EE 204 - Analog Circuits
Lecture 2

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Contents

1 Semiconductors

Semiconductors are essential in the development of all modern technologies such as diodes, transistors, chips and various processors.

Semiconductors are materials which have a conductivity between conductors and insulators. Semiconductors typically have resistivity from 10^{-3} to 10^{9} Ωcm.

Semiconductors can be classified into two categories:

1. Intrinsic (Pure)
2. Extrinsic (Impure)

The following classification gives a better picture between the categories

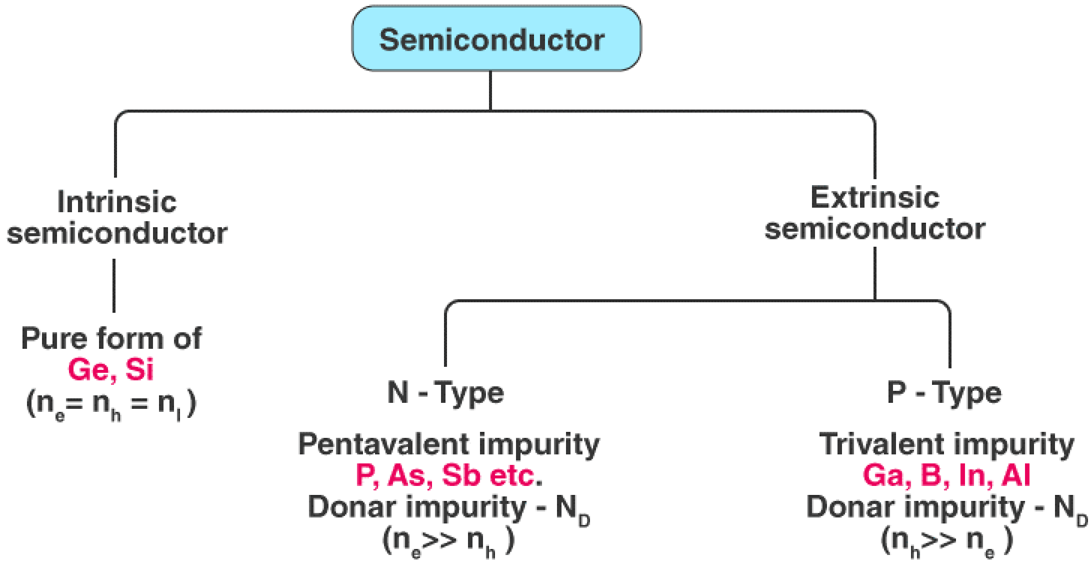

Figure 1: Semiconductor Categories

The n-type and p-type semiconductors can also be understood from the following periodic table :

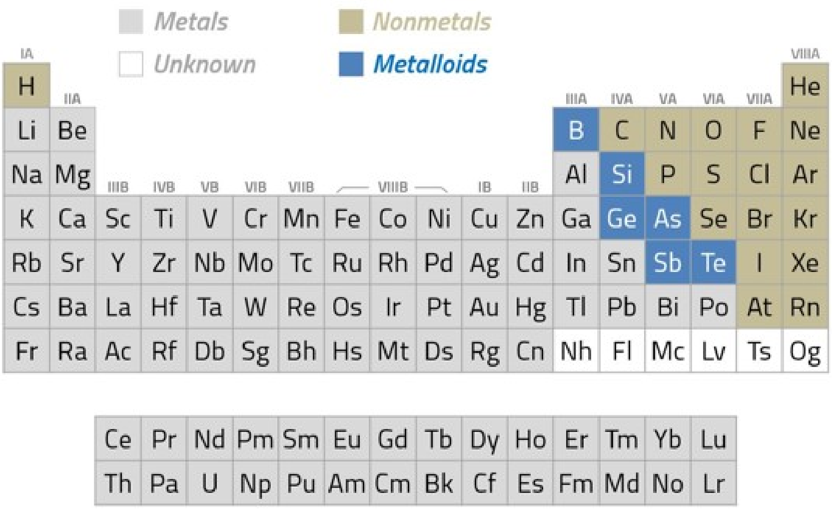

Figure 2: Periodic Table

Elements from Group 5 of the periodic table are generally n-type semiconductors whereas elements from Group 3 of the periodic table are p-type semiconductors.

By doping the n and/or p-type semiconductors with the intrinsic/pure semiconductors we get much better results and an increase in conductivity.

This results in n-type silicon semiconductors and p-type silicon semiconductors, which we will observe with the help of some diagrams in some detail. Doping is a very essential process in the semiconductor industry and should be doped in right proportions.

In later section, we will also study the Energy Band Levels for all the three categories of materials.

1.1 p-type Semiconductor

This is obtained when Si or Ge is doped with a trivalent impurity like Al, B, In, etc. The dopant has one valence electron less than Si or Ge and, therefore, this atom can form covalent bonds with neighbouring three Si atoms but does not have any electron to offer to the fourth Si atom. So the bond between the fourth neighbour and the trivalent atom has a vacancy or hole. Since the neighbouring Si atom in the lattice wants an electron in place of a hole, an electron in the outer orbit of an atom in the neighbourhood may jump to fill this vacancy, leaving a vacancy or hole at its own site. Thus the hole is available for conduction.

Therefore, the dopant atom of p-type material can be treated as core of one negative charge along with its associated hole.[1]

Note that the crystal maintains an overall charge neutrality as the charge of additional charge carriers is just equal and opposite to that of the ionised cores in the lattice.

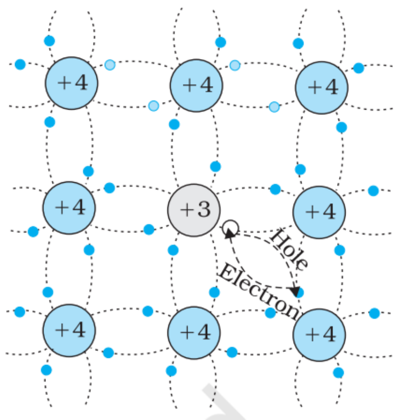

Figure 3: Trivalent acceptor atom (In, Al, B etc.) doped in tetravalent Si or Ge lattice giving p-type semiconductor.

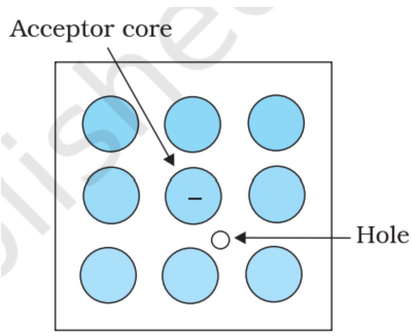

Figure 4: Commonly used schematic representation of p-type material which shows only the fixed core of the substituent acceptor with one effective additional negative charge and its associated hole.

[1]**Image Credits**: NCERT

1.2 n-type Semiconductor

This is obtained when Si or Ge is doped with a pentavalent impurity like As, Sb, P, etc. The dopant has one valence electron more than Si or Ge and, therefore, this atom can form covalent bonds with neighbouring four Si atoms while the fifth remains very weakly bound to its parent atom.

Thus, the pentavalent dopant is donating one extra electron for conduction and hence is known as donor impurity. The number of electrons made available for conduction by dopant atoms depends strongly upon the doping level and is independent of any increase in ambient temperature. On the other hand, the number of free electrons (with an equal number of holes) generated by Si atoms, increases weakly with temperature.[2]

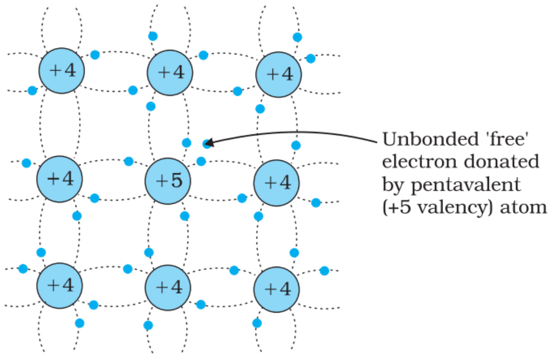

Figure 5: Pentavalent donor atom (As, Sb, P, etc.) doped for tetravalent Si or Ge giving ntype semiconductor,

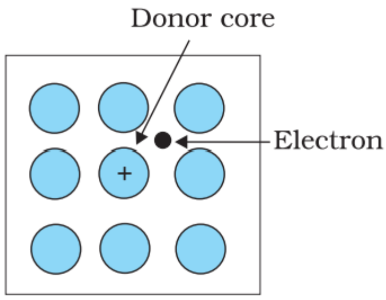

Figure 6: Commonly used schematic representation of n-type material which shows only the fixed cores of the substituent donors with one additional effective positive charge and its associated extra electron.

1.3 Energy Band Diagram

Inside the crystal each electron has a unique position and no two electrons see exactly the same pattern of surrounding charges. Because of this, each electron will have a different energy level. These different energy levels with continuous energy variation form what are called energy bands. The energy band which includes the energy levels of the valence electrons is called the valence band. The energy band above the valence band is called the conduction band.

[2]**Image Credits**: NCERT

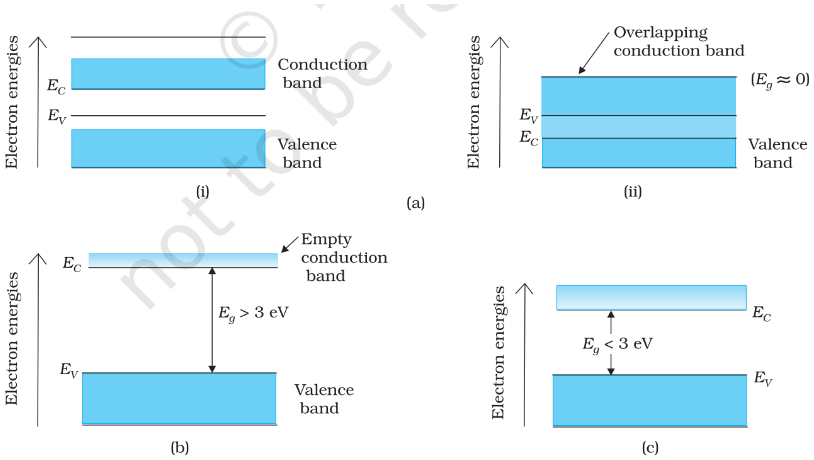

Figure 7: Difference between energy bands of (a) metals, (b) insulators and (c) semiconductors.

2 Diode

A p–n diode is a type of semiconductor diode based upon the p–n junction. The diode conducts current in only one direction, and it is made by joining a p-type semiconducting layer to an n-type semiconducting layer.

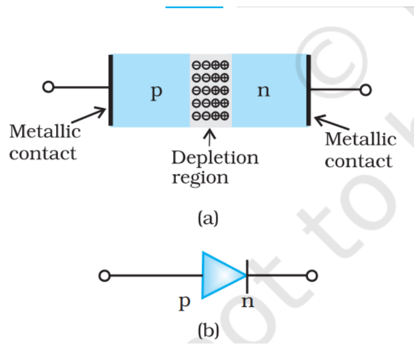

Figure 8: (a) Semiconductor diode, (b) Symbol for p-n junction diode

The V-I characteristics for a p-n diode are as follows:

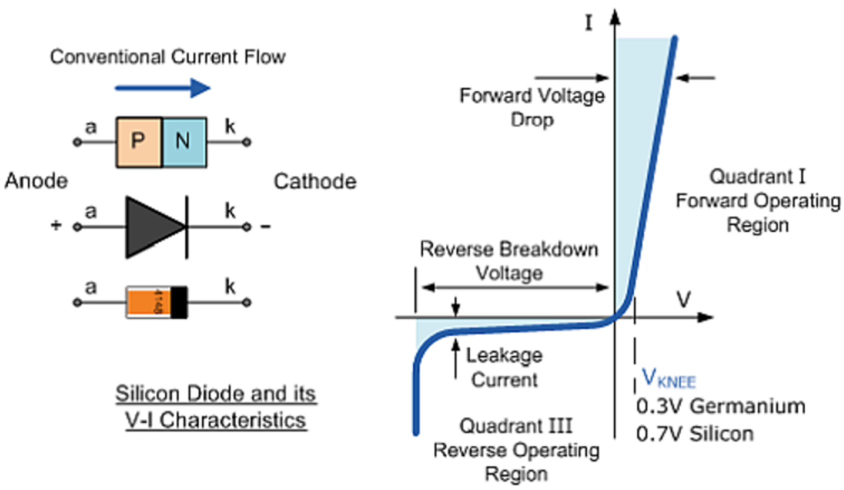

Figure 9: V-I characteristics

3 Rectifiers

A rectifier is an electronic device that converts an alternating current into a direct current by using one or more P-N junction diodes. A diode behaves as a one-way valve that allows current to flow in a single direction. This process is known as rectification

(Uncontrolled) Rectifiers are of three major types:

1. Half-wave Rectifier
2. Full-wave Rectifier
3. Bridge Rectifier

3.1 Half-wave Rectifier

If an alternating voltage is applied across a diode in series with a load, a pulsating voltage will appear across the load only during the half cycles of the ac input during which the diode is forward biased. Such rectifier circuit, is called a half-wave rectifier.

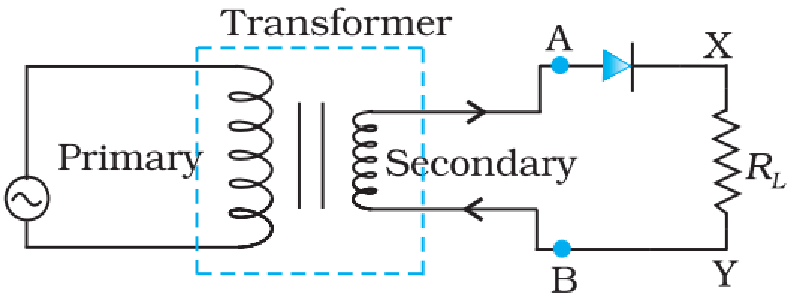

Figure 10: Half-wave rectifier

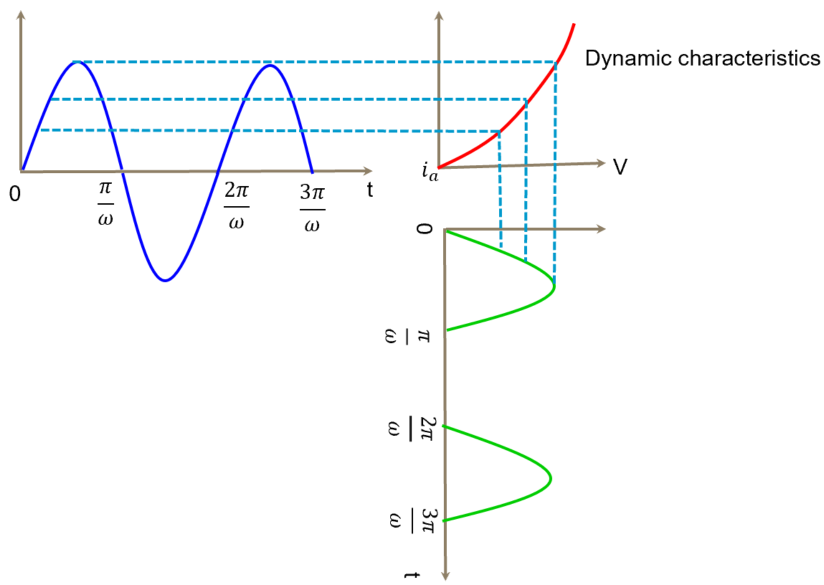

Figure 11: Output voltage waveform

- $i_{ac} = I_m sin(\omega t)$
- Therefore, $I_{dc} = \frac{I_m}{\pi}$ and $I_{rms} = \frac{I_m^2}{4}$
- Also, Power dissipated in load, $P_{dc} = I_{dc}^2 R_L$
  $P_{dc} = \frac{v_m^2}{\pi^2(r_a+R_L)^2} R_L$
- Input AC Power from source, $P_{ac} = \frac{v_m^2}{4(r_a+R_L)}$
- Ripple factor for Half wave rectifier is 1.21

3.2 Full-wave Rectifier

The circuit using two diodes, gives output rectified voltage corresponding to both the positive as well as negative half of the ac cycle. Hence, it is known as full-wave rectifier.

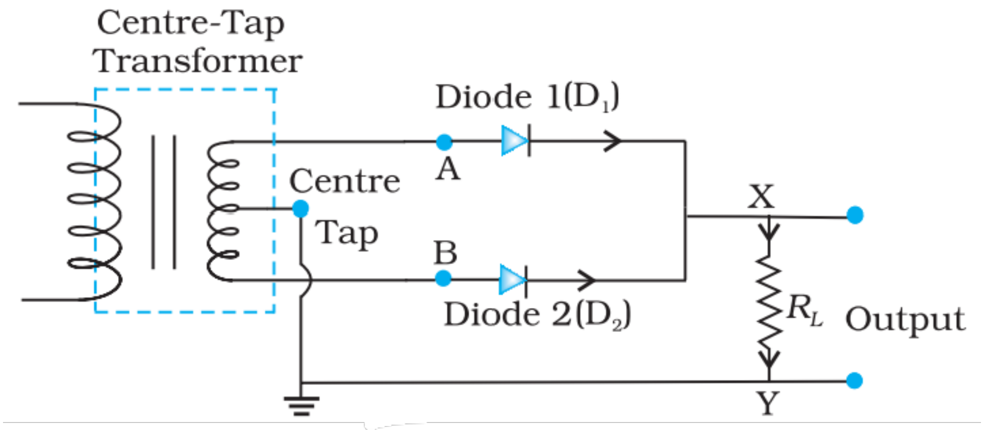

Figure 12: Full-wave rectifier

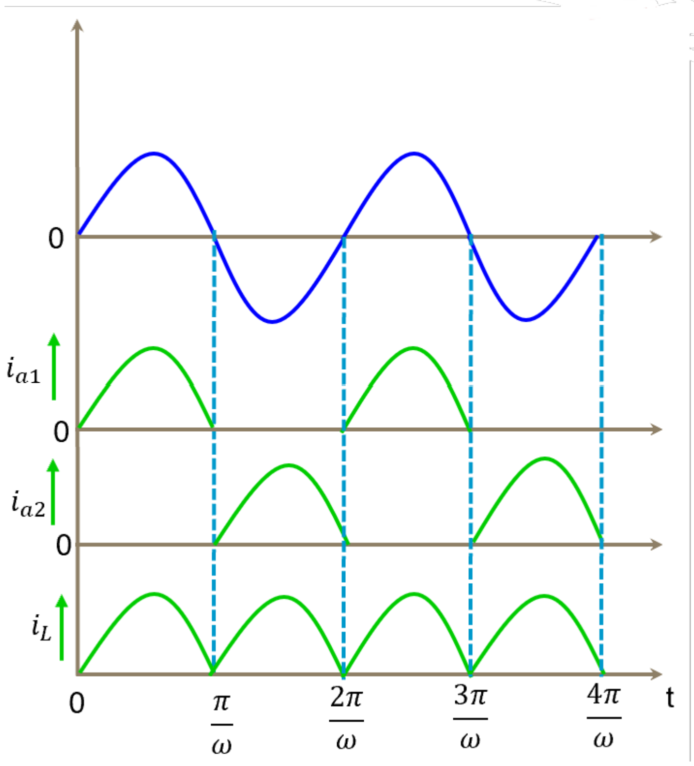

Figure 13: Output voltage waveform

- $i_{ac} = \pm I_m sin(\omega t)$
- Therefore, $I_{dc} = 2\frac{I_m}{\pi}$ and $I_{rms} = \frac{I_m^2}{4}$
- Also, Power dissipated in load, $P_{dc} = I_{dc}^2 R_L$
  $P_{dc} = 4\frac{v_m^2}{\pi^2(r_a+R_L)^2} R_L$
- Input AC Power from source, $P_{ac} = \frac{v_m^2}{2(r_a+R_L)}$
- Ripple factor for Half wave rectifier is 0.48

3.3 Bridge Rectifier

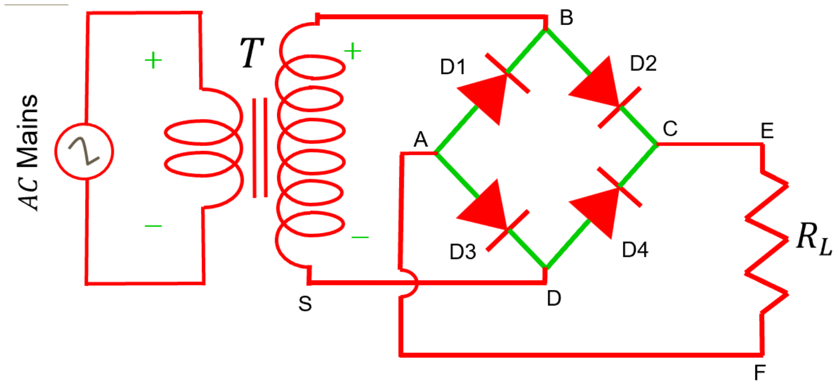

Figure 14: Bridge rectifier

During positive half cycle: D2 and D3 are forward bias and D4 and D1 are reversed bias Current through: BCEFADSB

During negative half cycle: D1 and D4 are forward bias and D3 and D2 are reversed bias Current through: DCEFABSD

4 Filters

To get steady dc output from the pulsating voltage a filter is connected across the output terminals (parallel to the load R_L)

There are various filters that we use to get our required output:

- Capacitor Filter
- Inductor Filter
- L-type LC Filter
- π-type LC Filter

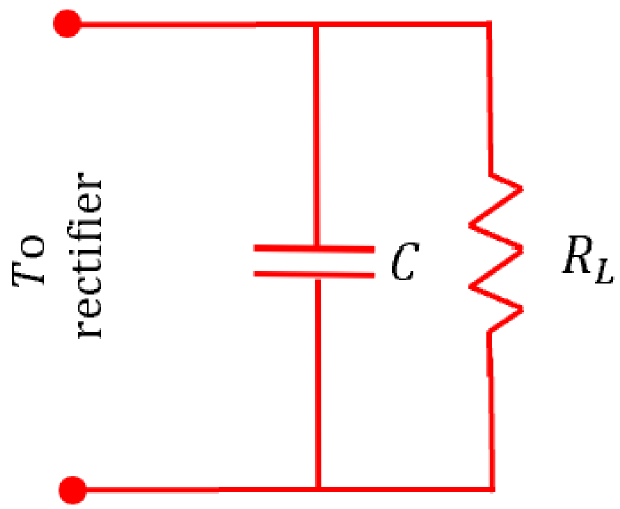

Figure 15: Capacitor Filter

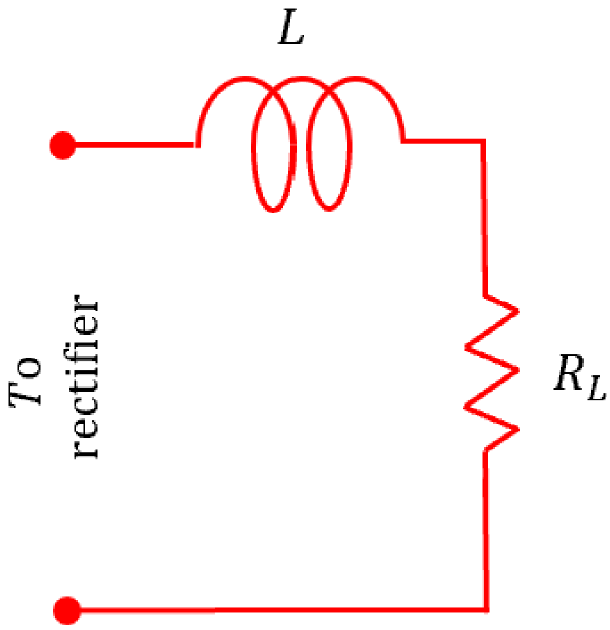

Figure 16: Inductor Filter

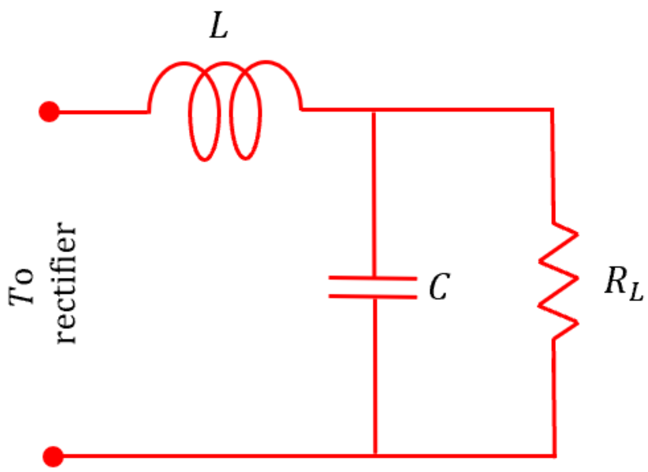

Figure 17: L-type LC Filter

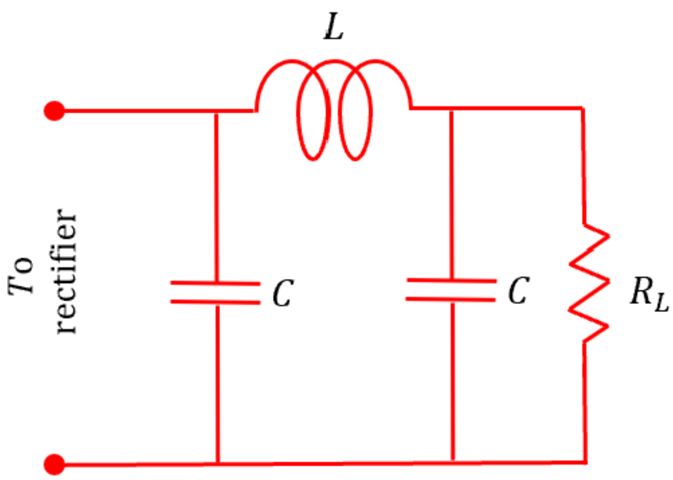

Figure 18: π-type LC Filter