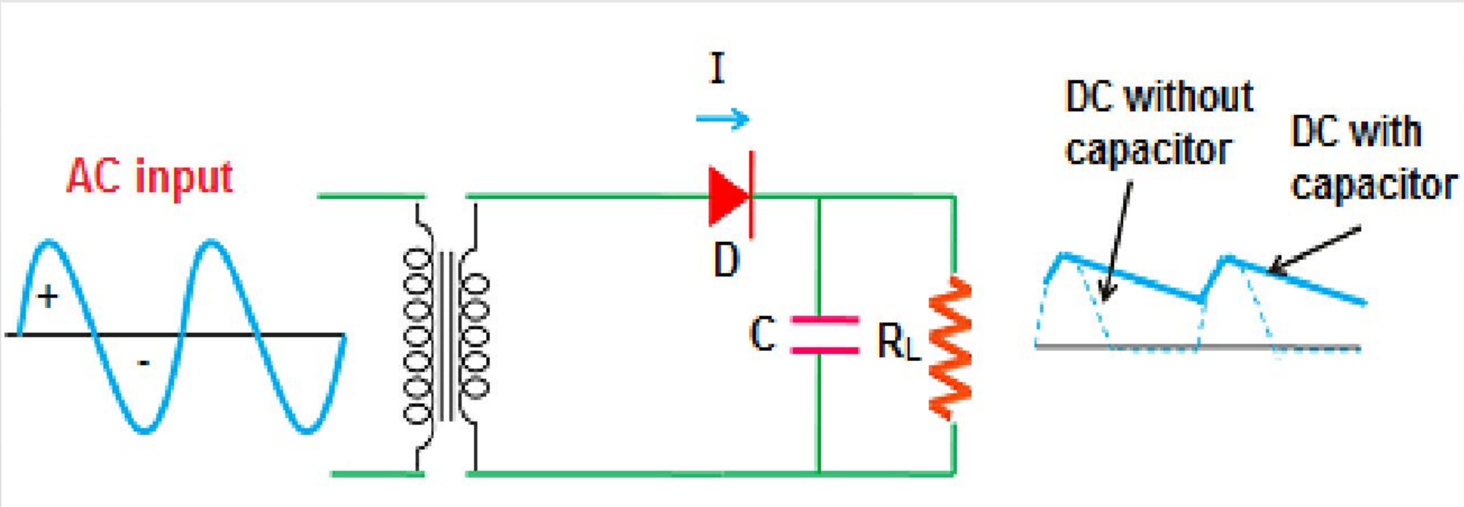
SHUNT CAPACITOR FILTER

FOR HALF WAVE RECTIFIER

A capacitor is connected in parallel with the load resistance as shown in the fig. Reactance of capacitor is given by: $X_c = \frac{1}{\omega C}$. Hence capacitor offers some opposition to the flow of current through it. But for d.c. ω=0, hence $X_c = \infty$ i.e capacitor behaves as open circuit for d.c. Therefore a.c. component in the output of rectifier passes through capacitor and very small amount of a.c. passes through the load. Whereas there is no effect on the amount of that passes through load resistance. Since a.c. component through load resistance decreases, hence ripple factor decreases.

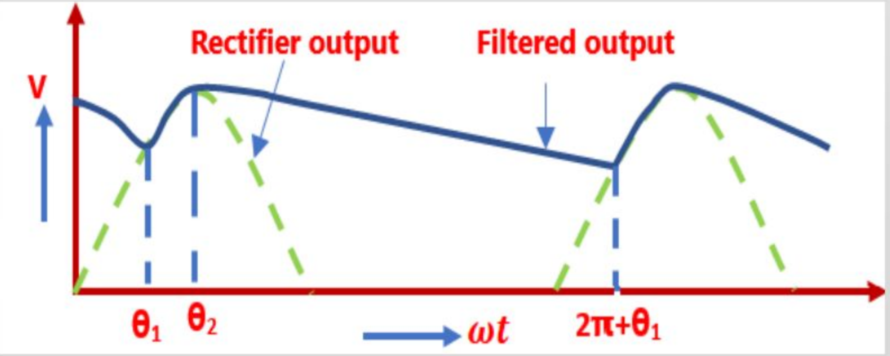


SHUNT CAPACITOR FILTER

Mathematical Analysis

During positive half cycle of input a.c., diode is forward biased and hence conducts electricity. Its resistance is negligible, hence at any time voltage across the capacitor as well as across the load resistance will be same as the input voltage. As the input voltage increase, charge/voltage across the capacitor also increases. This process continues until a.c. attains its peak value and is called charging period. After that input voltage starts decreasing and capacitor also starts discharging, but capacitor discharges slowly through load resistance. Hence input voltage decrease fast as compared to decrease in voltage across capacitor. Hence diode is reverse biased and stops conducting. Current through the diode remains zero and capacitor goes on discharging until next positive half cycle, when again diode is forward biased and starts charging. This time during which current through the diode remains zero is called discharging or non-conducting period.

In fig. angle θ_1 corresponds to the point when diode starts conduction called ignition angle or cut in angle. Conduction continues up to θ_2. Diode stops conducting at θ_2 and up to $2\pi+\theta_1$ non- conducting period continues. During this period Capacitor discharges through load resistance R_L.



SHUNT CAPACITOR FILTER

The voltage across the capacitor or load resistance during charging interval ωt_1 to ωt_2 is equal to supply voltage. i.e.

$$E_c = E = E_m \sin \omega t \qquad \omega t_1 < \omega t < \omega t_2 \qquad \text{....(45)}$$

Neglecting forward resistance of the diode, the current I_{R_L} through the resistance during the same interval is given by:

$$I_{R_L} = \frac{E_m \sin \omega t}{R_L} \qquad \text{.....(46)}$$

Current I_C through the capacitor

$$I_C = \frac{dq}{dt} = \frac{d}{dt}(CE_C) = C\frac{d}{dt}(E_C) = C\frac{d}{dt}(E_m \sin \omega t) = \omega C E_m \cos \omega t \qquad \text{.....(47)}$$

Total current through the diode during the conduction interval is sum of these two currents:

$$I = I_{R_L} + I_C$$

or $$I = \frac{E_m \sin \omega t}{R_L} + \omega C E_m \cos \omega t = E_m\left[\frac{\sin \omega t}{R_L} + \omega C \cos \omega t\right] \qquad \text{....(48)}$$

Multiplying and dividing by $\left(\omega^2 C^2 + \frac{1}{R_L^2}\right)^{1/2}$, we get:

SHUNT CAPACITOR FILTER

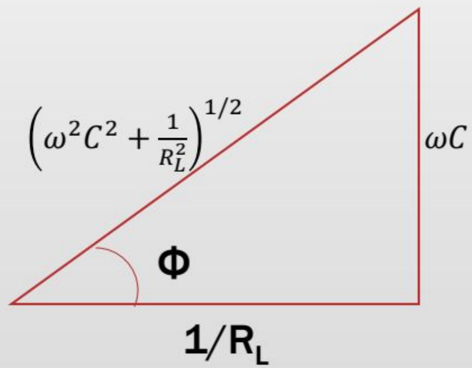
$$I = E_m\left(\omega^2C^2+\frac{1}{R_L^2}\right)^{1/2}\left[\frac{1/R_L}{\left(\omega^2C^2+\frac{1}{R_L^2}\right)^{1/2}}\sin\omega t+\frac{\omega C}{\left(\omega^2C^2+\frac{1}{R_L^2}\right)^{1/2}}\cos\omega t\right] \quad .....(49)$$

Now if Φ is phase difference between current and voltage in parallel combination of C and R_L, then from phase diagram:

$$\cos\emptyset = \frac{1/R_L}{\left(\omega^2C^2+\frac{1}{R_L^2}\right)^{1/2}} \quad .....(50)$$

$$\sin\emptyset = \frac{\omega C}{\left(\omega^2C^2+\frac{1}{R_L^2}\right)^{1/2}} \quad .....(51)$$

and $$\tan\emptyset = \frac{\omega C}{1/R_L} = \omega C R_L \quad .....(52)$$



Substituting in equation (49), we get:

$$I = E_m\left(\omega^2C^2+\frac{1}{R_L^2}\right)^{1/2}[\cos\emptyset\sin\omega t+\sin\emptyset\cos\omega t]$$

or $$I = E_m\left(\omega^2C^2+\frac{1}{R_L^2}\right)^{1/2}\sin(\omega t+\emptyset) \quad .....(53)$$

SHUNT CAPACITOR FILTER

When $t=t_2$, diode stops conducting. i.e. I = 0 at t = t_2, equation (48) becomes

$$0 = E_m \left[\frac{\sin \omega t_2}{R_L} + \omega C \cos \omega t_2\right]$$

or $\frac{\sin \omega t_2}{R_L} = -\omega C \cos \omega t_2$ or $\tan \omega t_2 = -\omega C\, R_L$

Using equation (52)

$-\tan \omega t_2 = \tan \emptyset$ or $\tan(\pi - \omega t_2) = \tan \emptyset$

or $(\pi - \omega t_2) = \emptyset$ or $\emptyset = \pi - \omega t_2$ .....(54)

Substituting in (53)

$$I = E_m \left(\omega^2 C^2 + \frac{1}{R_L^2}\right)^{1/2} \sin(\omega t + \pi - \omega t_2) = E_m \left(\omega^2 C^2 + \frac{1}{R_L^2}\right)^{1/2} \sin[\pi - (\omega t_2 - \omega t)]$$

or $I = E_m \left(\omega^2 C^2 + \frac{1}{R_L^2}\right)^{1/2} \sin(\omega t_2 - \omega t)$ .....(55)

After $\theta_2 = \omega t_2$, the capacitor discharges through R_L and voltage falls. So the diode stops conduction i.e. diode current becomes zero. Thus during non conducting period, we have:

$$I_C + I_{R_L} = 0$$

SHUNT CAPACITOR FILTER

or $C\frac{dE_C}{dt} + \frac{E_C}{R_L} = 0$ or $\frac{dE_C}{dt} + \frac{1}{C}\frac{E_C}{R_L} = 0$ or $\frac{dE_C}{dt} = -\frac{1}{C}\frac{E_C}{R_L}$ or $\frac{dE_C}{E_C} = -\frac{1}{R_L C}dt$

Integrating both sides, we get:

$lnE_C = -\frac{1}{R_L C}t + K$ Where K is constant of integration

Taking antilog on both sides, we get:

$E_C = Aexp\left(-\frac{t}{CR_L}\right)$ Where A is constant .....(56)

At $\omega t = \omega t_2$, $E_C = E_m \sin \omega t_2$

From (56) $Aexp\left(-\frac{t_2}{CR_L}\right) = E_m \sin \omega t_2$

or $A = E_m \sin \omega t_2 exp\left(\frac{t_2}{CR_L}\right)$

Substituting in equation (56)

$$E_C = E_m \sin \omega t_2 exp\left(\frac{t_2}{CR_L}\right) exp\left(-\frac{t}{CR_L}\right) = E_m \sin \omega t_2 exp\left(-\frac{t-t_2}{CR_L}\right)$$

or $E_C = E_m \sin \omega t_2 exp\left[-\frac{\omega(t-t_2)}{\omega CR_L}\right]$ .....(57)

At $\omega t = \omega t_1 + 2\pi$, diode again starts conducting. Therefore:

SHUNT CAPACITOR FILTER

$$E_C = E_m \sin \omega t_2 exp\left[-\frac{2\pi+\omega t_1-\omega t_2}{\omega C R_L}\right] \quad .....(58)$$

d.c. voltage across the load can be calculated by averaging the capacitor voltage over a cycle as:

$$E_{dc} = \frac{1}{2\pi}\int_{\omega t_1}^{\omega t_2} E_m \sin \omega t d(\omega t) + \frac{1}{2\pi}\int_{\omega t_2}^{2\pi+\omega t_1} E_m \sin \omega t_2 exp\left[-\frac{\omega(t-t_2)}{\omega C R_L}\right] d(\omega t) \quad .....(59)$$

The diode starts conducting at $\omega t = \omega t_1 + 2\pi$, so

$$E_C = E_m \sin(2\pi + \omega t_1) = E_m \sin \omega t_1 \quad .....(60)$$

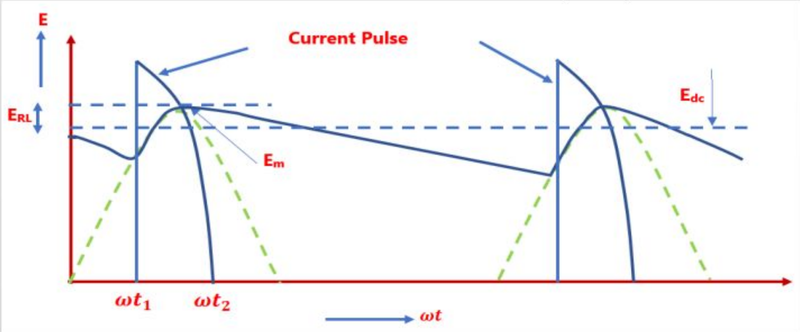
From equations (58) and (60), we have:

$$\sin \omega t_1 = \sin \omega t_2 exp\left[-\frac{2\pi+\omega t_1-\omega t_2}{\omega C R_L}\right] \quad .....(61)$$

Using equations (52), (54) and (61) in (59), we get:

$$E_{dc} = \frac{E_m}{2\pi}(1 + \omega^2 R_L^2 C^2)^{1/2}[1 - \cos(\omega t_2 - \omega t_1)] \quad ....(62)$$

This equation shows that high value of $\omega C R_L$ is needed for small ripple. It is difficult to calculate the ripple factor from equation (62). But if the output wave form is taken approximately as shown in fig., the result can be simplified from the fig. by denoting total capacitor discharge voltage by E_R, we get:



SHUNT CAPACITOR FILTER

$$E_{dc} = E_m - \frac{E_{R_L}}{2}$$

The capacitor discharges during the interval ωt_2 to $2\pi + \omega t_1$. It is assumed that the capacitor loses charges at a constant rate with a current I_{dc}.

The amount of charge lost is:

$$q = \left(\frac{2\pi}{\omega} + t_1 - t_2\right) I_{dc} = \frac{(2\pi + \omega t_1 - \omega t_2)}{\omega} I_{dc}$$

Therefore $$E_{R_L} = \frac{q}{C} = \frac{(2\pi + \omega t_1 - \omega t_2) I_{dc}}{\omega C}$$ .....(63)

The root mean square value of ripple component of the triangular wave is given by:

$$E_{ac} = \frac{E_{R_L}}{2\sqrt{3}}$$

Using (63), above equation can be written as:

$$E_{ac} = \frac{(2\pi + \omega t_1 - \omega t_2) I_{dc}}{2\sqrt{3}\omega C}$$

Ripple factor: $$\gamma = \frac{E_{ac}}{E_{dc}} = \frac{(2\pi + \omega t_1 - \omega t_2) I_{dc}}{2\sqrt{3}\omega C E_{dc}} = \frac{(2\pi + \omega t_1 - \omega t_2) I_{dc}}{2\sqrt{3}\omega C I_{dc} R_L} = \frac{(2\pi + \omega t_1 - \omega t_2)}{2\sqrt{3}\omega C R_L}$$

When $\omega t_1 - \omega t_2 \ll 2\pi$, $$\gamma = \frac{2\pi}{2\sqrt{3}\omega C R_L} = \frac{1}{2\sqrt{3} n C R_L}$$ ....(64)

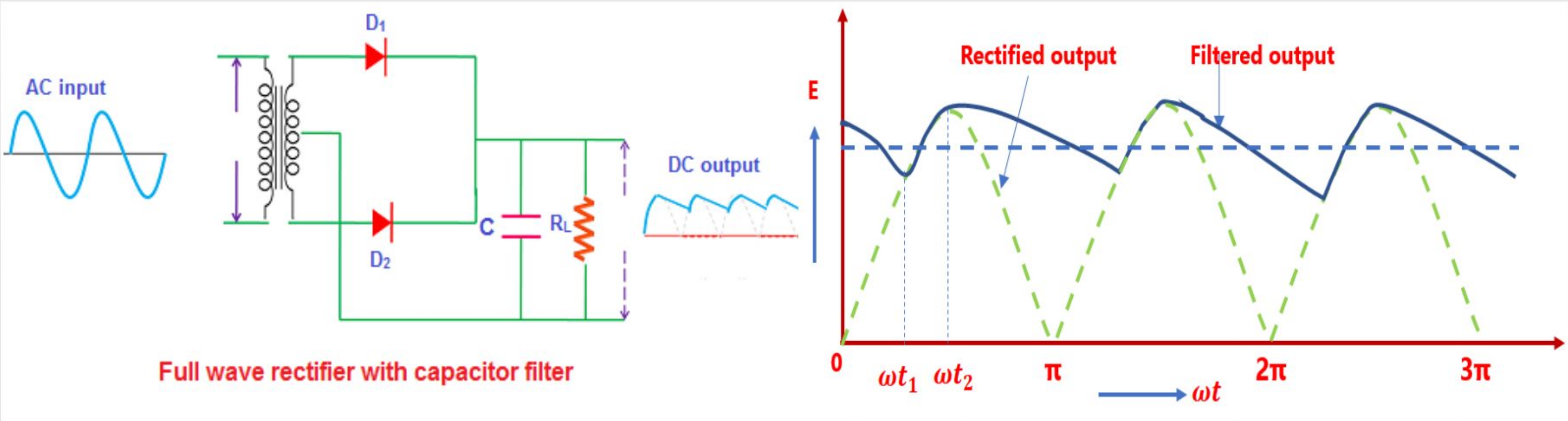
Where $\omega = 2\pi n$, n being frequency of a.c.

SHUNT CAPACITOR FILTER

FOR FULL WAVE RECTIFIER

Circuit diagram for shunt capacitor filter using full wave rectifier is shown in fig. We can also use it with bridge rectifier.

The operation of full wave rectifier shunt capacitor filter is same as that of half wave rectifier shunt capacitor filter, the only difference is that discharging time of capacitor is ωt_2 to $\pi + \omega t_1$ instead of $2\pi + \omega t_1$. Filtered output wave form is also shown in fig.



SHUNT CAPACITOR FILTER

Equation (61) for full wave rectifier can be written as: (replacing 2π with π)

$$\sin \omega t_1 = \sin \omega t_2 exp\left[-\frac{\pi+\omega t_1-\omega t_2}{\omega C R_L}\right] \qquad .....(65)$$

And d.c. output voltage can be obtained by averaging the capacitor voltage from ωt_1 to $\pi + \omega t_1$. The output d.c. will come out to be:

$$E_{dc} = \frac{E_m}{\pi}(1+\omega^2 R_L^2 C^2)^{1/2}[1-\cos(\omega t_2 - \omega t_1)] \qquad ....(66)$$

The value of a.c. component for FWR is given by:

$$E_{ac} = \frac{(\pi+\omega t_1-\omega t_2)I_{dc}}{2\sqrt{3}\omega C}$$

Ripple factor: $\gamma = \frac{E_{ac}}{E_{dc}} = \frac{(\pi+\omega t_1-\omega t_2)I_{dc}}{2\sqrt{3}\omega C E_{dc}} = \frac{(\pi+\omega t_1-\omega t_2)I_{dc}}{2\sqrt{3}\omega C I_{dc} R_L} = \frac{(\pi+\omega t_1-\omega t_2)}{2\sqrt{3}\omega C R_L}$

When $\omega t_1 - \omega t_2 \ll \pi,$ $\gamma = \frac{\pi}{2\sqrt{3}\omega C R_L} = \frac{1}{4\sqrt{3} n C R_L}$ ....(67)

Where $\omega = 2\pi n$, n being frequency of a.c.

We find that ripple factor of full wave rectifier is half of the ripple factor of half wave rectifier.

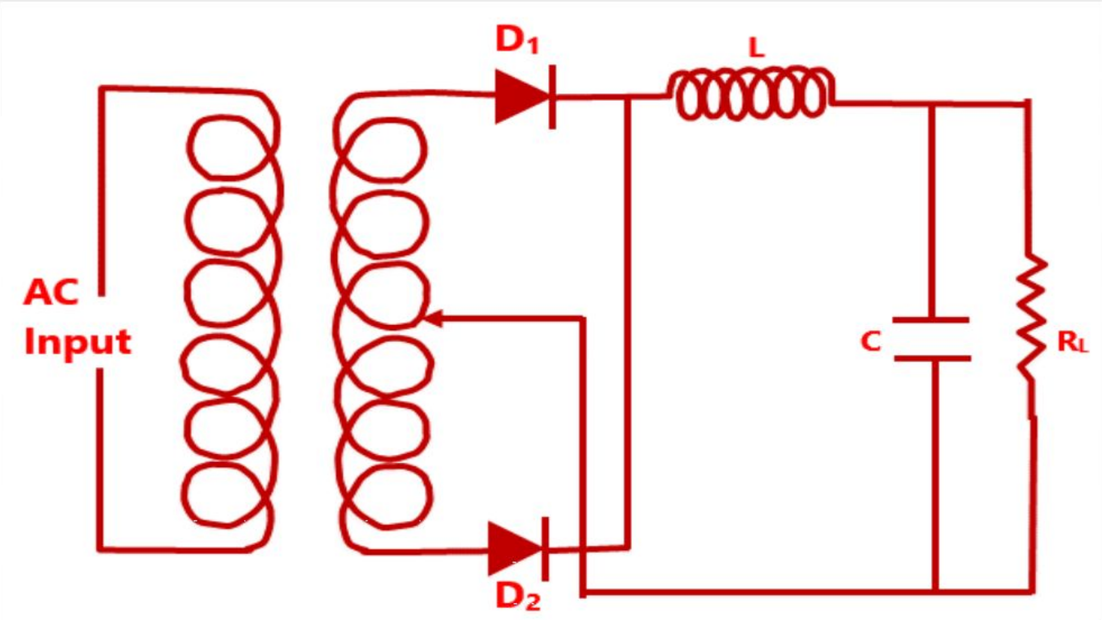
Also ripple factor will be small, if load resistance is large. Hence shunt capacitor filter is used for high load resistances.

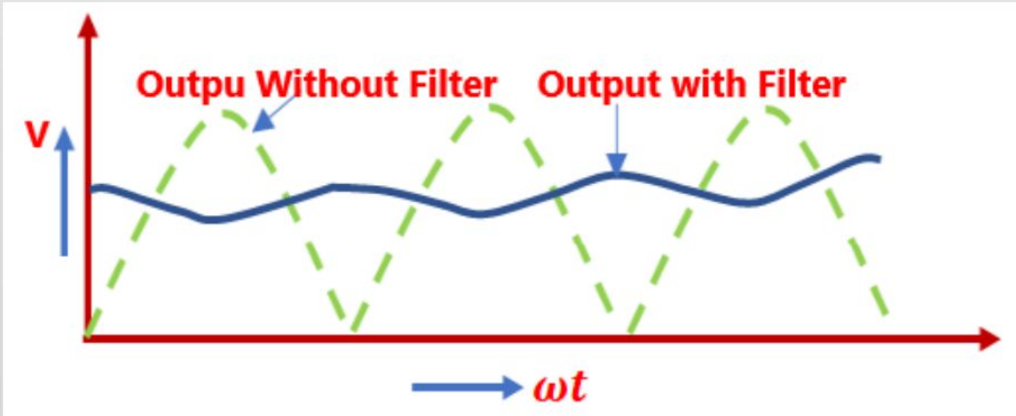
L-SECTION OR INDUCTOR INPUT FILTER

We have seen that series inductor filter is not suitable for high load resistance and shunt capacitor filter is suitable for high load resistance. Hence combination of these two filter circuits can make the ripple factor independent of load resistance.

FOR FULL WAVE RECTIFIER

Circuit diagram and output wave form of L-section filter using full wave rectifier is shown in fig.





L-SECTION OR INDUCTOR INPUT FILTER

Working

The inductor allows d.c. to pass through it easily whereas it opposed the flow of a.c. through it. Therefore it reduces the a.c. component present in the output of rectifier. For d.c. the capacitor behaves as open circuit and allows a.c. to pass through it with some reactance. Hence most of the a.c. coming from inductor passes through capacitor and d.c. passes through load resistance. Hence in the output across load, a.c. component will be very small and thus ripple factor will be reduced to very small value.

Ripple factor

According to Fourier series, the output of full wave rectifier is given by:

$$E = \frac{2E_m}{\pi} - \frac{4}{3}\frac{E_m}{\pi}cos2\theta - \frac{4}{15}\frac{E_m}{\pi}cos4\theta - \cdots \quad .....(68)$$

The first term of the above equation represents the average value of output voltage i.e.

$$E_{dc} = \frac{2E_m}{\pi} \quad ....(69)$$

All other terms represent a.c. components of various frequencies in output of full wave rectifier. These are called second harmonic, fourth harmonic and so on.

D.C. output current will be:

$$I_{dc} = \frac{2E_m}{\pi R_L} \quad ....(70)$$

L-SECTION OR INDUCTOR INPUT FILTER

Complex reactance of capacitor is $\frac{1}{j\omega C}$ and that of inductor is $j\omega L$. Total impedance of parallel combination of load resistance and capacitor is given by: [Using $R=R_1.R_2/(R_1+R_2)$]

$$Z_p = \frac{R_L \frac{1}{j\omega C}}{R_L + \frac{1}{j\omega C}}$$

Now inductor is in series with this combination. Hence total impedance is given by: (Using $R=R_1+R_2$)

$$Z = j\omega L + Z_p = j\omega L + \frac{R_L \frac{1}{j\omega C}}{R_L + \frac{1}{j\omega C}} \qquad .....(71)$$

For second harmonic component of a.c. above equation can be written as:

$$Z_2 = j2\omega L + \frac{R_L \frac{1}{j2\omega C}}{R_L + \frac{1}{j2\omega C}}$$

Since $R_L \gg \frac{1}{j2\omega C}$, Therefore:

$$Z_2 = j2\omega L + \frac{R_L \frac{1}{j2\omega C}}{R_L} = j2\omega L + \frac{1}{j2\omega C} = \frac{-4\omega^2 LC + 1}{j2\omega C} \quad \text{or} \quad |Z_2| = \frac{4\omega^2 LC - 1}{2\omega C} \qquad .....(72)$$

L-SECTION OR INDUCTOR INPUT FILTER

Peak value of second harmonic voltage is: $E_{02} = \frac{4}{3}\frac{E_m}{\pi}$

Peak value of second harmonic current is given by:

$$I_{02} = \frac{E_{02}}{Z_2} = \frac{\frac{4E_m}{3\ \pi}}{\frac{4\omega^2 LC-1}{2\omega C}} = \frac{4}{3}\frac{E_m}{\pi}.\frac{2\omega C}{4\omega^2 LC-1} \quad \text{.....(73)}$$

Root mean square value of second harmonic current is:

$$I_2 = \frac{I_{02}}{\sqrt{2}} = \frac{8\omega C E_m}{3\sqrt{2}\pi(4\omega^2 LC-1)}$$

Since in L-section filter $2\omega L \gg \frac{1}{2\omega C}$ **or** $4\omega^2 LC \gg 1$**, Hence:**

$$I_2 = \frac{8\omega C E_m}{3\sqrt{2}\pi(4\omega^2 LC)} = \frac{\sqrt{2}E_m}{3\pi\omega L} \quad \text{.....(74)}$$

Similarly, impedance due to fourth harmonic component of a.c. is:

$$Z_4 = j4\omega L + \frac{R_L \frac{1}{j4\omega C}}{R_L + \frac{1}{j4\omega C}}$$

Since $R_L \gg \frac{1}{j4\omega C}$**, Therefore:**

$$Z_4 = j4\omega L + \frac{R_L \frac{1}{j4\omega C}}{R_L} = j4\omega L + \frac{1}{j4\omega C} = \frac{-16\omega^2 LC+1}{j4\omega C} \quad \text{or} \quad |Z_4| = \frac{16\omega^2 LC-1}{4\omega C} \quad \text{.....(75)}$$

L-SECTION OR INDUCTOR INPUT FILTER

Peak value of fourth harmonic voltage is: $E_{04} = \frac{4}{15}\frac{E_m}{\pi}$

Peak value of fourth harmonic current is given by:

$$I_{04} = \frac{E_{04}}{Z_4} = \frac{\frac{4}{15}\frac{E_m}{\pi}}{\frac{16\omega^2 LC-1}{4\omega C}} = \frac{4}{15}\frac{E_m}{\pi}.\frac{4\omega C}{(16\omega^2 LC-1)} \quad .....(76)$$

Root mean square value of fourth harmonic current is:

$$I_4 = \frac{I_{04}}{\sqrt{2}} = \frac{16\omega C E_m}{15\sqrt{2}\pi(16\omega^2 LC-1)}$$

Again because $16\omega^2 LC \gg 1$, Hence:

$$I_4 = \frac{16\omega C E_m}{15\sqrt{2}\pi(16\omega^2 LC)} = \frac{\sqrt{2}E_m}{30\pi\omega L} \quad .....(77)$$

Dividing (74) and (77), we get:

$$\frac{I_4}{I_2} = \frac{\sqrt{2}E_m}{30\pi\omega L} \times \frac{3\pi\omega L}{\sqrt{2}E_m} = \frac{1}{10}$$

Hence a.c. component of current due to second harmonic is 10 times that due to fourth harmonic. i.e. contribution to ripple factor due to fourth and higher harmonics is very small as compared to second harmonic. Hence, we calculate ripple factor due to second harmonic only.

L-SECTION OR INDUCTOR INPUT FILTER

As the reactance of capacitor is very small as compared to load resistance, therefore almost whole of a.c. component of current passes through C. As C and R_L are parallel to each other, so the a.c. voltage across R_L is equal to a.c. voltage across C. Hence using (74)

$$E_2 = I_2 X_C = \frac{\sqrt{2}E_m}{3\pi\omega L} . \frac{1}{2\omega C} = \frac{\sqrt{2}E_m}{6\pi\omega^2 LC} \quad .....(78)$$

So ripple factor: Using (69) and (78)

$$\gamma = \frac{E_{ac}}{E_{dc}} = \frac{E_2}{E_{dc}} = \frac{\frac{\sqrt{2}E_m}{6\pi\omega^2 LC}}{\frac{2E_m}{\pi}} = \frac{\sqrt{2}E_m}{6\pi\omega^2 LC} \times \frac{\pi}{2E_m} = \frac{\sqrt{2}}{3} . \frac{1}{4\omega^2 LC} = 0.47 . \frac{1}{4\omega^2 LC} \quad ....(79)$$

Hence ripple factor is independent of load resistance.

From the output graph of filter, we can see that current does not fall to zero during any portion of the voltage variation. Also we find that filtered output voltage is less than the rectified peak value of voltage. This is because the series inductor does not allow the capacitor to charge to peak value when load current is drawn.

L-SECTION OR INDUCTOR INPUT FILTER

Voltage regulation

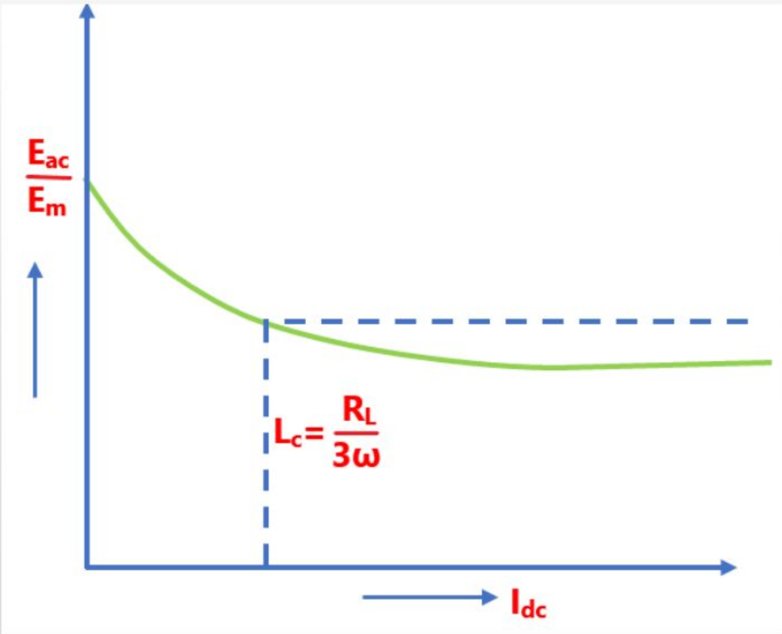
The output of L-Section filter shows that the current does not fall to zero during any portion of the voltage. To satisfy this condition we must have:

$(I_m)_{ac} \leq I_{dc}$ or using (73), we get:

$\frac{4E_m}{6\pi\omega L} \leq \frac{2E_m}{\pi R_L}$ or $\frac{1}{3\omega L} \leq \frac{1}{R_L}$

or $L \geq \frac{R_L}{3\omega}$

The regulation curve of the current for constant R_L and varying L is shown in fig. When L is zero, the filter is simple capacitor and output is almost equal to E_m. As L increases, the output decreases and when L is greater than critical value $\frac{R_L}{3\omega}$, there is no change in the voltage. So to keep L greater than critical value, a small resistance called **Bleeder Resistance** is connected in parallel with the load. This resistance also discharges the capacitor when rectifier is switched off.

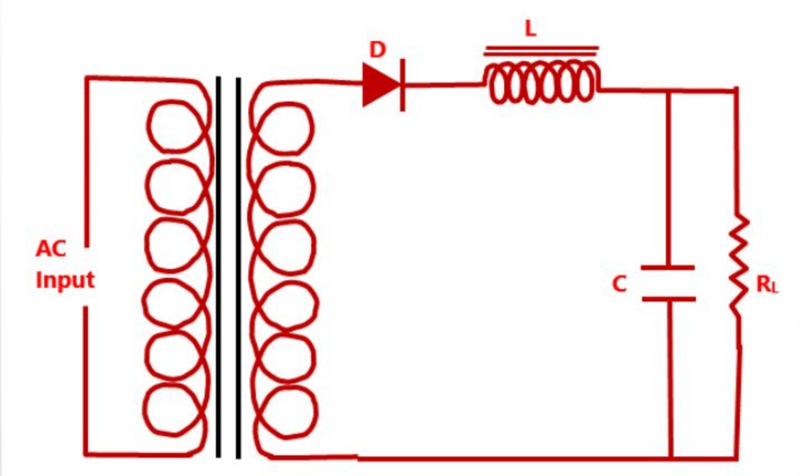


L-SECTION OR INDUCTOR INPUT FILTER

FOR HALF WAVE RECTIFIER

Circuit diagram for L-Section filter using half wave rectifier is shown in fig.

Working is same as explained for full wave rectifier.



Ripple factor

According to Fourier series, the output of half wave rectifier is given by:

$$E = \frac{E_m}{\pi} + \frac{E_m}{2}\sin\omega t - \frac{2}{3}\frac{E_m}{\pi}cos2\omega t - \frac{2}{15}\frac{E_m}{\pi}cos4\omega t - \cdots \quad .....(80)$$

The first term of the above equation represents the average value of output voltage i.e.

$$E_{dc} = \frac{E_m}{\pi} \quad ....(81)$$

All other terms represent a.c. components of various frequencies in output of half wave rectifier. These are called first harmonic, second harmonic, fourth harmonic and so on.

D.C. output current will be:

$$I_{dc} = \frac{E_m}{\pi R_L} \quad ....(82)$$

L-SECTION OR INDUCTOR INPUT FILTER

Complex reactance of capacitor is $\frac{1}{j\omega C}$ and that of inductor is $j\omega L$. Total impedance of parallel combination of load resistance and capacitor is given by: [Using $R=R_1.R_2/(R_1+R_2)$]

$$Z_p = \frac{R_L \frac{1}{j\omega C}}{R_L + \frac{1}{j\omega C}}$$

Now inductor is in series with this combination. Hence total impedance is given by: (Using $R=R_1+R_2$)

$$Z = j\omega L + Z_p = j\omega L + \frac{R_L \frac{1}{j\omega C}}{R_L + \frac{1}{j\omega C}} \quad \text{.....(83)}$$

For first harmonic component of a.c. above equation can be written as:

$$Z_1 = j\omega L + \frac{R_L \frac{1}{j\omega C}}{R_L + \frac{1}{j\omega C}}$$

Since $R_L \gg \frac{1}{j\omega C}$, Therefore:

$$Z_1 = j\omega L + \frac{R_L \frac{1}{j\omega C}}{R_L} = j\omega L + \frac{1}{j\omega C} = \frac{-\omega^2 LC + 1}{j\omega C} \quad \text{or} \quad |Z_1| = \frac{\omega^2 LC - 1}{\omega C} \quad \text{.....(84)}$$

L-SECTION OR INDUCTOR INPUT FILTER

For second harmonic component of a.c. above equation can be written as:

$$Z_2 = j2\omega L + \frac{R_L \frac{1}{j2\omega C}}{R_L + \frac{1}{j2\omega C}}$$

Since $R_L \gg \frac{1}{j2\omega C}$**, Therefore:**

$$Z_2 = j2\omega L + \frac{R_L \frac{1}{j2\omega C}}{R_L} = j2\omega L + \frac{1}{j2\omega C} = \frac{-4\omega^2 LC + 1}{j2\omega C} \quad \text{or} \quad |Z_2| = \frac{4\omega^2 LC - 1}{2\omega C} \qquad .....(85)$$

Peak value of first harmonic voltage is: $E_{01} = \frac{E_m}{2}$

Peak value of first harmonic current is given by:

$$I_{01} = \frac{E_{01}}{Z_1} = \frac{\frac{E_m}{2}}{\frac{\omega^2 LC - 1}{\omega C}} = \frac{E_m}{2} . \frac{\omega C}{\omega^2 LC - 1} \qquad .....(86)$$

Root mean square value of first harmonic current is:

$$I_1 = \frac{I_{01}}{\sqrt{2}} = \frac{\omega C E_m}{2(\omega^2 LC - 1)}$$

Since in L-section filter $\omega L \gg \frac{1}{\omega C}$ **or** $\omega^2 LC \gg 1$**, Hence:**

$$I_1 = \frac{\omega C E_m}{2(\omega^2 LC)} = \frac{E_m}{2\omega L} \qquad .....(87)$$

L-SECTION OR INDUCTOR INPUT FILTER

Peak value of second harmonic voltage is: $E_{02} = \frac{2}{3}\frac{E_m}{\pi}$

Peak value of second harmonic current is given by:

$$I_{02} = \frac{E_{02}}{Z_2} = \frac{\frac{2E_m}{3\ \pi}}{\frac{4\omega^2 LC-1}{2\omega C}} = \frac{2}{3}\frac{E_m}{\pi}.\frac{2\omega C}{4\omega^2 LC-1} \quad \text{.....(88)}$$

Root mean square value of second harmonic current is:

$$I_2 = \frac{I_{02}}{\sqrt{2}} = \frac{4\omega C E_m}{3\pi(4\omega^2 LC-1)}$$

Since in L-section filter $2\omega L \gg \frac{1}{2\omega C}$ or $4\omega^2 LC \gg 1$, Hence:

$$I_2 = \frac{4\omega C E_m}{3\pi(4\omega^2 LC)} = \frac{E_m}{3\pi\omega L} \quad \text{.....(89)}$$

Dividing (87) and (89), we get:

$$\frac{I_2}{I_1} = \frac{E_m}{3\pi\omega L} \times \frac{2\omega L}{E_m} = \frac{1}{5}$$

Hence a.c. component of current due to first harmonic is about 5 times that due to second harmonic. i.e. contribution to ripple factor due to second and higher harmonics is very small as compared to first harmonic. Hence, we calculate ripple factor due to first harmonic only.

L-SECTION OR INDUCTOR INPUT FILTER

As the reactance of capacitor is very small as compared to load resistance, therefore almost whole of a.c. component of current passes through C. As C and R_L are parallel to each other, so the a.c. voltage across R_L is equal to a.c. voltage across C. Hence using (87)

$$E_1 = I_1 X_C = \frac{E_m}{2\omega L} \cdot \frac{1}{\omega C} = \frac{E_m}{2\omega^2 LC} \quad .....(90)$$

So ripple factor: Using (81) and (90)

$$\gamma = \frac{E_{ac}}{E_{dc}} = \frac{E_1}{E_{dc}} = \frac{\frac{E_m}{2\omega^2 LC}}{\frac{E_m}{\pi}} = \frac{E_m}{2\omega^2 LC} \times \frac{\pi}{E_m} = \frac{\pi}{3} \cdot \frac{1}{\omega^2 LC} = 1.05 \cdot \frac{1}{\omega^2 LC} \quad ....(91)$$

Hence ripple factor is independent of load resistance.

π -SECTION OR CAPACITOR INPUT FILTER

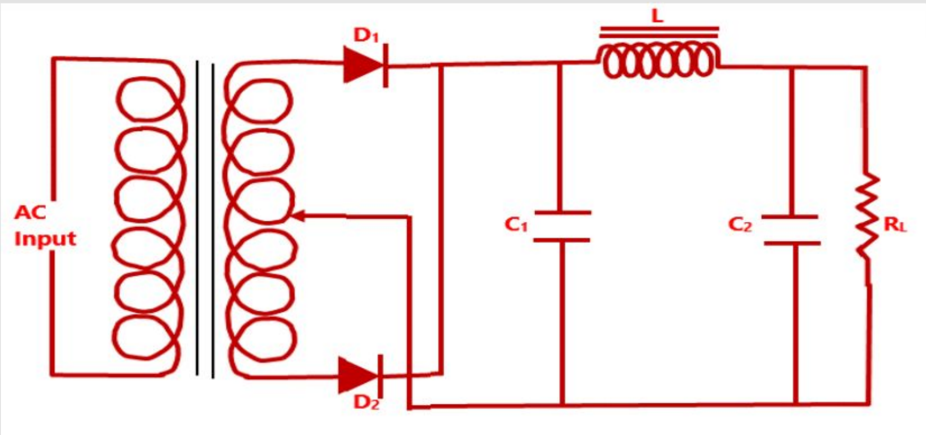
The π-filter is combination of capacitor filter and L-section filter. Circuit diagram of π-section filter used with full wave rectifier is shown in fig. along with the filtered output wave shape. This filter is used when a voltage higher than that obtainable with L-section is required.

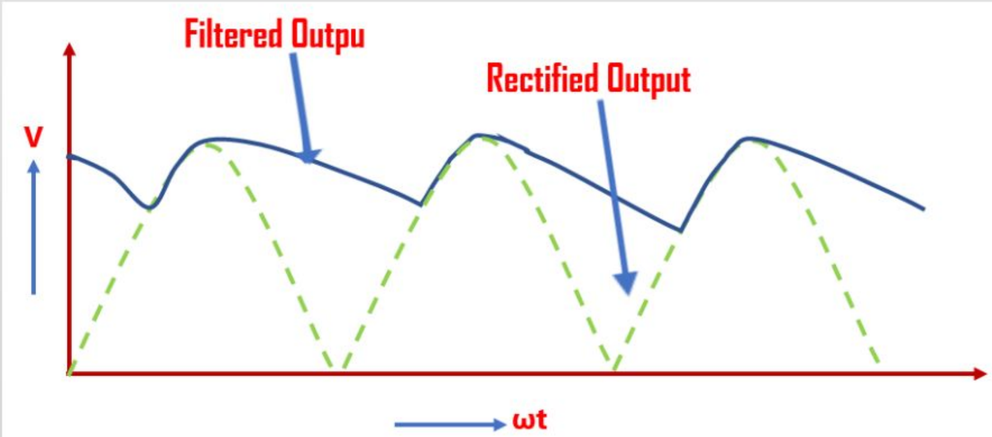
Ripple factor

The ripple factor of π-section filter is approximately equal to the product of ripple factor due to capacitor filter and the ripple factor due to L-section filter. i.e.

$$\gamma_\pi = \gamma_C \times \gamma_L$$

Now $$\gamma_\pi = \frac{\pi}{2\sqrt{3}\omega C_1 R_L} \times \frac{\sqrt{2}}{3} \cdot \frac{1}{4\omega^2 L C_2} = \frac{\sqrt{2}\pi}{3\sqrt{3}(8\omega^3 C_1 C_2 L R_L)} = \frac{0.854}{8\omega^3 L C_1 C_2 R_L}$$ From (67) and (79)





VOLTAGE MULTIPLIER CIRCUITS

A **Voltage Multiplier Circuit**, is a special type of rectifier circuit which produces a DC output voltage which is many times greater than its AC input voltage. Although it is usual to use a transformer to increase the voltage, sometimes a suitable step-up transformer or a specially insulated transformer required for high voltage applications may not be available. One alternative approach is to use a voltage multiplier circuit.

Voltage multipliers are AC-to-DC voltage converters used in electrical and electronic circuit applications such as in microwave ovens, cathode-ray tube (CRT) field coils, electrostatic and high voltage test equipment, etc, where it is necessary to have a very high DC voltage generated from a relatively low AC voltage. The high voltage produced by a *voltage multiplier circuit* is in theory unlimited, but due to their relatively poor voltage regulation and low current capability most multiplier circuits produce voltages in the range of about 10kV to 30kV with a low current of less than ten milliamperes.
Voltage multiplier circuits are constructed from series combinations of rectifier diodes and capacitors that give a DC output equal to some multiple of the peak voltage value of the AC input voltage.

VOLTAGE MULTIPLIER CIRCUITS

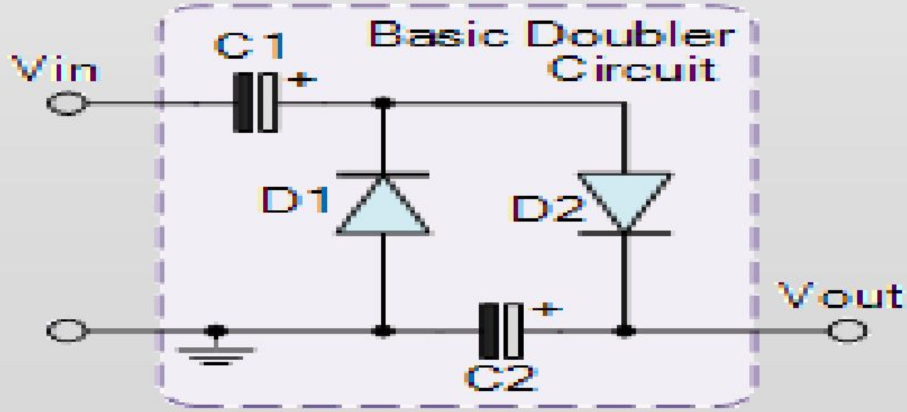
VOLTAGE DOUBLER

The **Voltage Doubler** circuit shown consists of only two diodes, two capacitors and an oscillating input voltage.

Working

During the negative half of the sinusoidal input waveform, diode D1 is forward biased and conducts charging up the pump capacitor, C1 to the peak value of the input voltage, (Vp). Capacitor C1 now acts as a battery in series with the supply. At the same time diode D2 conducts via D1 charging up capacitor, C2. During the positive half cycle, diode D2 is forward biased and diode D1 is reverse biased, adding the peak AC input voltage to the voltage Vp across capacitor C1 and transferring this summed voltage to capacitor, C2 through diode D2 as shown.

The voltage across capacitor, C2 is equal to the sum of the peak supply voltage and the voltage across input capacitor, C1. Then a half wave voltage doubler's output voltage can be calculated as: V_{out} = 2Vp, where V_p is the peak value of the input voltage.

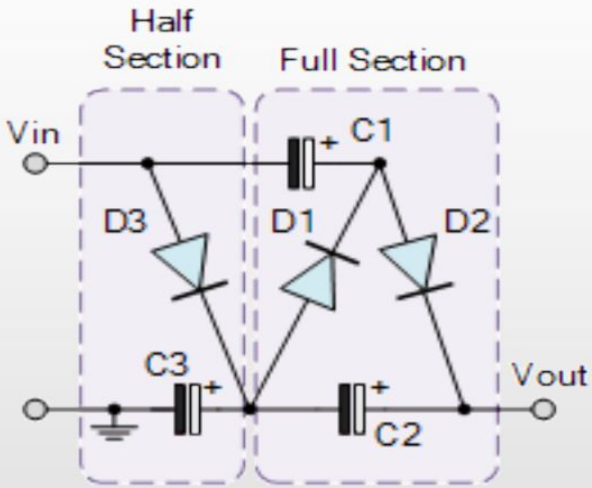


VOLTAGE MULTIPLIER CIRCUITS

VOLTAGE TRIPLER

By connecting the output of one multiplying circuit onto the input of the next (cascading), we can continue to increase the DC output voltage to produce voltage triplers, or voltage quadruples circuits, etc, as shown.

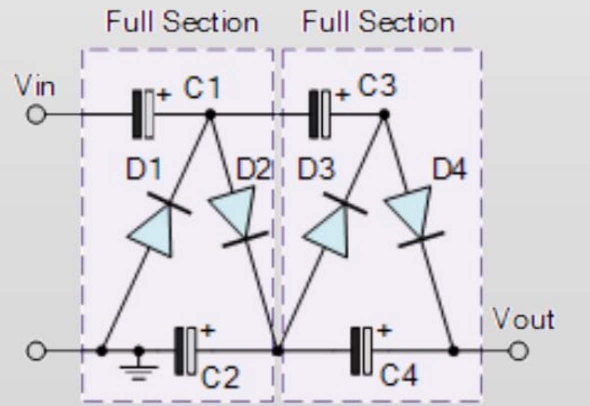
A "voltage tripler circuit" consists of one and a half voltage doubler stages. This voltage multiplier circuit gives a DC output equal to three times the peak voltage value (3Vp) of the sinusoidal input signal.



VOLTAGE QUADRUPLER

If a voltage tripler circuit can be made by cascading together one and a half voltage multipliers, then a "voltage quadrupler circuit" can be constructed by cascading together two full voltage doubler circuits as shown. The first stage doubles the peak input voltage and the second stage doubles it again, giving a DC output equal to four times the peak voltage value (4Vp) of the sinusoidal input signal.

By cascading together individual half and full multiplier stages in series, any desired amount of voltage multiplication can be obtained.



THANK YOU