Tishk International University
Engineering Faculty
Mechatronics Engineering Department
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Electronics Principles and Devices
Rectifier with Filter

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Outline

- Rectifier with Filters
- Operation of Capacitor filter
- Ripple voltage
- Ripple factor
- Ripple factor for Rectifier circuits without Filters
- Ripple factor for Rectifier circuits with Filters
- Examples

Power Supply Filters

- A power supply filter ideally eliminates the fluctuations in the output voltage of a half-wave or full-wave rectifier and produces a constant-level dc voltage.
- Filtering is necessary because electronic circuits require a constant source of dc voltage and current to provide power and biasing for proper operation.
- Filters are implemented with capacitors, as you will see in this Lecture. Voltage regulation in power supplies is usually done with integrated circuit voltage regulators.
- A voltage regulator prevents changes in the filtered dc voltage due to variations in input voltage or load.

Power Supply Filters

In most power supply applications, the standard 50 Hz ac power line voltage must be converted to an approximately constant dc voltage.

The 50 Hz pulsating dc output of a half-wave rectifier or the 100 Hz pulsating output of a full-wave rectifier must be filtered to reduce the large voltage variations. Figure 1 illustrates the filtering concept showing a nearly smooth dc output voltage from the filter. The small amount of fluctuation in the filter output voltage is called ***ripple***.

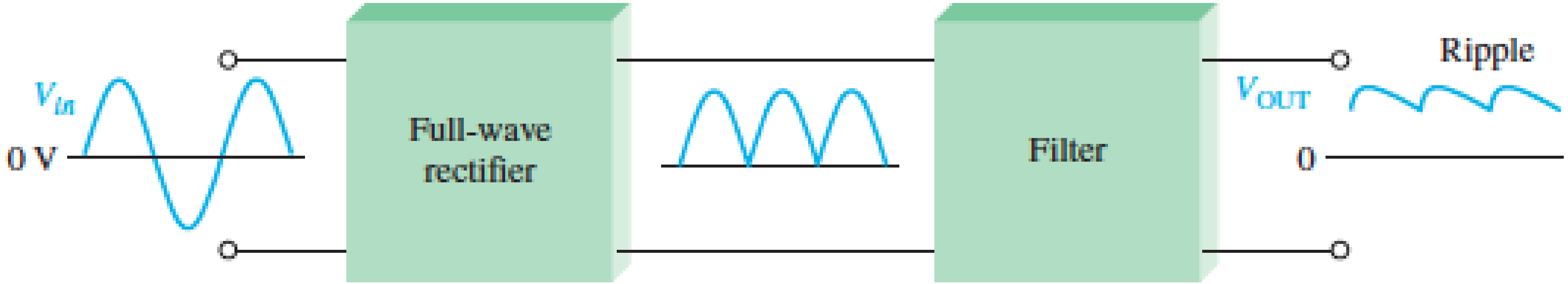


Figure 1: Rectifier with Filter

Capacitor Filter

A half-wave rectifier with a capacitor-input filter is shown in Figure 2. The filter is simply a capacitor connected from the rectifier output to ground. RL represents the equivalent resistance of a load. We will use the half-wave rectifier to illustrate the basic principle and then expand the concept to full-wave rectification.

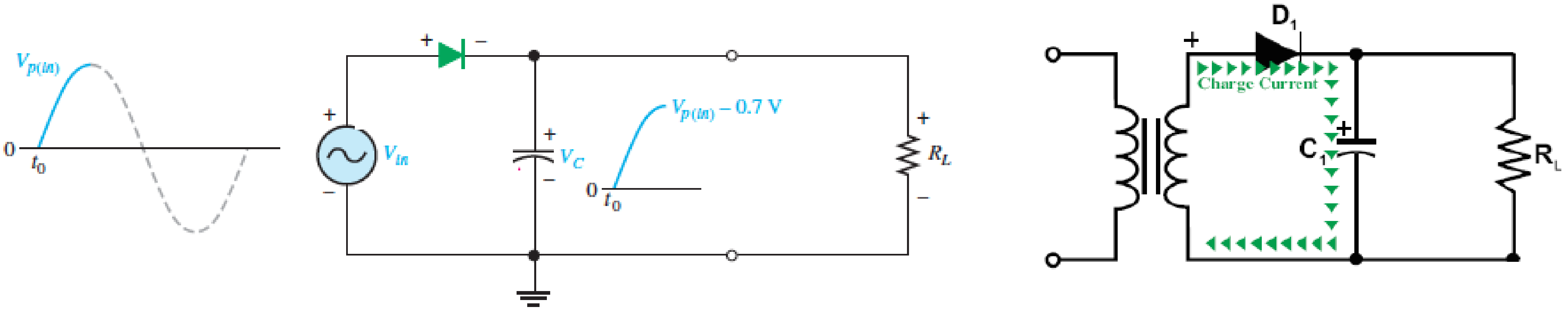


Figure 2 (a): Initial charging of the capacitor (diode is forward-biased) happens only once when power is turned on.

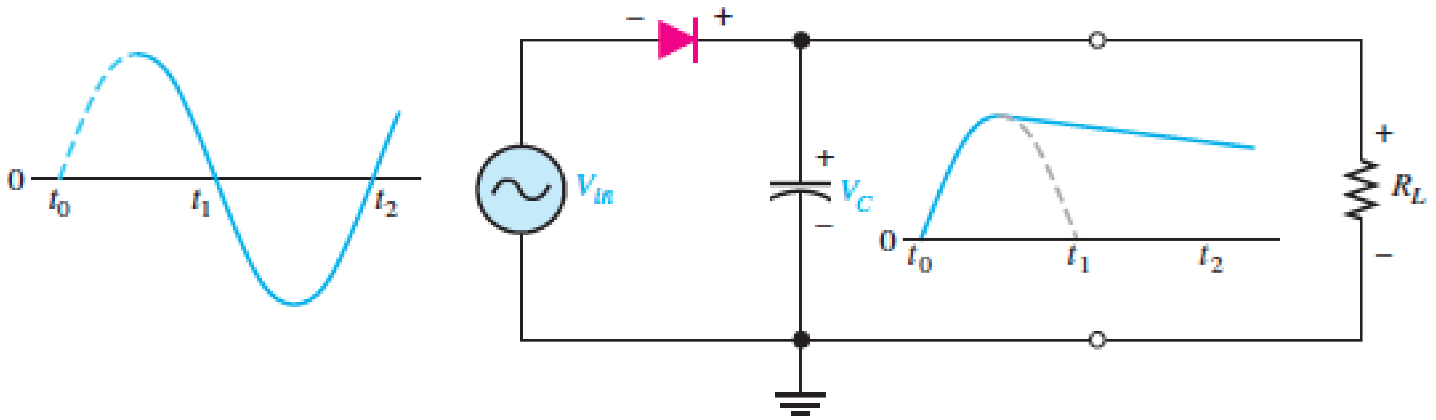
Capacitor Filter

During the positive first quarter-cycle of the input, the diode is forward-biased, allowing the capacitor to charge to peak voltage of the sinusoid, as illustrated in Figure 2(a).

When the input begins to decrease below its peak, as shown in Figure 2(b), the capacitor retains its charge and the diode becomes reverse-biased because the cathode is more positive than the anode.

Capacitor Filter

During the remaining part of the cycle, the capacitor can discharge only through the load resistance at a rate determined by the RLC time constant, which is normally long compared to the period of the input. The larger the time constant, the less the capacitor will discharge.



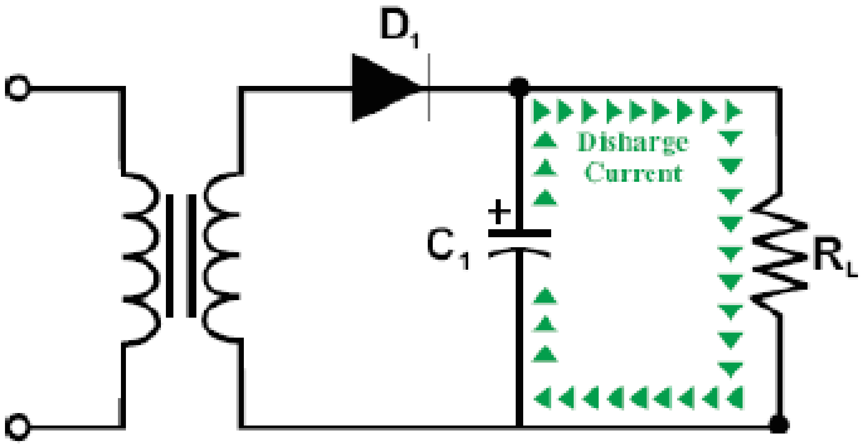


Figure 2 (b)

The capacitor discharges through RL as shown in Figure 2(b) after peak of positive alternation when the diode is reverse-biased. This discharging occurs during the portion of the input voltage indicated by the solid dark blue curve.

Capacitor Filter

During the first quarter of the next cycle, as illustrated in Figure 2 (c), the diode will again become forward-biased when the input voltage exceeds the capacitor voltage by approximately 0.7 V.

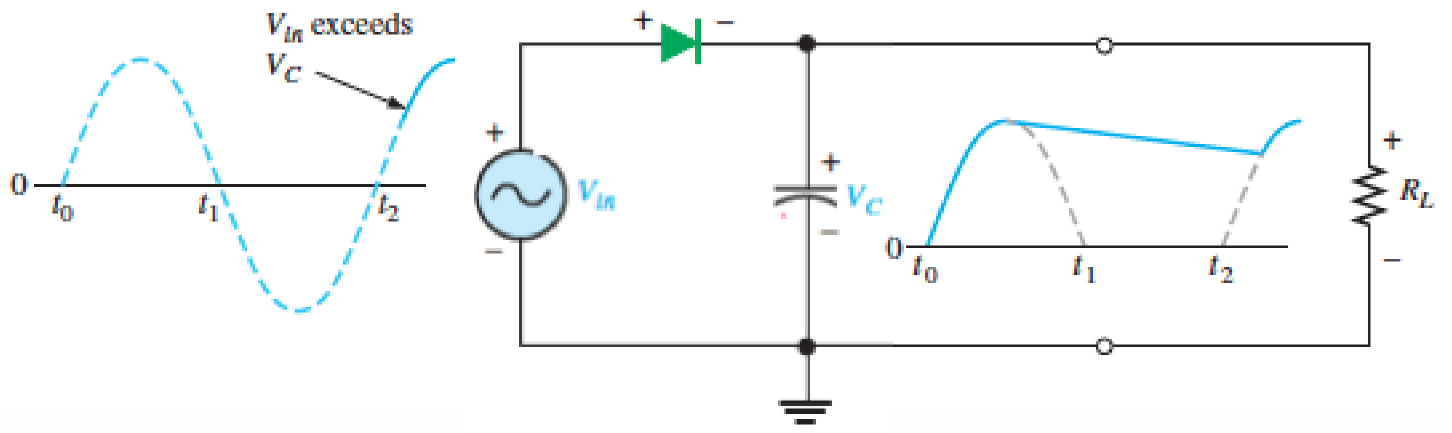


Figure 2 (c): The capacitor charges back to peak of input when the diode becomes forward-biased. This charging occurs during the portion of the input voltage indicated by the solid dark blue curve.

Ripple Voltage

As you have seen, the capacitor quickly charges at the beginning of a cycle and slowly discharges through RL after the positive peak of the input voltage (when the diode is reverse-biased). The variation in the capacitor voltage due to the charging and discharging is called the ***ripple voltage***. Generally, ripple is undesirable; thus, the smaller the ripple, the better the filtering action, as illustrated in Figure 3.

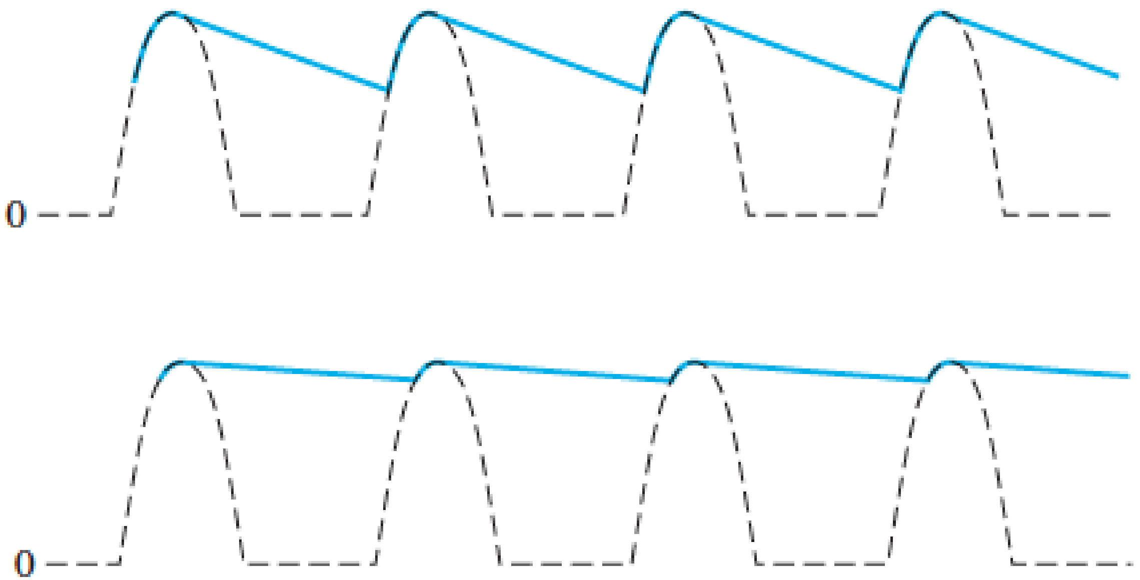


Figure 3

Top: Larger ripple (blue) means less effective filtering.
Bottom: Smaller ripple means more effective filtering.

Ripple Voltage

For a given input frequency, the output frequency of a full-wave rectifier is twice that of a half-wave rectifier, as illustrated in Figure 4.

This makes a full-wave rectifier easier to filter because of the shorter time between peaks. When filtered, the full-wave rectified voltage has a smaller ripple than does a half-wave voltage for the same load resistance and capacitor values.

The capacitor discharges less during the shorter interval between full-wave pulses, as shown in Figure 4.

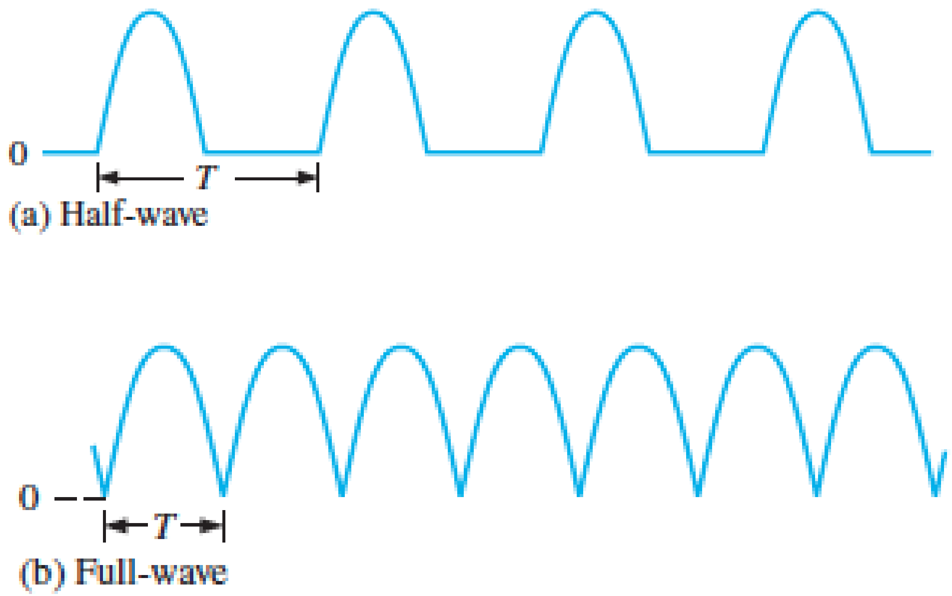


Figure 4

Ripple Factor

The ripple factor (r) is an indication of the effectiveness of the filter and is defined as:

$$r = \frac{V_{r(pp)}}{V_{DC}}$$

where $V_{r(pp)}$ is the peak-to-peak ripple voltage and V_{DC} is the dc (average) value of the filter's output voltage, as illustrated in Figure. The lower the ripple factor, the better the filter. The ripple factor can be lowered by increasing the value of the filter capacitor or increasing the load resistance.

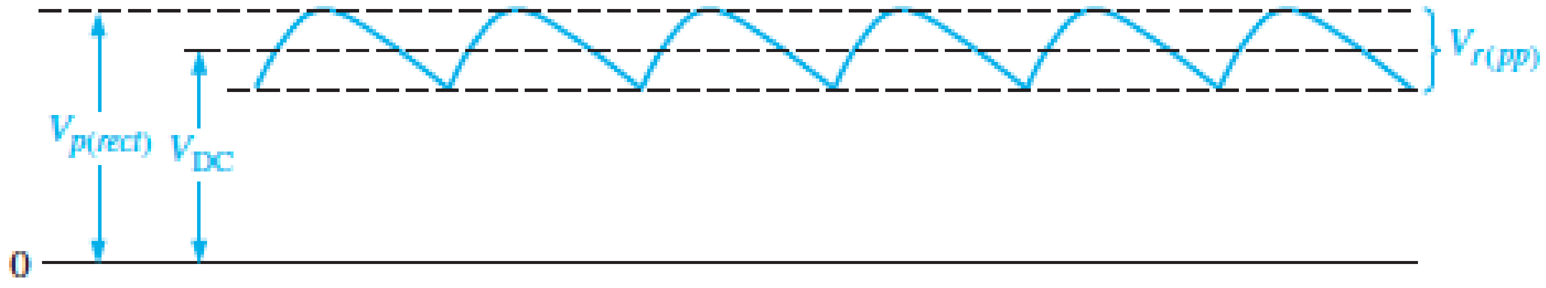


Figure 5: Vr and VDC determine the ripple factor.

Ripple Factor for Half-Wave Rectifier **without Filter**

$$r = \frac{V_{rrms}}{V_{dc}}$$

$$V_{rrms} = \sqrt{V_{orms}^2 - V_{dc}^2}$$

$$V_{orms} = \frac{V_{pout}}{2} \qquad V_{dc} = \frac{V_{pout}}{\pi}$$

$$V_{rrms} = \sqrt{\frac{V_{pout}^2}{4} - \frac{V_{pout}^2}{\pi^2}} = 0.38\,V_{pout}$$

$$r = \text{ripple factor} = \frac{0.38\,V_{pout}}{V_{pout}/\pi} = 1.21 = 121\%$$

Ripple Factor for Full-Wave Rectifier **without Filter**

$$r = \frac{V\,rrms}{V\,dc}$$

$$V\,rrms = \sqrt{V\,orms^2 - V\,dc^2}$$

$$V\,orms = \frac{V\,pout}{\sqrt{2}} \qquad V\,dc = \frac{2 * V\,pout}{\pi}$$

$$V\,rrms = \sqrt{\frac{V\,pout^2}{2} - \frac{4 * V\,pout^2}{\pi^2}} = 0.307\ V\,pout$$

$$r = ripple\ factor = \frac{0.307\ V\,pout}{2 * V\,pout/\pi} = 0.483 = 48.3\%$$

Ripple Factor for Capacitor Filter

For a full-wave rectifier with a capacitor-input filter, approximations for the peak-to peak ripple voltage, Vr(pp), and the dc value of the filter output voltage, VDC, are given in the following equations. The variable Vp(rect) is the unfiltered peak rectified voltage. Notice that if RL or C increases, the ripple voltage decreases and the dc voltage increases.

$$V_{r(pp)} \simeq \left(\frac{1}{fR_LC}\right)V_{p(rect)}$$

$$V_{DC} \simeq \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)}$$

Derivation of Ripple Factor for Rectifier with Capacitor Filter

Consider an output waveform for a full wave rectifier circuit using a capacitor input filter, as shown in the Figure 7.

Let: T = Time period of the a.c. input voltage, T/2 = Half of the time period

T_1= Time for which diode is conducting, T_2= Time for which diode is nonconducting.

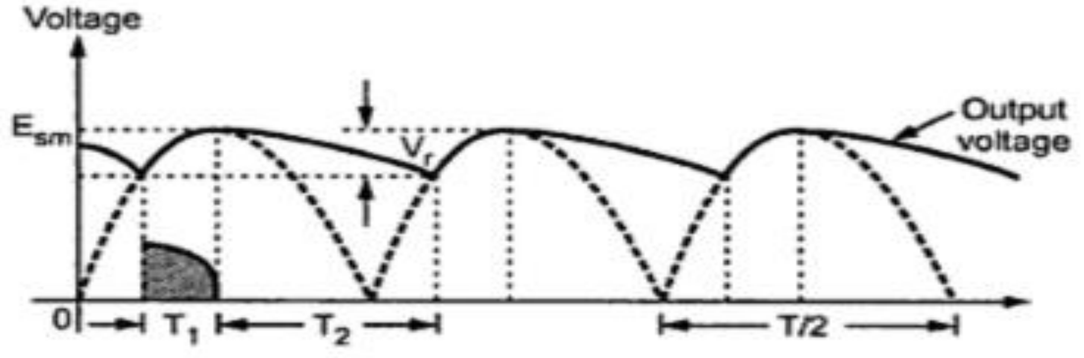


Figure7 : Derivation of Ripple Factor

Ripple factor for Full wave rectifier with Capacitor Filter

During time T_1, capacitor gets charged and this process is quick. During time T_2, capacitor gets discharged through R_L. As time constant R_LC is very large, discharging process is very slow and hence $T_2 >> T_1$.

Let V_r be the peak to peak value of ripple voltage, which is assumed to be triangular as shown in the Figure 8.

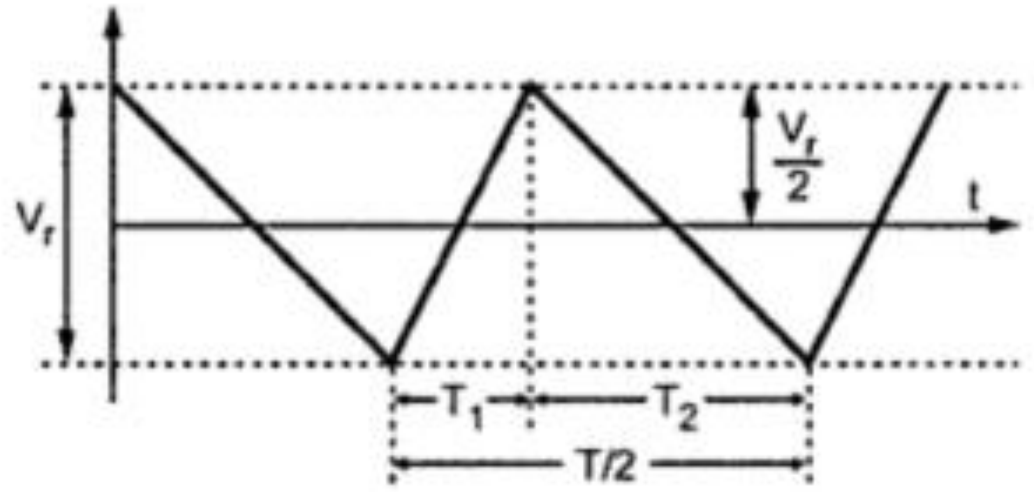


Figure 8: Triangle approximation of ripple voltage

Ripple factor for Full wave rectifier with Capacitor Filter

It is known mathematically that the r.m.s. value of such a triangular waveform is,

$$V_{rrms} = \frac{V_{pout}}{2\sqrt{3}}$$

During the time interval T_2, the capacitor C is discharging through the load resistance R_L. The charge lost is:

$$Q = C * V_{pout}$$

$$i = \frac{dQ}{dt} \Rightarrow Q = \int_0^{T_2} i\,dt = I_{DC} * T_2$$

$$I_{DC} * T_2 = C * V_{pout} \Rightarrow V_{pout} = \frac{I_{DC} * T_2}{C}$$

Ripple factor for Full wave rectifier with Capacitor Filter

$$T_1 + T_2 = \frac{T}{2} \implies Normally\ T_2 \gg T_1$$

$$T_1 + T_2 = T_2 = \frac{T}{2} \quad where\ T = \frac{1}{f}$$

$$V pout = \frac{I_{DC}}{C}\left[\frac{T}{2}\right] = \frac{I_{DC} * T}{2C} = \frac{I_{DC}}{2fC}$$

$$I_{DC} = V_{DC} / R_L$$

$$V pout = \frac{V_{DC}}{2fCR_L} = Peak\ to\ peak\ ripple\ Voltage$$

Ripple factor for Full wave rectifier with Capacitor Filter

$$Ripple\ Factor = \frac{V rrms}{V_{DC}} = \frac{V_{DC}/2fCR_L}{2\sqrt{3}/V_{DC}}$$

$$Ripple\ Factor = \frac{1}{4\sqrt{3}fCR_L} \quad for\ full\ wave\ rectifier$$

$$Ripple\ Factor = \frac{1}{2\sqrt{3}fCR_L} \quad for\ half\ wave\ rectifier$$

Example 1

A 50 load resistance is connected across a half wave rectifier. The input supply voltage is 230V (rms) at 50 Hz. Determine the DC output (average) voltage, peak-to-peak ripple in the output voltage (Vp-p), and the output ripple frequency (fr).

Vp = 1.414 * 230 = 325.3 V

Vav = (Vp - 0.7)/π = 103.32V

Ripple Voltage = (Vorms^2 - Vav^2)^0.5 = 125.67V

Ripple Percentage = (Vrrms/Vav) = 122%

Fr = 50 Hz

Example 2

In the circuit of example 1, a 100μF filter capacitor is added across the load resistor. The voltage across the secondary terminals of the transformer is 230V (rms). Determine the DC output voltage (i.e. average voltage), load current, peak-to-peak ripple in the output voltage, and the output ripple frequency.

Lecture 7 Outline

- Rectifier with Inductor Filter
- Rectifier with LC Filter
- Rectifier with CLC Filter (Pie Filter)
- Examples

Rectifier with Inductor Filter

- The inductor filter is shown in Figure 1.
- This type of filter is also called choke filter. It consists of an inductor L which is inserted between the rectifier and the load resistance RL.
- The rectifier contains AC components as well as DC components.

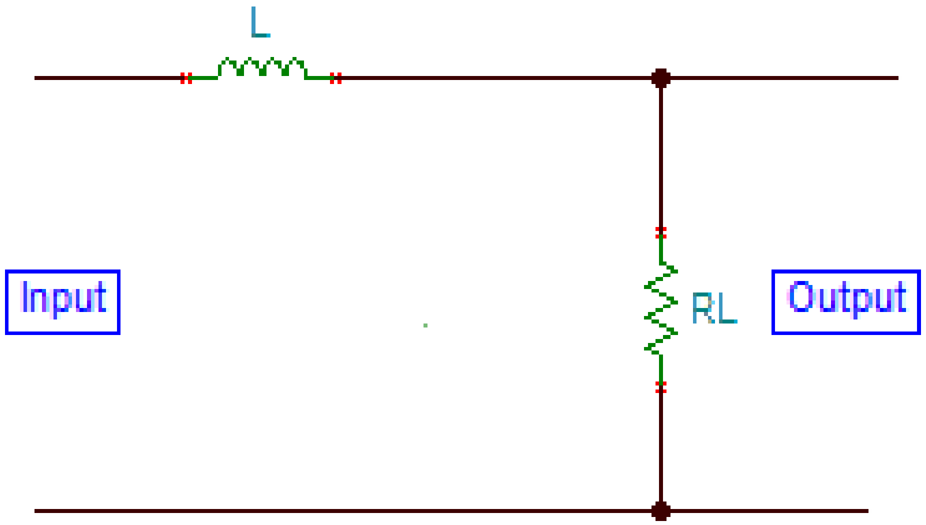


Figure 1: Inductor Filter

Rectifier with Inductor Filter

- When the output passes through the inductor, it offers a high resistance to the AC component and no resistance to DC components. Therefore, AC components of the rectified output is blocked and only DC components reached at the load.

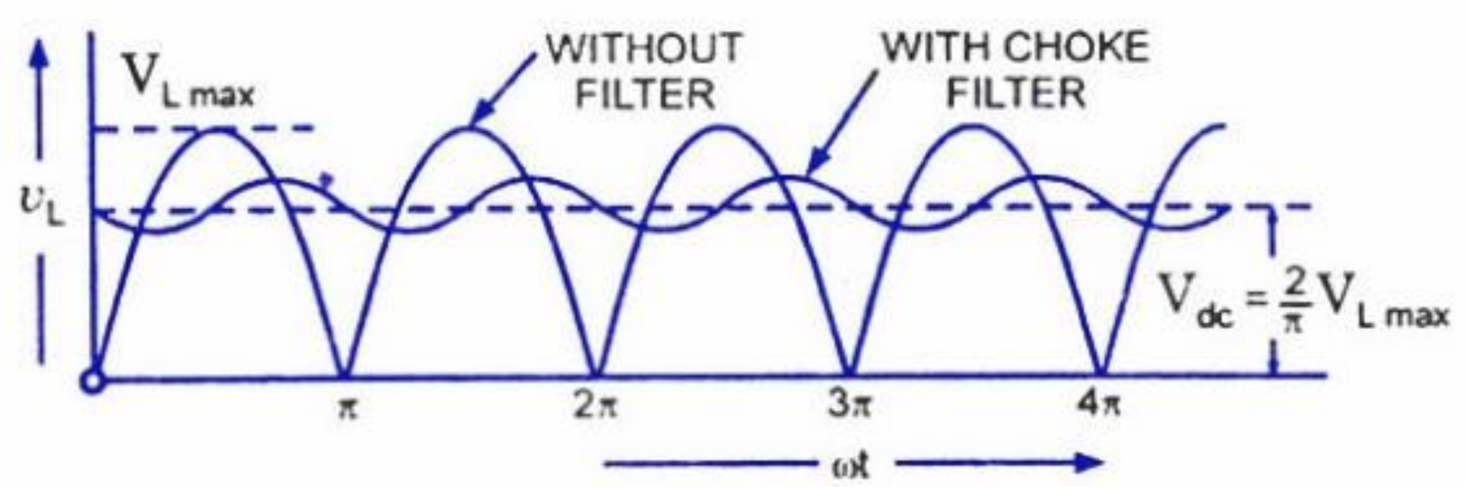


Figure 2: The output waveform with Inductor Filter

Rectifier with Inductor Filter

- 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.
- 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.

Rectifier with Inductor Filter

- The Ripple Factor for the Inductor Filter is: $\frac{R_L}{3\sqrt{2}\omega L}$ $when \quad \omega = \pi f$

- The ripple factor equation for the inductor filter shows that ripple will decrease when L is increased and R_L is decreased.
- The inductor filter is more effective only when the load current is high (small R_L).
- The larger value of the inductor can reduce the ripple and at the same time the output dc voltage will be lowered as the inductor has a higher dc resistance.
- The operation of the inductor filter depends on its property to oppose any change of current passing through it.

Derivation of the Ripple Factor equation for the Full Wave Rectifier with Inductor Filter

$$Ripple\ Factor = \frac{V\,rrms}{V\,dc} = \frac{R_L}{3\sqrt{2}\omega L} \quad when \quad \omega = \pi f$$

Rectifier with Inductor Filter

- 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.

Rectifier with LC Filter

In the simple shunt capacitor filter circuit explained previously, 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) as shown in Figure 3, 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.

Rectifier with LC Filter

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.

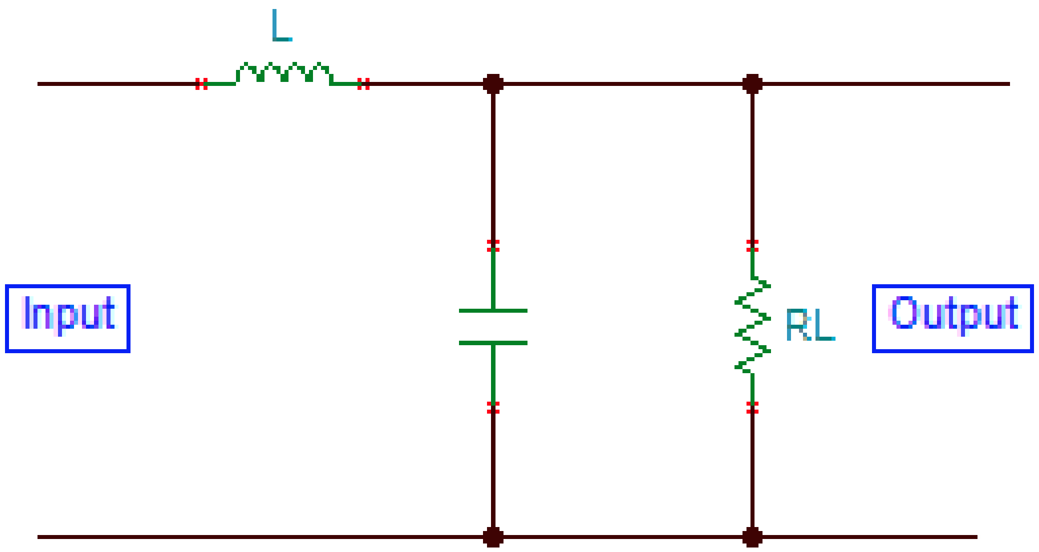


Figure 3: LC Filter

Rectifier with LC Filter

As shown in the circuit diagram in Figure 3, 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 R_{load}. The number of ripples can be reduced to a great amount by making the value of XL greater than Xc at ripple frequency.

Rectifier with LC Filter

The output waveform for the Full Wave Rectifier with LC filter is shown in Figure 4.

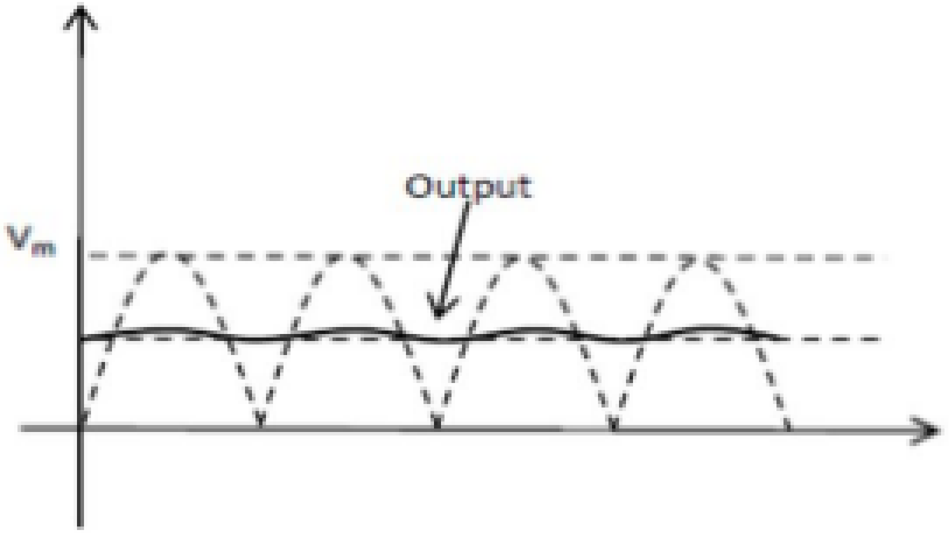


Figure 4: Output Waveform at LC Filter

Derivation of the LC filter

$$Ripple\ Factor = \frac{V\,rrms}{V\,dc} = \frac{\sqrt{2}}{3} * \frac{XC}{XL}$$

$$= \frac{\sqrt{2}}{3} * \frac{1/2\pi fC}{2\pi fL} = \frac{1}{6\sqrt{2}\pi^2 f^2 C\,L}$$

If the value of inductance is increased it will increase the time of conduction. At some critical value of inductance, one diode in the Full Wave rectifier circuit, either D1 or D2 will always conducting.

Rectifier with CLC Filter (Pie Filter)

Figure 5 shows CLC or ***π*** type filter, which basically consists of a capacitor filter, followed by LC section.

The three components are arranged in shape of Greek letter Pi.

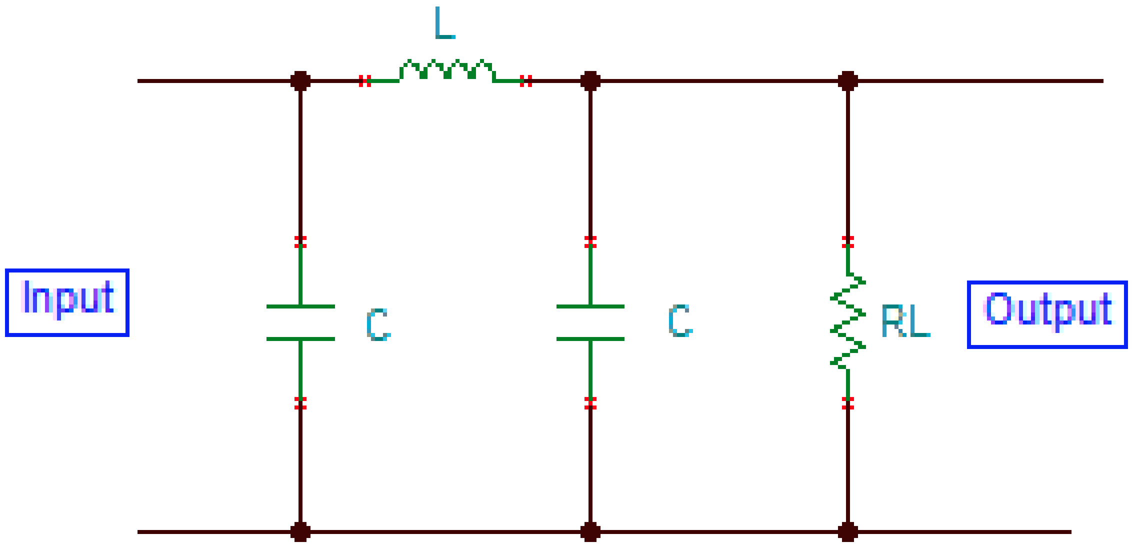


Figure 5: CLC Filter

Rectifier with CLC Filter (Pie Filter)

- The input capacitor C1 is selected to offer a very low reactance to the repel frequency hence the majority of filtering is done by C1.
- Most of the remaining ripples are removed by the combining action of L and C2. This circuit gives a much better filter than LC filter. However C1 is still directly connected across the supply and would need high pulas of current if load current is large.
- This filter is used for the low current equipment. And it offers a fairly smooth output and is characterized by highly peaked diode currents and poor regulation.

Derivation of the Rectifier with CLC Filter (Pie Filter)

$$Ripple\ Factor = \sqrt{2} * \frac{XC1}{R_L} * \frac{XC2}{X_L} = \frac{1}{4\sqrt{2}\ \pi^3 f^3 C_1 C_2 L R_L}$$

Example 1

A <u>1KΩ load resistance</u> is connected across a <u>Full wave rectifier,</u> an LC filter added to the circuit 100µF and 200mH. The input <u>supply voltage is 230V (rms)</u> at <u>50 Hz</u>. Determine the DC output (average) voltage, peak-to-peak ripple in the output voltage (Vp-p), and the output ripple frequency (fr).

Answer:

Ripple Frequency = 2* 50Hz = 100 Hz. (because it is a full wave rectifier)

Ripple Factor = $1/ (6\sqrt{2}\, \pi^2 * f^2 * C * L) = 0.059$

Vodc = $2 * V_{op} / \pi = 2 * (230\sqrt{2} - 0.7) / \pi = 206.63$V

Ripple Factor = Ripple Voltage / Vodc

Ripple Voltage = Ripple Factor * Vodc = 12.19V

Example 2

A 1KΩ load resistance is connected across a Full wave rectifier, an CLC filter added to the circuit C1 100μF, C2 1000μF and H1 200mH. The input supply voltage is 230V (rms) at 50 Hz. Determine the DC output (average) voltage, peak-to-peak ripple in the output voltage (Vp-p), and the output ripple frequency (fr).

Answer:

Ripple Frequency = 2* 50Hz = 100 Hz. (because it is a full wave rectifier)

Ripple Factor = 1/ (4√2 π^3 * f^3 * C1 * C2 * R * L) = 2.85 * 10^-4

Vodc = 2* Vop /π = 2* (230√2 - 0.7) /π = 206.63V

Ripple Factor = Ripple Voltage / Vodc

Ripple Voltage = Ripple Factor * Vodc = 0.0589V