FILTER CIRCUITS
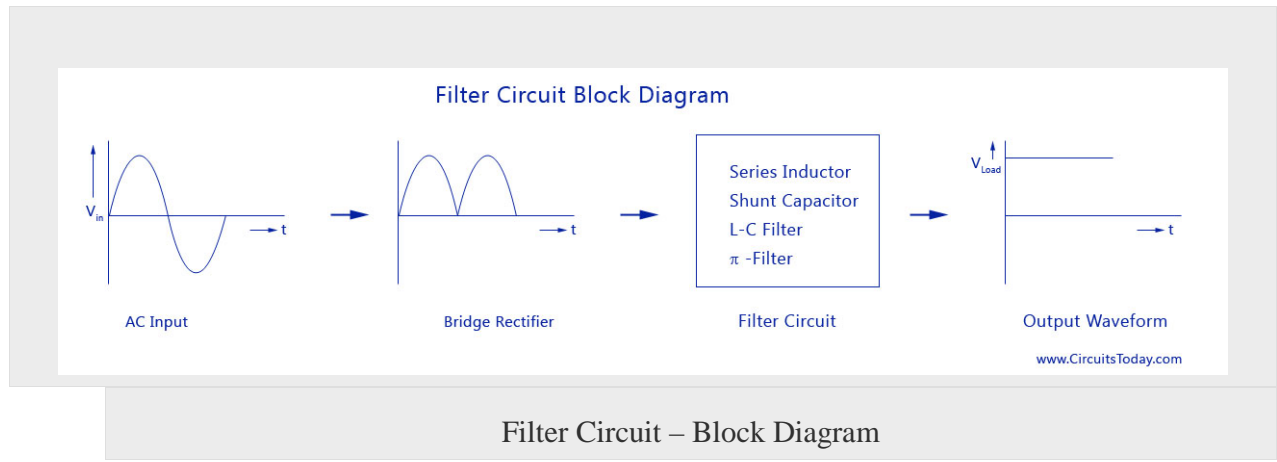

Filter Circuit – Block Diagram

We have learnt in **rectifier circuits** about converting a sinusoidal ac voltage into its corresponding pulsating dc. Apart from the dc component, this pulsating dc voltage will have unwanted ac components like the components of its supply frequency along with its harmonics (together called ripples). These ripples will be the highest for a **single-phase half wave rectifier** and will reduce further for a **single-phase full wave rectifier**. The ripples will be minimum for **3-phase rectifier circuits**. Such supply is not useful for driving complex electronic circuits. For most supply purposes constant dc voltage is required than the pulsating output of the rectifier. For most applications the supply from a rectifier will make the operation of the circuit poor. If the rectifier output is smoothened and steady and then passed on as the supply voltage, then the overall operation of the circuit becomes better. Thus, the output of the rectifier has to be passed though a filter circuit to filter the ac components.

The filter is a device that allows passing the dc component of the load and blocks the ac component of the rectifier output. Thus the output of the filter circuit will be a steady dc voltage.
The filter circuit can be constructed by the combination of components like capacitors, resistors, and inductors. Inductor is used for its property that it allows only dc components to pass and blocks ac signals. Capacitor is used so as to block the dc and allows ac to pass. All the combinations and their working are explained in detail below.

Series Inductor Filter
The circuit diagram of a full wave rectifier with a series inductor filter is given below.
As the name of the filter circuit suggests, the Inductor L is connected in series between the rectifier circuit and the load. The inductor carries the property of opposing the change in current that flows through it.

In other words, the inductor offers high impedance to the ripples and no impedance to the desired dc components. Thus the ripple components will be eliminated. When the rectifier output current increases above a certain value, energy is stored in it in the form of a magnetic field and this energy is given up when the output current falls below the average value. Thus all the sudden changes in current that occurs in the circuit will be smoothened by placing the inductor in series between the rectifier and the load.

The waveform below shows the use of inductor in the circuit.
From the circuit, for zero frequency dc voltage, the choke resistance Ri in series with the load resistance RL forms a voltage divider circuit, and thus the dc voltage across the load is
Vdc = RL/(Ri + RL)
Vdc is the output from a full wave rectifier. In this case, the value of Ri is negligibly small when compared to RL.

The effect of higher harmonic voltages can be easily neglected as better filtering for the higher harmonic components take place. This is because of the fact that with the increase in frequency, the reactance of the inductor also increases. It should be noted that a decrease in the value of load resistance or an increase in the value of load current will decrease the amount of ripples in the circuit. So, the series inductor filter is mostly used in cases of high load current or small load resistance. A simple series inductor filter may not be properly used. It is always better to use a shunt capacitor (C) with series inductor (L) to form an LC Filter.
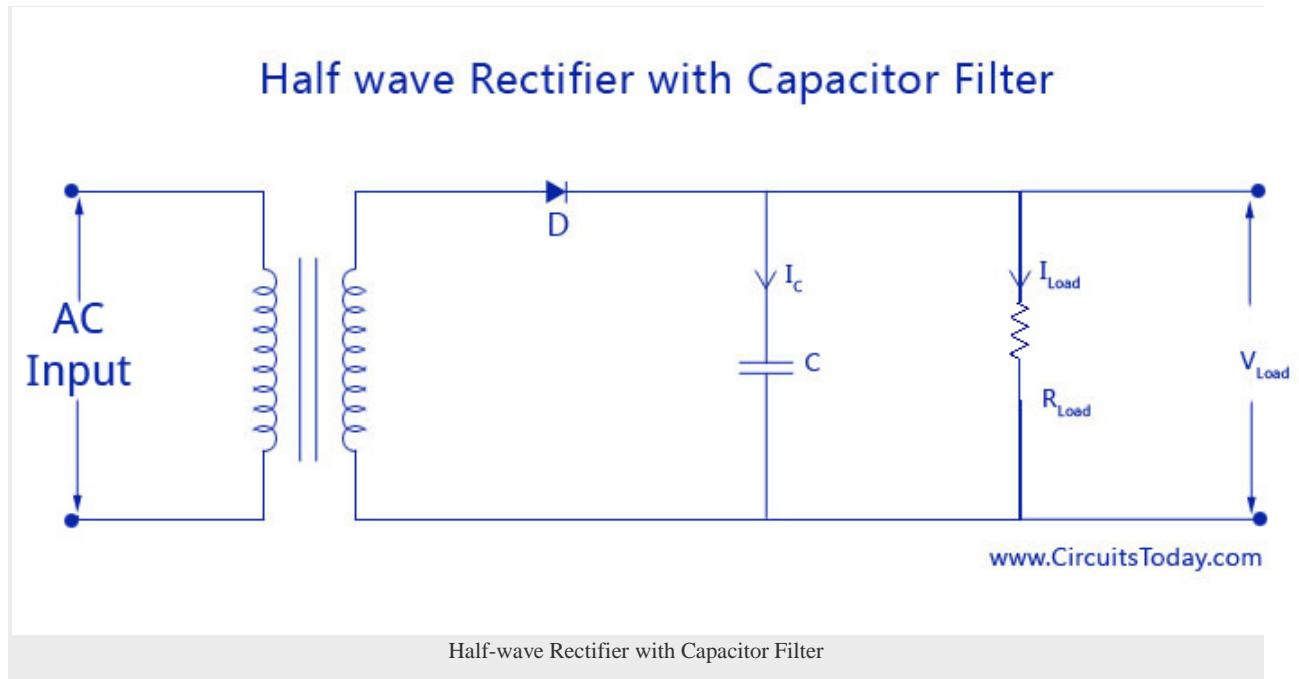
Shunt Capacitor Filter

As the name suggests, a capacitor is used as the filter and this high value capacitor is shunted or placed across the load impedance. This capacitor, when placed across a rectifier gets charged and stores the charged energy during the conduction period. When the rectifier is not conducting, this energy charged by the capacitor is delivered back to the load. Through this energy storage and delivery process, the time duration during which the current flows through the load resistor gets increased and the ripples are decreased by a great amount. Thus for the ripple component with a frequency of 'f' megahertz, the capacitor 'C' will offer a very low impedance. The value of this impedance can be written as:

Shunt Capacitor Impedance = 1/2 fC
Thus the dc components of the input signal along with the few residual ripple components, is only allowed to go through the load resistance RLoad. The high amount of ripple components of current gets bypassed through the capacitor C.
Now let us look at the working of Half-wave rectifier and Full-wave rectifier with Capacitor filters, their output filtered waveform, ripple factor, merits and demerits in detail.
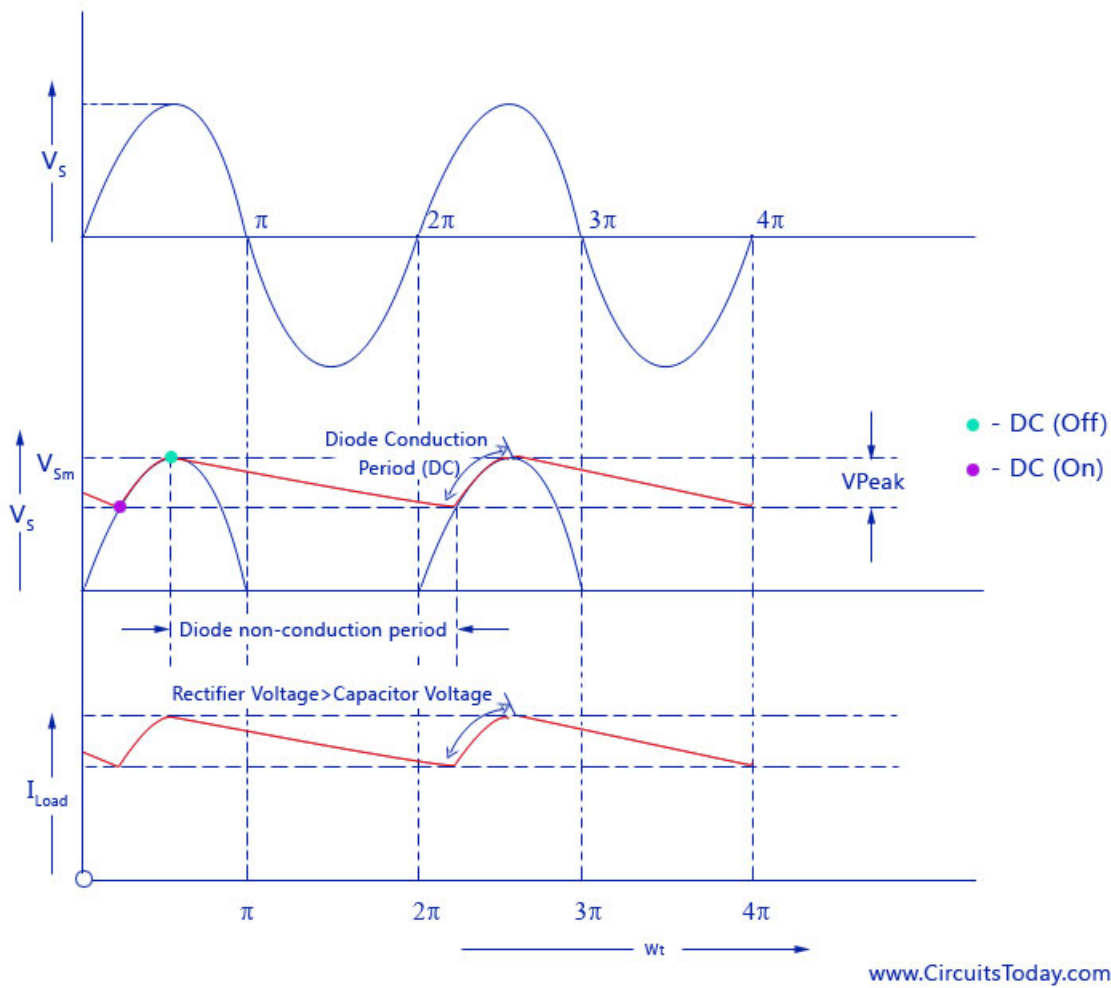
2.1 Half-wave Rectifier with Capacitor Filter

Half-wave Rectifier with Capacitor Filter

The circuit diagram above shows a half-wave rectifier with a capacitor filter. The filter is applied across the load RLoad. The output of the RLoad is VLoad, the current through it is ILoad. The current through the capacitor is Ic.

During the positive half cycle of the input ac voltage, the diode D will be forward biased and thus starts conducting. During this period, the capacitor 'C' starts charging to the maximum value of the supply voltage Vsm. When the capacitor is fully charged, it holds the charge until the input ac supply to the rectifier reaches the negative half cycle. As soon as the negative half supply is reached, the diode gets reverse biased and thus stops conducting. During the non-conducting period, the capacitor 'C' discharges all the stored charges through the output load resistance RLoad. As the voltage across RLoad and the voltage across the capacitor 'C' are the same (VLoad = Vc), they decrease exponentially with a time constant (C*RLoad) along the curve of the non-conducting period. This is shown in the graph below.

Half-wave Rectifier with Capacitor Filter - Waveform

The value of the discharge time constant (C*RLoad) being very large, the capacitor 'C' will not have enough time to discharge properly. As soon as the capacitor starts discharging, the time becomes over. Thus the value of RLoad at the discharge time will also be high and have just a little less value that the output of RLoad. This is when the positive half cycle repeats again and the diode starts conducting. The condition to be considered at this stage is that the rectified voltage takes value more than the capacitor voltage . When the condition occurs the capacitor starts charging to a value of Vsm. The condition again changes when the negative half cycle comes into pace, and the whole cycle is again repeated to form the output waveform as shown above. The output shows a nearly constant dc voltage at the load and that the output voltage is increased considerably.

Thus, in short:

- If the value of load resistance is large, the discharge time constant will be of a high value, and thus the capacitors' time to discharge will get over soon. This lowers the amount of ripples in the output and increases the output voltage. If the load resistance is small, the discharge time constant will be less, and the ripples will be more with decrease in output voltage.
- The value of the capacitor used plays an important role in determining the output ripples and the average dc level. If the capacitor value is high, the amount of charge it can store will be high and the amount it discharges will be less. Thus the ripples will be less and the average dc level will be high. But, there is a limit on how much capacitance can b increased. If the capacitor value is increased to a very high value, the amount of current required to charge the capacitor to a given voltage will be high. This value of current depends on the manufacturer of the diode and will be surely limited to a certain value. Thus, there is a limit in increasing the capacitor value in a half-wave rectifier shunt capacitor filter circuit.
- Poor voltage regulation.

Ripple Factor

The rms value depends on the peak value of charging and discharging magnitude, Vpeak.
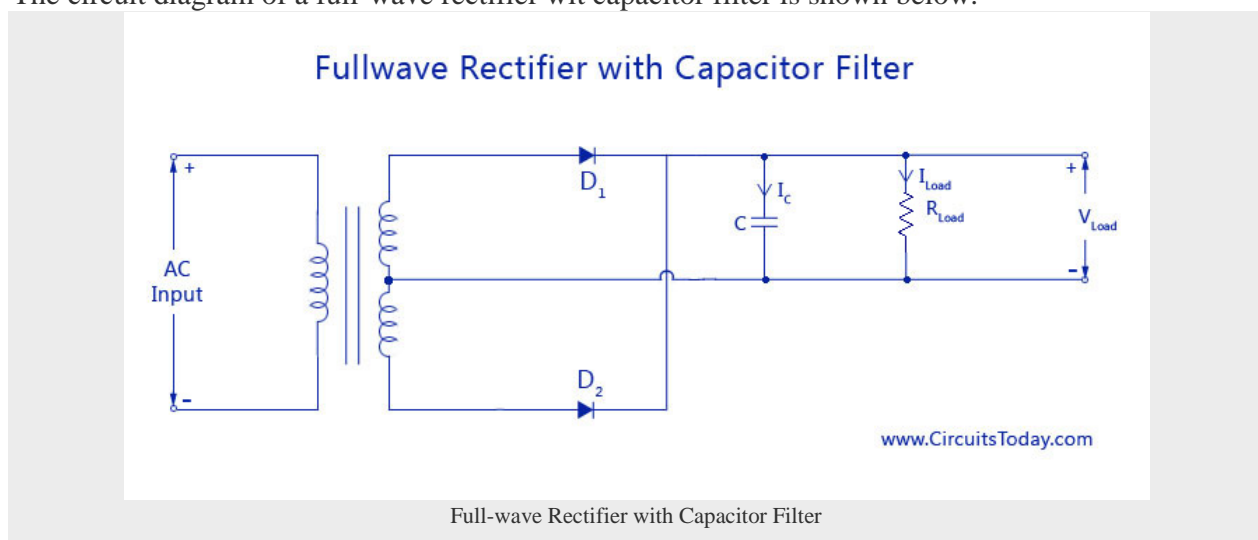
Vac rms = Vpeak/2

Vpeak = Idc/fC

Ripple Factor = Vac rms/Vdc = (Vpeak/2) * (1/Idc.RLoad)

= Idc/(2 .Idc.RLoad.f.C) = 1/(2 fCRLoad)

2.2 Full-wave Rectifier with Shunt Capacitor Filter

The circuit diagram of a full-wave rectifier wit capacitor filter is shown below.

Full-wave Rectifier with Capacitor Filter

The filter capacitor C is placed across the resistance load RLoad. The whole working is pretty much similar to that of a half-wave rectifier with shunt capacitor explained above. The only difference is that two pulses of current will charge the capacitor during alternate positive (D1) and negative (D2)

half cycles. Similarly capacitor C discharges twice through RLoad during one full cycle. This is shown in the waveform below.
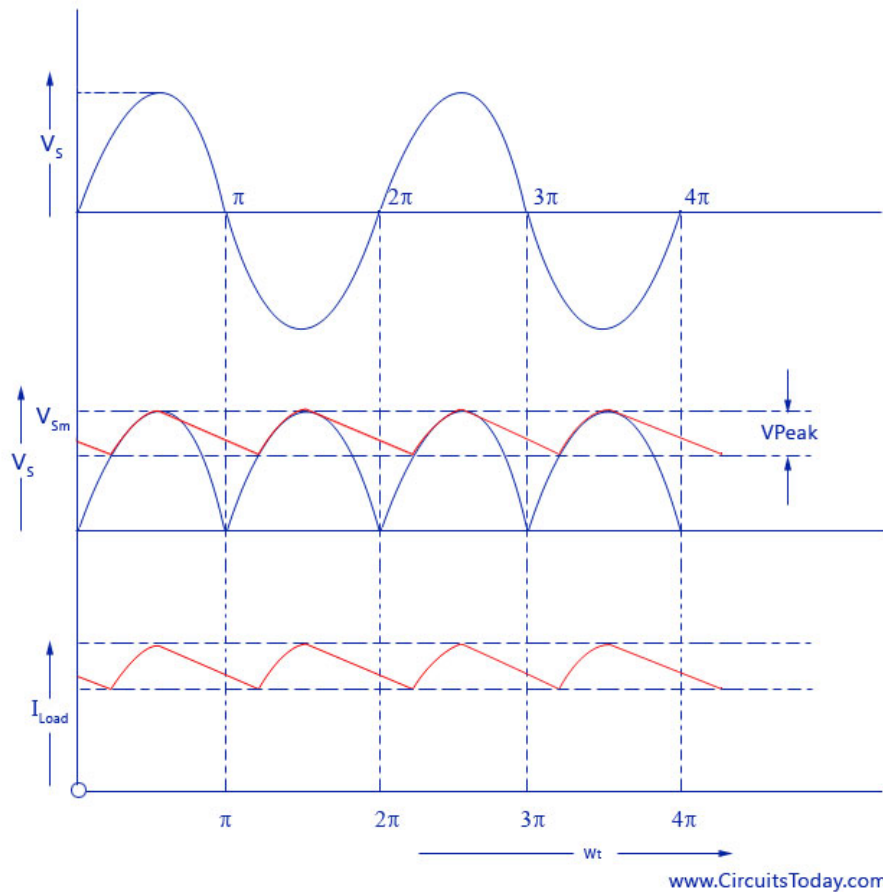
Full-wave Rectifier with Capacitor Filter - Waveform

The load current reduces by a smaller amount before the next pulse is received as there are 2 current pulses per cycle. This causes a good reduction in ripples and a further increase in the average dc load current.

L-C Filters

In the simple shunt capacitor filter circuit explained above, we have concluded that the capacitor will reduce the ripple voltage, but causes the diode current to increase .This large current may damage the diode and will further cause heating problem and decrease the efficiency of the filter. On the other hand, a simple series inductor reduces both the peak and effective values of the output current and output voltage. Then if we combine both the filter (L and C), a new filter called the L-C filter can be designed which will have a good efficiency, with restricted diode current and enough ripple removal

factor .The voltage stabilizing action of shunt capacitor and the current smoothing action of series inductor filter can be combined to form a perfect practical filter circuit.

L-C filters can be of two types: Choke Input L-section Filter and L-C Capacitor input filter

Choke Input L-Section Filter

An inductor filter increases the ripple factor with the increase in load current Rload. A capacitor filter has an inversely proportional ripple factor with respect to load resistance. Economically, both inductor filter and capacitor filter are not suitable for high end purpose

L-C inductor input or L-section filter consists of an inductor ' L' connected in series with a half or full wave rectifier and a capacitor 'C' across the load. This arrangement is also called a choke input filter or L-section filter because it's shape resembles and inverted L-shape. To increase the smoothing action using the filter circuit, just one L-C circuit will not be enough. Several L-section filters will be arranged to obtain a smooth filtered output. The circuit diagram and smoothened waveform of a Full wave rectifier output is shown below.

L-C Filter Inductor input L-Section Filter
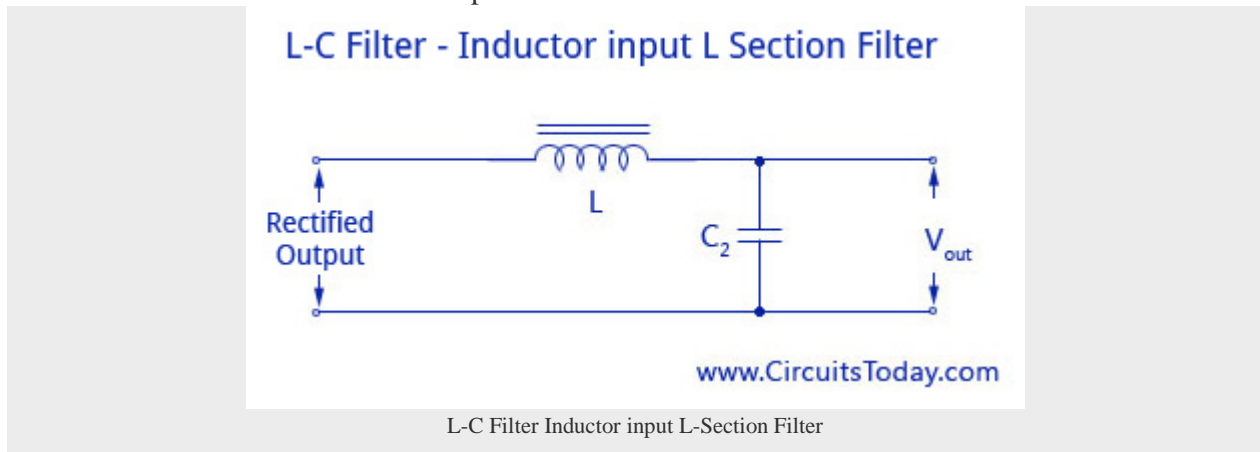
As shown in the circuit diagram above, the inductor L allows the dc to pass but restricts the flow of ac components as its dc resistance is very small and ac impedance is large. After a signal passes through the choke, if there is any fluctuation remaining the current, it will be fully bypassed before it reaches the load by the shunt capacitor because the value of Xc is much smaller than Rload. The number of ripples can be reduced to a great amount by making the value of XL greater than Xc at ripple frequency.

Ripple Factor

Ripple Factor = Vac rms/Vdc = $(\sqrt{2}/3)(Xc/XL) = (\sqrt{2}/3)(1/[2wc])(1/[2wL]) = 1/(6\sqrt{2}w^2LC)$

Though the L-C filter has all these advantages, it has now become quite obsolete due the huge size of inductors and its cost of manufacturing. Nowadays, IC voltage regulators are more commonly used along with active filters, that reduce the ripples and keeps the output dc voltage constant.

The diagram of L-C Capacitor input filter and waveform is shown below.

Π – Filter or Capacitance Input Filter

The name pi – Filter implies to the resemblance of the circuit to a Π shape with two shunt capacitances (C1 and C2) and an inductance filter 'L'. As the rectifier output is provided directly into the capacitor it also called a capacitor input filter.

The output from the rectifier is first given to the shunt capacitor C. The rectifier used can be half or full wave and the capacitors are usually electrolytic even though they large in size. In practical applications, the two capacitances are enclosed in a metal container which acts as a common ground for the two capacitors. Circuit diagram and the waveform are given below.

L-C Filter-Capaitor input Filter
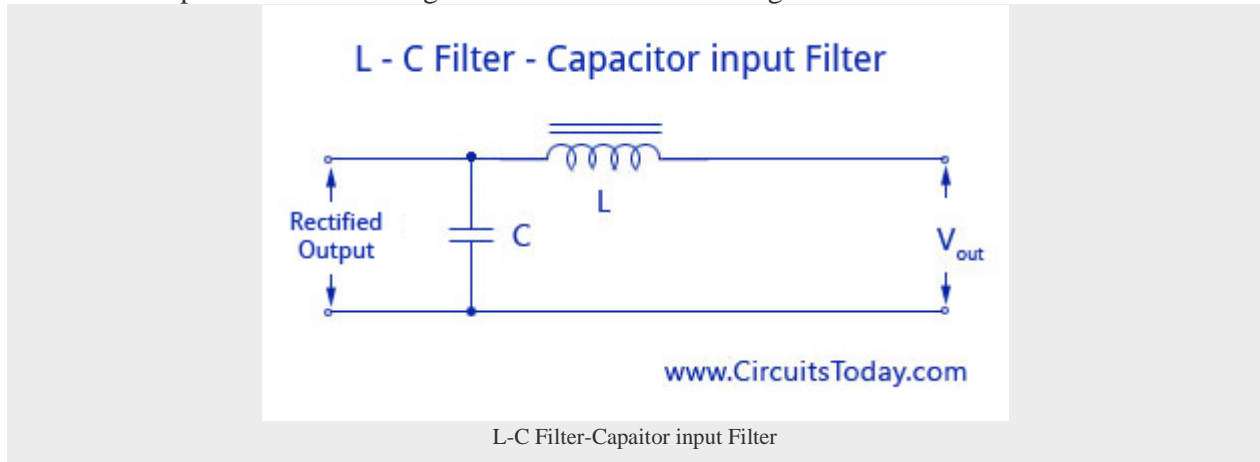
When compared to other type of filters, the Π – Filter has some advantages like higher dc voltage and smaller ripple factor. But it also has some disadvantages like poor voltage regulation, high peak diode current, and high peak inverse voltage.

This filter is divided into two – a capacitor filter and a L-section filter. The capacitor C1 does most of the filtering in the circuit and the remaining ripple os removed by the L-section filter (L-C2). C1 is selected to provide very low reactance to the ripple frequency. The voltage regulation is poor for this circuit as the output voltage falls off rapidly with the increase in load current.

Ripple Factor

Ripple Factor = $\sqrt{2}/(8w^3 C1 C2 L R load)$

R-C Filter

We have already discussed about the drawbacks of using a pi-filter. The main reason for all these drawbacks is the use of inductor in the filter circuit. If we use a resistance in series, instead of the inductor as the filter, these drawbacks can be overcome. Thus the circuit is named as R-C filter. In this circuit, the ripples have to be made to drop across the resistance R instead of the load resistance RL. For this, the value of RL is kept much larger than the value of reactance of capacitor C2 (XC2). This means that each section reduces the ripple by a factor of at least 10.

R-C Filter
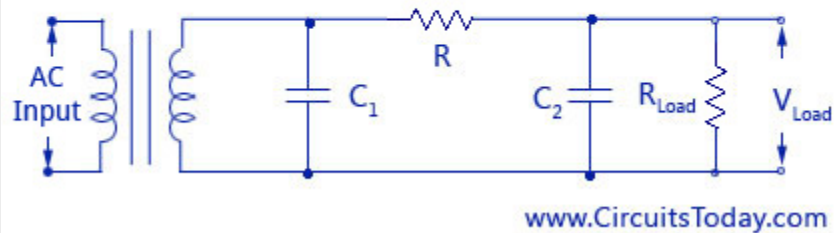
R-C Filter

Though the circuit nullifies certain drawbacks of the pi-filter, the circuit on its own has some problems as well. The filter has very poor voltage regulation. There is a large voltage drop in the resistance R. The circuit also develops a lot of heat and this has to be dissipated through enough and adequate ventilation. Thus, the filter is only suitable for small load current or large load resistance circuits.

Source : http://www.circuitstoday.com/filter-circuits#series-inductor-filter