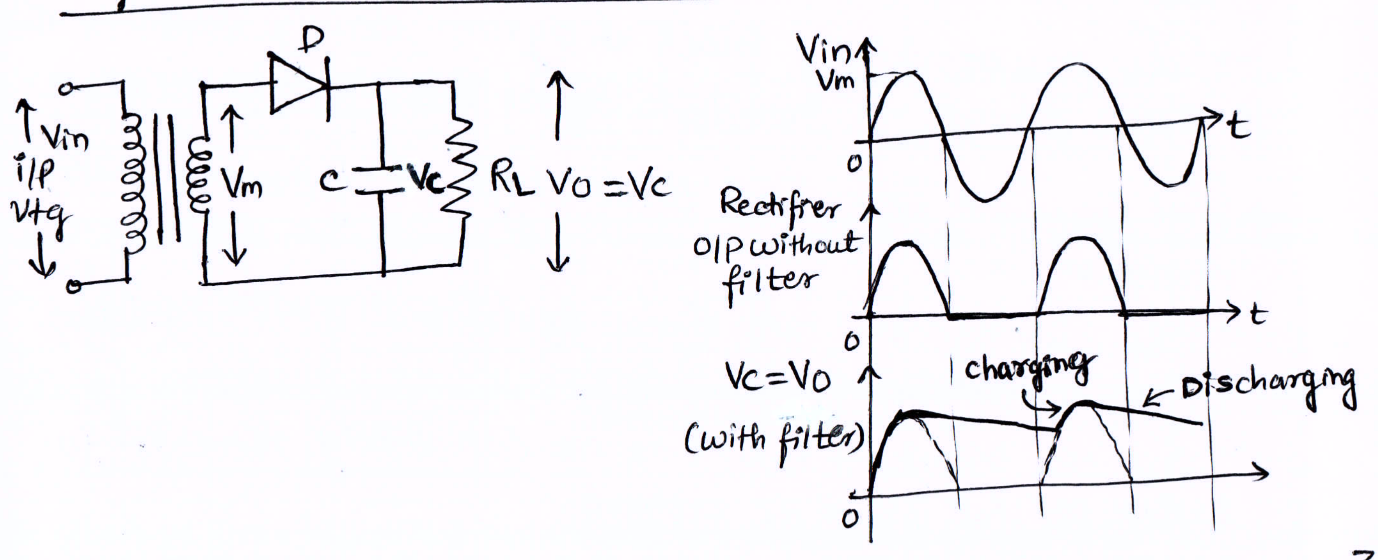
→ A filter circuit is constructed using two main components, inductor and capacitor.

→ An Inductor allows dc and blocks ac
→ An Capacitor allows ac and blocks dc

→ We use capacitor filter because of its small size & less power consumption.

→ As the characteristics of capacitor says it allows ac and blocks dc, so we have to connect it always in parallel with resistive load, R_L in rectifier circuits.

Half Wave Rectifier with Capacitor Filter.



→ The above fig. shows a HWR circuit with a single capacitor filter (C) and a load resistor (R_L) and the input, output waveforms.

→ During positive half cycle of input signal (V_{in}), the diode 'D' becomes forward biased and starts conducting.

→ In this condition, the capacitor is charged almost to the maximum peak value of input voltage, V_m.

$$\therefore \quad V_C = V_m \leftarrow \text{Ideal condition}$$

$$V_C = V_m - V_F \leftarrow \text{Practical Condition.}$$

where V_F is the voltage drop of diode, D (built in potential)

→ Once the capacitor gets charged, it will hold the value for longer time as its discharging time is greater wrt charging time by increasing R_LC time constant.

→ When the instantaneous level of input voltage (at diode anode) falls below V_m, the diode becomes reverse-biased because the capacitor voltage V_C (at diode cathode) remains close to V_m.

→ With the diode reverse-biased, there is no capacitor charging current, and capacitor begins to discharge through the load resistor (R_L). So V_C falls slowly as shown in above waveforms.

→ The diode remains reverse-biased (as V_C decreases) throughout the rest of the input positive half cycle, the negative half cycle, and the first part of next positive half cycle again until the instantaneous level of V_{in} becomes greater than V_C once more.

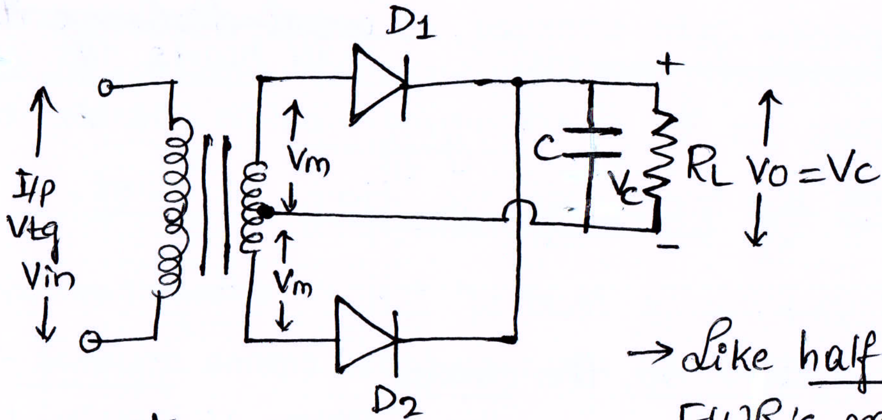
→ Once the Vin becomes greater than Vc, again the diode goes into forward biased and starts conducting.

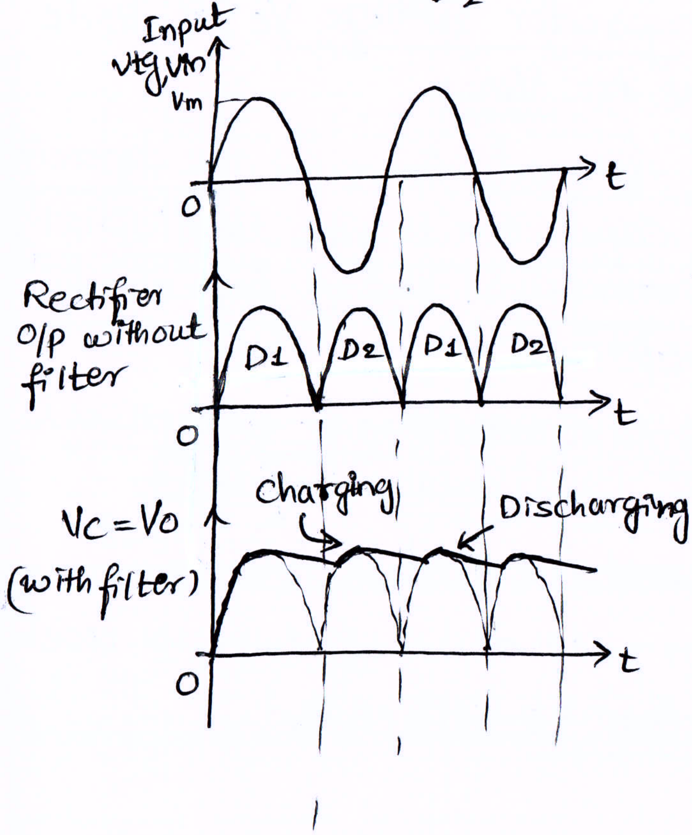
→ Again the capacitor get recharged back to Vm in case of ideal condition and (Vm − VF) in case of practical condition.

→ This process continuous how long Vin is present.

→ The charging and discharging of the capacitor cause the small increase and decrease in the capacitor voltage, which is also the circuit output voltage because of parallel connection as shown in above diagrams.

Full wave Rectifier with Capacitor Filter.





→ Like half wave rectifiers, FWR's requires filter circuit in order to convert the O/P waveform to direct voltage.

→ The figure shows FWR circuit with a reservoir capacitor.

→ This operates exactly as explained for the half wave rectifier circuit, with a few important exceptions.

→ The only difference is that, in HWR only one half cycle (either +ve or −ve) of the input AC current will charge the capacitor. But in full wave rectifier, both positive and negative half cycles of the input AC current will charge the capacitor.

→ During positive half cycle of input voltage (V_{in}), the diode D_1 becomes forward biased and D_2 becomes reverse biased.

→ In this condition, D_1 starts conducting and capacitor gets charged with maximum peak value of V_{in} i.e, 'V_m'. and holds the charged value for longer time as its discharging is slow.

→ When the instantaneous level of input voltage (at diode D_1 anode) falls below V_m, D_1 becomes reverse biased because the capacitor voltage, V_c (at diode D_1 cathode) remains close to V_m.

→ At this condition, both diodes D_1 and D_2 will be in reverse biased. and capacitor begins to discharge through load resistor (R_L). So V_c falls slowly as shown above.

→ During negative half cycle of input voltage (V_{in}), the diode D_2 becomes forward biased, and D_1 becomes reverse biased.

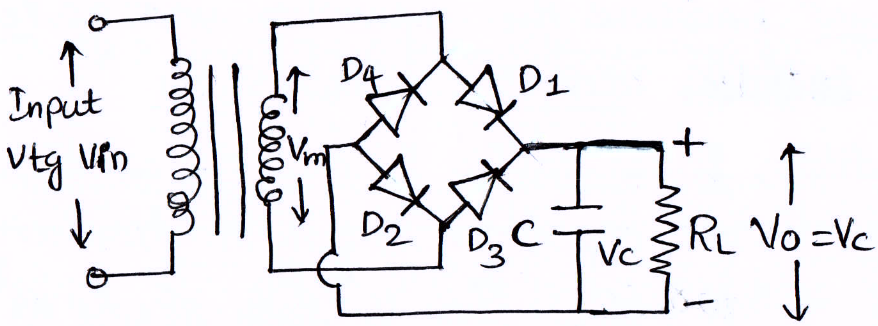
→ In this condition, D_2 starts conducting and capacitor again gets charged with maximum value of V_m. and holds it.

→ When the instantaneous level of negative input voltage (at diode D_2 anode) falls below V_m, D_2 becomes reverse biased, because the voltage across capacitor V_c (at diode D_2 cathode) remains close to maximum V_m.

→ At this condition, again both D_1 and D_2 will be in reverse biased and capacitor begins to discharge slowly through load resistor (R_L) as shown above.

Note: Capacitor charges when any one diode becomes forward biased and starts conducting.
Capacitor discharges only when both diodes becomes reverse biased and stops conducting.

Bridge Rectifier with Capacitor Filter.



→ The above figure shows the bridge rectifier with a capacitor filter.

→ Input and output waveforms are same as FWR with 'C' filter.

→ During positive half cycle of input voltage Vin, diodes D_1 and D_2 becomes forward biased and starts conducting whereas diodes D_3 and D_4 becomes reverse biased and doesn't conducts.

MCL

→ In this condition, capacitor gets charged to the maximum value of input voltage, V_m.

→ When the instantaneous level of positive input voltage (at diodes D_1 and D_2 anode) falls below V_m, D_1 and D_2 becomes reverse biased.

→ At this conditions, all the diodes D_1, D_2, D_3 and D_4 will be in reverse biased and capacitor begins to discharge its value V_c through R_L.

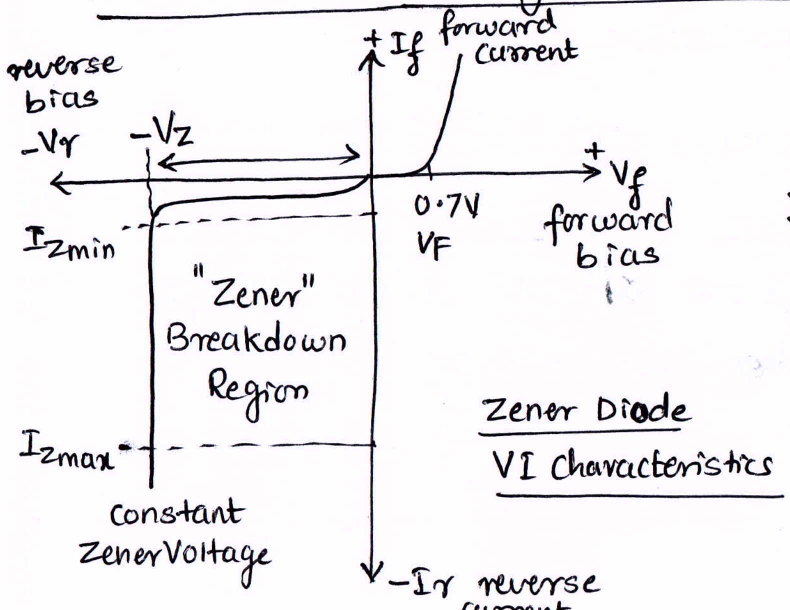
→ During negative half cycle of input voltage (V_{in}), the diodes D_3 and D_4 becomes forward biased, and D_1 and D_2 becomes reverse biased.

→ With this, capacitor again gets charged to the maximum peak value of input voltage, V_m.

→ When the instantaneous level of negative input voltage (at diodes D_3 and D_4 anode) falls below V_m, D_3 and D_4 becomes reverse biased.

→ In this condition, again all diodes will be in reverse biased and helps capacitor to discharge its value V_c through R_L.

Zener Diode Voltage Regulators



V_z = Zener Breakdown vtg.

I_{zmin} = minimum zener current

I_{zmax} = maximum zener current

V_r = reverse bias vtg.

I_r = reverse current.

V_f = forward bias vtg

I_f = forward current.

V_F = diode built-in vtg.

→ The zener diode is used in its "reverse bias" or reverse breakdown mode i.e., diode's anode connects to negative supply.

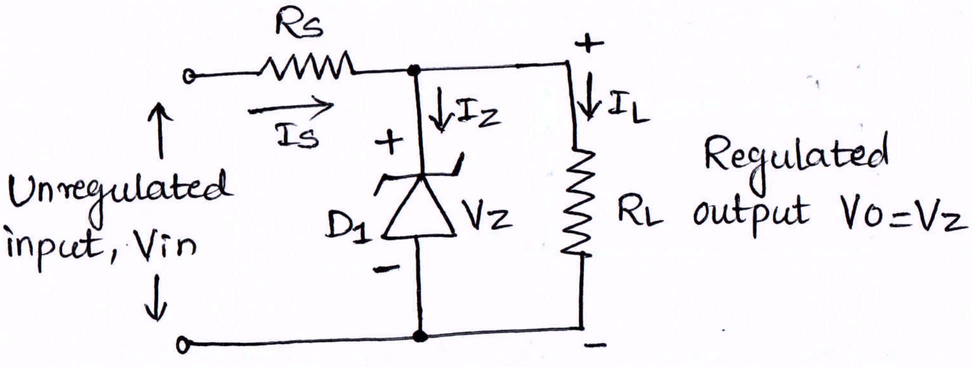
→ From the V-I characteristics curve above, we can see that the zener diode has a region in its reverse bias characteristics of almost a constant negative voltage regardless of the value of the current flowing through the diode.

→ This voltage remains almost constant even with large changes in current providing the zener diodes current remains between the breakdown current I_{zmin} and its I_{zmax} (current rating).

→ This ability of the zener diode to control itself can be used to great effect to regulate or stabilise a voltage source against supply or load variations.

→ The voltage across the diode in breakdown region is almost constant turns out to be an important characteristic of zener diode as it can be used in the voltage regulator applications.

→ The function of a voltage regulator is to provide a constant output voltage to a load connected in parallel with diode in spite of the ripples in the supply voltage or variations in the load current.



Zener Diode Voltage Regulator.

→ The circuit of zener regulator is as shown above.

→ It consists of an unregulated input voltage (V_{in}) connected to current limiting resistor (R_s), a Zener diode (D_1) in parallel with load resistor (R_L).

→ In order to work as a voltage regulator, the following conditions must be satisfied.

1) Zener diode must be reverse biased.
2) Input voltage (V_{in}) must be greater than zener breakdown voltage (V_z).
3) The load current (I_L) should be less than $I_{Z(max)}$.

→ Since R_L and D_1 (zener diode) are in parallel,

voltage across R_L = Voltage across D_1

i.e., $\boxed{V_o = V_z}$.

→ From above equation, we find that V_o remains constant even if V_{in} happens to change due to the fluctuations in unregulated voltage.

→ From above figure, it can be seen that

$$\boxed{I_S = I_Z + I_L}$$

$$\therefore \boxed{I_Z = I_S - I_L}$$

Regulation with varying Vin (Line Regulation).

→ In this condition, load parameters are made constant.

→ Only line parameters are varied.

→ With this I_L and R_L will be made constant.

$$\therefore \boxed{I_S = I_Z + I_{L\,constant}}$$

→ When Vin increases, Is also increases. This will effect I_Z and I_L.

→ Though I_L is made constant, the overall effect will be on I_Z. Therefore I_Z increases.

→ As long as the current through zener diode is between I_{Zmin} and I_{Zmax}, the voltage across it is constant. So I_Z can increase only upto I_{Zmax}.

→ This will be controlled by current limiting resistor R_S.

→ Similarly, when Vin decreases, Is also decreases.

→ With this I_Z also decreases with I_L constant.

→ I_Z can decrease only till I_{Zmin}.

→ Hence Voltage is made constant.

Designing of Current Limiting Resistor (R_s).

→ Since the current through zener diode varies with change in input voltage to have proper current through R_s.

→ This has to be taken between two extreme cases.

Thus, $\boxed{R_{s\,min} \leq R_s \leq R_{s\,max}}$

→ When a load (R_L) is connected, the zener current (I_z) will fall as current is diverted into the load resistance.

→ I_z should not fall below minimum current rating of zener diode (I_{zmin}).

→ Similarly, I_z will rise incase of increase in the input voltage (V_{in}). I_z should not exceed I_{zmax} current rating of zener diode.

→ In order to do so, the resistor R_s should be selected properly.

→ The resistors R_s and R_L forms the potential divider network in the above regulator circuit.

→ The ratio of R_s to R_L is thus important.

→ At the point at which the circuit just begins to vary to regulate:

$$\boxed{V_z = V_{in} \frac{R_L}{R_s + R_L}}$$

Thus the maximum value of R_s can be calculated as

$$R_L + R_S = \frac{V_{in} \cdot R_L}{V_Z}$$

$$\therefore R_S = \frac{V_{in} R_L}{V_Z} - R_L$$

$$\therefore \boxed{R_{S_{max}} = R_L\left(\frac{V_{in}}{V_Z} - 1\right)}$$

→ The power dissipated in the zener diode, will be given by $\boxed{P_Z = I_Z \times V_Z}$

→ Hence the minimum value of Rs can be calcuted as

$$R_{S_{min}} = \frac{V_{in} - V_Z}{I_Z} = \frac{V_{in} - V_Z}{P_Z / V_Z} = \frac{(V_{in} - V_Z) \times V_Z}{P_Z}$$

$$\therefore \boxed{R_{S\,min} = \frac{V_{in} V_Z - V_Z^2}{P_{Zmax}}}$$

where P_{Zmax} is the max. rated power dissipated for diode

Numerical.

1) A 5V zener diode has a maximum rated power dissipation of 500mW. If the diode is to be used in a simple regulator circuit to supply a regulated 5V to a load having a resistance of 400Ω. Determine a suitable value of series resistor for operation in conjunction with a supply of 9V.

Solⁿ: Given: $P_{Zmax} = 500\,mW$, $V_Z = 5V$, $R_L = 400\Omega$, $V_{in} = 9V$.

$$\therefore R_{S\,max} = R_L\left(\frac{V_{in}}{V_Z} - 1\right) = 400 \times \left(\frac{9}{5} - 1\right) = \boxed{320\Omega}$$

& $R_{s\,min} = \frac{V_{in} V_Z - V_Z^2}{P_{Z\,max}} = \frac{(9\times5)-5^2}{500\times10^{-3}} = \frac{45-25}{0.5}$

$= \boxed{40\,\Omega}$

$\therefore \boxed{40\,\Omega \leq R_s \leq 320\,\Omega}$

Hence a suitable value of R_s would be $\boxed{150\,\Omega}$ (averaged value).

2) If a 9V zener diode is to be used in a simple shunt regulator circuit to supply a load having a nominal resistance of 300 Ω, determine the maximum value of series resistor for operation in conjunction with a supply of 15V.

Soln: Given, $V_Z = 9V$, $R_L = 300\,\Omega$, $V_{in} = 15V$

$$\therefore R_{s\,max} = R_L\left(\frac{V_{in}}{V_Z} - 1\right)$$

$$= 300\left(\frac{15}{9} - 1\right)$$

$$\boxed{R_{s\,max} = 200\,\Omega}$$

Output Resistance and Voltage Regulation.

→ The output resistance of a power supply is defined as change in output voltage divided by the corresponding change in output current. Hence

$$R_{out} = \frac{\text{change in o/p vtg}}{\text{Change in o/p Current}}$$

$$\therefore \boxed{R_{out} = \frac{\Delta V_{out}}{\Delta I_{out}}}$$

→ The voltage regulation of a power supply is given by the relationship:

$$\text{Regulation} = \frac{\text{Change in o/p voltage}}{\text{Change in i/p voltage}} \times 100\%$$

$$= \boxed{\frac{\Delta V_{out}}{\Delta V_{in}} \times 100\%}$$

Numerical.

1) The following data was obtained during a test carried out on a dc power supply:

i) Load test

Output voltage (no load) = 12V
Output voltage (2A load current) = 11.5V.

ii) Regulation test

Output voltage (mains input, 220V) = 12V
Output voltage (mains input, 200V) = 11.9V.

Determine (a) the equivalent output resistance of power supply and (b) the regulation of the power supply.

Soln:

$$R_{out} = \frac{\Delta V_{out}}{\Delta I_{out}} = \frac{12-11.5}{2-0} = \boxed{0.25\ \Omega}$$

$$\& \text{ Regulation} = \frac{\Delta V_{out}}{\Delta V_{in}} = \frac{12-11.9}{220-200} = \frac{0.1}{20} \times 100\%$$

$$= \boxed{0.5\%}$$

Voltage Multipliers.

→ The voltage multiplier is an electronic circuit that delivers the output voltage whose amplitude is two, three or more times greater than the amplitude of the input voltage.

→ It converts the low AC voltage into high DC voltage

→ It is madeup of diodes and capacitors.

→ Voltage multipliers has different stages. Each Stage is made up of one diode and one capacitor.

→ Although it is usual in electronic circuits to use a voltage transformer to increase a voltage.

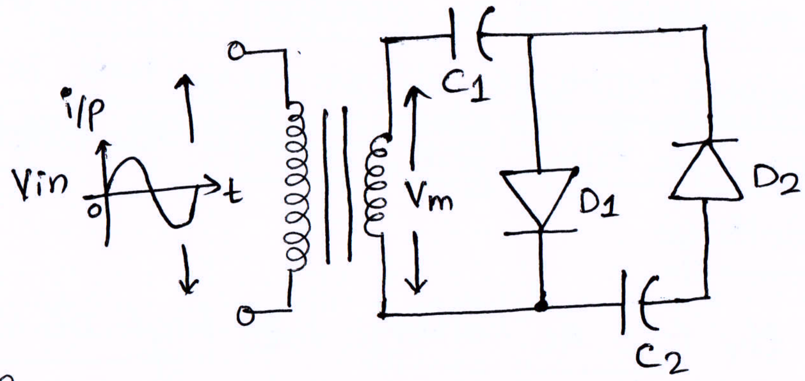
→ Sometimes a suitable step-up transformer required for high voltage applications may not always be available. If so, its size and power consumption will be more.

→ One alternative approach is to use a diode voltage multiplier circuit which increases or "steps-up" the voltage without the use of a transformer.

Types of Voltage Multipliers.

1) Voltage Doubler
2) Voltage Tripler.

Voltage Doubler.



→ The above circuit shows a voltage doubler.

→ During the positive half cycle of input voltage 'Vin', diode 'D_1' becomes forward biased and starts conducting.

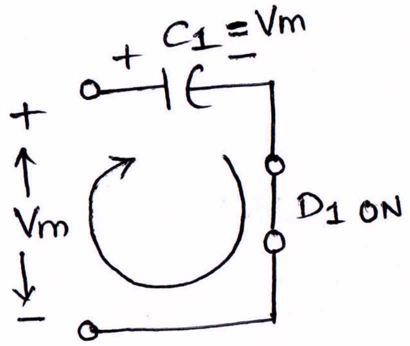
→ In this condition, capacitor 'C_1' starts charging up with maximum peak value of secondary voltage, 'V_m'.

→ Because there is no return path for capacitor 'C_1' to discharge into, it remains fully charged acting as a storage device with the voltage supply.

→ During the negative half cycle of input voltage, diode 'D_1' becomes reverse biased blocking the discharging of 'C_1', while diode 'D_2' becomes forward biased and starts conducting, charging up capacitor 'C_2'

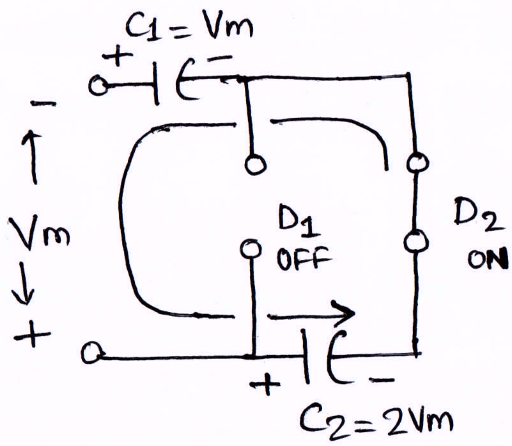
→ But because there is a voltage across capacitor 'C_1' already equal to the peak input voltage (V_m), capacitor 'C_2' charges to twice the peak voltage value of input signal.

→ The detailed working of voltage doubler is as shown below with circuits and analysis.



During +ve half cycle

$$\boxed{V_{C1} = V_m}$$



During −ve half cycle

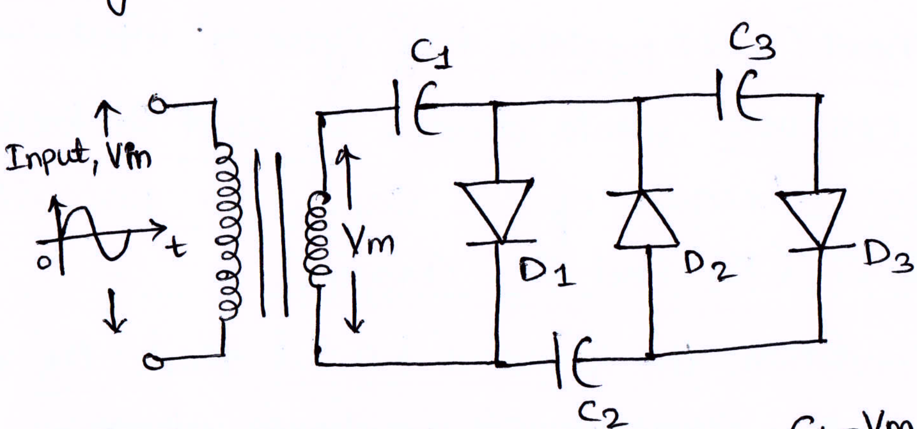
$$-V_{C1} - V_m + V_{C2} = 0$$

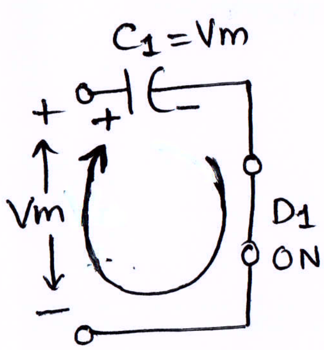
$$\therefore V_{C2} = V_m + V_{C1}$$

$$= V_m + V_m$$

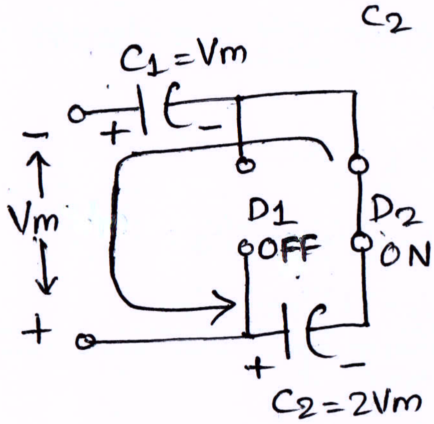
$$\therefore \boxed{V_{C2} = 2V_m}$$

Voltage Tripler

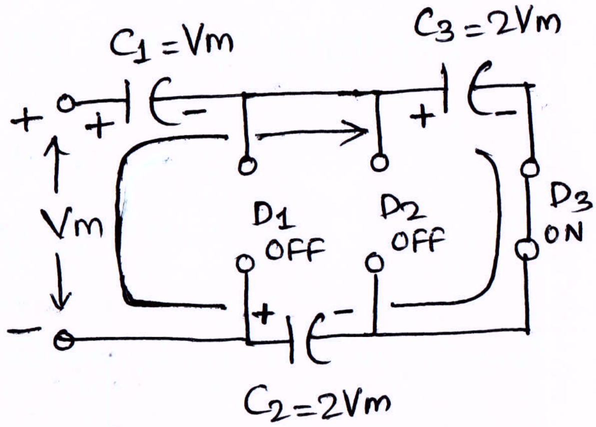




During 1st positive half cycle



During 1st negative half cycle



During 2nd positive half cycle

→ The above figures shows the voltage trippler and working of it in three different stages.

→ During 1st positive half cycle of input voltage V_{in}, diode 'D_1' becomes forward biased and starts conducting, charging up the capacitor 'C_1' as shown above.

$$\therefore \boxed{V_{C1} = V_m}$$

→ During 1st negative half cycle of input voltage V_{in}, diode 'D_1' becomes reverse biased, while diode 'D_2' becomes forward biased and starts conducting, charging up the capacitor 'C_2' as shown above.

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

$$\therefore V_{C2} = V_m + V_{C1} = V_m + V_m = \boxed{2V_m}$$

→ During next (2nd) positive half cycle of input voltage V_{in}, diode D_3 conducts, while diodes D_1 and D_2 becomes reverse biased. because of the capacitor polarity (-ve) across their (D_1 and D_2) anodes.

→ In this condition, the forward biased diode D_3 starts charging up the capacitor C_3 as shown above.

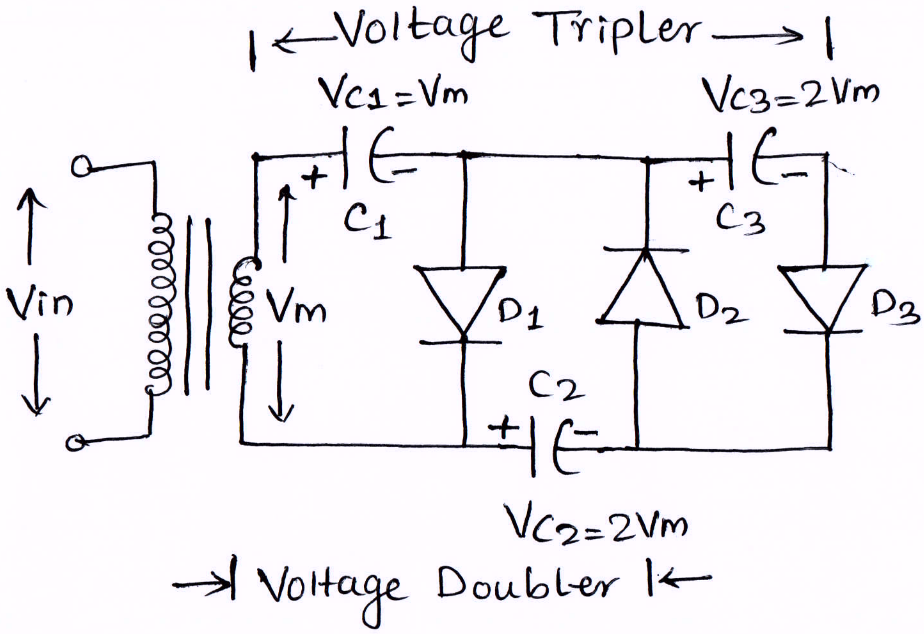
$$-V_{C2} - V_m + V_{C1} + V_{C3} = 0$$

$$\therefore V_{C3} = V_{C2} + V_m - V_{C1}$$

$$= 2V_m + V_m - V_m$$

$$\therefore \boxed{V_{C3} = 2V_m}$$

→ As there is no return path for any capacitors (C_1, C_2, C_3) to discharge into, it remains fully charged acting as storage device.



→ From the above circuit, we can observe that

at C_1 we get V_m

at C_2 we get $2V_m$ → Voltage Doubler

at C_3 we get $2V_m$, to get thrice the input voltage we have to add V_{C1} and V_{C3}, as they are connected in series.

$$\therefore \quad V_{C1} + V_{C3} = V_m + 2V_m = \boxed{3V_m}$$

↑ Voltage Tripler