SUB: Electronic Devices and Circuits

by

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Lecture -3, Tutorial -1 Credit -4

- **Course Objectives:**
- 1. To introduce components such as diodes, BJTs and FETs.
- 2. To know the applications of components.
- 3. To know the switching characteristics of components
- 4. To give understanding of various types of amplifier circuits

- **Course Outcomes:** Upon completion of the Course, the students will be able to:
- 1. Know the characteristics of various components.
- 2. Understand the utilization of components.
- 3. Understand the biasing techniques
- 4. Design and analyze small signal amplifier circuits.

Syllabus

- UNIT – I Diode and Applications: Diode - Static and Dynamic resistances, Equivalent circuit, Load line analysis, Diffusion and Transition Capacitances, Diode Applications: Switch-Switching times. Rectifier - Half Wave Rectifier, Full Wave Rectifier, Bridge Rectifier, Rectifiers with Capacitive and Inductive Filters, Clippers-Clipping at two independent levels, Clamper-Clamping Circuit Theorem, Clamping Operation, Types of Clampers.
- UNIT – II Bipolar Junction Transistor (BJT): Principle of Operation, Common Emitter, Common Base and Common Collector Configurations, Transistor as a switch, switching times, Transistor Biasing and Stabilization - Operating point, DC & AC load lines, Biasing - Fixed Bias, Self Bias, Bias Stability, Bias Compensation using Diodes.
- UNIT – III Junction Field Effect Transistor (FET): Construction, Principle of Operation, Pinch-Off Voltage, VoltAmpere Characteristic, Comparison of BJT and FET, Biasing of FET, FET as Voltage Variable Resistor. Special Purpose Devices: Zener Diode - Characteristics, Voltage Regulator. Principle of Operation - SCR, Tunnel diode, UJT, Varactor Diode.
- UNIT – IV Analysis and Design of Small Signal Low Frequency BJT Amplifiers: Transistor Hybrid model, Determination of h-parameters from transistor characteristics, Typical values of h- parameters in CE, CB and CC configurations, Transistor amplifying action, Analysis of CE, CC, CB Amplifiers and CE Amplifier with emitter resistance, low frequency response of BJT Amplifiers, effect of coupling and bypass capacitors on CE Amplifier.
- UNIT – V FET Amplifiers: Small Signal Model, Analysis of JFET Amplifiers, Analysis of CS, CD, CG JFET Amplifiers. MOSFET Characteristics in Enhancement and Depletion mode, Basic Concepts of MOS Amplifiers

TEXT BOOKS:

- 1. Electronic Devices and Circuits- Jacob Millman, McGraw Hill Education
- 2. Electronic Devices and Circuits theory- Robert L. Boylestead, Louis Nashelsky, 11th Edition, 2009, Pearson. file:///C:/Users/User/Downloads/Electronic_devices_and_circuit_theory_ro.pdf

REFERENCE BOOKS:

- 1. Electronic Devices and Circuits, David A. Bell – 5th Edition, Oxford. 2. Pulse, Digital and Switching Waveforms – J. Millman, H. Taub and Mothiki S. Prakash Rao, 2Ed., 2008, Mc Graw Hill.

Introduction to Electronics

ELECTRONICS

- Electronics is that branch of science and technology which makes use of the controlled motion of electrons through different media and vacuum. The ability to control electron flow is usually applied to information handling or device control.

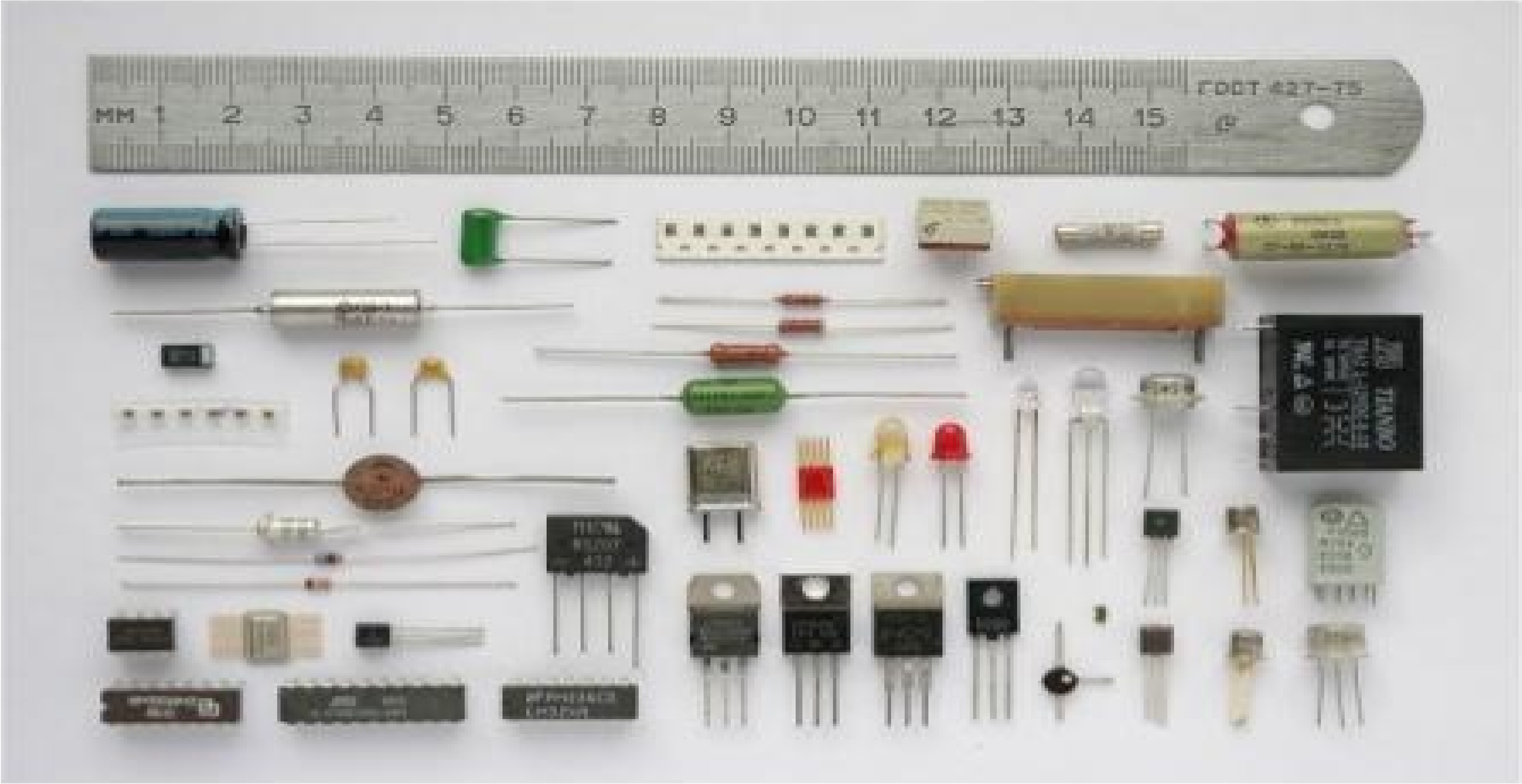
APPLICATION OF ELECTRONICS

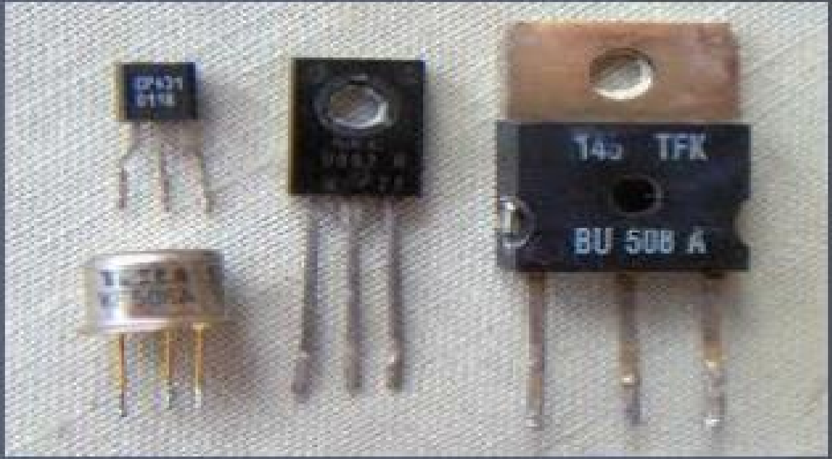
- Communication and Entertainment .
- Industrial.
- Medical science.
- Defence.

ELECTRONICS COMPONENTS

- ACTIVE COMPONENT.
- PASSIVE COMPONENT.

ELECTRONICS COMPONENT

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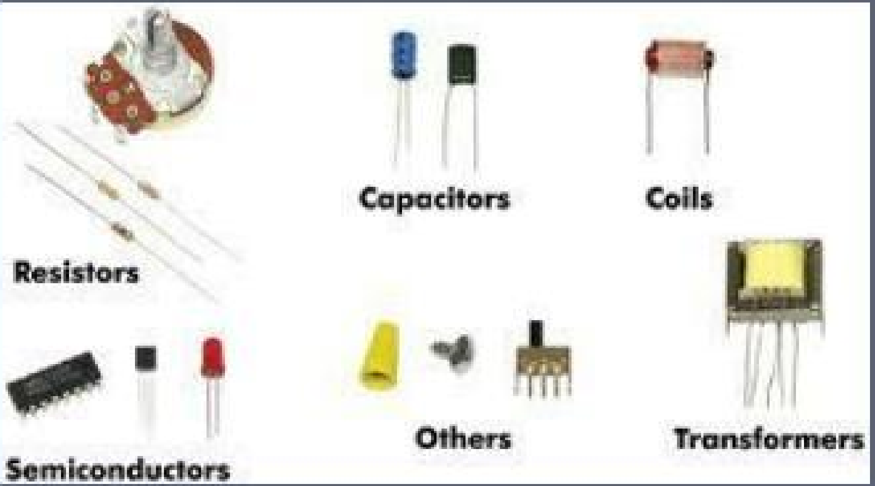
Capacitors
Coils
Resistors
Semiconductors
Others
Transformers


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PASSIVE COMPONENTS

- The electronics components which are not capable of amplifying or processing an electrical signal are called as passive component.
- EXAMPLES –

1. Resistor.
2. Capacitor.
3. Inductor.

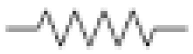
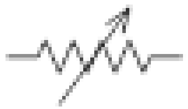
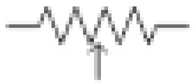
A resistor is a device in which the flow of an electric current is restricted resulting in an energy conversion. For example, when electricity flows through a light bulb,
the electricity is converted into a different form of energy such as heat and/or light. The resistance of an element is measured in ohms Ω.

The measure of resistance in a given circuit is given by -

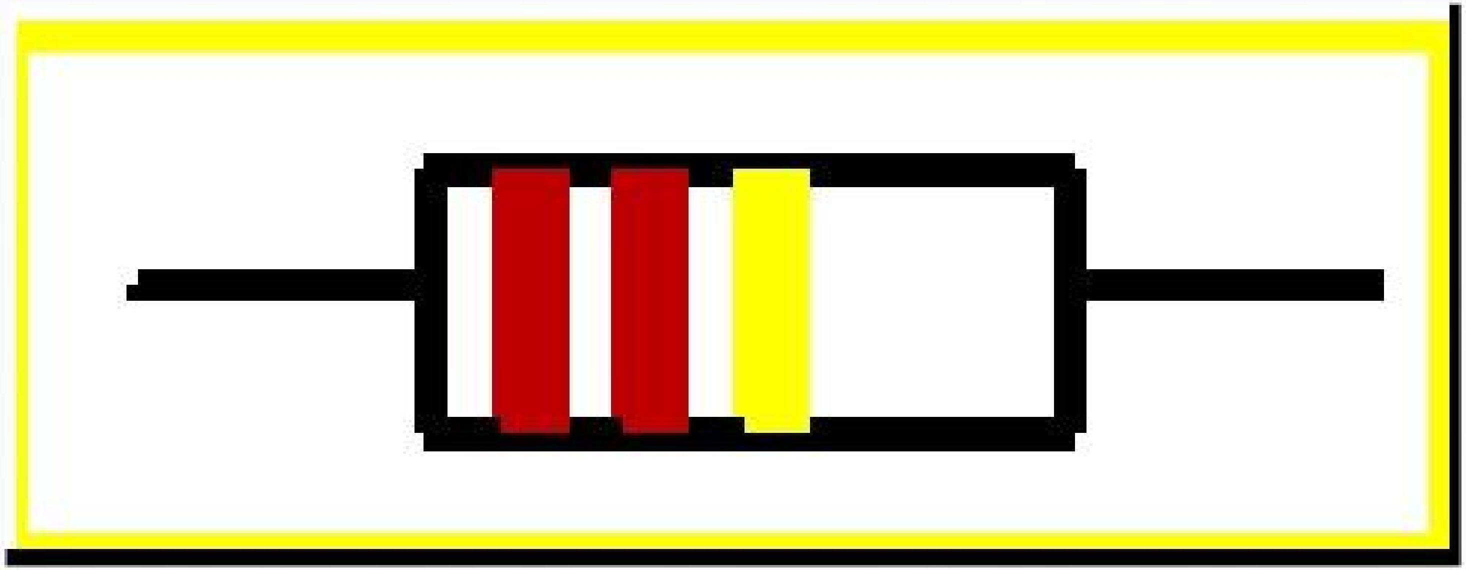
$$R=\rho L/A$$

Where **R** - resistance; **ρ** - resistivity; **L** - length of wire; and **A** - cross-sectional area of wire

Symbol of Various Resistors

Resistor	
A variable resistor	
A potentiometer	

RESISTOR



Resistors

- Coding
- Types of values written
  - 47R
  - 5R6
  - 6k8
  - 1M2
- Uses

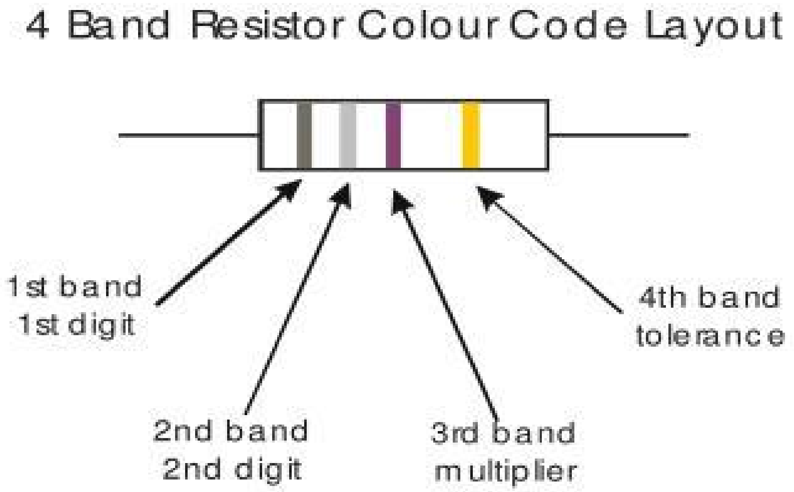
The standard resistor color code table:

Color	Digit 1	Digit 2	Digit 3*	Multiplier	Tolerance	Temp. Coef.	Fail Rate
Black	0	0	0	$\times10^0$			
Brown	1	1	1	$\times10^1$	±1% (F)	100 ppm/K	1%
Red	2	2	2	$\times10^2$	±2% (G)	50 ppm/K	0.1%
Orange	3	3	3	$\times10^3$		15 ppm/K	0.01%
Yellow	4	4	4	$\times10^4$		25 ppm/K	0.001%
Green	5	5	5	$\times10^5$	±0.5% (D)		
Blue	6	6	6	$\times10^6$	±0.25% (C)		
Violet	7	7	7	$\times10^7$	±0.1% (B)		
Gray	8	8	8	$\times10^8$	±0.05% (A)		
White	9	9	9	$\times10^9$			
Gold				x0.1	±5% (J)		
Silver				x0.01	±10% (K)		
None					±20% (M)		

** 3rd digit - only for 5-band resistors*

Resistor Value Calculation

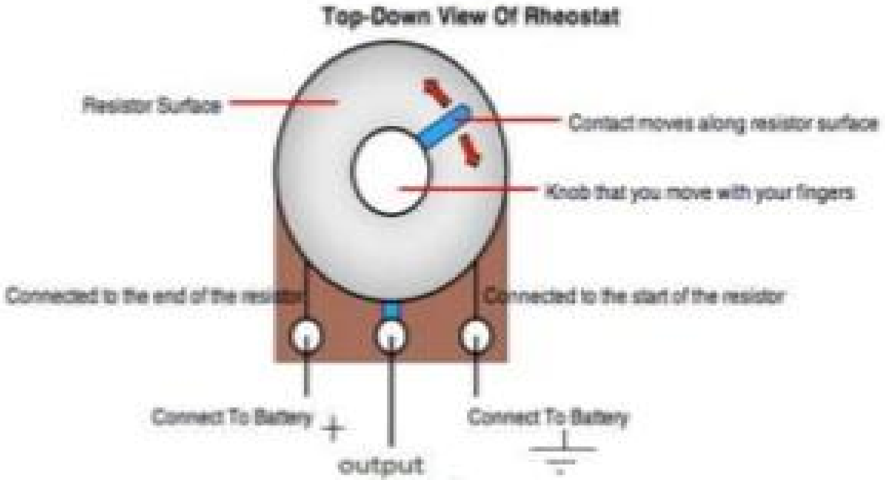
If the colours on the resistor are:
1st band – red
2nd band – violet
3rd band – brown
4th band – gold



Then its value is: 2(red) 7(Violet) x 10(Brown) with a 5% tolerance (Gold) i.e. 270ohms 5% tolerance.

Variable resistors

Used in two configurations
- As variable resistor
- As potentiometer



Other types of resistors

Thermistors

- Equation of operation

$$\Delta R = k\Delta T$$

- PTC
  - Resistance increases with temperature

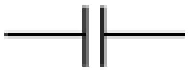
- NTC
  - Resistance decreases with temperature

LDR

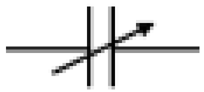
- Light Dependent resistor
- Made of CdS,CdSe,PbS
- Uses
  - On off light relay
  - As a light meter to measure intensity of light

Capacitor

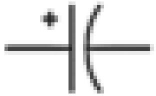
A capacitor refers to an electrical device that has two conducting materials also known as plates separated by an insulator known as a dielectric. It uses electric field to store electric energy. The electric field is
developed when the capacitor is connected to a battery, thus making positive electric charges accumulate on one plate and negative electric charges on the other plate.
When energy is stored in the electrical field of a capacitor, the process is called charging, and when energy is removed, the process is called discharging. The level of electrical energy stored in a capacitor is called
capacitance and is measured in farads 'F'. One farad is the one coulomb per volt given by 1 C/V.



Capacitor



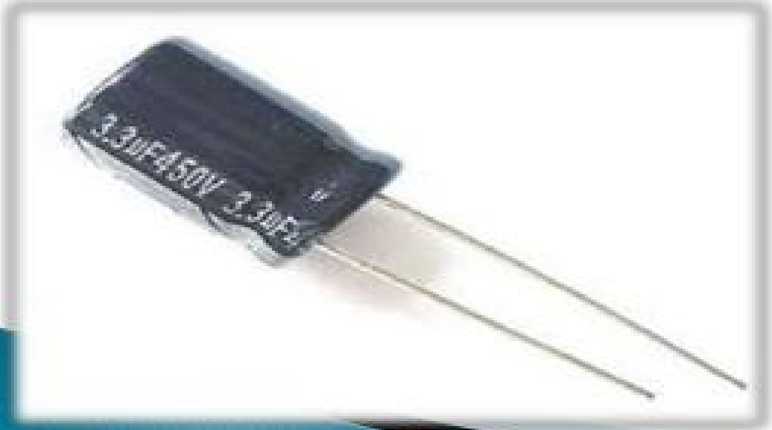
Variable capacitor

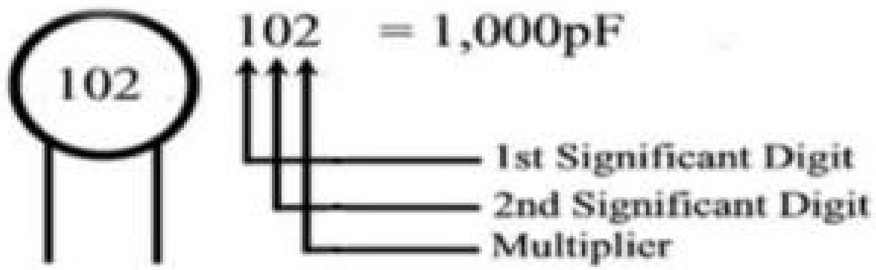


Polarized Capacitor

Capacitors

- Types
  - Ceramic
  - Electrolytic
- Measuring
- Uses

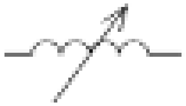




Inductors

Inductors are electronic devices that use magnetic field to store electric energy. The simplest form of an inductor is a coil or a wire in loop form where the inductance is directly proportional to the number of loops in the wire. In addition, the inductance depends on the type of material in the wire and the radius of the loop.
Given a certain number of turns and radius size, only the air core can result in the least inductance. The dielectric materials, which serve the same purpose as air include wood, glass, and plastic. These materials help in the process of winding the inductor. The amount of energy that an inductor can store is known as inductance. It is measured in Henry H.

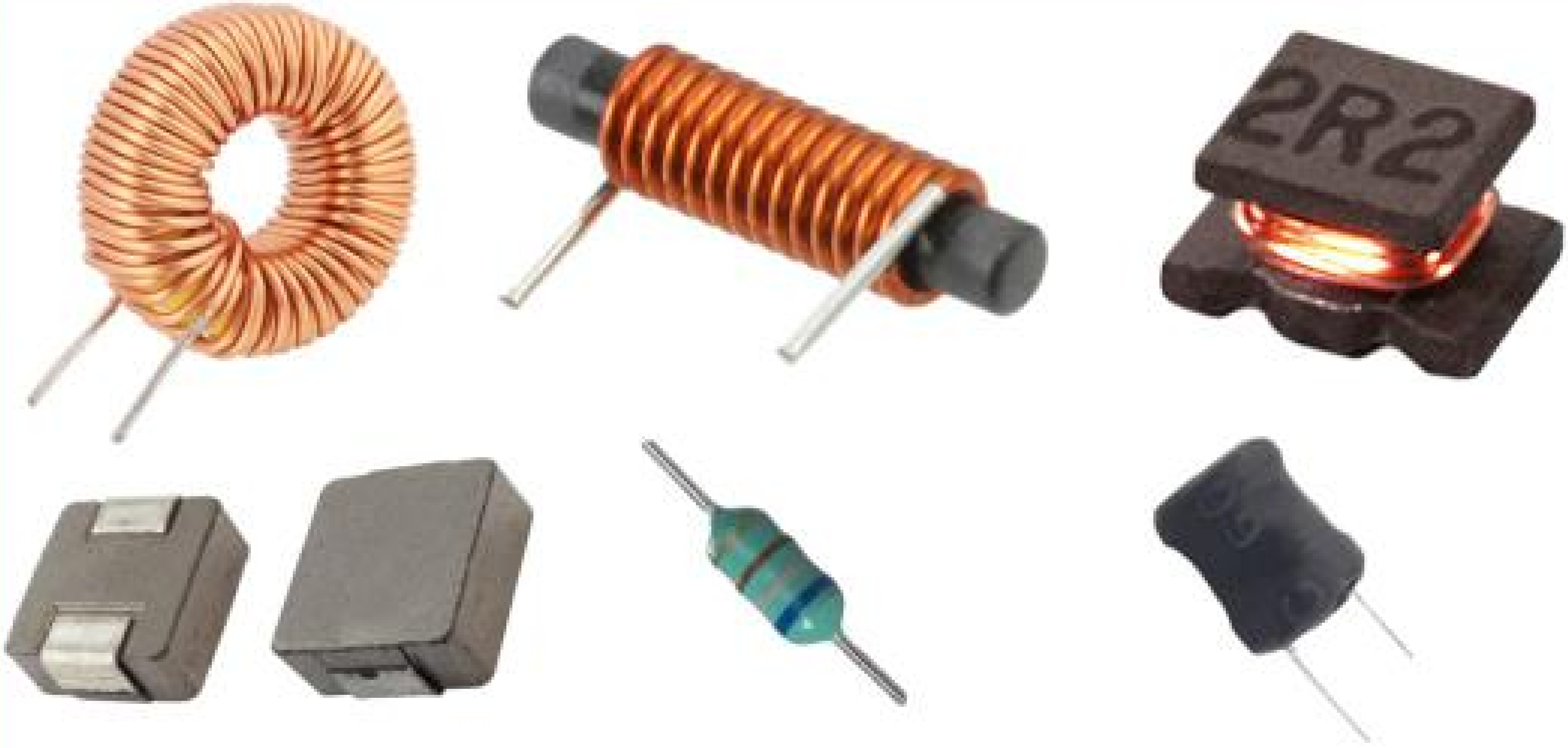
Fixed Inductor



Variable Inductor

- Inductors resist or oppose changes of current but will easily pass a steady state DC current. This ability of an inductor to resist changes in current is called Inductance which denoted by symbol L. Inductance of a coil is measured in Henry's. One Henry is the amount of inductance required to produce an e. m. f. of 1 volt in a conductor when the current in the conductor changes at the rate of 1 Ampere per second.

- Factors Affecting Inductance: The amount of inductance in an inductor is dependent on:
- The number of turns of wire in the inductor.
- The material of the core, the shape and size of the core.
- The shape, size and arrangement of the wire making up the coils.
- Applications: Inductors are used in many analog circuits and are also used along with capacitors for forming filter circuits and thus signal processing. They are also used in Switched Mode Power Supplies (SMPS), oscillators, transmitters, receivers, voltage regulators etc.



Different Types of Inductors

Introduction

Radios
Televisions
Audio equipments
Computers
Industrial Control and
Automation

The field of *electronics* deals with the design and applications of electronic devices

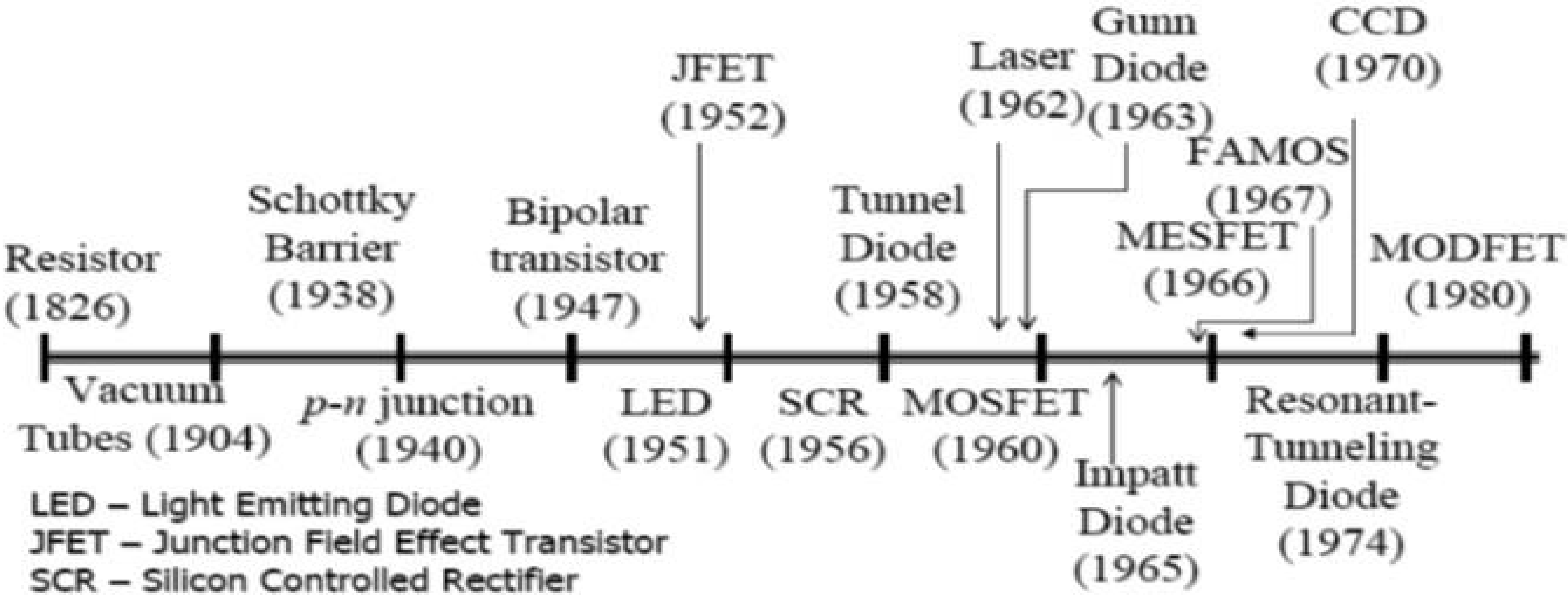
Thank You

Introduction to Semiconductors

Introduction

- What is electronics?
  - Use of electricity for measurement , control , communications , computing and similar applications.
- Use of electronics in daily life
  - Alarms , lights , calculators , televisions , computers , telephon fridges ,microwave ovens , etc.

Inventions in Electronics



LED – Light Emitting Diode
JFET – Junction Field Effect Transistor
SCR – Silicon Controlled Rectifier
MOSFET – Metal-Oxide Semiconductor Field Effect Transistor
MESFET – Metal-Semiconductor Field Effect Transistor
FAMOS – Floating Gate Avalanche MOS
CCD – Charge-Couple Devices
MODFET – Modulation Doping Field-Effect Transistor

Developments in Electronics

- VLSI Circuits (Very Large Scale Integrated)
- Broadband Communication Systems
- Typewriters-replaced by Computers which are networked-can communicate with one another
- Old fashioned roll of stamps replaced-automatic electronic mailing machines
- Developments in computer systems-introduction of tablet-mini size handy computer

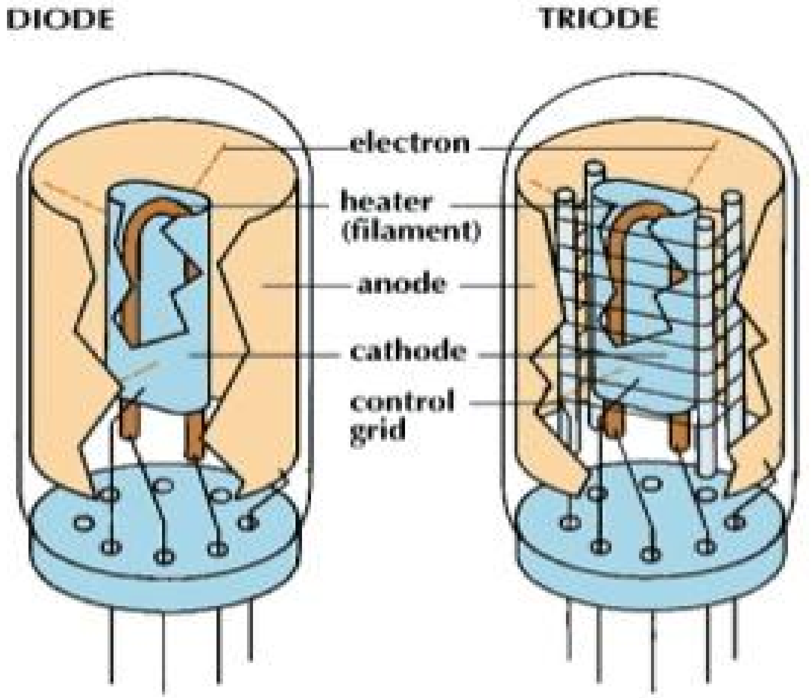
Advantages

- Printing made easy
- Several copies of documents
- Photostat machines
- Hand held tape recorders
- Computer writing- more effective-tools for spelling and grammar
- Internet-connects all over the world
- www-Huge resource of information
- Mobile devices with technological advancements
- Benefits of tracking system , digital maps
- Technology in education

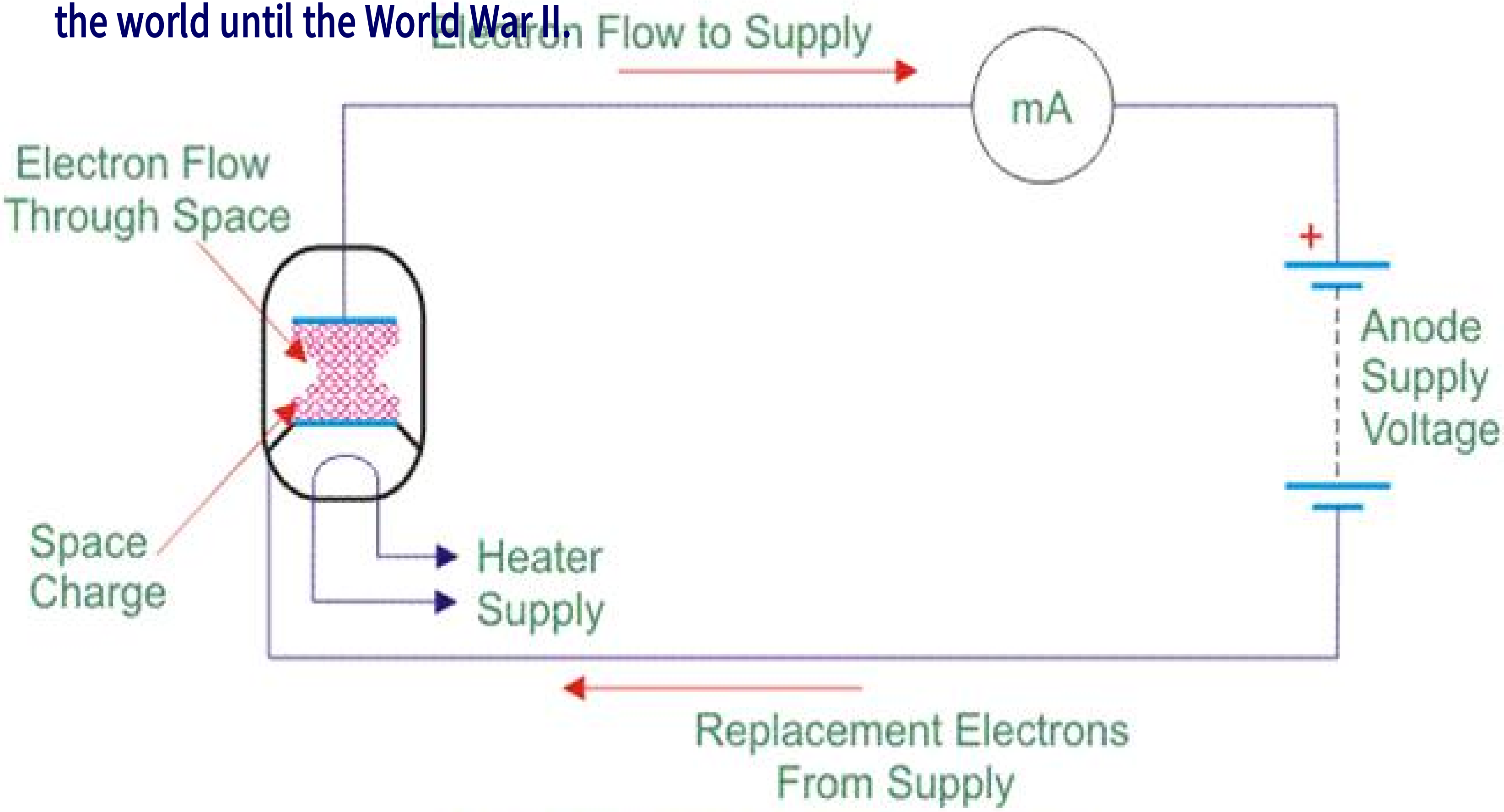
Disadvantages

- Careless usage-irrepairable problems
- Threat to confidential information
- Manufacturing materials-plastics-non bio-degradable
- Process of manufacturing-pollutes environment

Vacum Tubes


DIODE
TRIODE
electron
heater
(filament)
anode
cathode
control
grid

Electronics' actual history began with the invention of vacuum diode by J.A. Fleming, in 1897. This led to the introduction of triode, tetrode and pentode tubes that dominated the world until the World War II.



Schematic of Vacuum Diode

Transistors

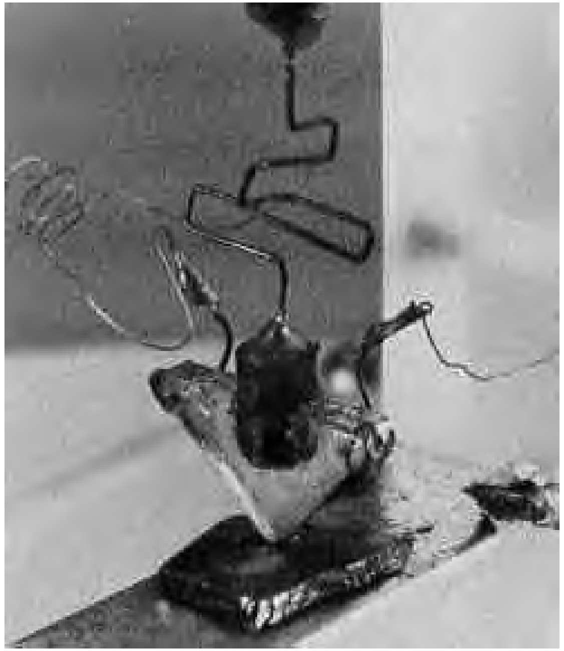
- The transistor era began with the junction transistor invention in 1948.
- *1948- William Schockley, John Bardeen and Watter Brattain- Transistor*
- The use of germanium and silicon semiconductor materials made these transistor gain the popularity and wide-acceptance usage in different electronic circuits.
- And the trend further carried forward with the JFETS and MOSFETs that were developed during 1951 to 1958 by improving the device designing process and by making more reliable and powerful transistors.

1947

John Bardeen, William Shockley and Walter Brattain

Working at Bell Telephone, they were trying to understand the nature of the electrons at the interface between a metal and a semiconductor (germanium).

First Transistor



It consisted of a plastic triangle lightly suspended above a germanium crystal which itself was sitting on a metal plate attached to a voltage source.

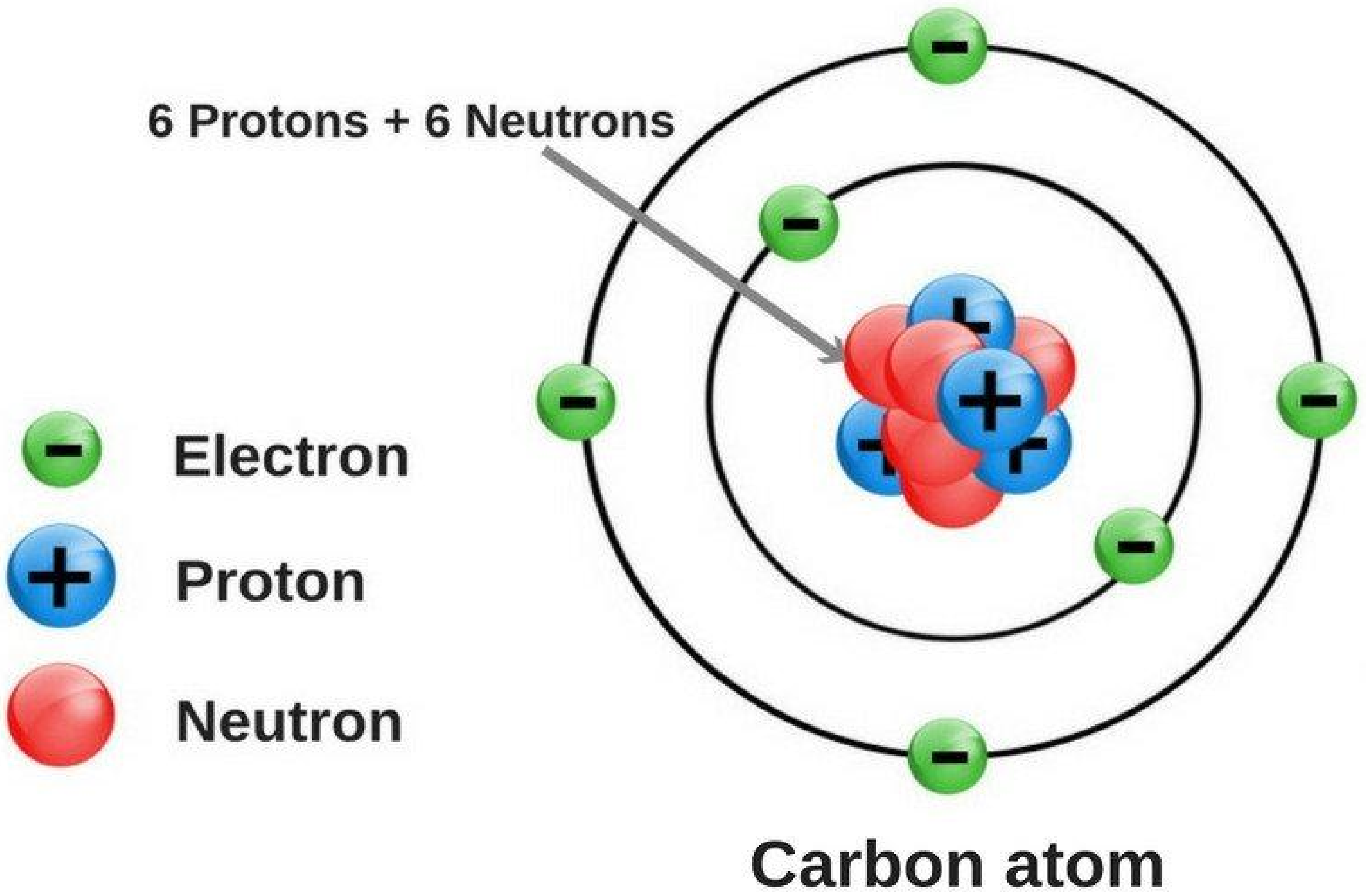
Semiconductors

Silicon.

Thew term tetravalent means that Carbon, Silicon and Germanium have four electrons in their outermost shell (orbital).

5 B Boron	6 C Carbon	7 N Nitrogen
13 Al Aluminium	14 Si Silicon	15 P Phosphorus
31 Ga Gallium	32 Ge Germanium	33 As Arsenic

Atomic Structure



Electronic Materials

- The goal of electronic materials is to generate and control the flow of an electrical current.
- Electronic materials include:

1. **Conductors**: have low resistance which allows electrical current flow
2. **Insulators**: have high resistance which suppresses electrical current flow
3. **Semiconductors**: can allow or suppress electrical current flow

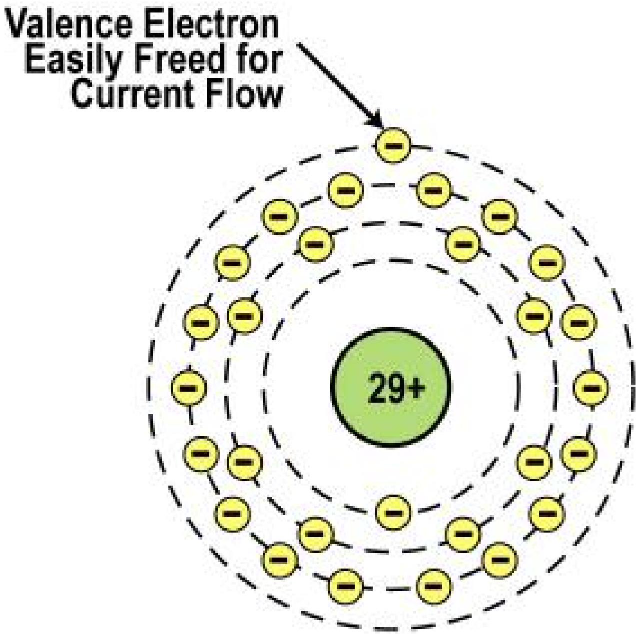
Conductors

- Good conductors have low resistance so that electrons can flow through them with ease.
- **Best** element conductors include:
  - Copper, silver, gold, aluminum, & nickel
- Alloys are also good conductors:
  - Brass & steel

- The number free electron density in conductors is very high, approximately in the order of 10^{28} free electrons per cubic metre.

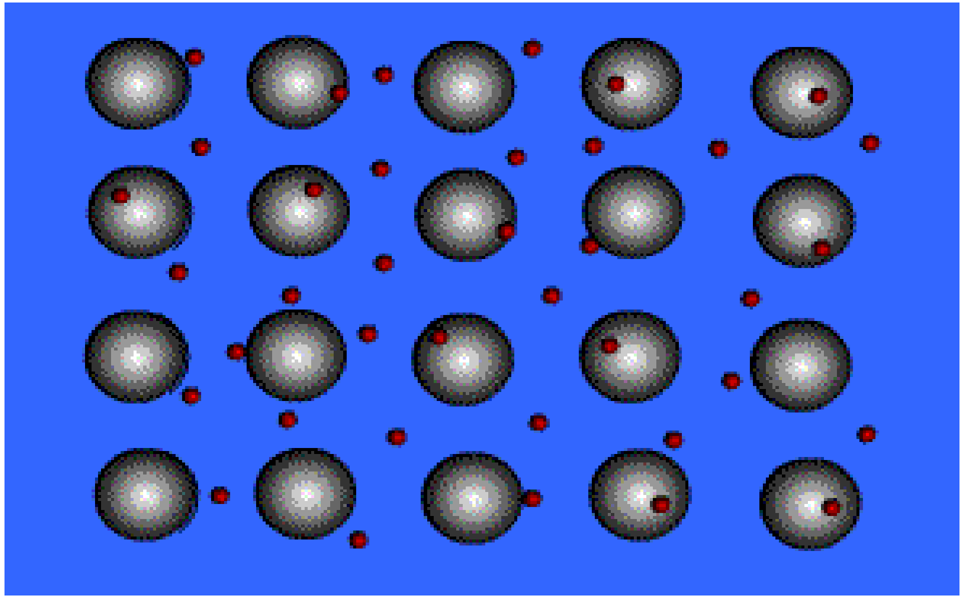
Conductor Atomic Structure

- The atomic structure of good conductors usually includes only <u>one electron in their outer shell</u>.
  - It is called a valence electron.
  - It is easily striped from the atom, producing current flow.



Copper Atom

Conductors



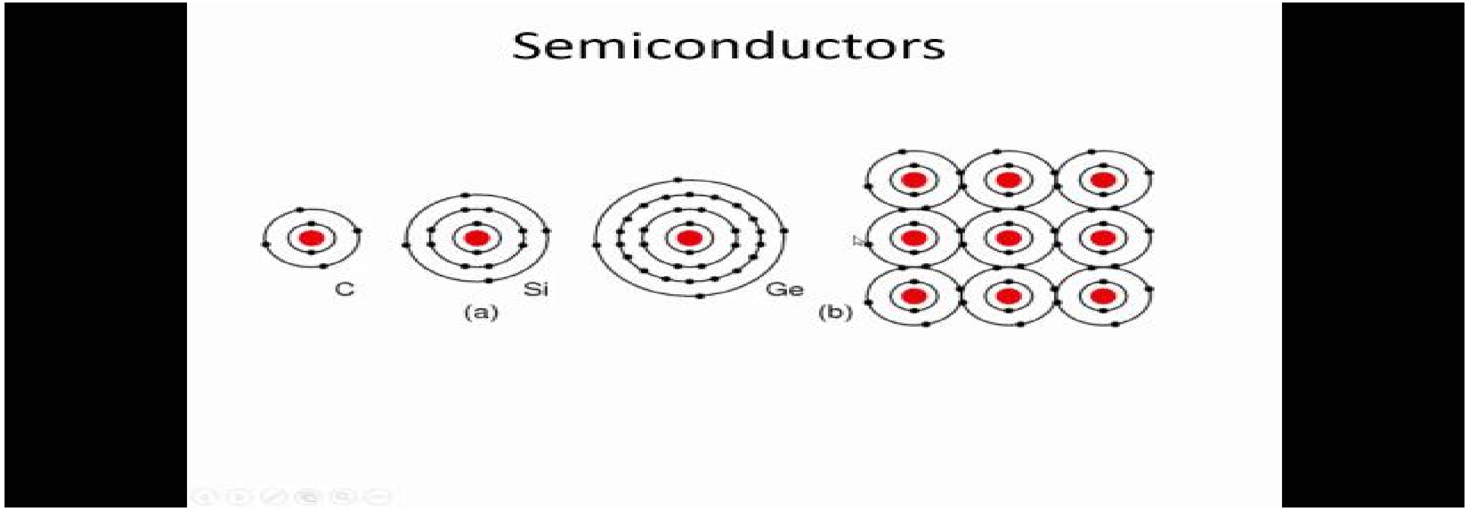
In a conductor, electrons can move freely among these orbitals within an energy band as long as the orbitals are not completely occupied.

Insulators

- Insulators have a high resistance so current does not flow in them.
- Good insulators include:
  - Glass, ceramic, plastics, & wood
- Most insulators are compounds of several elements.
- The atoms are tightly bound to one another so electrons are difficult to strip away for current flow.
- **The number free electron density in insulators is very low, approximately in the order of 10^9 free electrons per cubic metre.**

Semiconductors

- Semiconductors are materials that essentially can be conditioned to act as good conductors, or good insulators, or any thing in between.
- Common elements such as **carbon**, **silicon**, and **germanium** are semiconductors.
- Silicon is the best and most widely used semiconductor.

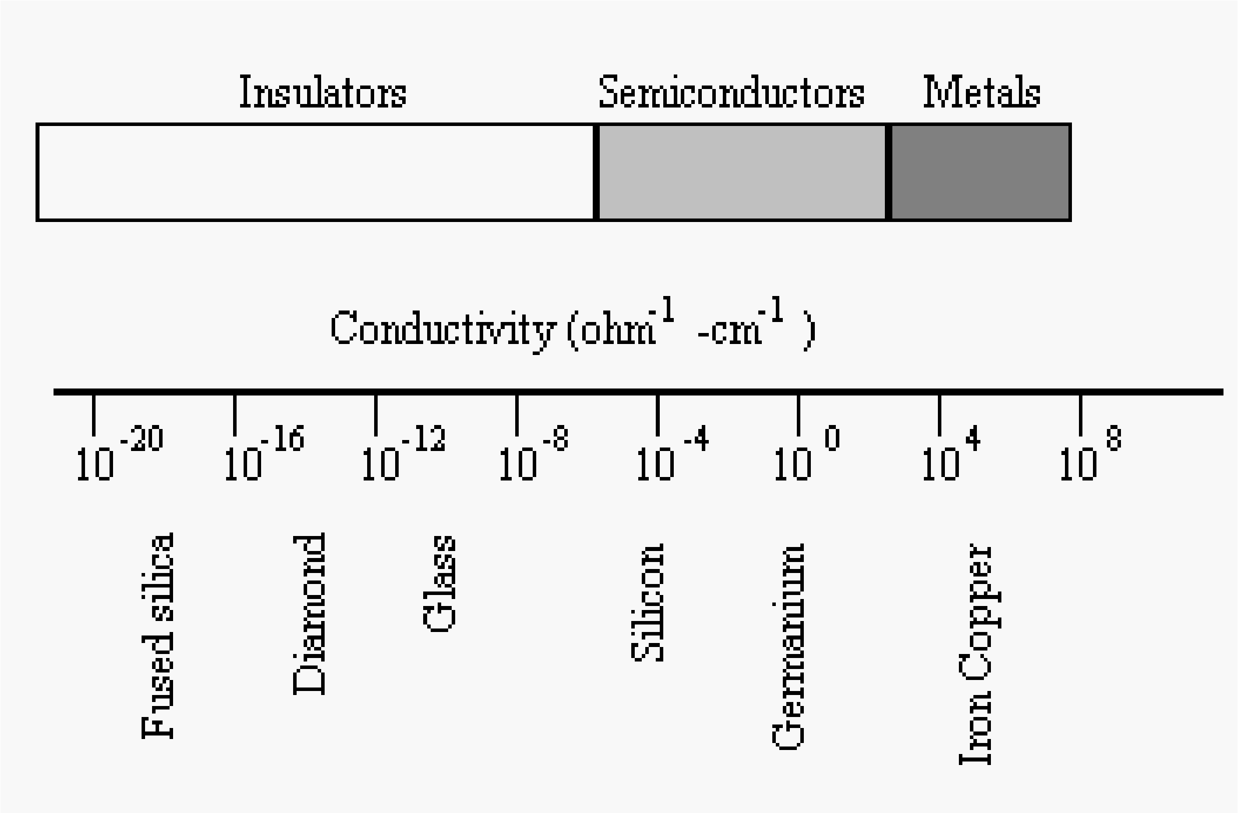


Free Electron Number Density

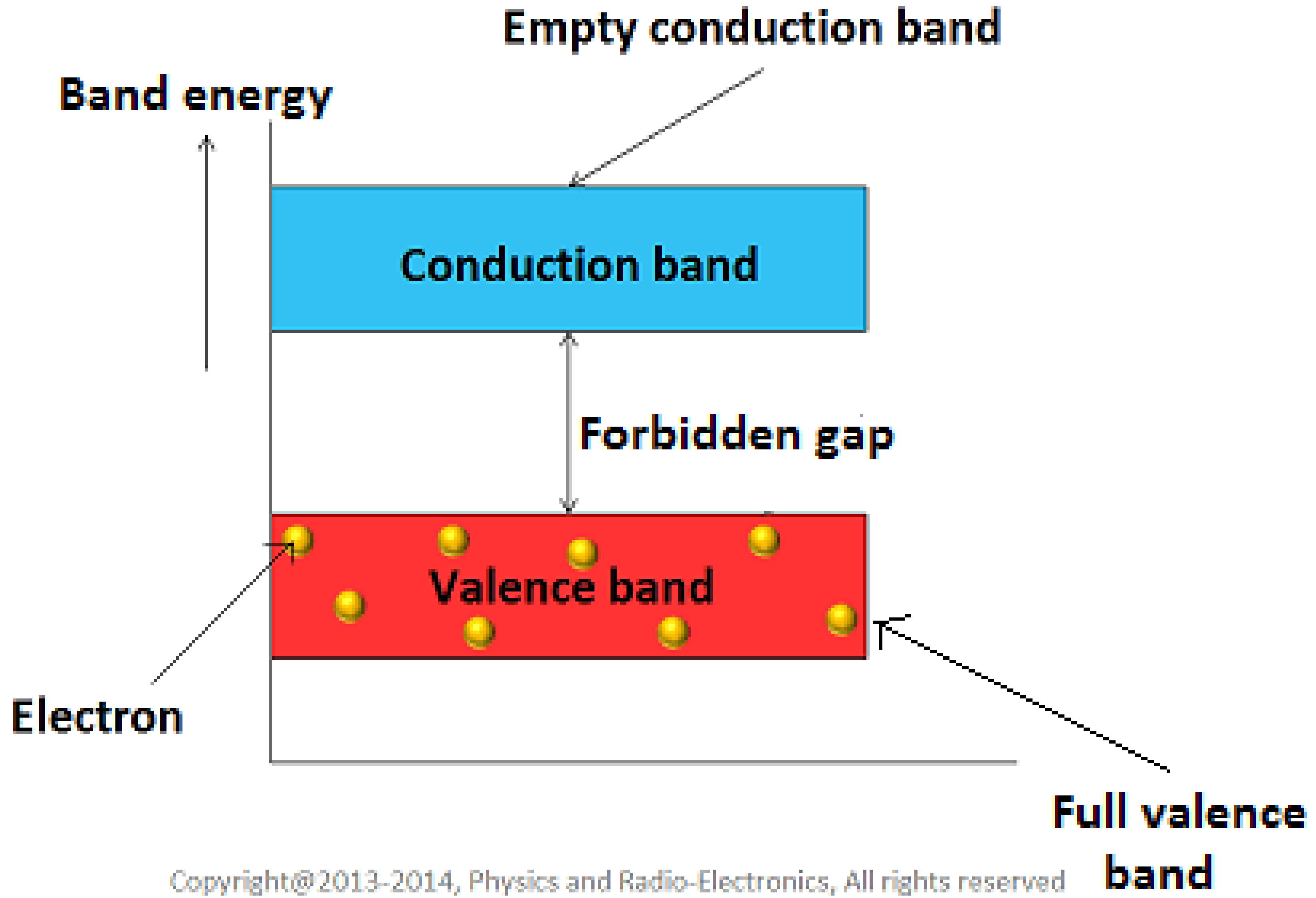
- The table below shows some typical values for n.

Type of material	Number of free electrons per m^3 (n)
Conductor	$\sim 1 \times 10^{29}$
Semiconductor	$\sim 1 \times 10^{19}$
Insulator	$\sim 1 \times 10^{9}$

Range of Conductivity

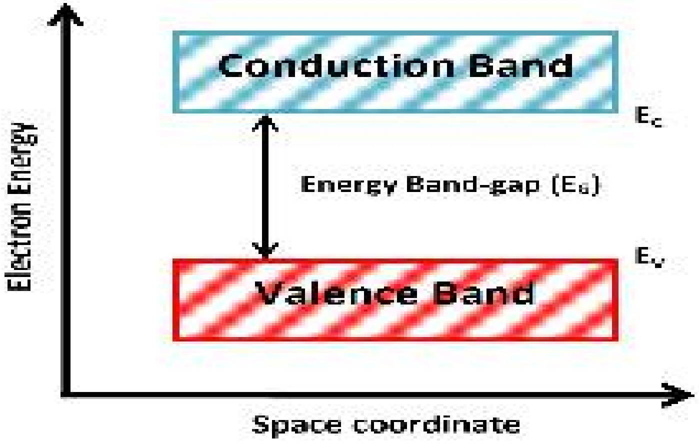


The semiconductors fall somewhere midway between conductors and insulators.

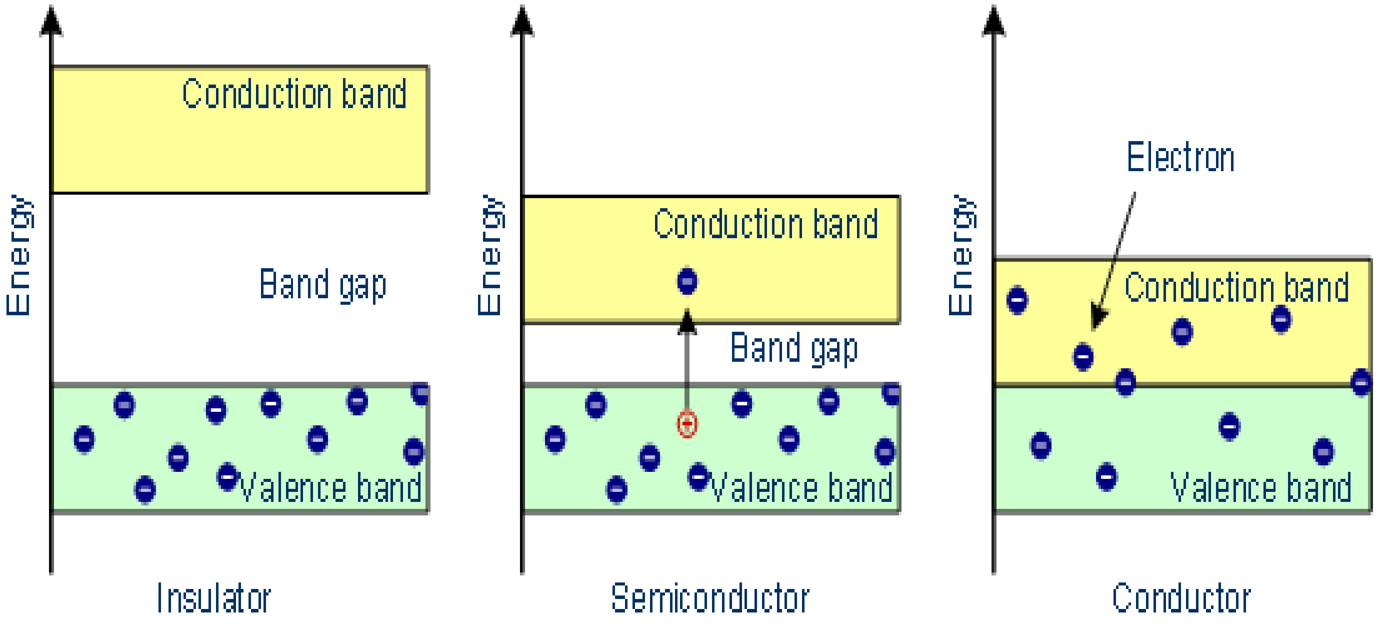

Empty conduction band
Band energy
Conduction band
Forbidden gap
Valence band
Electron
Full valence band

1 eV: is the amount of kinetic energy gained by a single electron accelerating from rest through an electric potential difference of one volt in vacuum.

$$1eV = 1.602\times10^{-19} \text{ joule}$$

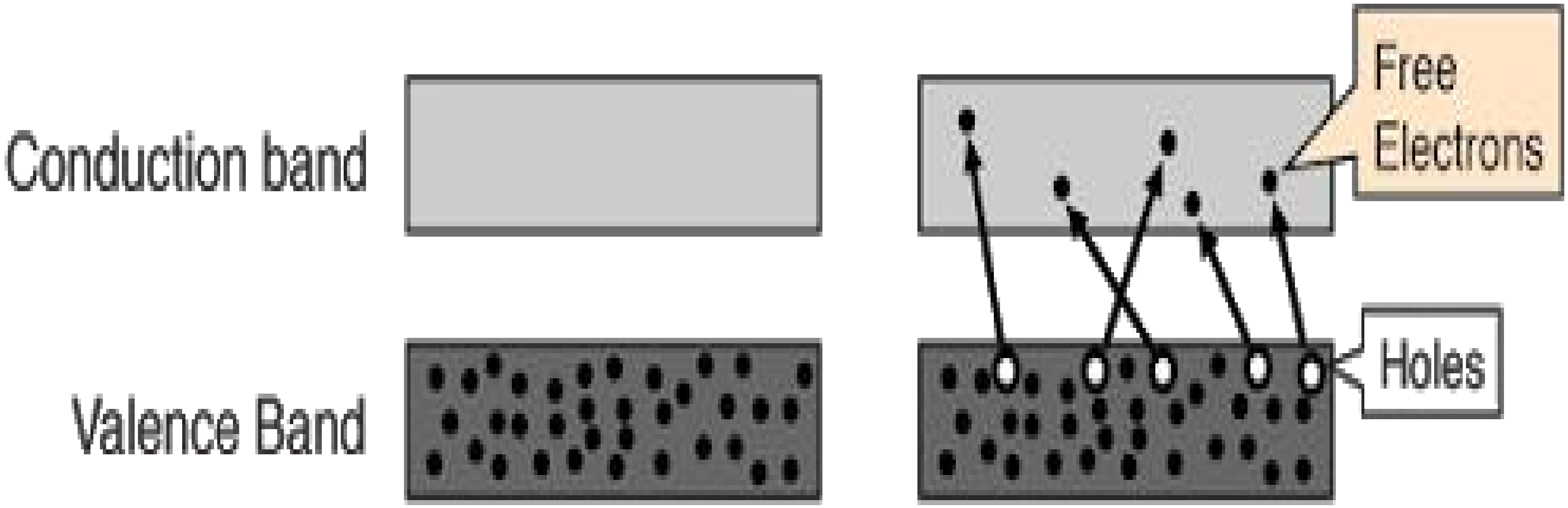


Energy band diagram



$Eg = 6eV$ $\qquad$ $Eg = 1\ eV$

Intrinsic Semiconductor Ge ($E_g = 0.7\ eV$), Si ($E_g = 1.1\ eV$)


Conduction band
Valence Band
Free Electrons
Holes

Conduction Band and Valence Band in Semiconductors

Valence Band:

The energy levels of valence electrons is known as the valence band. It is the highest occupied energy band. When compared with insulators, the bandgap in semiconductors is smaller. It allows the electrons in the valence band to jump into the conduction band on receiving any external energy.

Conduction Band:

It is the lowest unoccupied band that includes the energy levels of free electrons charge carriers. It has conducting electrons resulting in the flow of current. The conduction band possess high energy level and are generally empty. The conduction band in semiconductors accepts the electrons from the valence band.

Energy band gap: Essentially, the **band gap** represents the minimum **energy** that is required to excite an electron up to a state in the conduction **band** where it can participate in conduction.

Semiconductor

- Semiconductors are materials whose electronic properties are intermediate between those of Metals and Insulators.
- They have conductivities in the range of 10^{-4} to 10^{+4} S/m.
- The interesting feature about semiconductors is that they are bipolar and current is transported by two charge carriers of opposite sign.
- These intermediate properties are determined by

  1. Crystal Structure bonding Characteristics.
  2. Electronic Energy bands.

Why Semiconductors?

Semiconductors can conduct electricity under preferable conditions or circumstances. This unique property makes it an excellent material to conduct electricity in a controlled manner as required.

Unlike conductors, the charge carriers in semiconductors arise only because of external energy (thermal agitation). It causes a certain number of valence electrons to cross the energy gap and jump into the conduction band, leaving an equal amount of unoccupied energy states, i. e. holes. Conduction due to electrons and holes are equally important.

Thank You

Diffusion & Diffusion current

An electric current flows in a semiconductor even in the absence of an applied voltage, if a concentration gradient exists in the material. A concentration gradient exists when the number of either electrons or holes is greater in one region of a semiconductor as compared to the rest of the region.

If the concentration gradient of charge carriers exists in a material, the carriers tend to move from the region of higher concentration to the region of lower concentration. This process is called "Diffusion". And the electric current due to this process is known as " Diffusion current".

Let us consider, a piece of semiconductor in which the concentration of free electrons (n) is not uniform. Also let concentration of electrons be non-uniform in the x-direction.

The rate of change of concentration or concentration gradient is dn/dx.

The concentration of electrons is changing with x, the density of electrons in one site is more than the density in the other side. Electrons are free to move from the greater concentration side to the lower concentration side.

Diffusion & Diffusion current

The diffusion current density J_n for electrons is proportional to the concentration gradient.

$$j_n \propto \frac{dn}{dx}$$

Or $$J_n = qDn\frac{dn}{dx}$$

The diffusion current density J_p for holes,

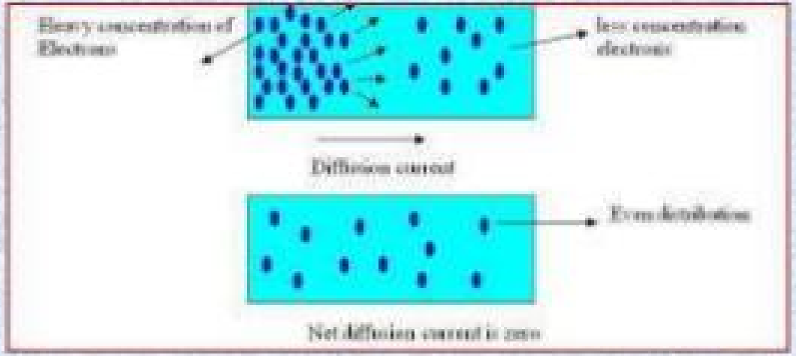
$$J_p = -qDp\frac{dn}{dx}$$

where-

D_p & D_n= Diffusion constant for holes and electrons

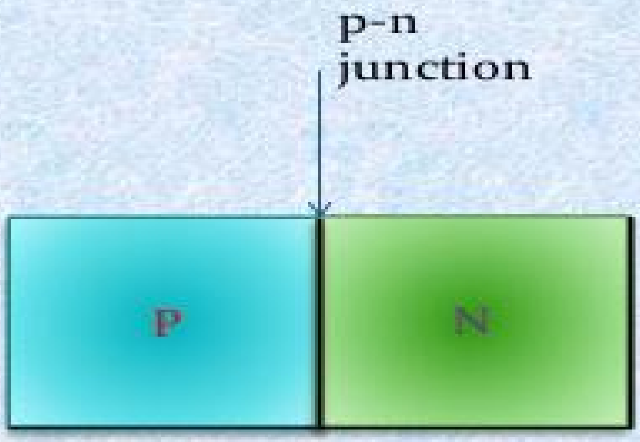
q= charge of an electrons

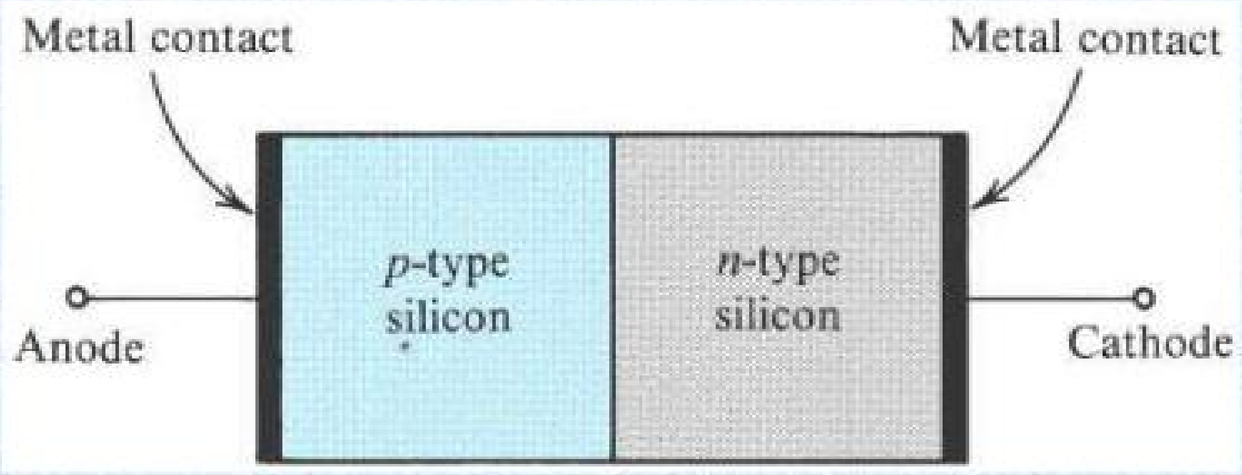
The negative sign shows that $\frac{dn}{dx}$ is negative when the charge density falls with increase of x.



p-n junction

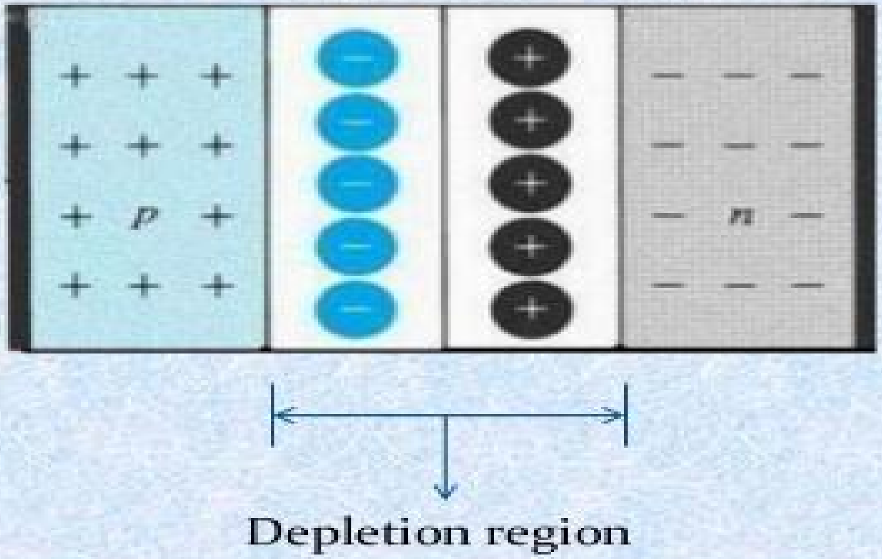
- A piece of p –type semiconductor is joined to a piece of n – type semiconductor in such a manner that the crystal structure remains continuous at the boundary, then "p-n junction" is formed.
- To form p-n junction, a special fabrication techniques are required.
- A wafer of the semiconductor material is doped so that one region is n-type and the other region is p-type.





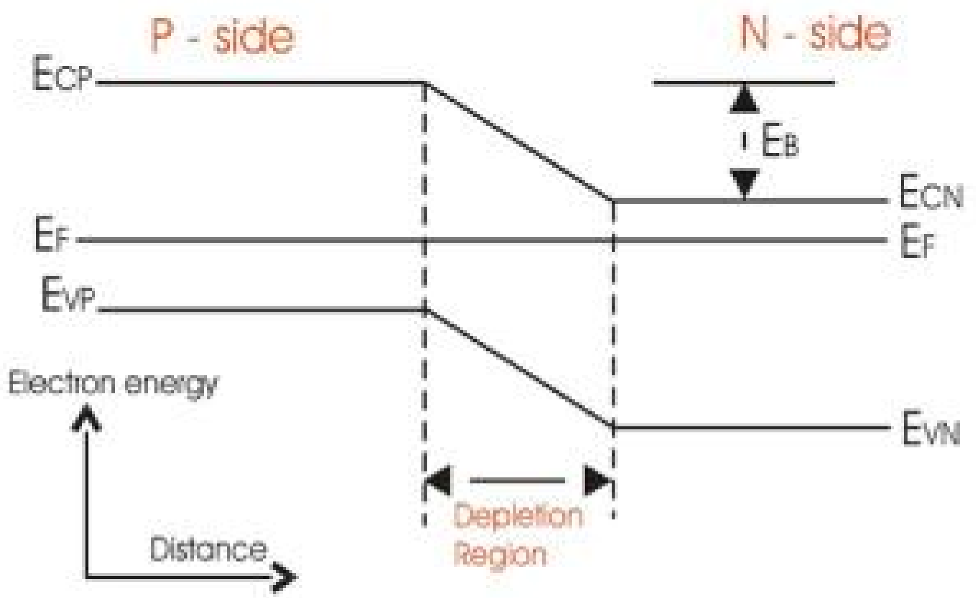
➢The formation of this barrier may be given in following steps :-

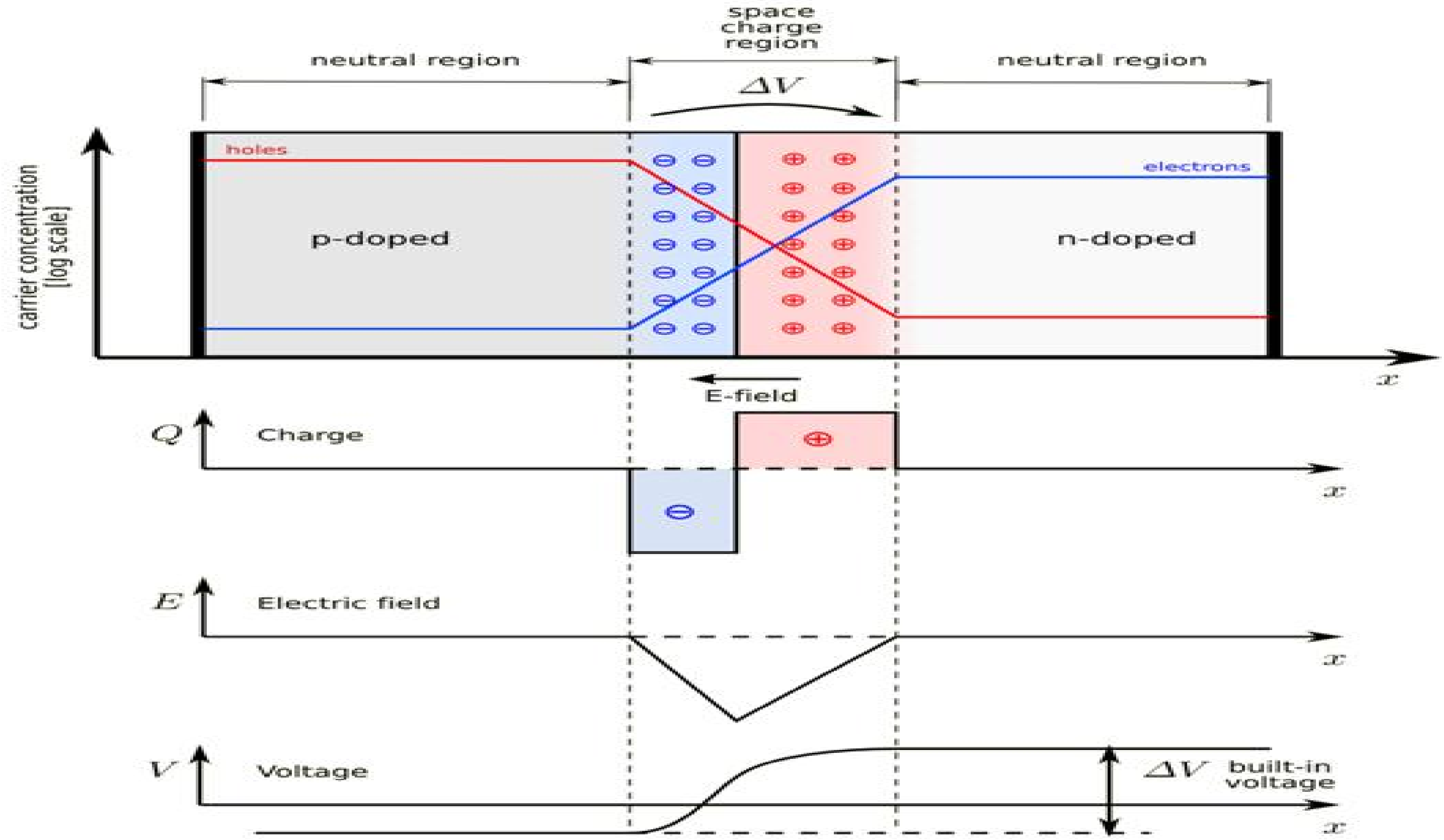
- As the p-n junction is formed, some of holes in the p- region and some of the electrons in the n- region diffuse in each other and recombine.
- Each recombination eliminates a hole and a free electron.
- The negative acceptor ions in the p-region and positive donor ions in the n-region are left uncovered or uncompensated in the neighbourhood of the junction.



- Holes trying to diffuse into n- region are repelled by the uncovered positive charge of the donor ions. Similarly, electrons trying to diffuse into p- region are repelled by the uncovered negative charge of the acceptor ions.
- Due to this , further diffusion of holes and electrons across the junction is stopped.
- The region having uncompensated acceptor and donor ions is called *“depletion region”.*
- This depletion region is also called “space-charge region”
- The width of depletion region depends upon the doping level of impurity in n-type and p-type semiconductor.
- The greater the doping level, the depletion region will be thinner.

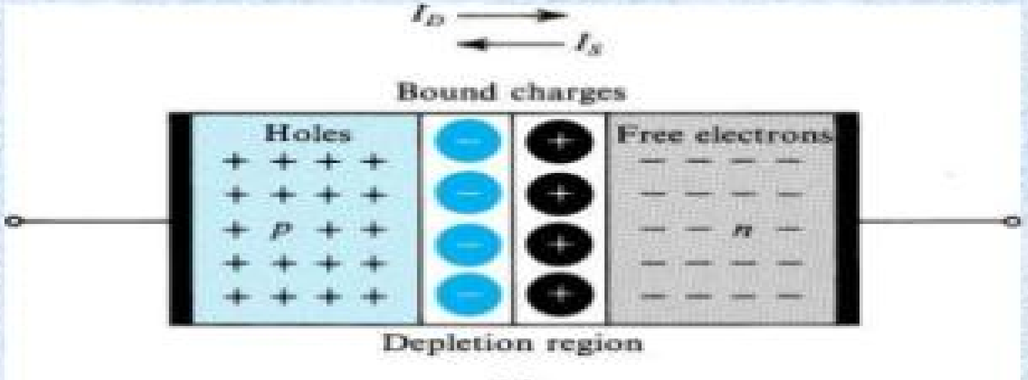
Energy Band Diagram of PN Junction Diode





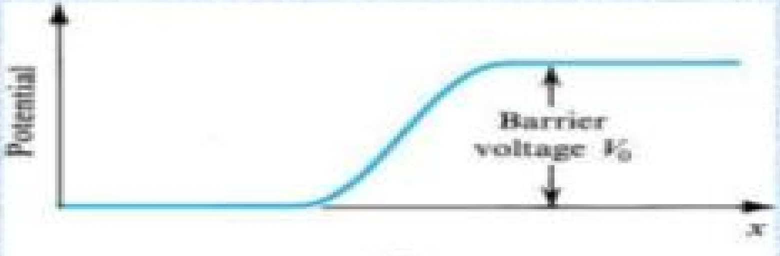
space
charge
region
neutral region
neutral region
ΔV
carrier concentration
[log scale]
holes
electrons
p-doped
n-doped
x
E-field
Q
Charge
x
E
Electric field
x
V
Voltage
ΔV
built-in
voltage
x

pn Junction Under Open-Circuit Condition



(a)

Fig **(a)** shows the *pn* junction with no applied voltage (open-circuited terminals).



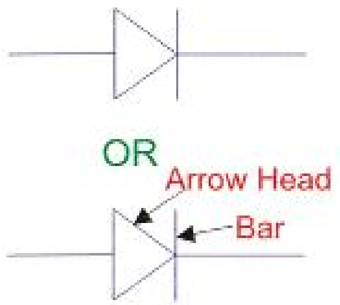
(b)

Fig.**(b)** shows the potential distribution along an axis perpendicular to the junction.

Concept of Diode

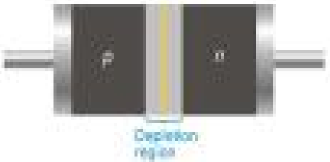
- What is a diode?: a diode is such a semi conductor device which does not follow Ohm's Law.
- In electronics, a **diode** is a two-terminal electronic component with an asymmetric transfer characteristic, with low (ideally zero) resistance to current flow in one direction, and high (ideally infinite) resistance in the other.
- A **semiconductor diode**, the most common type today, is a crystalline piece of semiconductor material with a p-n junction connected to two electrical terminals.

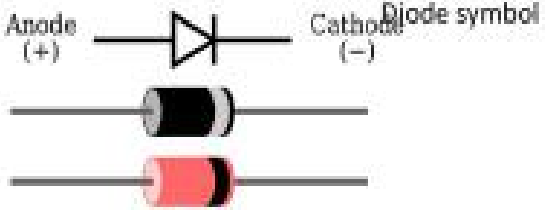
Diodes



- Diode, semiconductor material, such as silicon, in which half is doped as p-region and half is doped as n-region with a pn-junction in between.

- The p region is called **anode** and n type region is called **cathode.**





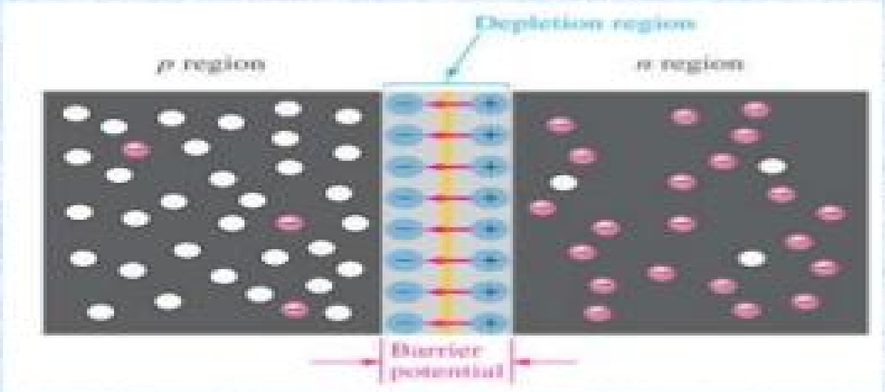
DIODE

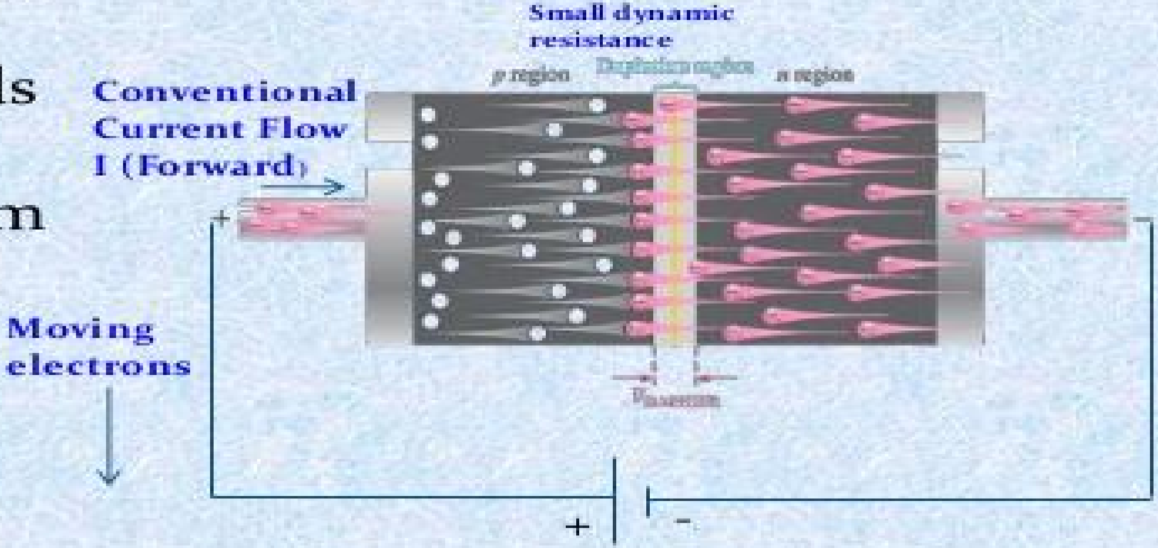
Types of Diode

Biasing of Diode

The pn Junction Under Forward-Bias Conditions

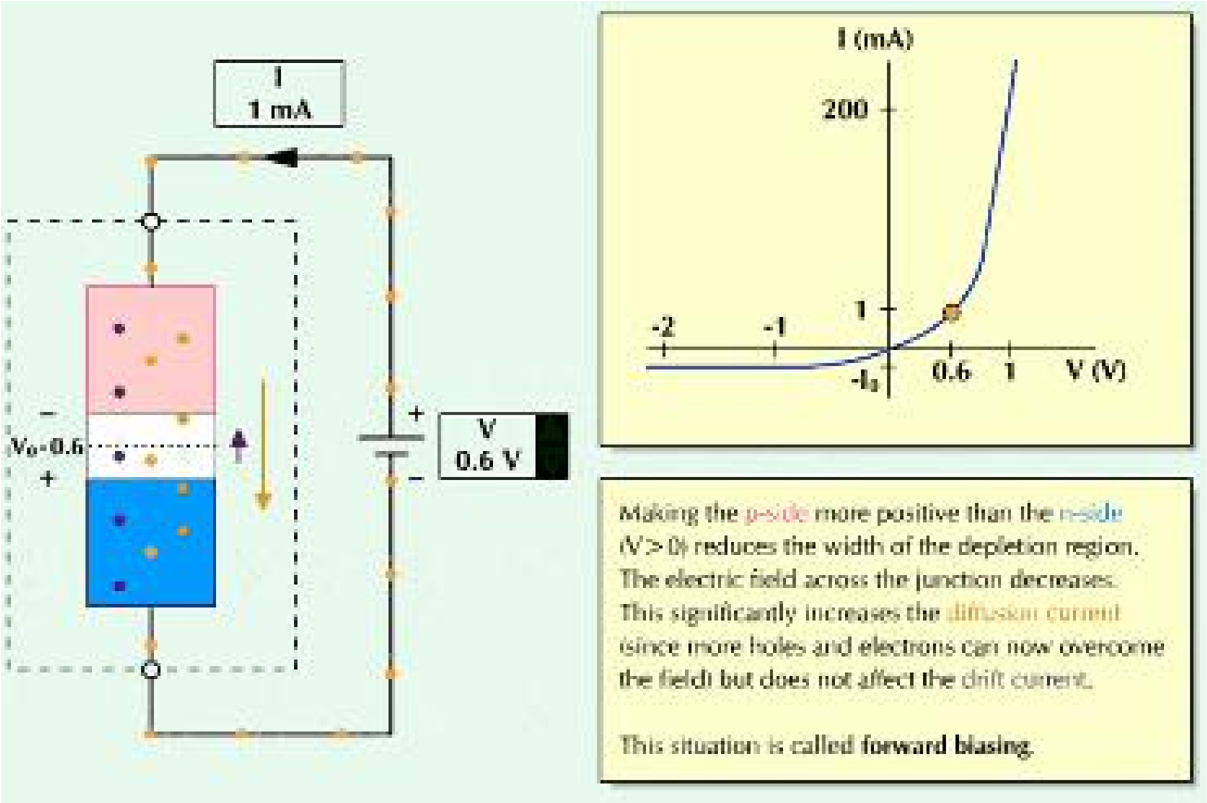
- Positive terminal of the battery is connected to the p-side and the negative terminal to the n-side.
- Holes are repelled from the positive terminal of the battery and forced towards the junction.
- Electrons are repelled from the negative terminal of the battery and forced towards the junction.





Pink -P;   Blue -N

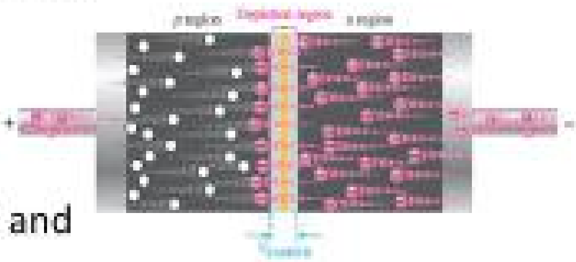
Diode in forward bias



Forward Biased

- Forward bias is a condition that allows current through pn junction.

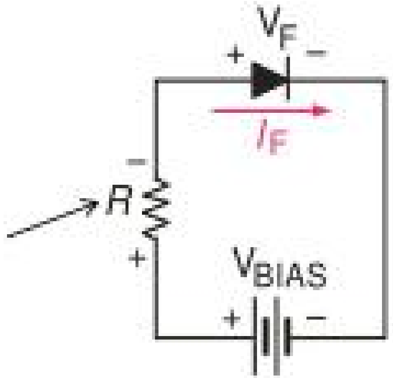
  - A dc voltage (V_{bais}) is applied to bias a diode.
  - Positive side is connected to p-region (anode) and negative side is connected with n-region.
  - V_{bais} must be greater than 'barrier potential'

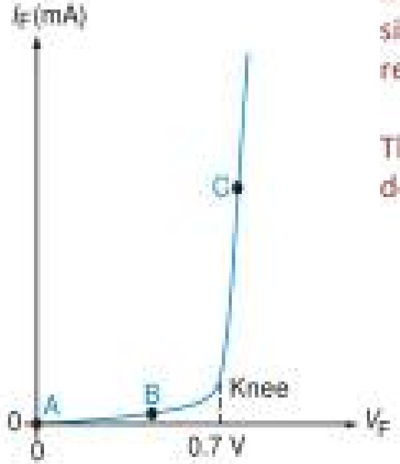


As more electrons flow into the depletion region reducing the number of positive ions and similarly more holes move in reducing the positive ions.

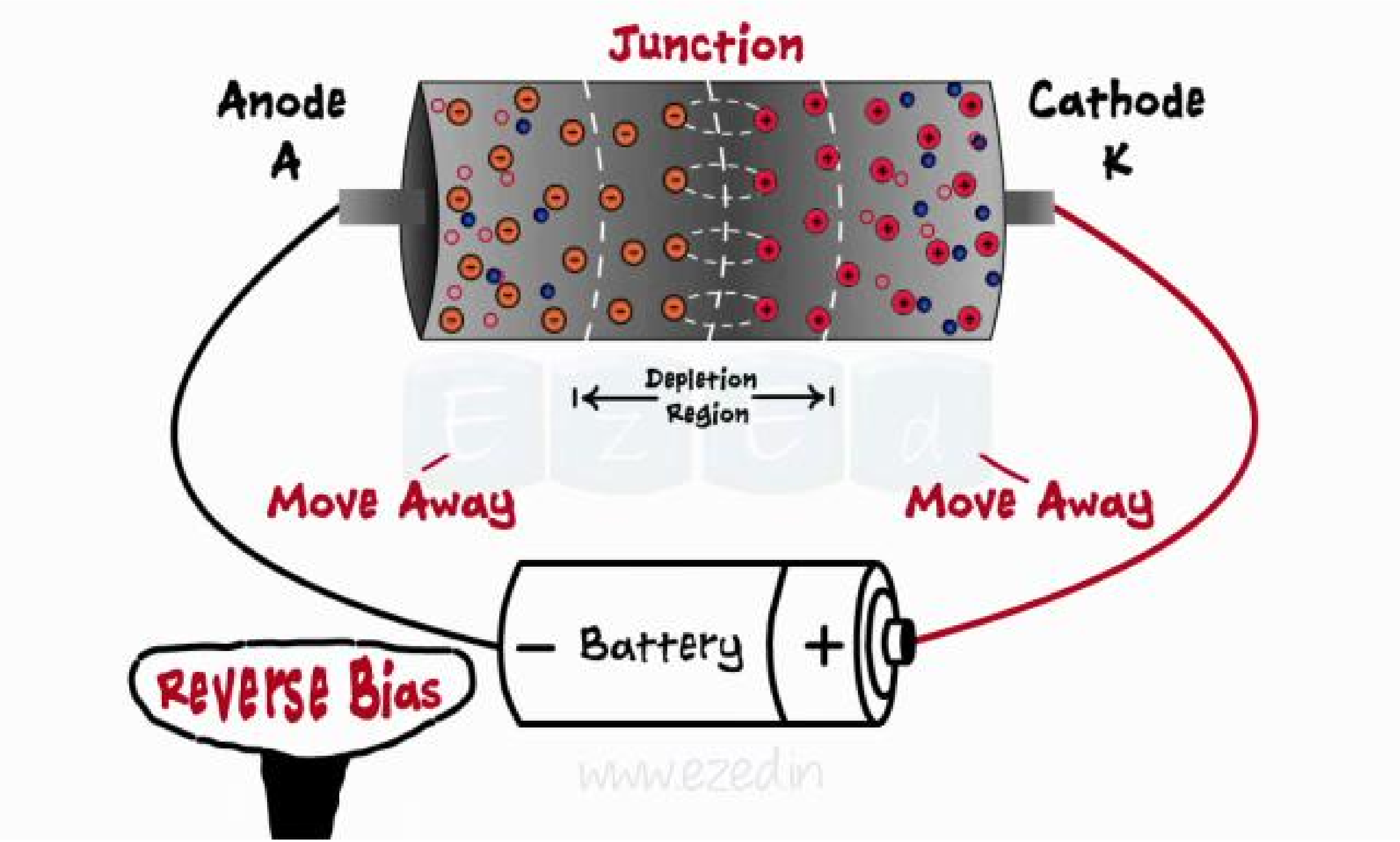
This reduces the width of depletion region.

Current limiting resistance



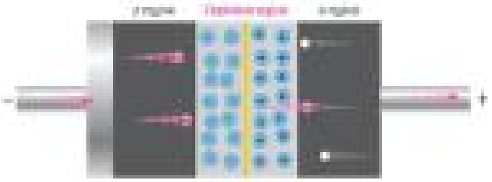


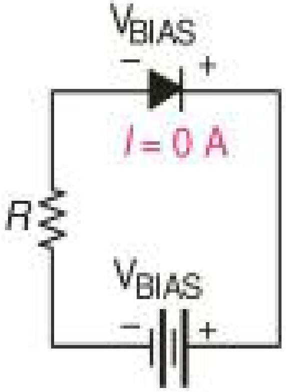
Reverse bias condition

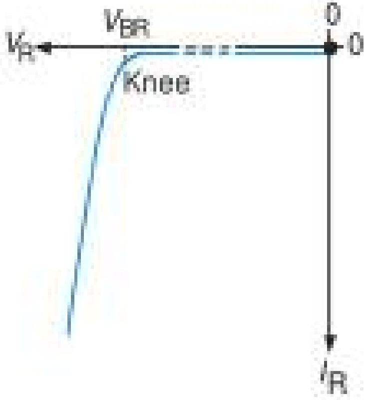


Reverse Biased

- Reverse bias is a condition that prevents current through junction.
- Positive side of V_{bias} is connected to the n-region whereas the negative side is connected with p-region.
- Depletion region get wider with this configuration.



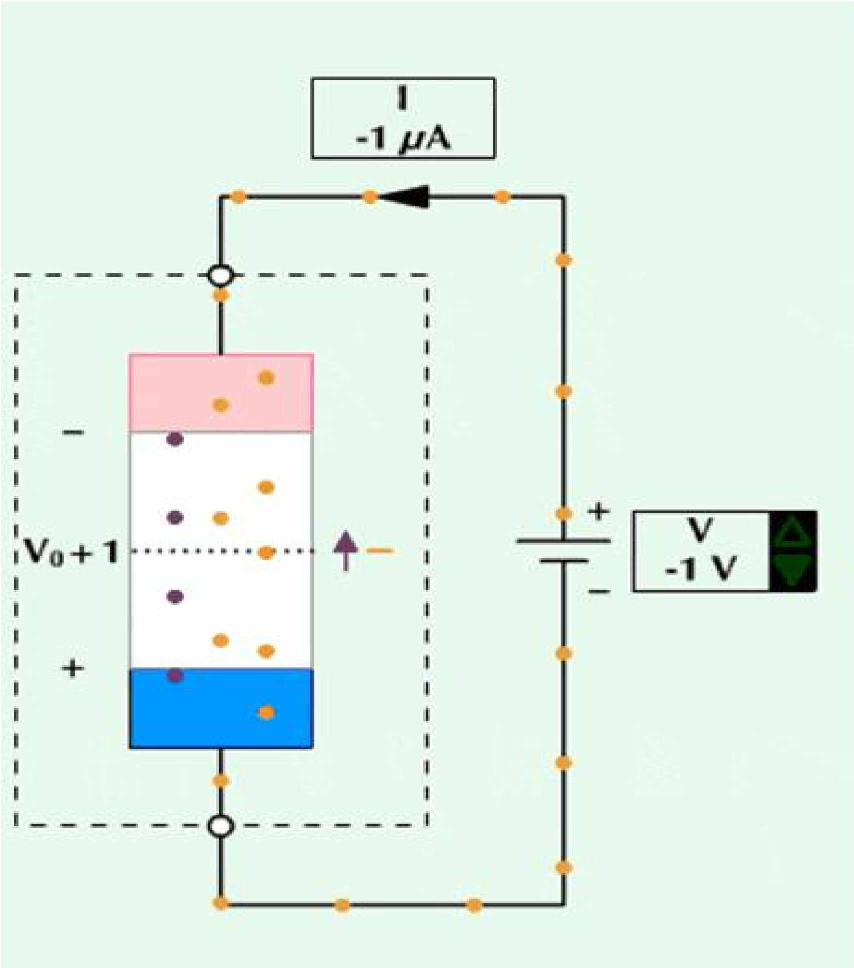


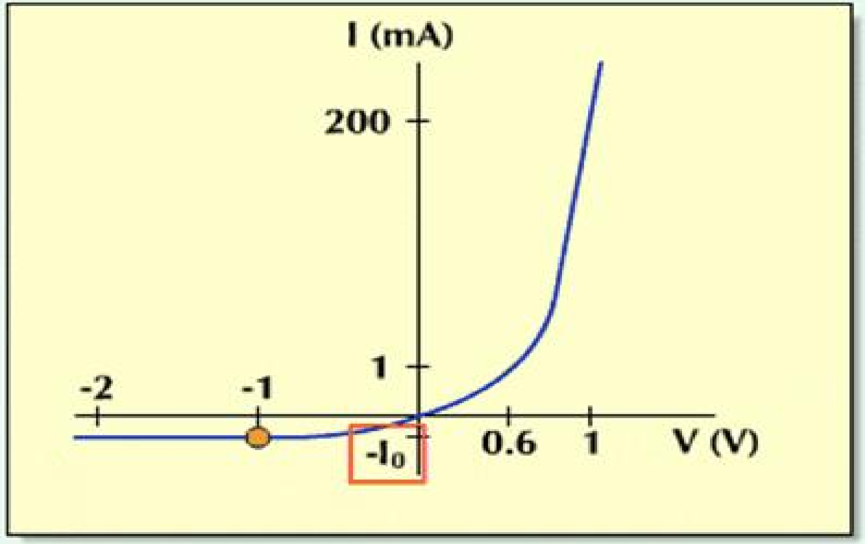


The positive side of bias voltage attracts the majority carriers of n-type creating more positive ions at the junction.

This widens the depletion region.

Diode under reverse bias



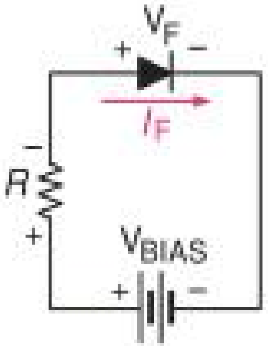


Making the n-side more positive than the p-side ($V < 0$) pulls the depletion region wider. The electric field across the junction increases. This significantly reduces the diffusion current but does not affect the drift current.

This situation is called **reverse biasing** and the net current I_0 is called the **reverse saturation current**.

Diode V-I Characteristic

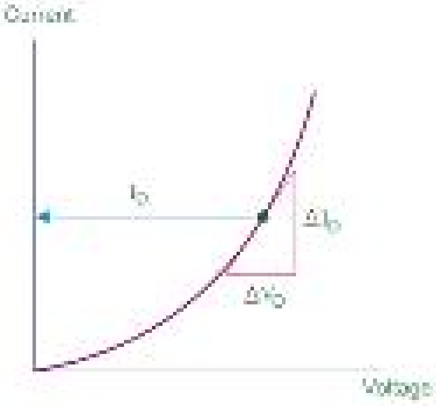
- **VI Characteristic for forward bias.**
  - The current in forward biased called *forward current* and is designated I_f
  - At 0V (V_{bias}) across the diode, there is no forward current.
  - With gradual increase of V_{bias}, the forward voltage and forward current increases.
  - A resistor in series will limit the forward current in order to protect the diode from overheating and permanent damage.
  - A portion of forward-bias voltage drops across the limiting resistor.
  - Continuing increase of V_f causes rapid increase of forward current but only a gradual increase in voltage across diode.

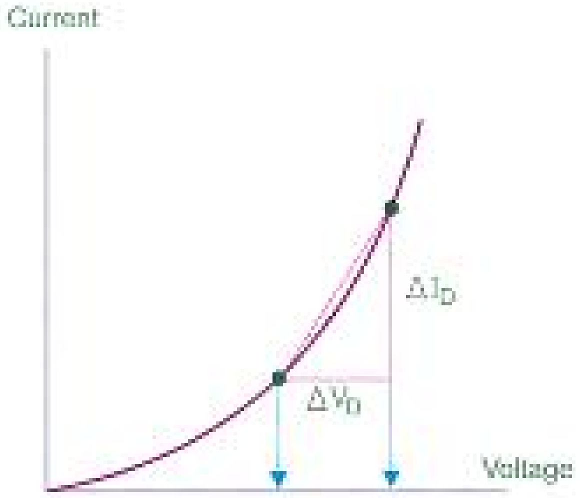


Diode V-I Characteristic

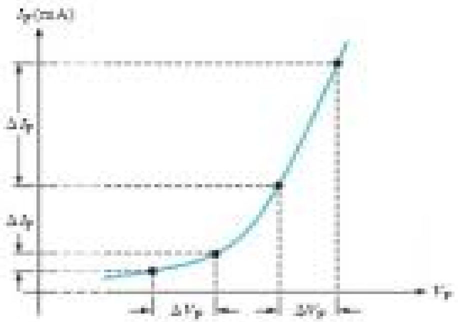
❖ **Dynamic Resistance:**

- The resistance of diode is not constant but it changes over the entire curve. So it is called dynamic resistance.





Range of Operation Voltage



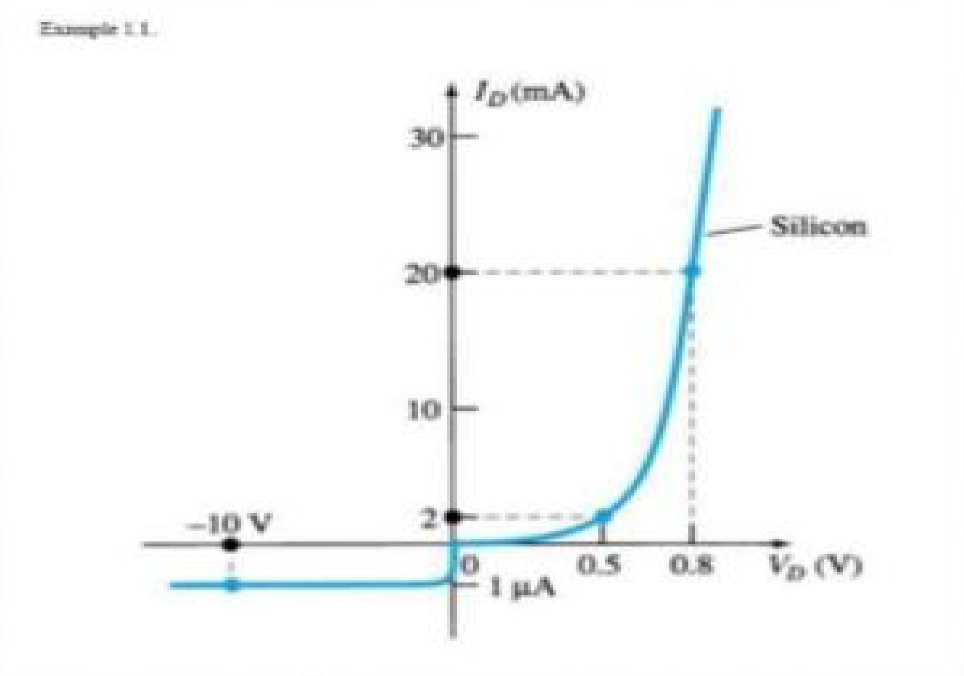
The dynamic resistance r'_d decreases as you move up the curve, as indicated by the decrease in the value of $\Delta V_F / \Delta I_F$.

Dynamic resistance $r_d = \Delta V_D / \Delta I_D$

Static resistance $R = V_D / I_D$

DC or Static Resistance

Determine the DC Resistance levels for the diode of following figure at $I_D = 2$ mA, $I_D = 20$ mA, $V_D = -10$ V



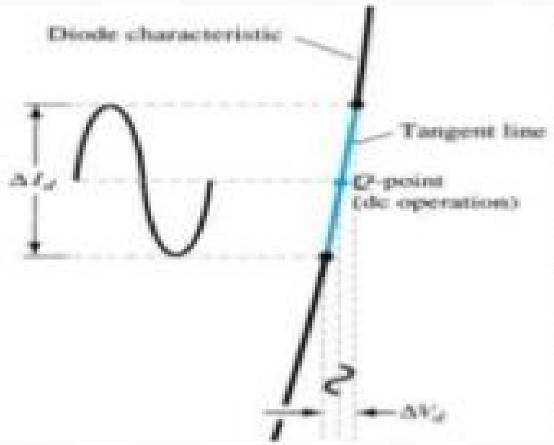
a) At $I_D = 2$ mA , $V_D = 0.5$ V and thus $R_D = 250\ \Omega$

b) At $I_D = 20$ mA , $V_D = 0.8$ V and thus $R_D = 40\ \Omega$

c) At $V_D = -10$ V , $I_D = -I_S = -1$ μA and thus $R_D = 10$ MΩ

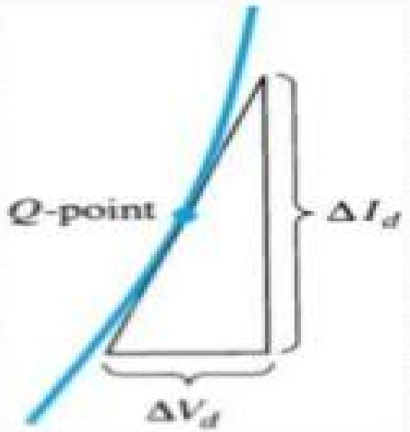
Continued...

- With no applied varying signal, the point of operation would be the Q-point
- A straight line drawn tangent to the curve through the Q-point will define a particular change in voltage and current that can be used to determine the ac or dynamic resistance for this region of the diode characteristics
- An effort should be made to keep the change in voltage and current as small as possible and equidistant to either side of the Q-point



Defining the dynamic or ac resistance.

$$r_D = \frac{\Delta V_D}{\Delta I_D}$$



Determining the ac resistance at a *Q*-point.

Derivation of Dynamic Resistance

$$I = I_0 \left(e^{v/\eta v_T} - 1\right)$$

This is the equation of Diode current

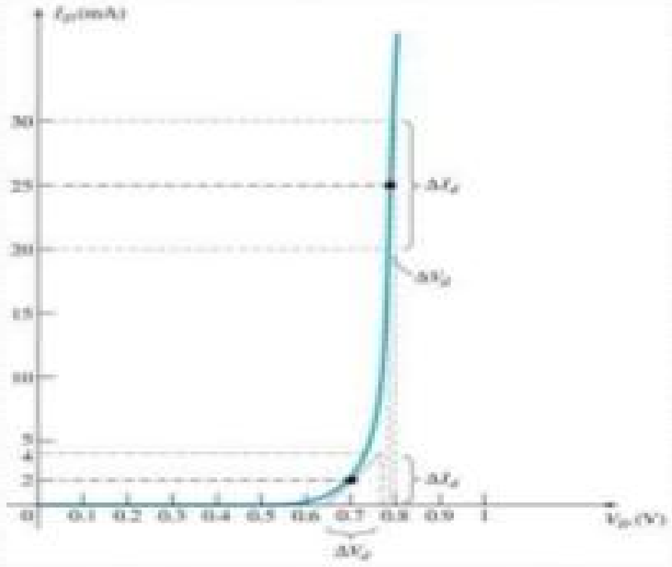
$$\frac{dI}{dv} = \frac{d}{dv}\left[I_0 \left(e^{v/\eta v_T} - 1\right)\right]$$

$$= \frac{I_0 e^{v/\eta v_T}}{\eta v_T} = \frac{I + I_0}{\eta v_T} = \frac{I}{\eta v_T}$$

$$r_f = \frac{dv}{dI} = \frac{\eta v_T}{I} = \frac{26\, mV}{I}$$

Continued…

- In general, the lower the Q-point of operation (smaller current or lower voltage) the higher the ac resistance
- For the characteristics of Figure below:
    - (a) Determine the ac resistance at $I_D = 2$ mA.
    - (b) Determine the ac resistance at $I_D = 25$ mA.
    - (c) Compare the results of parts (a) and (b) to the dc resistances at each current level



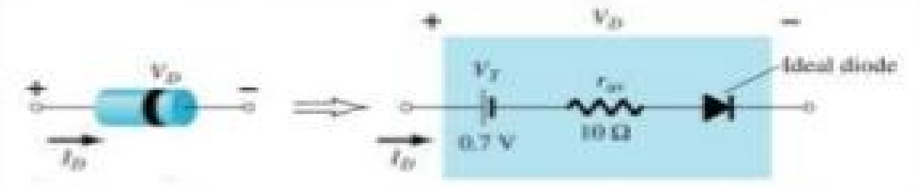
(a) $r_d = 27.5\Omega$

(b) $r_d = 2\ \Omega$

(c) $R_D = 350\ \Omega >> 27.5\ \Omega$

$31.62\ \Omega >> 2\ \Omega$

Diode Equivalent Circuits



Components of the piecewise-linear equivalent circuit.

- The ideal diode establishes that there is only one direction of conduction through the device and a reverse bias condition will result in the open circuit state

- The average ac resistance r_{av} defines the resistance level of the device when it is in the 'on' state

- The battery V_T which opposes the conduction direction appears in the circuit to establish that the Si semiconductor does not reach the conduction state until V_D reaches 0.7 with a forward bias

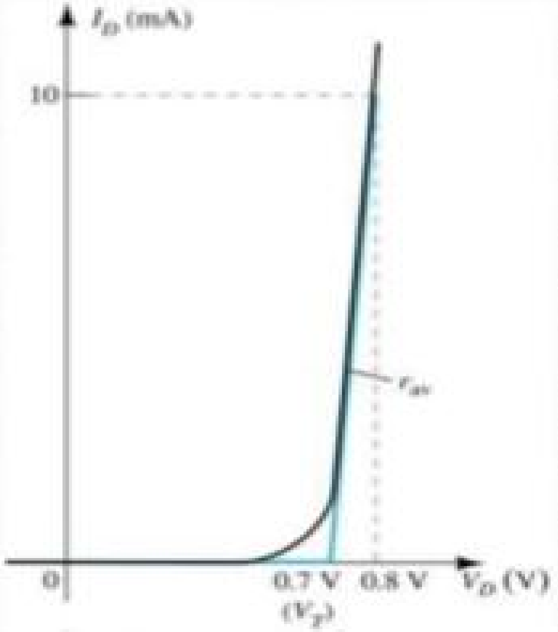


Fig: Defining the piecewise-linear equivalent circuit using straight-line segments to approximate the characteristic curve.

Thank you

Diode Current

Diode equation

There exists a relationship between the voltage applied to the diode and the current flowing through it. It has the following form:

$$I = I_o\left(e^{Vq/KT} - 1\right)$$

where

I is the current flowing through the diode

Io is the reverse leakage current (typically 1×10^{-10} A)

V is the applied voltage

q is the charge on an electron 1.602×10^{-19} C

K is Boltzmann's Constant 1.38×10^{-23} JK^{-1}

T is the absolute temperature (°C + 273)

In equlibrium condition

To calculate the Barrier Potential V_0 , The Boltzmann relationship is given as

$$\frac{p_{n0}}{N_A} = \frac{n_{p0}}{N_D} = \exp\left(-qV_0/kT\right)$$

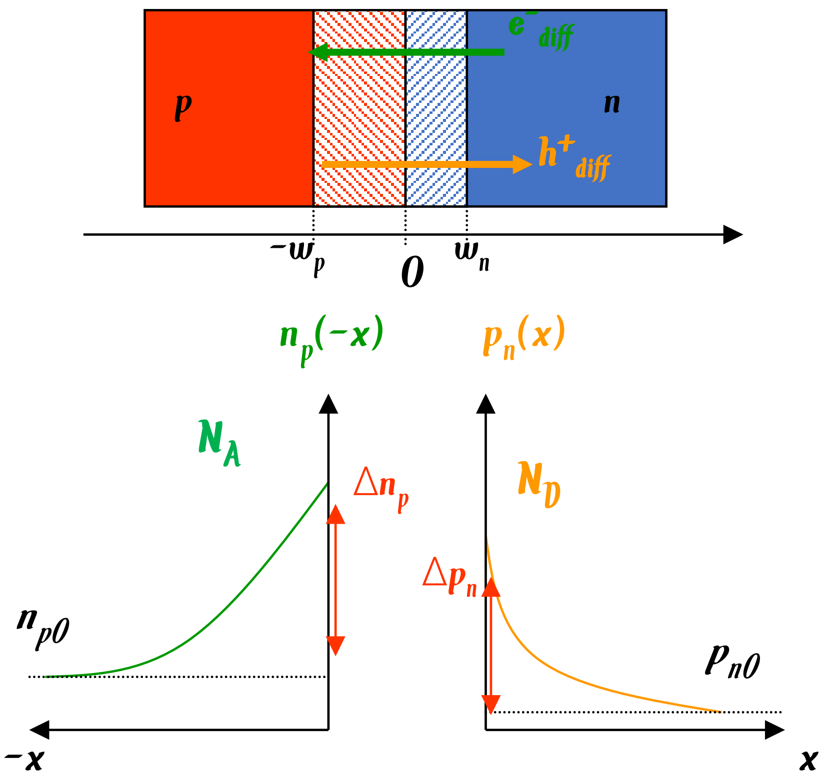
$$V_0 = \frac{kT}{q}\log\left(N_D/n_{po}\right)$$

$$= \frac{kT}{q}\log\left(N_A/p_{no}\right)$$

$$= \frac{kT}{q}\log\left(N_D N_A/n_i^2\right)$$

$$n_{p0} = n_i^2/N_A$$

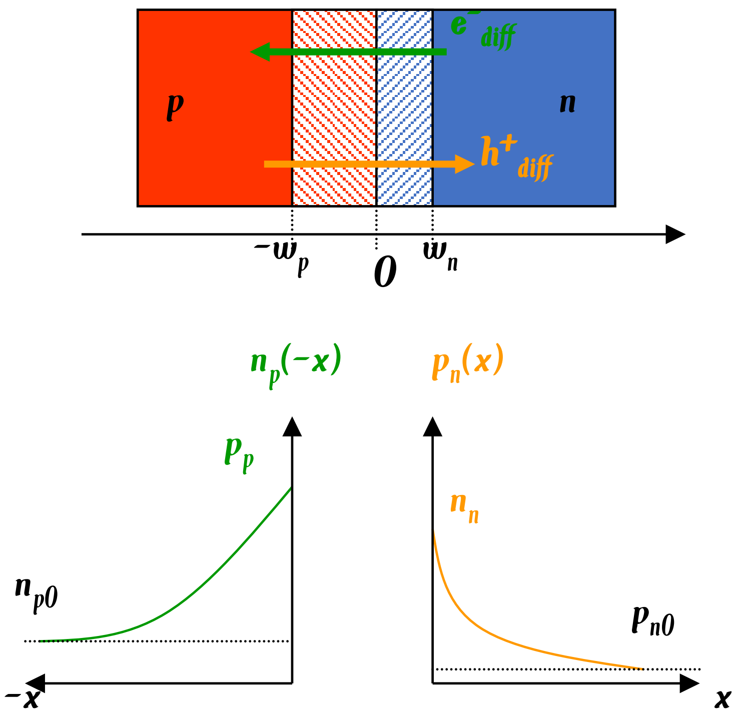
$$p_{n0} = n_i^2/N_D$$



N_A and N_D are the concentration of holes and electrons in p-side and n-side respectively whereas

p_{no} and n_{po} are the concentration of holes and electrons (minority carriers) in n-side and p-side respectively

Carrier injections: forward bias



$n_{p0}=n_i^2/N_A$ & $p_p=N_A$

$p_{n0}= n_i^2/N_D$ & $n_n=N_D$

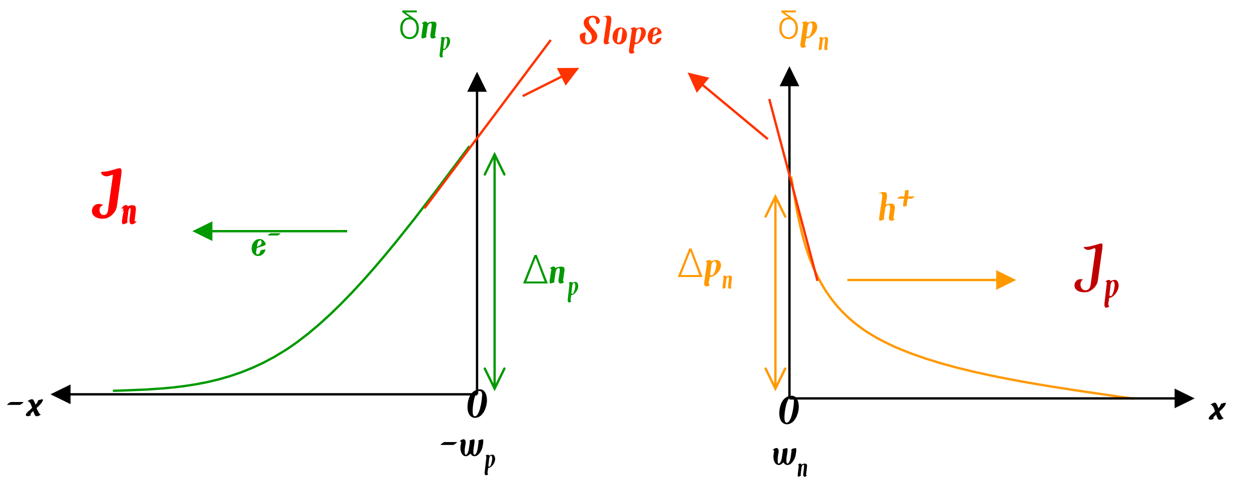
- Carrier injection across junction
  - $$n_n = n_{p_0} \exp\left(\frac{V}{V_T}\right)$$
    $$p_p = p_{n_0} \exp\left(\frac{V}{V_T}\right)$$
- Creates minority carrier concentration gradients

$p_p = p_{no} \exp(E/kT)$ and $V_T = kT/q$

And $E = qV_B$ where P_p is the concentration of holes in p-side and p_n is the concentration of holes n-side.

Excess carrier concentration gradient

Maximum diffusion currents at the edges of the transition region



$I_n = e\,A\,D_n\, d\delta n_p/dx$
$= max$ @ $x=0$

$I_p = -e\,A\,D_p\, d\delta p_n/dx$
$= max$ @ $x=0$

Diffusion Current Density

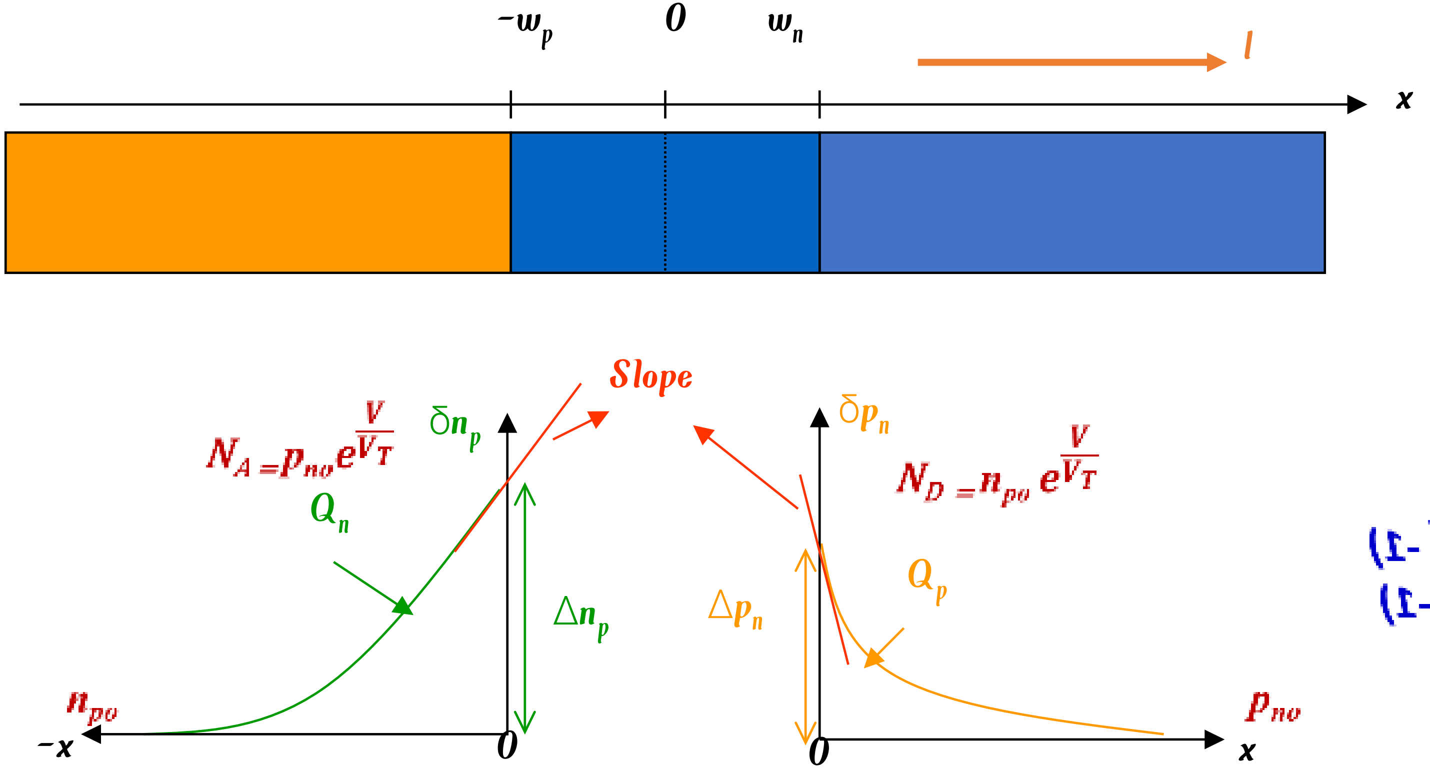
- Current density is directly proportional to the gradient of carrier concentration.

$$J_n = qD_n\left[\frac{dn}{dx}\right] \qquad J_p = -qD_p\left[\frac{dp}{dx}\right]$$

- D_n and D_p are the diffusion constants for electrons and holes respectively.

$$dn = \Delta n_p = n_{po}\,(e^{qV_o/kT} - 1)$$
$$dp = \Delta p_n = p_{no}\,(e^{qV_o/kT} - 1)$$

To calculate current



$dn = n_{p0}\,(e^{qV/kT} - 1)$

$dp = p_{n0}\,(e^{qV/kT} - 1)$

Apply KCL $J = J_p + J_n$

$$J_p = (qD_p \cdot p_{no}e^{\frac{V}{V_T}} - p_{no})/L_p \text{ and } J_n = (qD_n \cdot n_{po}e^{\frac{V}{V_T}} - n_{po})/L_n$$

$$J_p = (qD_p .\, p_{no} e^{\frac{V}{V_T}} - p_{no})/L_p \quad \textit{and} \quad J_n = (qD_n . n_{po} e^{\frac{V}{V_T}} - n_{po})/L_n$$

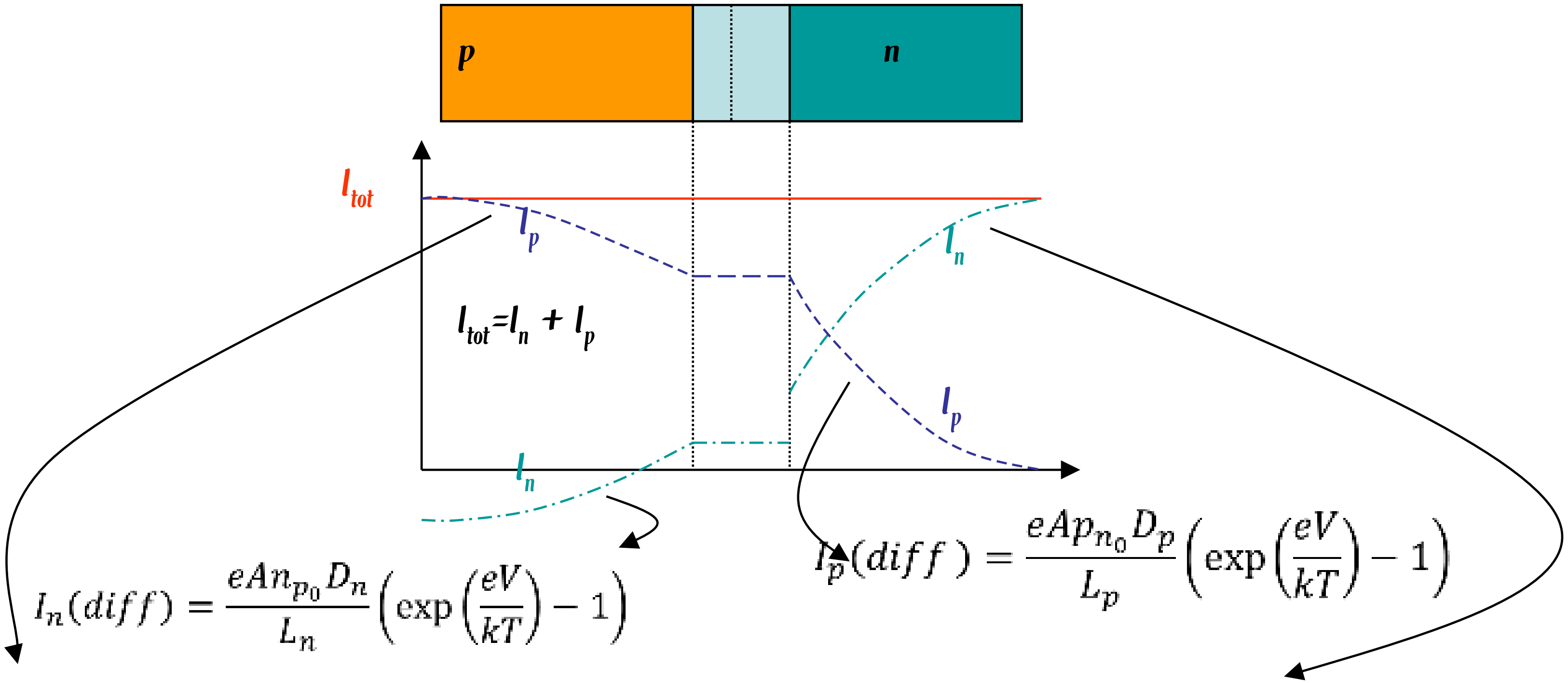
$$J = J_p + J_n = \frac{qD_p . p_{no}}{L_p} (e^{\frac{V}{V_T}} - 1) + \frac{qD_n . n_{po}}{L_n} (e^{\frac{V}{V_T}} - 1)$$

$$I = \left(\frac{A\, qD_p . pno}{L_p} + \frac{A\, qD_n . n_{po}}{L_n}\right) (e^{\frac{V}{V_T}} - 1)$$

$$I = I_0 (e^{\frac{V}{V_T}} - 1)$$

$$\textit{where } I_0 = \left(\frac{A\, qD_p . pno}{L_p} + \frac{A\, qD_n . npo}{L_n}\right)$$

Changing gradient!
$\rightarrow$
Changing diffusion current density

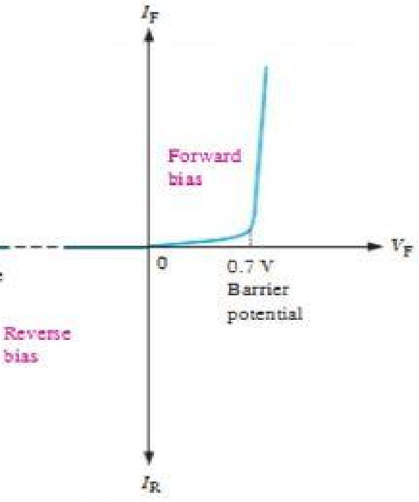


$$I_n(diff) = \frac{eAn_{p_0}D_n}{L_n}\left(\exp\left(\frac{eV}{kT}\right) - 1\right)$$

$$I_p(diff\,) = \frac{eAp_{n_0}D_p}{L_p}\left(\exp\left(\frac{eV}{kT}\right) - 1\right)$$

Diode V-I Characteristic

- ❖ The complete V-I characteristic curve

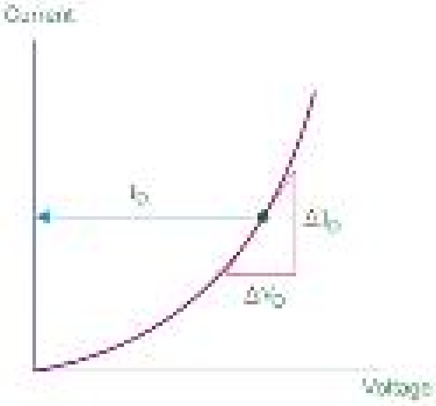


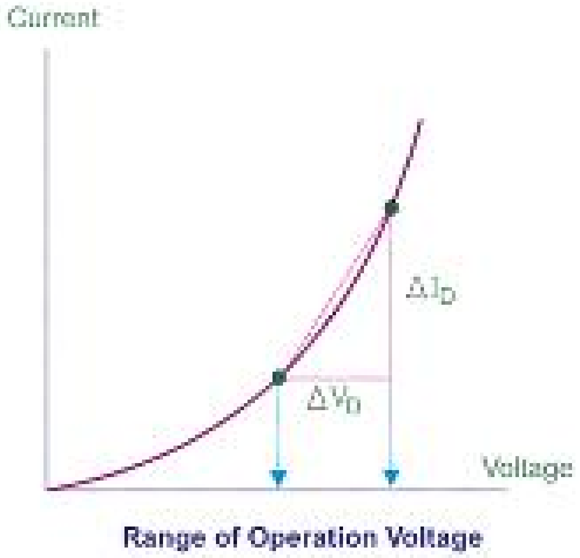
The complete *V-I* characteristic curve for a diode.

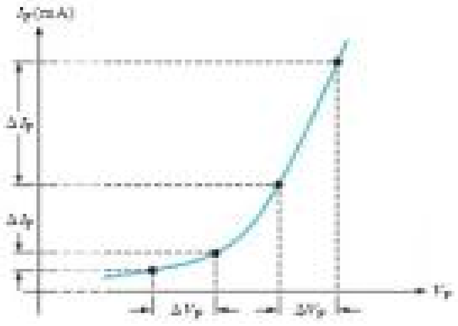
Diode V-I Characteristic

❖ **Dynamic Resistance:**

- The resistance of diode is not constant but it changes over the entire curve. So it is called dynamic resistance.







The dynamic resistance r'_d decreases as you move up the curve, as indicated by the decrease in the value of $\Delta V_F / \Delta I_F$.

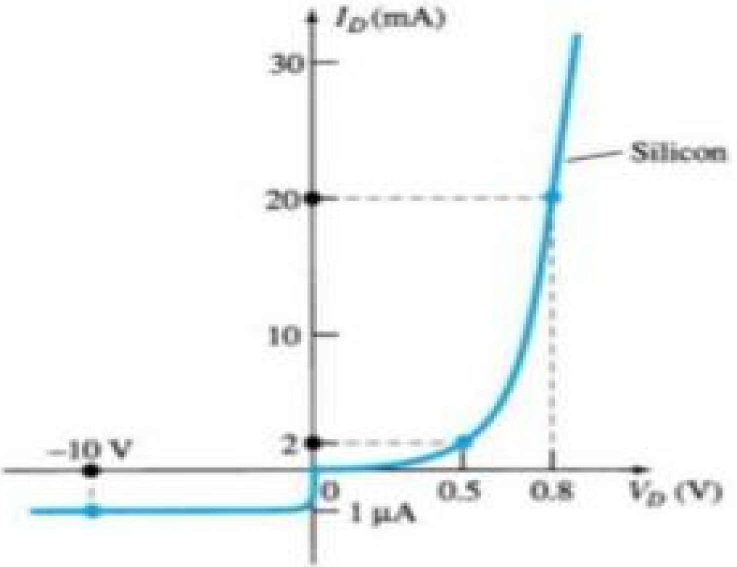
Dynamic resistance $r_d = \Delta V_D / \Delta I_D$

Static resistance $R = V_D / I_D$

DC or Static Resistance

Determine the DC Resistance levels for the diode of following figure at $I_D = 2$ mA, $I_D = 20$ mA, $V_D = -10$ V

Example 1.1.



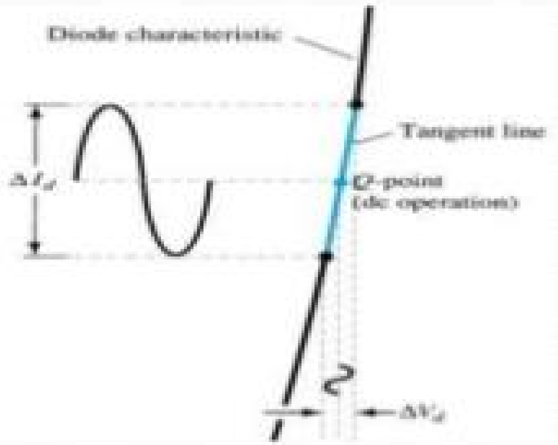
a) At $I_D = 2$ mA , $V_D = 0.5$ V and thus $R_D = 250\ \Omega$

b) At $I_D = 20$ mA , $V_D = 0.8$ V and thus $R_D = 40\ \Omega$

c) At $V_D = -10$ V , $I_D = -I_S = -1$ μA and thus $R_D = 10\ M\Omega$

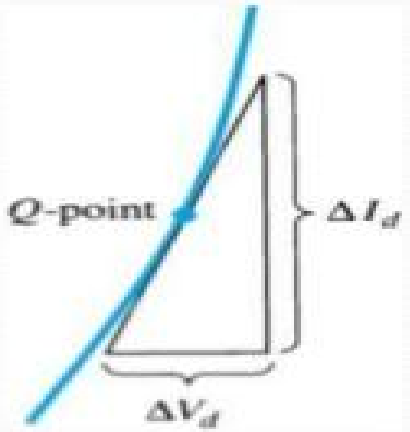
Continued...

- With no applied varying signal, the point of operation would be the Q-point
- A straight line drawn tangent to the curve through the Q-point will define a particular change in voltage and current that can be used to determine the ac or dynamic resistance for this region of the diode characteristics
- An effort should be made to keep the change in voltage and current as small as possible and equidistant to either side of the Q-point



Defining the dynamic or ac resistance.

$$r_D = \frac{\Delta V_D}{\Delta I_D}$$



Determining the ac resistance at a Q-point.

Derivation of Dynamic Resistance

$$I = I_0 \left(e^{v/\eta v_T} - 1\right)$$

This is the equation of Diode current

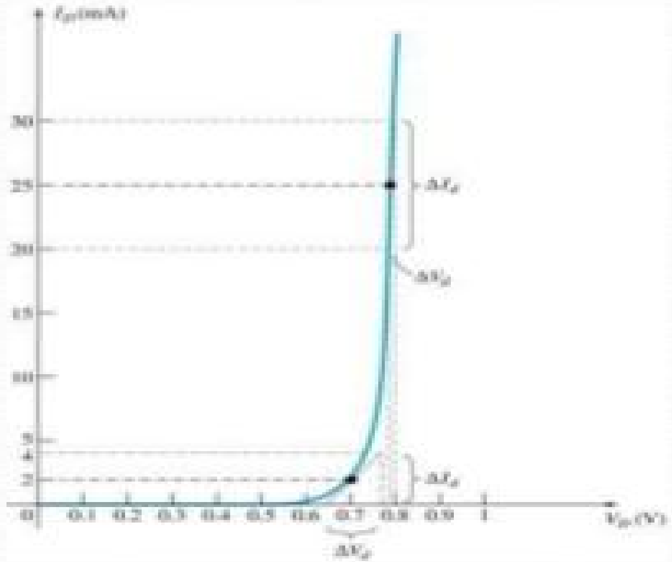
$$\frac{dI}{dv} = \frac{d}{dv}\left[I_0 \left(e^{v/\eta v_T} - 1\right)\right]$$

$$= \frac{I_0 e^{v/\eta v_T}}{\eta v_T} = \frac{I + I_0}{\eta v_T} = \frac{I}{\eta v_T}$$

$$r_f = \frac{dv}{dI} = \frac{\eta v_T}{I} = \frac{26\, mV}{I}$$

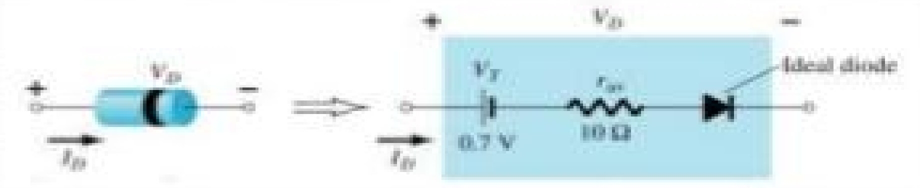
Continued...

- In general, the lower the Q-point of operation (smaller current or lower voltage) the higher the ac resistance
- For the characteristics of Figure below:
  - (a) Determine the ac resistance at $I_D = 2$ mA.
  - (b) Determine the ac resistance at $I_D = 25$ mA.
  - (c) Compare the results of parts (a) and (b) to the dc resistances at each current level



(a) $r_d = 27.5\Omega$
(b) $r_d = 2\ \Omega$
(c) $R_D = 350\ \Omega >> 27.5\ \Omega$
$31.62\ \Omega >> 2\ \Omega$

Diode Equivalent Circuits



Components of the piecewise-linear equivalent circuit.

- The ideal diode establishes that there is only one direction of conduction through the device and a reverse bias condition will result in the open circuit state

- The average ac resistance r_{av} defines the resistance level of the device when it is in the 'on' state

- The battery V_T which opposes the conduction direction appears in the circuit to establish that the Si semiconductor does not reach the conduction state until V_D reaches 0.7 with a forward bias

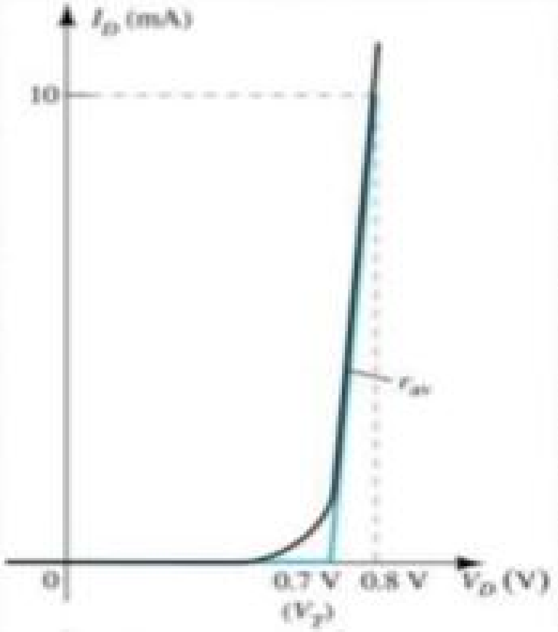


Fig: Defining the piecewise-linear equivalent circuit using straight-line segments to approximate the characteristic curve.

Thank You

Effect of Temperature on Diode Characteristics

$$J_p = (qD_p \cdot p_{no}e^{\frac{V}{V_T}} - p_{no})/L_p \quad \text{and} \quad J_n = (qD_n \cdot n_{po}e^{\frac{V}{V_T}} - n_{po})/L_n$$

$$J = J_p + J_n = \frac{qD_p.pno}{L_p}(e^{\frac{V}{V_T}} - 1) + \frac{qD_n.n_{po}}{L_n}(e^{\frac{V}{V_T}} - 1)$$

$$I = \left(\frac{A\,qD_p.pno}{L_p} + \frac{A\,qD_n.npo}{L_n}\right)(e^{\frac{V}{V_T}} - 1)$$

$$I = I_0(e^{\frac{V}{V_T}} - 1) = I_0(e^{\frac{V}{\eta V_T}} - 1); \quad \eta = 1 \text{ for Ge and } \eta = 2 \text{ for Si}$$

$$\text{where } I_0 = \left(\frac{A\,qD_p.pno}{L_p} + \frac{A\,qD_n.npo}{L_n}\right)$$

Variation of I_0 with Temperature

Dependence of I_0 on temperature T is given by

$$I_0 = KT^m e^{-V_{G0}/\eta V_T} \quad (1)$$

Taking the logarithm of equation (1)

$$\ln(I_o) = \ln(KT^m e^{-V_{G0}/\eta V_T}) = \ln K + \ln T^m + \ln(e^{-V_{G0}/\eta V_T}) \quad (2)$$

Taking the derivative of the logarithm of Eq.(2) (keeping $V_T = kT$)

$$\frac{d(\ln I_0)}{dT} = \frac{1}{I_0}\frac{dI_0}{dT} = \frac{m}{T} + \frac{V_{G0}}{\eta T V_T} \quad (3)$$

At room temperature, assume there is a variation $dT = 1^0C$ and

for Ge $\eta = 1$; m=2; $V_{G0} = 0.785V$ and

for Si $\eta = 2$; m=1.5; $V_{G0} = 1.21V$

$dI_0/I_0 = 0.08$ for silicon and for Ge this variation is 0.11.

Practically it is seen that the variation is 7 percent $/^0C$

Since $(1.07)^{10} = 2$, this concludes that the reverse saturation current approximately doubles for every 10^0C rise in temperature.

$$I_{02} = I_{01}(2^{\Delta T/10})$$

I_{02}= Reverse saturation current at T_2 and I_{01}= Reverse saturation current at T_1

$\Delta T = T_2 - T_1$

Variation of Junction Voltage with Temperature

$I = I_0\,(e^{V/\eta V_T})$ (1)

$\ln(I) = \ln(I_0\,(e^{V/\eta V_T}))$ (2)

$\ln(I) = \ln(I_0) + \frac{V}{\eta V_T}$ (3)

Differentiate Eq.(3) with respect to T [keeping V_T = kT] and assuming that the change in current w.r.t. T is zero.

$$\frac{d}{dT}(\ln(I)) = \frac{d}{dT}(\ln(I_0) + \frac{V}{\eta V_T}) = (\frac{1}{I_0}\frac{dI_0}{dT}) + \frac{1}{\eta V_T}(\frac{dV}{dT} - \frac{V}{T})$$

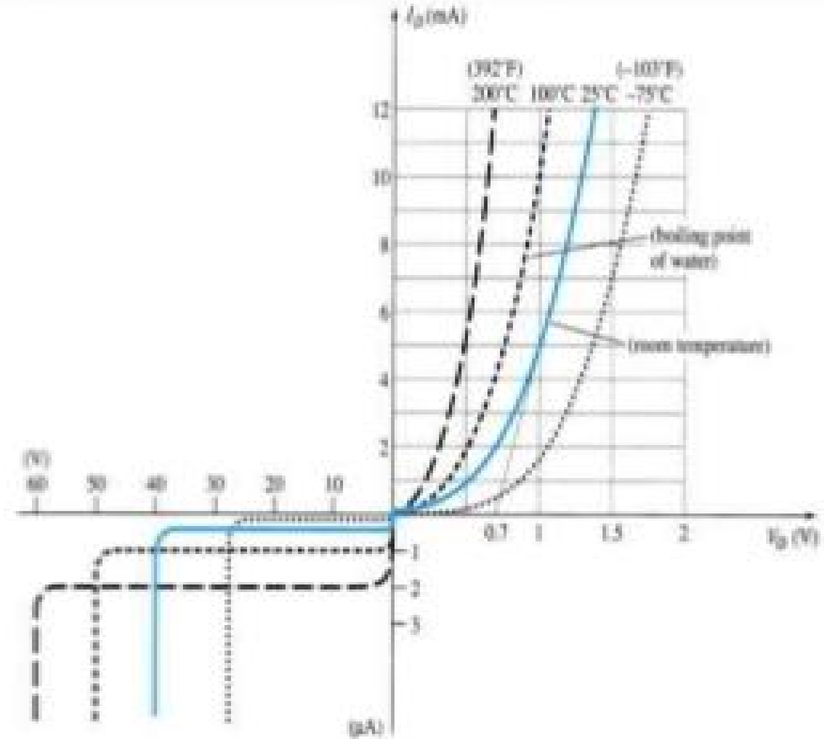
keeping $\frac{d}{dT}(\ln(I)) = 0;$

we get $\frac{dV}{dT} = \frac{V}{T} - \eta V_T(\frac{1}{I_0}\frac{dI_0}{dT}) = \frac{V-(V_{G0}+m\eta V_T)}{T}$ $\left[\frac{1}{I_0}\frac{dI_0}{dT} = \frac{m}{T} + \frac{V_{G0}}{\eta T V_T}\right]$

This gives that $\frac{dV}{dT}$ = -2.1mV for Ge; and $\frac{dV}{dT}$ = -2.3mV for Si

Based on average characteristics this is assumed $\frac{dV}{dT}$ = -2.5mV/^{0}C for both

Temperature Effects



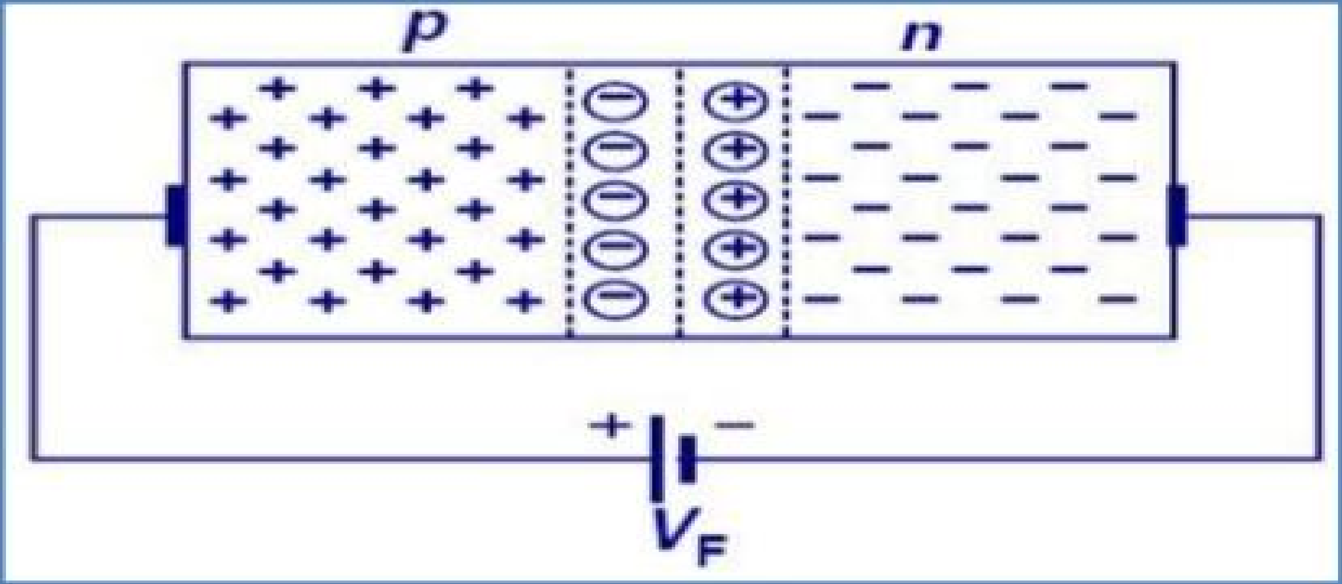
Variation in Si diode characteristics with temperature change

- In the forward bias region the characteristics of a Si diode shift to the left at a rate of 2.5 mv per centigrade degree increase in temperature
- The reverse saturation current I_s will just about double in magnitude for every 10°C increase in temperature.
- The reverse breakdown voltage of a semiconductor diode will increase or decrease with temperature depending on the zener potential
- At room temperature Si and GaAs have relatively small reverse saturation current

Junction Capacitance

- Diffusion Capacitance
  - Charge stored in bulk region changes with the change of voltage across *pn* junction gives rise to capacitive effect.
  - Small-signal diffusion capacitance
- Depletion capacitance
  - Charge stored in depletion layer changes with the change of voltage across *pn* junction gives rise to capacitive effect.
  - Small-signal depletion capacitance

DIFFUSION CAPACITANCE



$C = dQ/dV$

When a P-N junction is forward biased ,a capacitance which is much larger than the transition capacitance , comes into play . This type of capacitance is called the Diffusion Capacitance and is denoted by C_D.

FORMULA FOR DIFFUSION CAPACITANCE

The formula for C_D is given by $$C_D = dQ/dV$$ where dQ represents the change in the number of minority carriers stored outside the depletion region when a change in voltage across diode ,dV, applied .

If τ is mean lifetime of charge carriers, then a flow of charge Q yields a diode current I is given as

$$I = Q/\tau$$

In case of forward bias current is given by- $$I = I_0 (e^{V/\eta V_T} - 1)$$

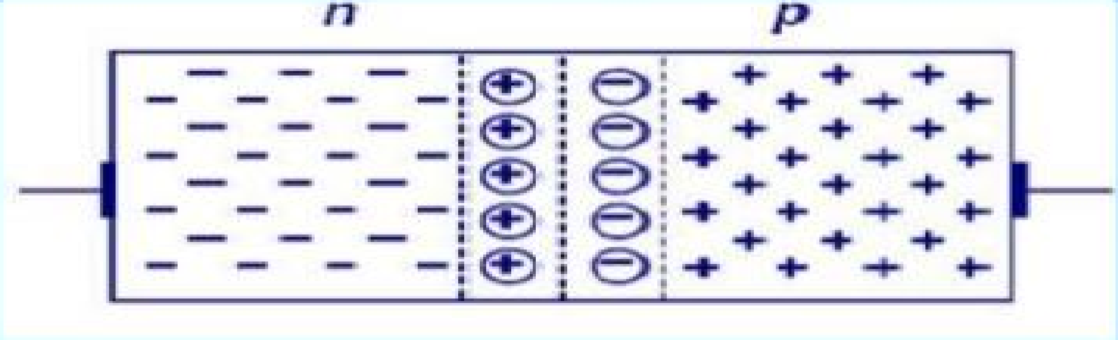
$$Q = \tau I_0 (e^{V/\eta V_T} - 1) = \tau I_0 e^{V/\eta V_T} \quad \text{as} \quad e^{V/\eta V_T} >> 1$$

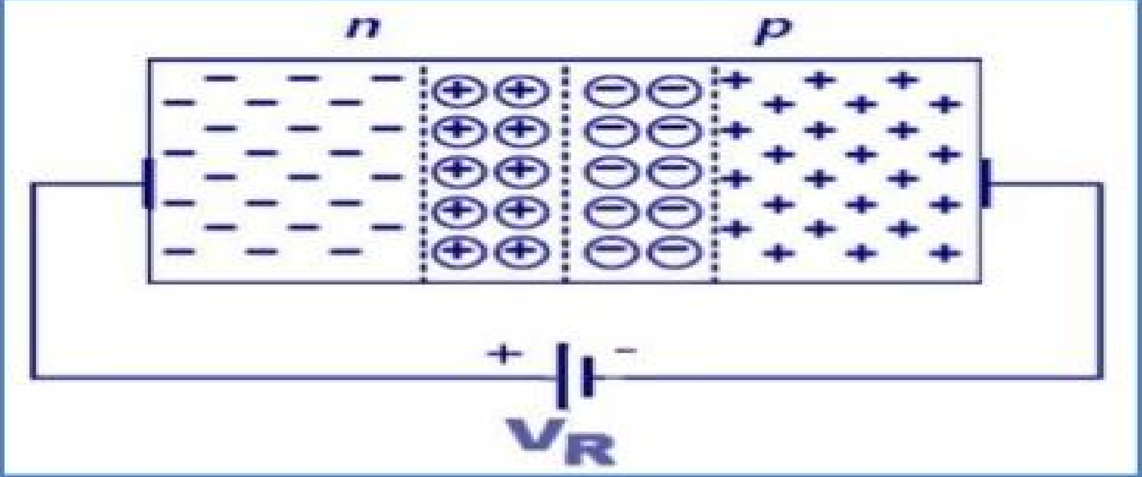
So diffusion capacitance $$C_D = \frac{dQ}{dV} = \frac{d(\tau I_0 e^{V/\eta V_T})}{dV}$$

$$= \frac{\tau (I + I_0)}{\eta V_T}$$ here $I >> I_0$

So $$C_D = \frac{\tau I}{\eta V_T}$$

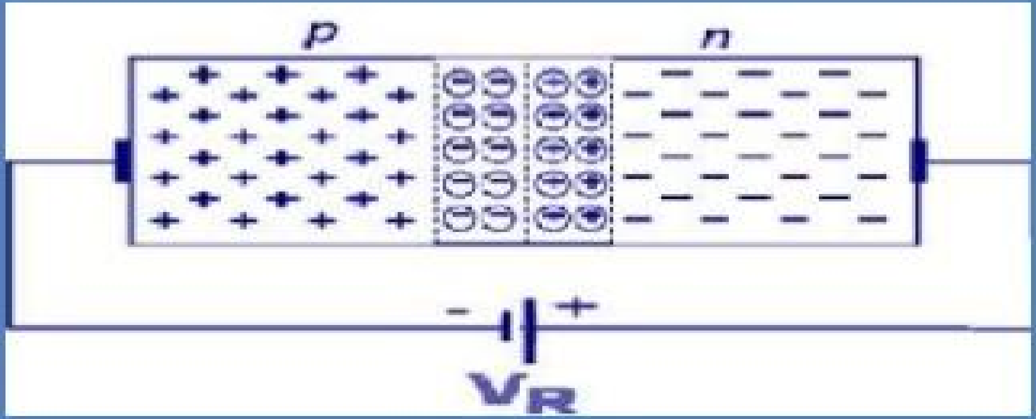
WIDTH OF DEPLETION LAYER IN REVERSE BIAS





When the P-n junction is reverse biased , the depletion region is widened and the barrier potential is also increased.

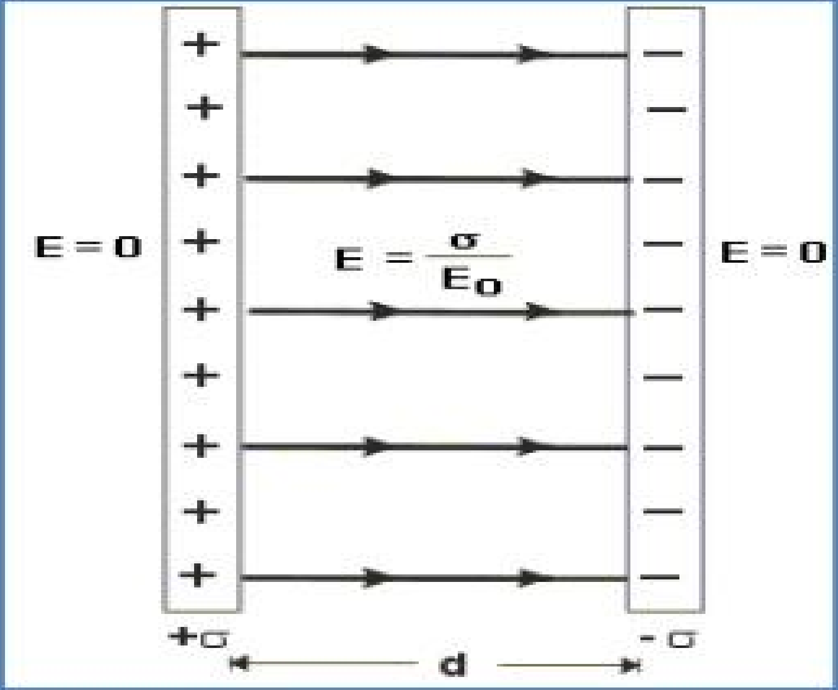
TRANSITION CAPACITANCE

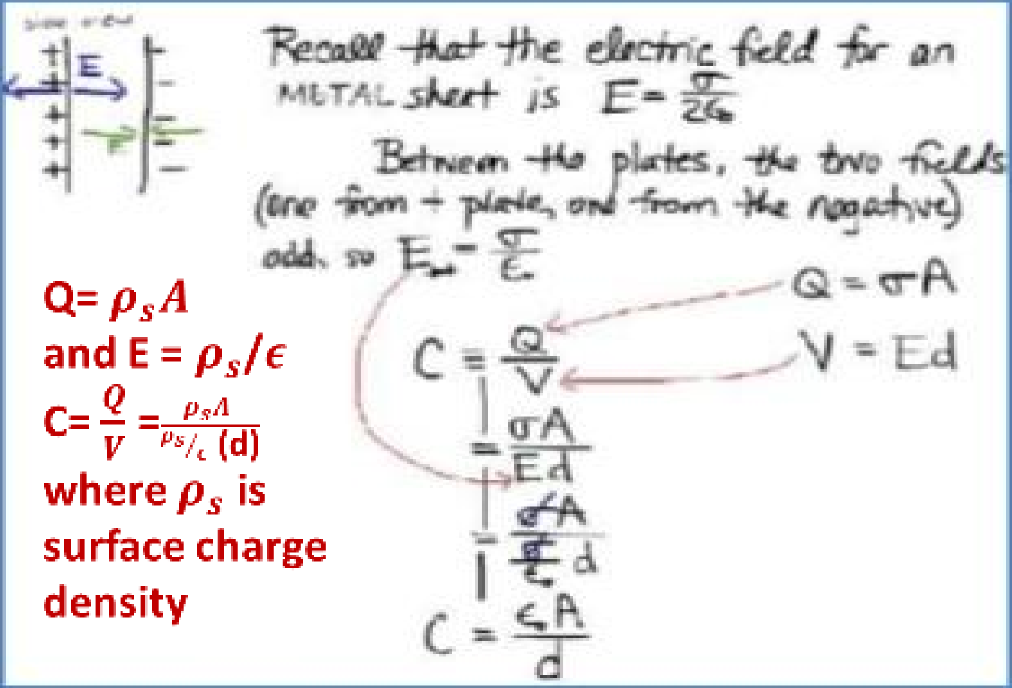


When a p-N junction is reverse biased the depletion region acts like an insulator or dielectric material while the P and N type regions on either side have a low resistance and act as the plates. Thus P-N junction may be considerd as a parrallel plate capacitor.The jumction capacitance is termed as space charge capacitance or transition capacitance and is denoted by C_T.

As mentioned earlier, a reverse bias causes majority carriers to move away from the junction, thereby uncovering more immobile charges. So the thickness W of the depletion layer increases with the increase in reverse bias voltage . This increase in uncovered charge with applied voltage may be considered a capacitative effect . The incremental capacitance may be defined as- C_T = **dQ/dV** where dQ is increase in charge with increase in voltage, dV.

CAPACITANCE





$Q = \rho_s A$

and $E = \rho_s/\epsilon$

$C = \frac{Q}{V} = \frac{\rho_s A}{\rho_s/_\epsilon\,(d)}$

where ρ_s is surface charge density

Capacitance is the property to hold charge by a capacitor. In case of a parrallel plate capacitor the formula for the capacitance is given by

$$C=\varepsilon A/D=Q/V$$

A = cross section area of capacitor plates,D=separation b/w capacitor plates, ε=absolute permittivity of the medium b/w the capacitor plates, Q=charge stored on capacitor plates,V=potential applied

Depletion Capacitance

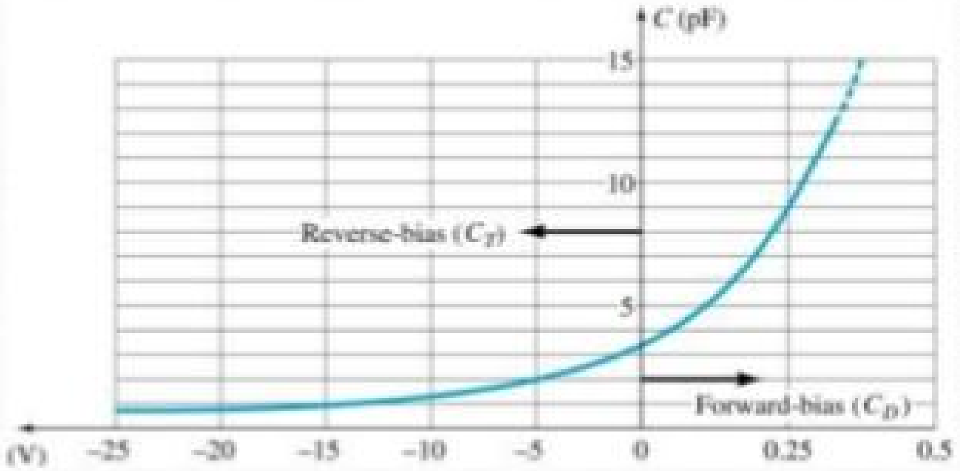
- A more general formula for depletion capacitance is :

$$C_j = \frac{C_{j0}}{(1+V_R/V_0)^m}$$

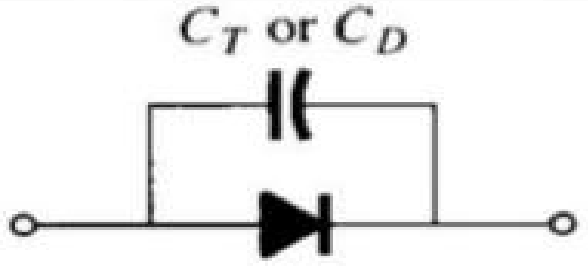
- Where m is called grading coefficient. $m = \frac{1}{3} \sim \frac{1}{2}$
- If the concentration changes sharply, $m = \frac{1}{2}$
- Forward-bias condition, $C_j \approx 2C_{j0}$
- Reverse-bias condition, $C_j << C_d$

For alloy junction m=1/2
For grown junction m=1/3

Transition and Diffusion Capacitance



Transition and diffusion capacitance versus applied bias for a silicon diode.



Including the effect of the transition or diffusion capacitance on the diode.

Electronic devices are inherently sensitive to very high frequencies.

Most shunt capacitive effects can be ignored at lower frequencies because the reactance XC =1/2πfC is very large

This, however, cannot be ignored at very high frequencies. X_C will become sufficiently small due to the high value of f to introduce a low-reactance "shorting" path.

In the p-n semiconductor diode, there are two capacitive effects to be considered. Both types of capacitance are present in the forward- and reverse-bias regions, but one so outweighs the other in each region that we consider the effects of only one in each region.

In the reverse-bias region we have the transition- or depletion-region capacitance (CT), while in the forward-bias region we have the diffusion (CD) or storage capacitance.

Continued...

Capacitance of a parallel plate capacitor, $C = \varepsilon A/d$

Here, ε = permittivity of the dielectric (insulator) between the plates of area A separated by a distance d

- In the reverse-bias region there is a depletion region (free of carriers) that behaves essentially like an insulator between the layers of opposite charge.

- Since the depletion width (d) will increase with increased reverse-bias potential, the resulting transition capacitance will decrease.

- Although the transition capacitance effect will also be present in the forward-bias region, it is overshadowed by a capacitance effect directly dependent on the rate at which charge is injected into the regions just outside the depletion region.

- In this case the charge carriers will reduce the depletion region and hence will result in an increased levels of diffusion capacitance.

Junction Capacitance

Remember:

a) *Diffusion and depletion capacitances are incremental capacitances, only are applied under the small-signal circuit condition.*
b) *They are not constants, they have relationship with the voltage across the pn junction.*

Thank You

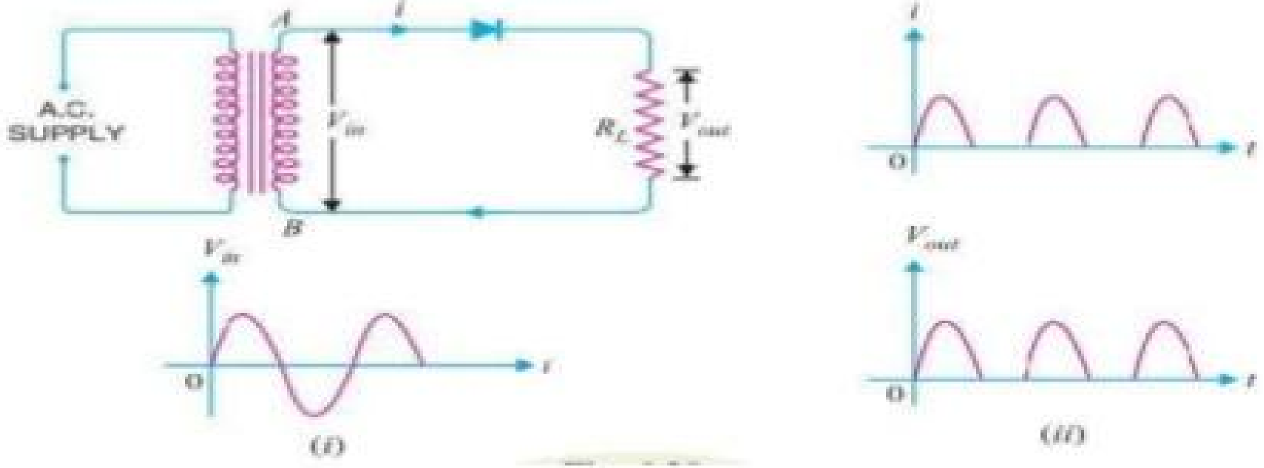
Half Wave Rectifier

Half wave Rectifier

- The process of removing one-half the input signal to establish a dc level is called *half-wave rectification*.

- In Half wave rectification, the rectifier conducts current during positive half cycle of input ac signal only.

- Negative half cycle is suppressed or clipped.



Ripple frequency

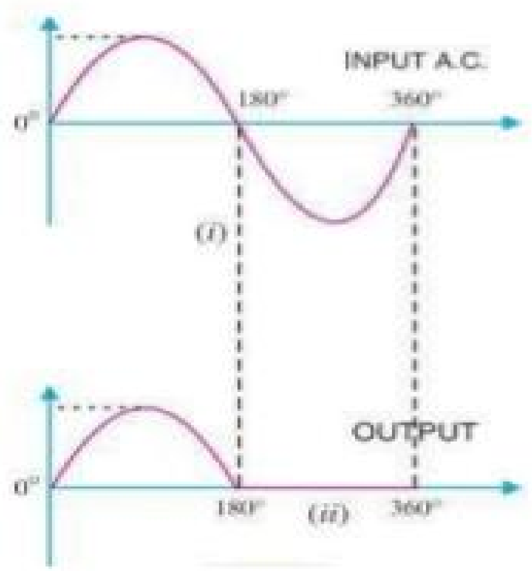
Half wave Rectifier

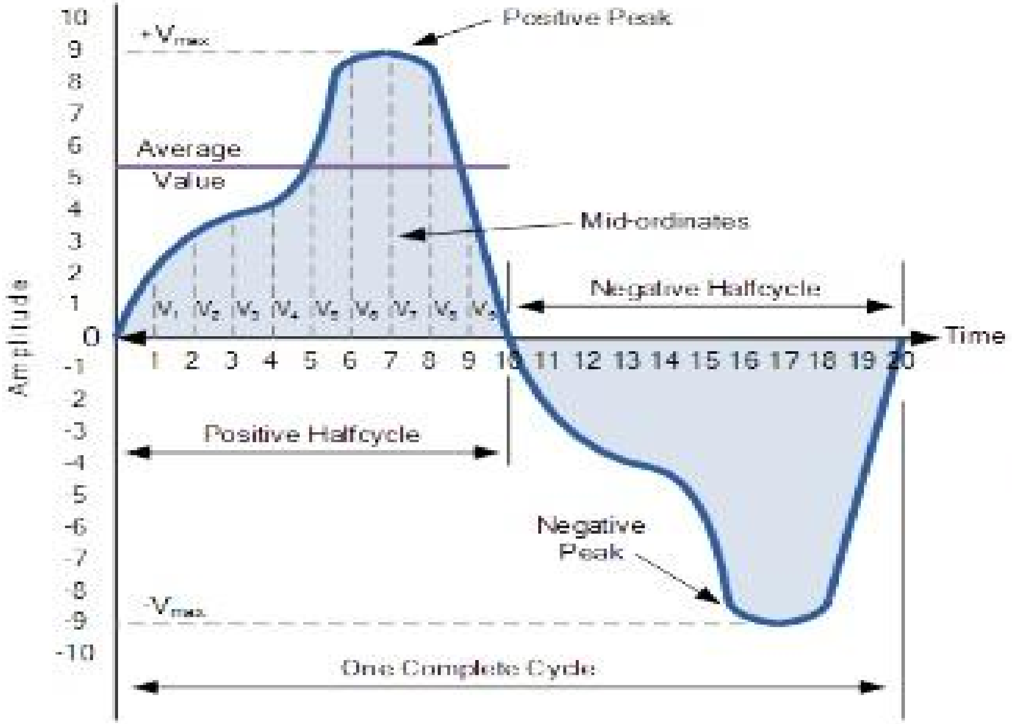
- Output frequency of HWR:

➢ Output frequency of HWR is equal to input frequency.

➢ This means when input ac completes one cycle, rectified wave also completes one cycle.

$$f_{out} = f_{in}$$





$$V_{average} = \frac{V_1 + V_2 + V_3 + V_4 + \ldots + V_n}{n}$$

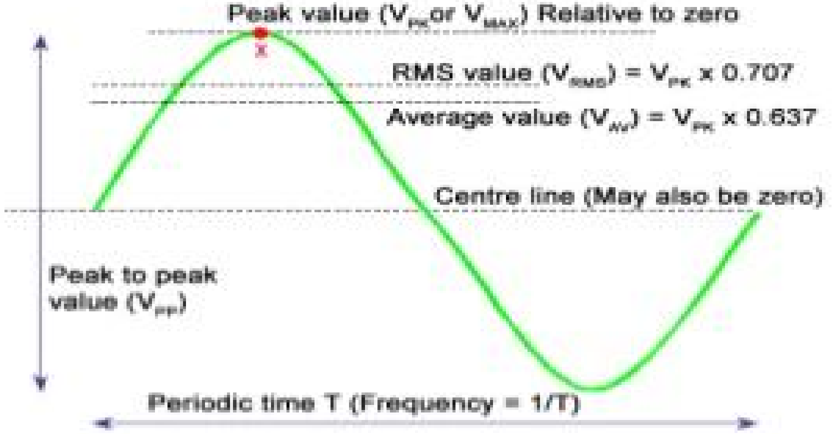
$$V_{RMS} = \sqrt{\frac{V_1^2 + V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}{n}}$$

For a **pure sinusoidal waveform** this average or mean value will always be equal to 0.637 x V_{max}

The effective or R.M.S. value will always be equal to $1/\sqrt{2}$ x V_{max} which is equal to 0.707 x V_{max}

$$\text{Form Factor} = \frac{\text{R.M.S value}}{\text{Average value}} = \frac{0.707 \times V_{max}}{0.637 \times V_{max}} = 1.1$$

$$\text{Crest Factor} = \frac{\text{Peak value}}{\text{R.M.S value}} = \frac{V_{max}}{0.707 \times V_{max}} = 1.414$$



The value of the R.M.S. current is given by

$$I_{rms} = \left[\frac{1}{2\pi} \int_0^{2\pi} i^2 d(\omega t) \right]^{\frac{1}{2}}$$

$$= \left[\frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2 \omega t . d(\omega t) + \frac{1}{2\pi} \int_{\pi}^{2\pi} .0. d(\omega t) \right]^{\frac{1}{2}}$$

$$= \left[\frac{I_m^2}{2\pi} \int_0^{\pi} \left(\frac{1 - \cos 2\omega t}{2} \right) d(\omega t) \right]^{\frac{1}{2}}$$

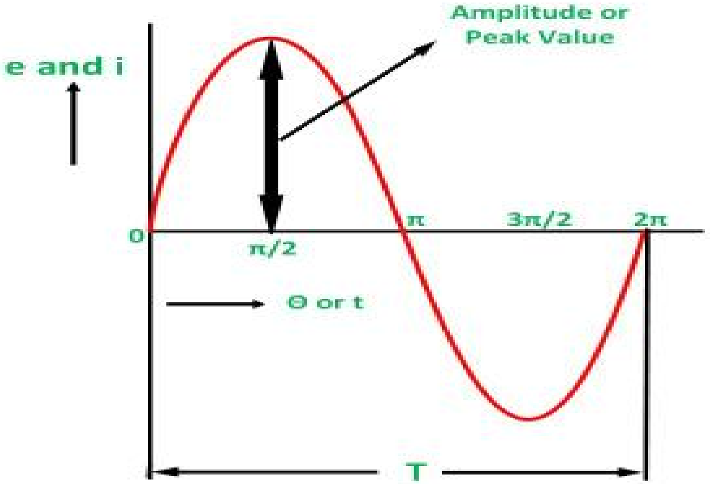
$$= \left[\frac{I_m^2}{4\pi} \left\{ (\omega t) - \frac{1}{2} \sin 2\omega t \right\}_0^{\pi} \right]^{\frac{1}{2}}$$

$$= \left(\frac{I_m}{2}\right) \sqrt{\left(\frac{1}{\pi}\right) [\pi - 0)]}$$

$$= \frac{I_m}{2}$$

The term "RMS" stands for "Root-Mean-Squared". Most books define this as the "amount of AC power that produces the same heating effect as an equivalent of DC power",

$$I_{eff} = \sqrt{\frac{i_1^2 + i_2^2 + i_3^2 + \ldots\ldots\ldots + i_n^2}{n}}$$



$$\frac{d}{d\theta} \cos\theta = -\sin\theta,$$

$$\frac{d}{d\theta} \sin\theta = \cos\theta,$$

$$\int \sin\theta (d\theta) = -\cos\theta$$

$$\int \cos\theta (d\theta) = \sin\theta$$

Calculation of V_{av} or V_{dc}

$$I_{av} = I_{dc} = \frac{\text{area under the } i_L \text{ curve over a cycle}}{\text{base}} = \frac{\int_0^{\pi} i_L \, d(\omega t)}{2\pi}$$

$$= \frac{1}{2\pi}\int_0^{\pi} i_L \, d(\omega t) = \frac{1}{2\pi}\int_0^{\pi} \frac{V_m \sin wt \; d(\omega t)}{R_f + R_L}$$

$$= \frac{V_m}{2\pi(R_f + R_L)} \int_0^{\pi} \sin \omega t \; d(\omega t)$$

$$= \frac{V_m}{2\pi(R_f + R_L)} \left[-\cos \omega t \right]_0^{\pi}$$

$$= \frac{V_m}{2\pi(R_f + R_L)} \text{ X } 2 = \frac{V_m}{\pi(R_f + R_L)}$$

$$= \frac{I_m}{\pi} \left(\therefore I_m = \frac{V_m}{R_f + R_L} \right)$$

$i_L = I_m \sin\omega t$

$I_m = V_m/(R_f+R_L)$

Where R_f is forward resistance of diode and R_L is load resistance

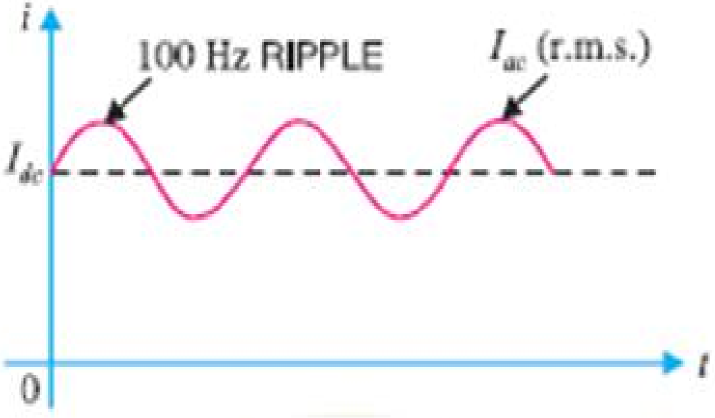
Ripple Factor

The output of a rectifier consists of a d.c. component and an a.c. component (also known as *ripple*). The a.c. component is undesirable and accounts for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of a.c. component in the output ; the smaller this component, the more effective is the rectifier.

The ratio of r.m.s. value of a.c. component to the d.c. component in the rectifier output is known as **ripple factor** *i.e.*

$$\text{Ripple factor} = \frac{\text{r.m.s. value of a.c component}}{\text{value of d.c. component}} = \frac{I_{ac}}{I_{dc}}$$

Therefore, ripple factor is very important in deciding the effectiveness of a rectifier. The smaller the ripple factor, the lesser the effective a.c. component and hence more effective is the rectifier.



Mathematical analysis. The output current of a rectifier contains d.c. as well as a.c. component. The undesired a.c. component has a frequency of 100 Hz (*i.e.* double the supply frequency 50 Hz) and is called the *ripple* (See Fig. 6.39). It is a fluctuation superimposed on the d.c. component.

By definition, the effective (*i.e.* r.m.s.) value of total load current is given by :

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

or

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

Dividing throughout by I_{dc}, we get,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2}$$

But I_{ac}/I_{dc} is the ripple factor.

$$\therefore \quad \text{Ripple factor} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

For half-wave rectification. In half-wave rectification,

$$I_{rms} = I_m/2 \quad ; \quad I_{dc} = I_m/\pi$$

$$\therefore \quad \text{Ripple factor} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

It is clear that a.c. component exceeds the d.c. component in the output of a half-wave rectifier. This results in greater pulsations in the output. Therefore, half-wave rectifier is ineffective for conversion of a.c. into d.c.

Rectification efficiency

$$\therefore \eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 R_L = \frac{I_m^2 R_L}{\pi^2}$$

$$P_{ac} = I_{rms}^2 (R_L + R_f) = \frac{I_m^2}{4}(R_L + R_f)$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{I_m^2 R_L}{\pi^2} \times \frac{4}{I_m^2 (R_L + R_f)} = \frac{4}{\pi^2}\left(\frac{R_L}{R_L + R_f}\right) = 40.6(R_L / R_L + R_f)$$

$$\eta_{max} = 40.6 \text{ peccent}$$

Transformer Utilization Factor (TUF)

- Transformer Utilization Factor indicates how well the input transformer is being utilized.
- So, the transformer utilization factor is defined as :

$$TUF = \frac{d.c.\ power\ to\ be\ delivered\ to\ the\ load}{a.c.\ rating\ of\ the\ transformer\ secondary}$$

$$(TUF) = \frac{I_{DC}^2 R_L}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{2}}$$

$$= \frac{I_m^2 R_L \times 2\sqrt{2}}{\Pi^2 V_m I_m}$$

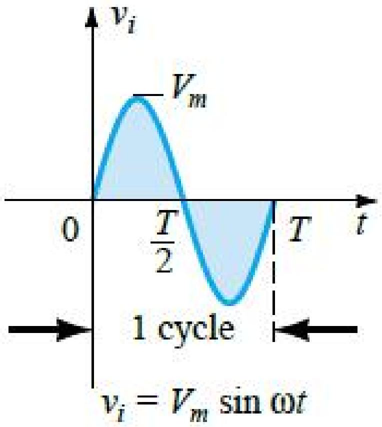
$$= 0.286 \times \left(\frac{R_L}{R_L + R_f + R_s}\right)$$

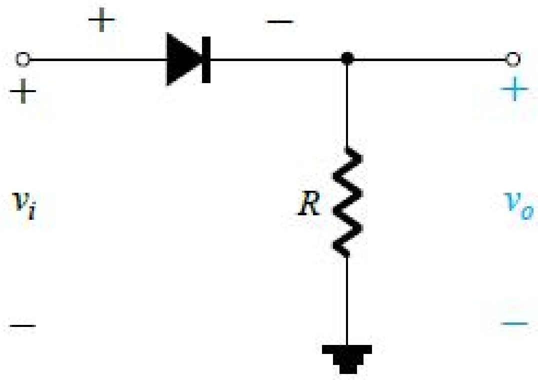
TUF =0.287 OR 28.7%

- Ideal value of TUF should be 100% and practically it should be as high as possible .
- In case of half wave rectifier the value of TUF is too low .

Peak Inverse Voltage (PIV)

Peak Inverse Voltage (PIV) is the maximum voltage that the diode can withstand during reverse bias condition. If a voltage is applied more than the PIV, the diode will be destroyed.





$$PIV = V_{max} = V_m$$

Disadvantages of Half Wave Rectifier

- More amount of ripple content
- Transformer utilization factor is very low
- Rectification efficiency is low
- Generates harmonics
- Low output voltage or current

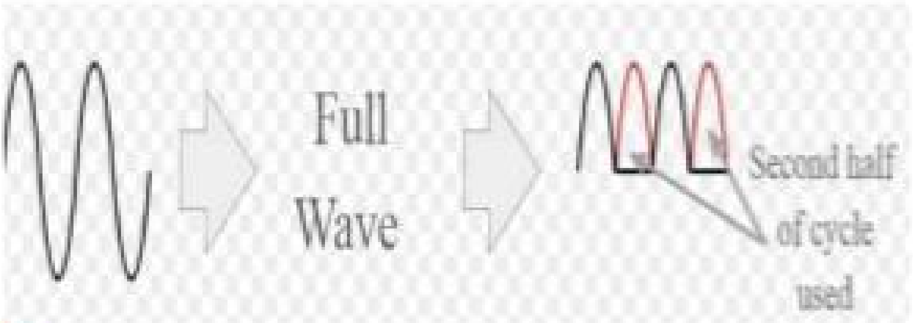
Full wave Rectifier

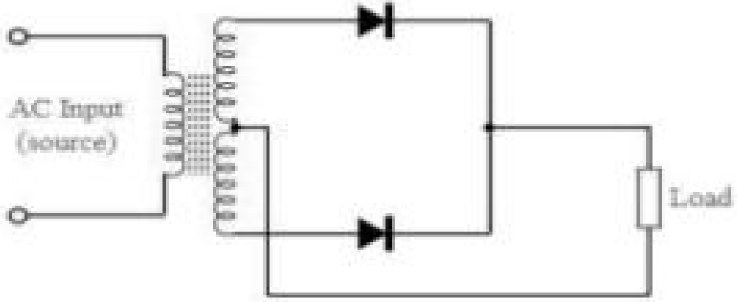
Full-Wave Rectifier

In Full wave rectification current flow through the load in same direction for both half cycle of input ac.

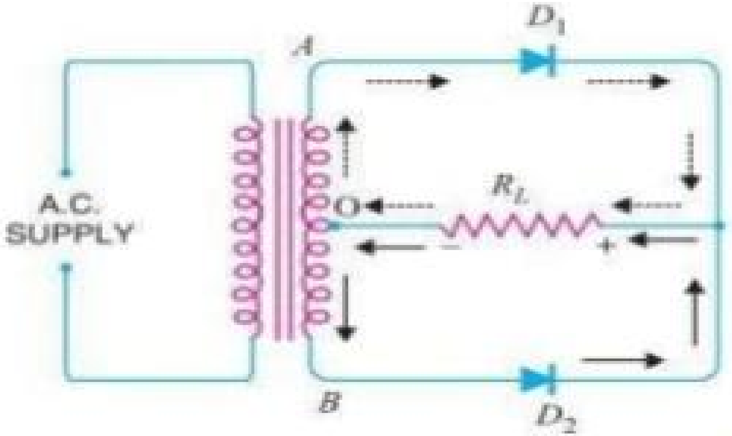
This can be achieved with two diodes working alternatively.

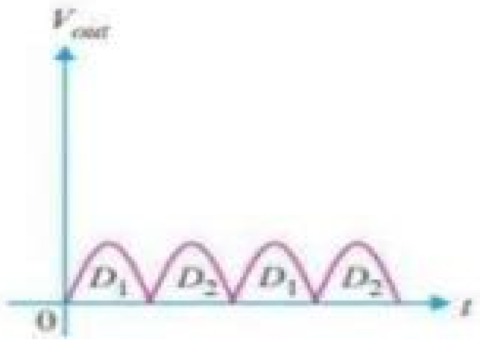
For one half cycle one diode supplies current to load and for next half cycle another diode works.





Centre Tap Full Wave Rectifier





- Circuit has two diodes D1 , D2 and a centre tap transformer.
- During positive half cycle Diode D1conducts and during negative half cycle Diode D2 conducts.
- It can be seen that current through load RL is in the same direction for both cycle.

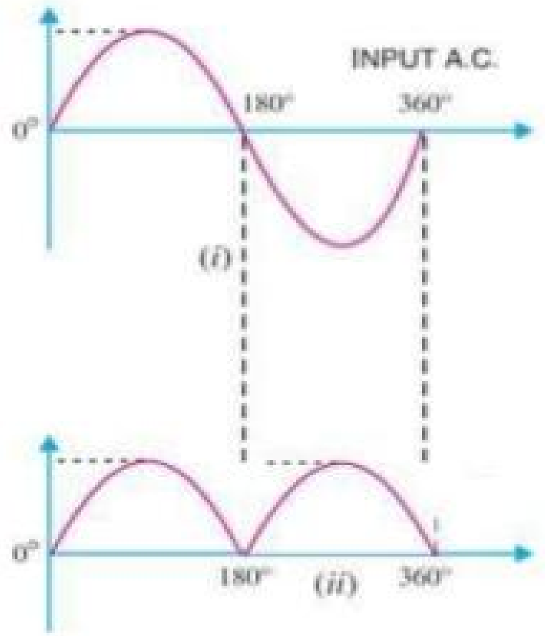
Full wave Rectifier

- Output frequency of FWR:

➢ Output frequency of FWR is equal to double of input frequency.

➢ This means when input ac completes one cycle, rectified wave completes two cycles

$$f_{out} = 2 f_{in}$$



Full wave rectifier I_{av} or I_{dc}

Average Value of FWR

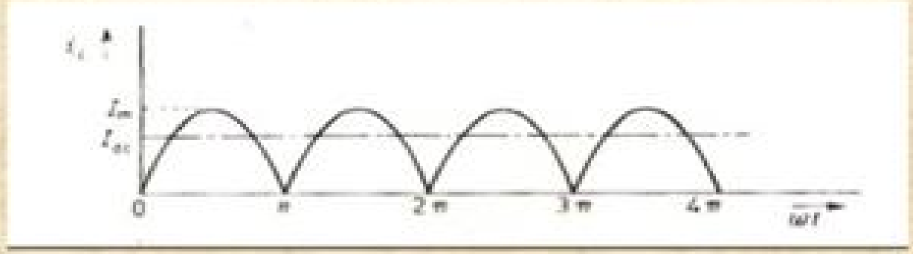
$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} i_L \, d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t)$$

$$= \frac{I_m}{\pi}\left|-\cos\omega t\right|_0^{\pi}$$

$$= \frac{I_m}{\pi}(+1+1)$$

$$= \frac{2I_m}{\pi}$$

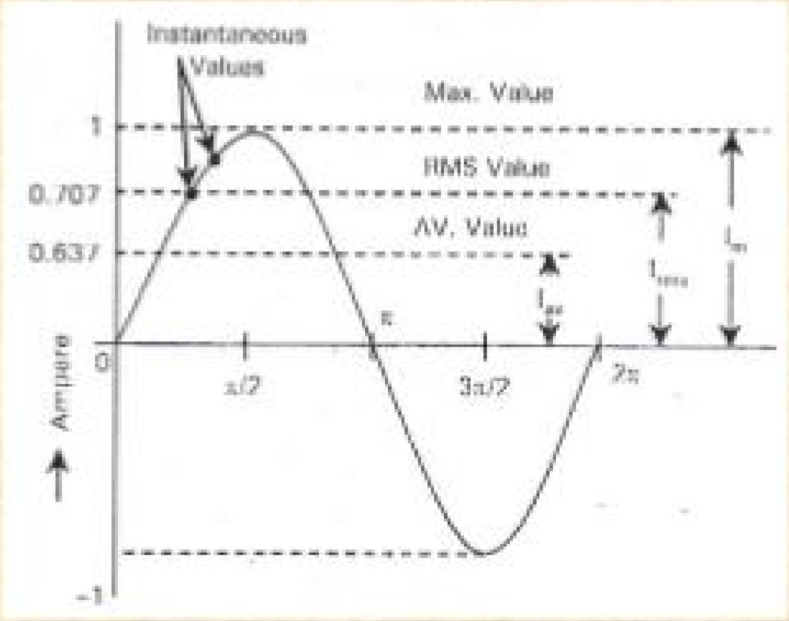


$\int \sin\theta(d\theta) = -\cos\theta$; $\int \cos\theta(d\theta) = \sin\theta$

RMS Value of FWR

$$i_L = I_m Sin\omega t$$

RMS value of the voltage at the load resistance is



$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i_L^2 d(\omega t)} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 Sin^2\omega t d(\omega t)}$$

$$= \sqrt{\left(\frac{I_m^2}{\pi}\right)\int_0^{\pi}\left(\frac{1-COS2\omega t}{2}\right)d(\omega t)}$$

$$= \sqrt{\left(\frac{I_m^2}{\pi}\right)\left[\frac{\omega t}{2}-\frac{Sin2\omega t}{4}\right]_0^{\pi}}$$

$$= \sqrt{\frac{I_m^2}{\pi}\cdot\frac{\pi}{2}} = \frac{I_m}{\sqrt{2}}$$

Ripple Factor

$$I_{rms} = \frac{I_m}{\sqrt{2}} \quad ; \quad I_{dc} = \frac{2\,I_m}{\pi}$$

$$\therefore \quad \text{Ripple factor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2\,I_m/\pi}\right)^2 - 1} = 0.48$$

$$i.e. \quad \frac{\text{effective a.c. component}}{\text{d.c. component}} = 0.48$$

Rectification efficiency (η)

$$\therefore \eta = \frac{P_{dc}}{P_{ac}}$$

For Half Wave Rectifier

$$P_{dc} = I_{dc}^2 R_L = \frac{I_m^2 R_L}{\pi^2}$$

$$P_{ac} = I_{rms}^2 \; R_L + R_f \; = \frac{I_m^2}{4} \; R_L + R_f$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{I_m^2 R_L}{\pi^2} \times \frac{4}{I_m^2 \; R_L + R_f} = \frac{4}{\pi^2}\left(\frac{R_L}{R_L + R_f}\right)$$

For Full Wave Rectifier

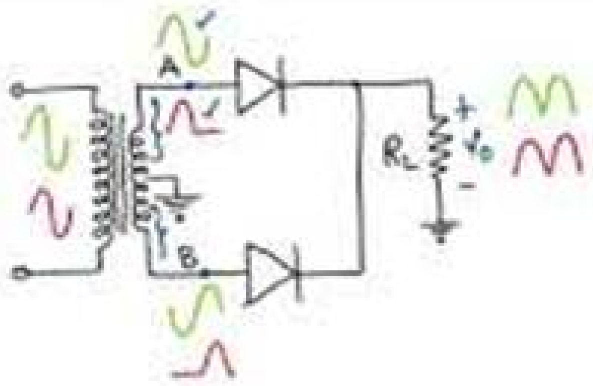
$$\frac{V_{dc}^2 / R_L}{V_{rms}^2 / R_L} = \frac{\left[2V_m / \pi\right]^2}{\left[V_m / \sqrt{2}\right]^2} = 8/\pi^2 = 0.812 = \underline{\underline{81.2\%}}$$

(This is maximum efficiency if $R_f \ll R_L$)

Form Factor

$$= \frac{\left(V_m / \sqrt{2}\right)}{\left(2V_m / \pi\right)} = \frac{\pi}{2\sqrt{2}} = \underline{\underline{1.11}}$$

Center Tapped FWR - TUF



TUF of Secondary

$$TUF = \frac{P_{o,dc}}{\text{Ac rating of Secondary winding}}$$

$$= \frac{I_{dc}^2 R_L}{2\times(V_{rms}\times I_{rms})}$$

$V_{rms} \downarrow \frac{V_m}{\sqrt{2}}$ $\quad$ $I_{rms} \downarrow \frac{I_m}{2}$

$$I_{dc} = \frac{2I_m}{\pi}$$

$$V_m = I_m(R_f+R_L)$$

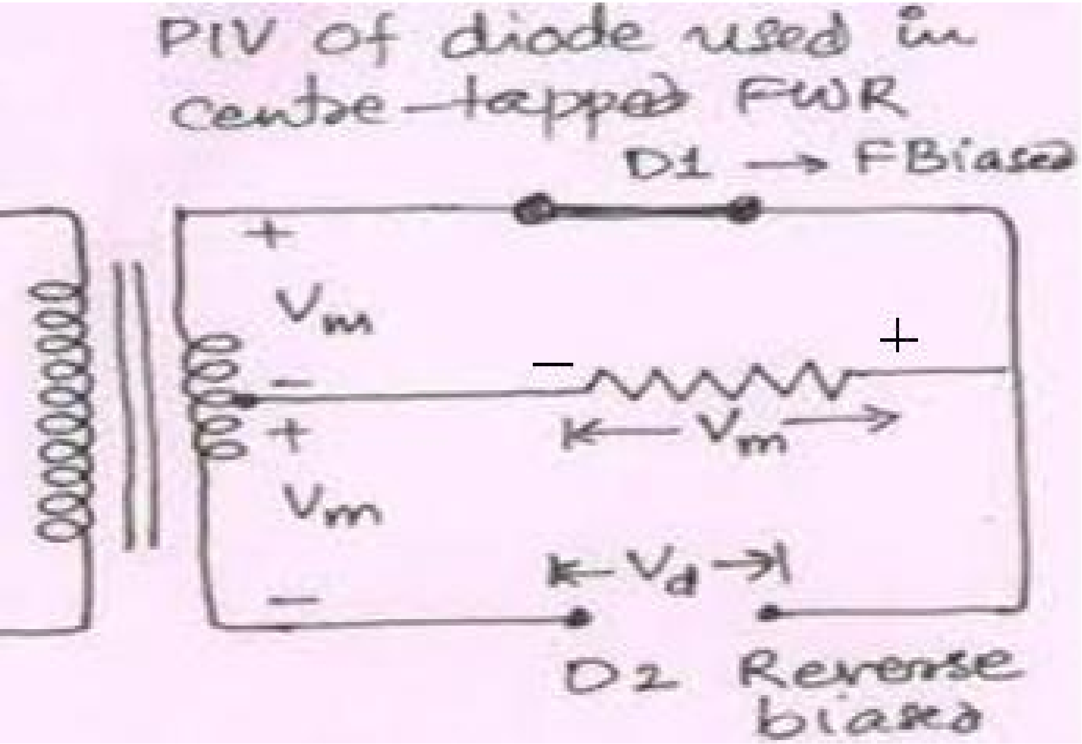
$$= \frac{\frac{4I_m^{\cancel{2}}}{\pi^2} R_L}{\cancel{2}\times \frac{I_m^{\cancel{2}}}{\cancel{2}\sqrt{2}}(R_f+R_L)} = \frac{4\sqrt{2}}{\pi^2}\,\frac{R_L}{R_f+R_L} = 0.573\,\frac{R_L}{R_f+R_L}$$

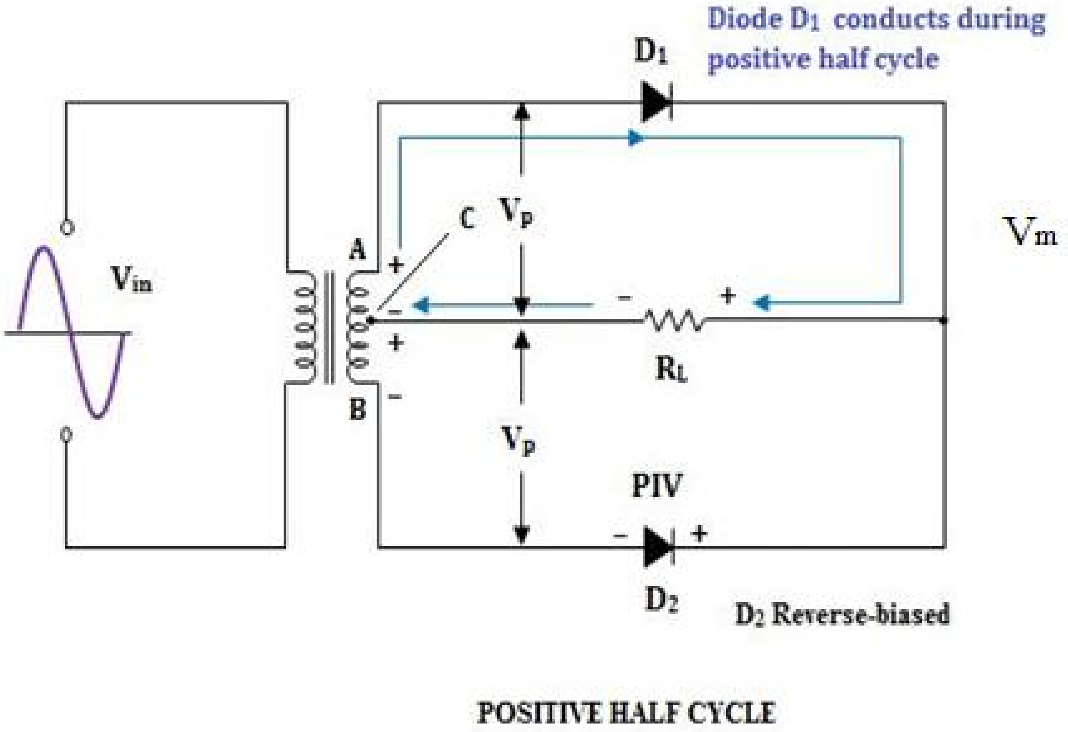
TUF of Primary is Type equation here. $\frac{V_{dc}I_{dc}}{V_{rms}.I_{rms}}$

= 0. 812

TUF = (TUF)p +(TUF) s = (0. 573+0. 812)/2 = 0. 693

PIV of FWR





$PIV = 2\,V_m$

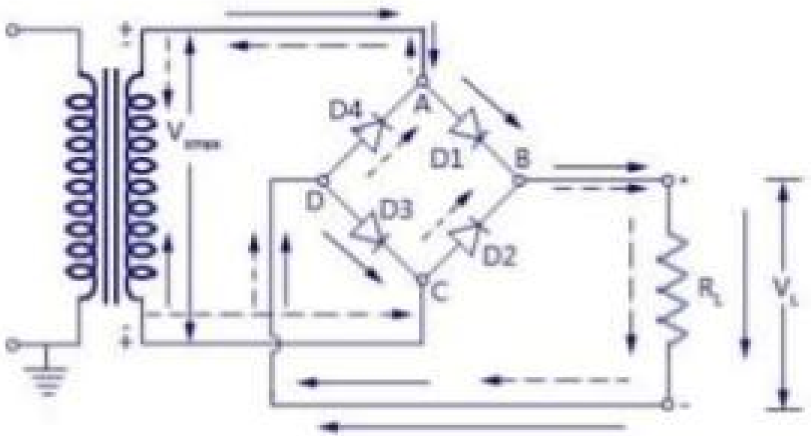
Advantages of Full wave rectifier with center tapped transformer

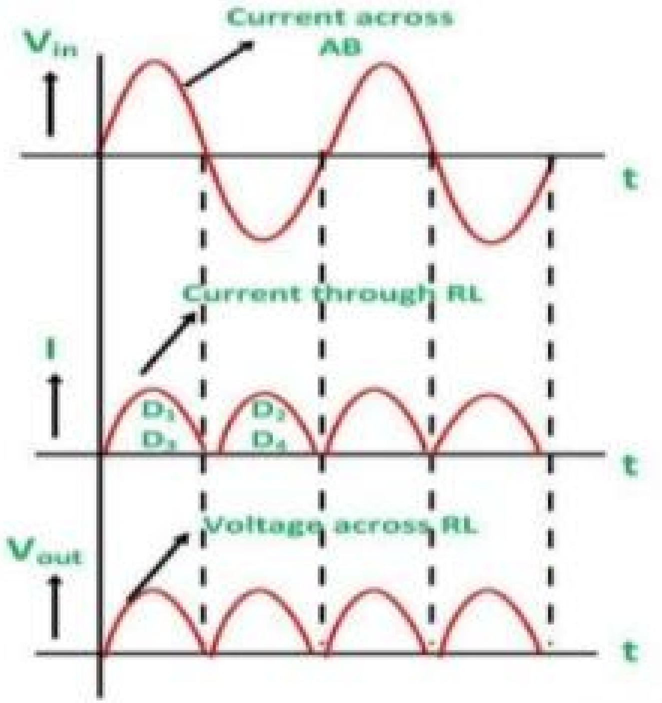
- Low ripple factor as compared to Half wave rectifier .
- Better rectification efficiency.
- Better transformer utilization factor.
- Higher values of average load and average load current.
- No possibility of transformer core saturation because transformer current flows equally in both the half cycles.

Disadvantages of Full wave rectifier

- More complicated than half-wave rectifier.
- PIV rating of the diode is higher (i. e. $2V_m$)
- Higher PIV diodes are larger in size and much costlier.
- The cost of the center tap transformer is high.
- Lower transformer Utilization Factor (TUF)

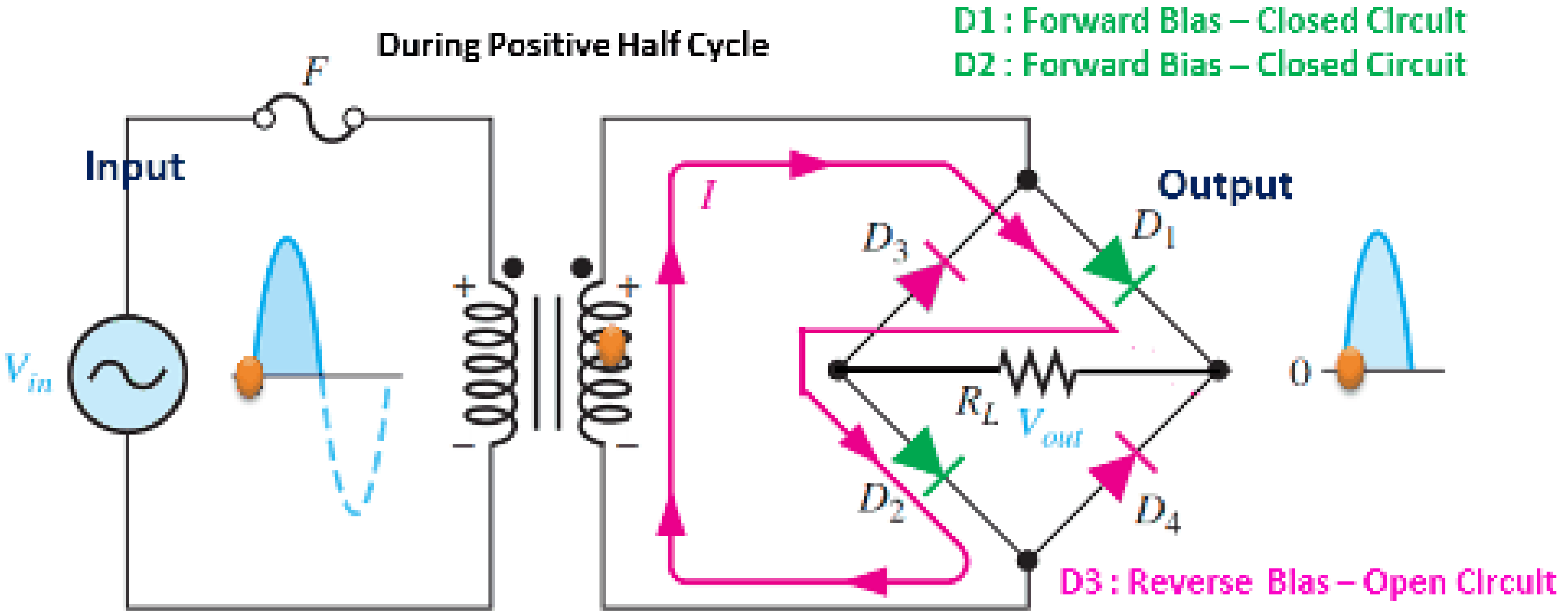
Full Wave Bridge Rectifier





- Consists of 4 diodes instead of 2.

Bridge Full Wave Rectifier



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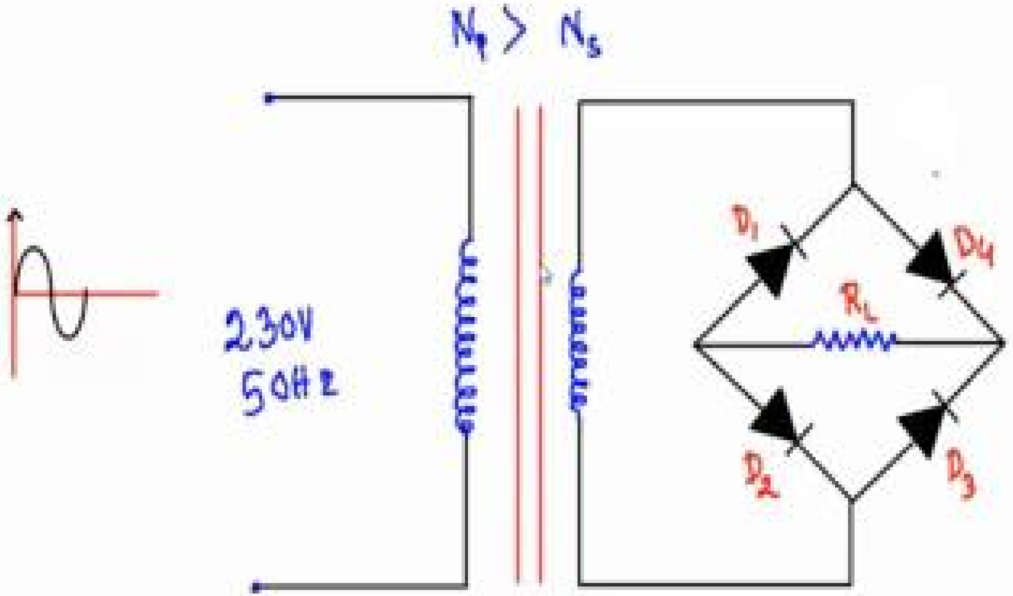
Transformer Utilization Factor (TUF)

- Transformer Utilization Factor indicates how well the input transformer is being utilized.
- So, the transformer utilization factor is defined as :

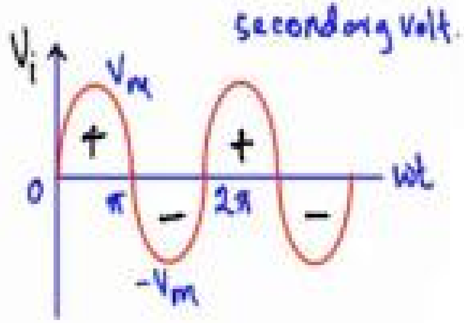
$$TUF = \frac{d.c.\,power\ to\ be\ delivered\ to\ the\ load}{a.c.\,rating\ of\ the\ transformer\ secondary}$$

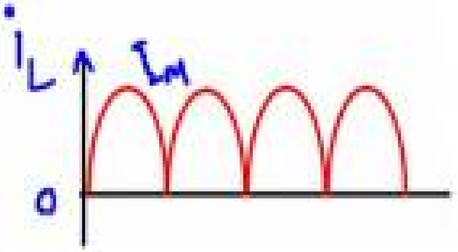
- TUF for Center tapped full wave rectifier is 0.693 and for Full wave bridge rectifier is 0.812

Transformer Utilization Factor of Full Wave Rectifier:



$$V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707\,V_m$$





$$TUF = \frac{I_{dc}^2 R_L}{V_{rms}\, I_{rms}}$$

$$= \frac{\frac{4I_m^2}{\pi^2} \times R_L}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}$$

$$= \frac{8 I_m^2 R_L}{\pi^2 \times I_m \times V_m}$$

$$= \frac{8\, I_m R_L}{\pi^2 V_m}$$

$$= \frac{8 V_m}{\pi^2 V_m} = 0.812$$

$$TUF = 0.812 = \frac{P_{dc}}{1}$$

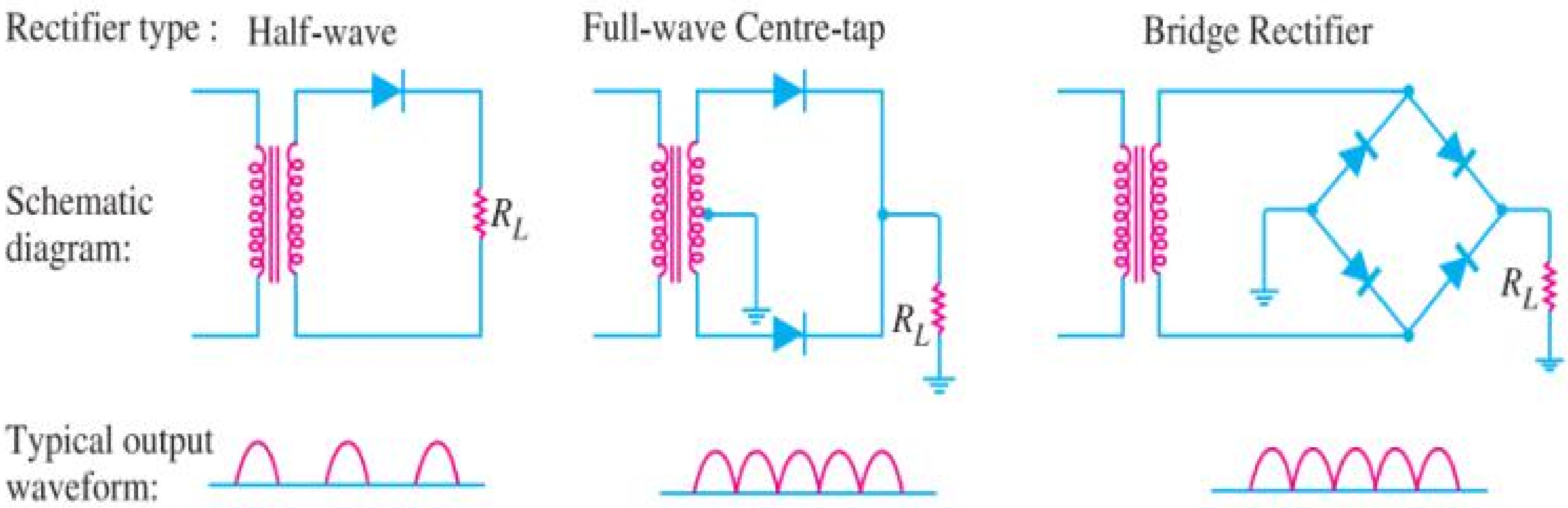
Full Wave Bridge Rectifier

Advantage:

I. Need for centre tap trnsformer is eliminated.
II. Output is twice than that of centre tap circuit.

Disadvantage

I. Requires 4 diodes.
II. Internal resistance voltage drop is twice than that of Centre Tap Circuit.



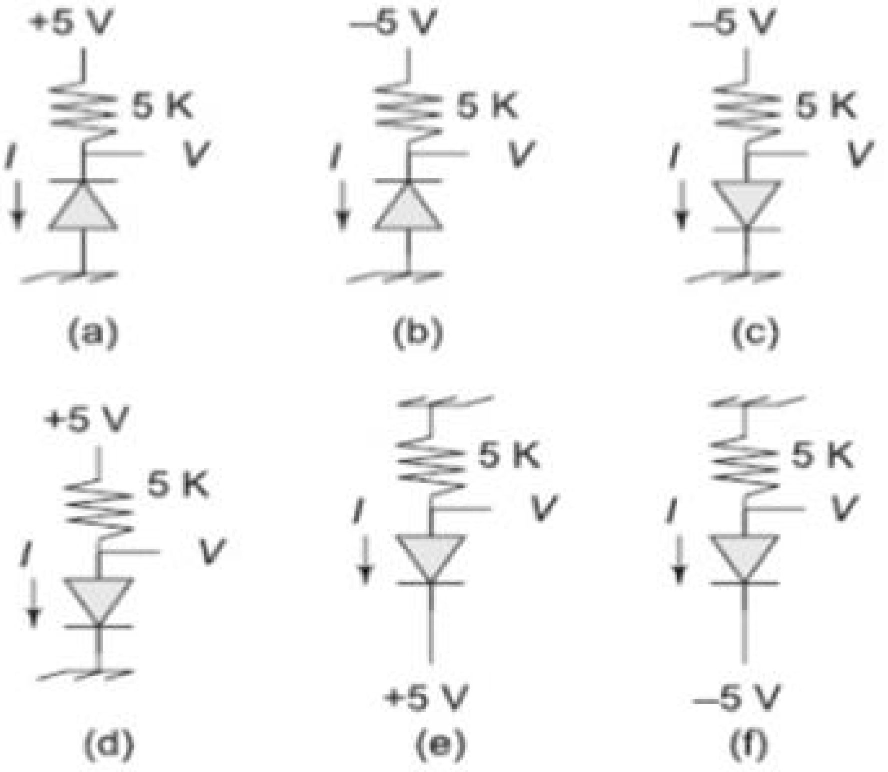
S. No.	Particulars	Half-wave	Centre-tap	Bridge type
1	No. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2 f_{in}$	$2 f_{in}$
6	Peak inverse voltage	V_m	$2 V_m$	V_m

Comparison

Sr. No.	Parameter	Half wave	Full wave	Bridge
1.	Number of diodes	1	2	4
2.	Average D.C. current (I_{DC})	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
3.	Average D.C. voltage (E_{DC})	$\frac{E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$
4.	R.M.S. current (I_{RMS})	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
5.	D.C. power output (P_{DC})	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4}{\pi^2} I_m^2 R_L$	$\frac{4}{\pi^2} I_m^2 R_L$
6.	A.C. power input (P_{AC})	$\frac{I_m^2 (R_L + R_f + R_s)}{4}$	$\frac{I_m^2 (R_f + R_s + R_L)}{2}$	$\frac{I_m^2 (2R_f + R_s + R_L)}{2}$
7.	Maximum rectifier efficiency (η)	40.6 %	81.2 %	81.2 %
8.	Ripple factor (γ)	1.21	0.482	0.482
9.	Maximum load current (I_m)	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + 2R_f + R_L}$
10.	PIV rating of diode	E_{sm}	$2\ E_{sm}$	E_{sm}
11.	Ripple frequency	50 Hz	100 Hz	100 Hz
12.	T.U.F.	0.287	0.693	0.812

Problems on Rectifiers

Obtain the value of V and I in each case of Figs. (a–f), assuming the drop across the diode of 0.7 V.



(a) Diode reverse biased $I = 0$, $V = 5$ V

(b) $I = \dfrac{-5+0.7}{5\text{ K}} = \dfrac{-4.3}{5\text{ K}} = -0.86$ mA,

$V = -0.7$ V

(c) $I = 0$, $V = -5$ V

(d) $I = \dfrac{5-0.7}{5\text{ K}} = 0.86$ mA, $V = 0.7$ V

(e) $I = 0$, $V = 0$ V

(f) $I = \dfrac{5-0.7}{5\text{ K}} = 0.86$ mA, $V = -5\text{ K} \times$

$0.86 = 4.3$ V

Q1. The applied input a. c. power to a half-wave rectifier is 100 watts. The d. c. output power obtained is 40 watts.
(i) What is the rectification efficiency ?
(ii) What happens to remaining 60 watts ?

Solution :

$$\text{Rectification efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{40}{100} = 0.4 = 40\%$$

40% efficiency of rectification does not mean that 60% of power is lost in the rectifier circuit. In fact, a crystal diode consumes little power due to its small internal resistance. The 100 W a. c. power is contained as 50 watts in positive half-cycles and 50 watts in negative half-cycles. The 50 watts in the negative half-cycles are not supplied at all. Only 50 watts in the positive half-cycles are converted into 40 watts.

$$\therefore \quad \text{Power efficiency} = \frac{40}{50} \times 100 = 80\%$$

Q2. A crystal diode having internal resistance $r_f = 20\Omega$ is used for half-wave rectification. If the applied voltage $v = 50 \sin \omega t$ and load resistance $R_L = 800\ \Omega$, find :
(i) Im, Idc, Irms (ii) a. c. power input and d. c. power output (iii) d. c. output voltage (iv) efficiency of rectification.

Solution :

$$v = 50 \sin \omega t$$

$$\therefore \quad \text{Maximum voltage, } V_m = 50 \text{ V}$$

$$I_m = \frac{V_m}{r_f + R_L} = \frac{50}{20 + 800} = 0.061 \text{ A} = 61 \text{ mA}$$

$$I_{dc} = I_m/\pi = 61/\pi = 19.4 \text{ mA}$$

$$I_{rms} = I_m/2 = 61/2 = 30.5 \text{ mA}$$

$$\text{a.c. power input} = (I_{rms})^2 \times (r_f + R_L) = \left(\frac{30.5}{1000}\right)^2 \times (20 + 800) = 0.763 \text{ watt}$$

$$\text{d.c. output voltage} = I_{dc} R_L = 19.4 \text{ mA} \times 800\ \Omega = 15.52 \text{ volts}$$

$$\text{Efficiency of rectification} = \frac{0.301}{0.763} \times 100 = 39.5\%$$

Q3. A half-wave rectifier is used to supply 50V d. c. to a resistive load of 800 Ω. The diode has a resistance of 25 Ω. Calculate a. c. voltage required.

Solution :

Output d.c. voltage, $V_{dc} = 50\text{ V}$

Diode resistance, $r_f = 25\ \Omega$

Load resistance, $R_L = 800\ \Omega$

Let V_m be the maximum value of a.c. voltage required.

$$\therefore \quad V_{dc} = I_{dc} \times R_L$$

$$= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi(r_f + R_L)} \times R_L \qquad \left[\because I_m = \frac{V_m}{r_f + R_L}\right]$$

or

$$50 = \frac{V_m}{\pi(25 + 800)} \times 800$$

$$\therefore \quad V_m = \frac{\pi \times 825 \times 50}{800} = 162\text{ V}$$

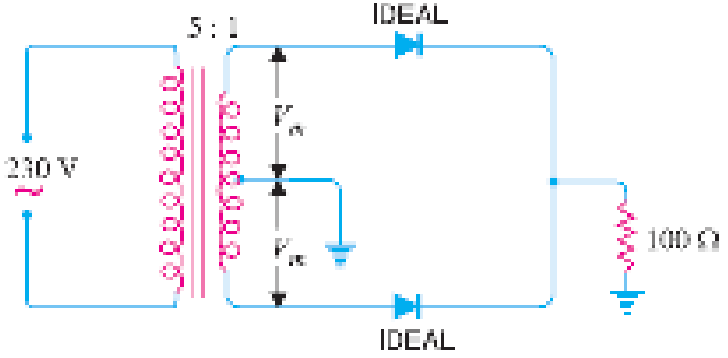
Hence a.c. voltage of maximum value 162 V is required.

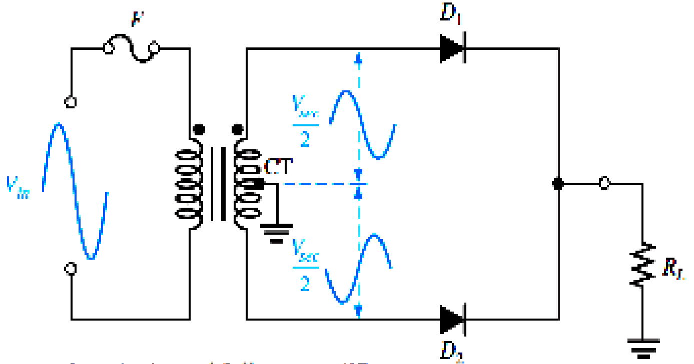
Q4. In the Centre-tap circuit shown in Figure, the diodes are assumed to be ideal i. e. having zero internal resistance. Find :

(i) d. c. output voltage

(ii) peak inverse voltage

(iii) rectification efficiency.





A center-tapped full-wave rectifier

R.M.S. primary voltage = 230 V

∴ R.M.S. secondary voltage

$$= 230 \times (1/5) = 46 \text{ V}$$

Maximum voltage across secondary

$$= 46 \times \sqrt{2} = 65\text{V}$$

Maximum voltage across half secondary winding is

$$V_m = 65/2 = 32.5 \text{ V}$$

$$I_{dc} = \frac{2V_m}{\pi R_L} = \frac{2 \times 32.5}{\pi \times 100} = 0.207 \text{ A}$$

$$PIV = 65 \text{ V}$$

$$\text{Rectification efficiency} = \frac{0.812}{1 + \dfrac{r_f}{R_L}}$$

$$\text{Since } r_f = 0$$

$$\text{Rectification efficiency} = 81.2\ \%$$

Q5. In the bridge type circuit shown in Fig. 3, the diodes are assumed to be ideal. Find : (i) d. c. output voltage (ii) peak inverse voltage (iii) output frequency. Assume primary to secondary turns to be 4.

Solution :

Primary/secondary turns, $N_1/N_2 = 4$

R.M.S. primary voltage $= 230$ V

$\therefore$ R.M.S. secondary voltage $= 230\,(N_2/N_1) = 230 \times (1/4) = 57.5$ V

Maximum voltage across secondary is

$$V_m = 57.5 \times \sqrt{2} = 81.3 \text{ V}$$

(*i*) Average current, $I_{dc} = \dfrac{2V_m}{\pi R_L} = \dfrac{2 \times 81.3}{\pi \times 200} = 0.26$ A

$\therefore$ d.c. output voltage, $V_{dc} = I_{dc} \times R_L = 0.26 \times 200 = \mathbf{52\ V}$

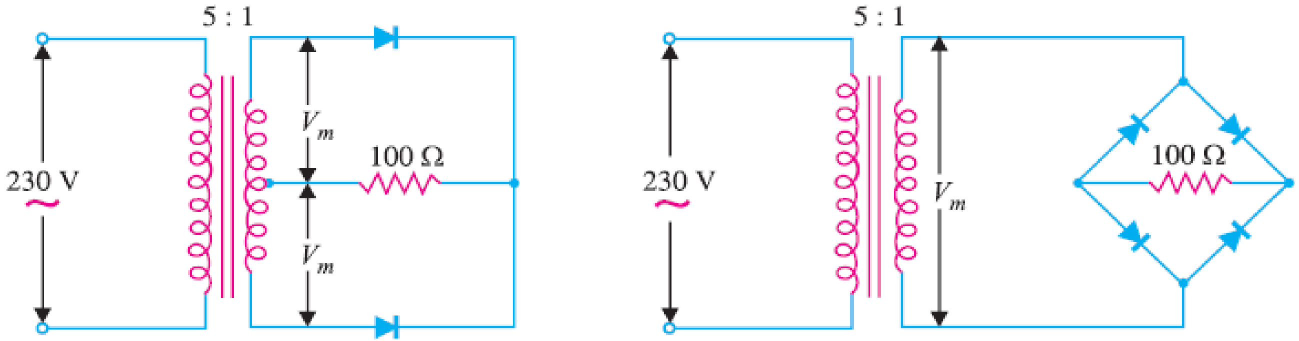
(*ii*) The peak inverse voltage is equal to the maximum secondary voltage *i.e.*

$$PIV = \mathbf{81.3\ V}$$

(*iii*) In full-wave rectification, there are two output pulses for each complete cycle of the input a.c. voltage. Therefore, the output frequency is twice that of the a.c. supply frequency *i.e.*

$$f_{out} = 2 \times f_{in} = 2 \times 50 = \mathbf{100\ Hz}$$

Q6. Fig. (i) and Fig. (ii) show the centre-tap and bridge type circuits having the same load resistance and transformer turn ratio. The primary of each is connected to
230V, 50 Hz supply. (i) Find the d. c. voltage in each case. (ii) PIV for each case for the same d. c. output. Assume the diodes to be ideal.



(i) (ii)

Centre-tap Circuit

$$\text{R.M.S. secondary voltage} = 230 \times 1/5 = 46 \text{ V}$$

$$\text{Max. voltage across secondary} = 46 \times \sqrt{2} = 65 \text{ V}$$

Max. voltage appearing across half secondary winding is

$$V_m = 65/2 = 32.5 \text{ V}$$

$$\text{Average current, } I_{dc} = \frac{2V_m}{\pi R_L}$$

$$\text{D.C. output voltage, } V_{dc} = I_{dc} \times R_L = \frac{2V_m}{\pi R_L} \times R_L$$

$$= \frac{2V_m}{\pi} = \frac{2 \times 32.5}{\pi} = 20.7 \text{ V}$$

Bridge circuit

$$\text{Max. voltage across secondary, } V_m = 65 \text{ V}$$

$$\text{D.C. output voltage, } V_{dc} = I_{dc} R_L = \frac{2V_m}{\pi R_L} \times R_L = \frac{2V_m}{\pi} = \frac{2 \times 65}{\pi} = 41.4 \text{ V}$$

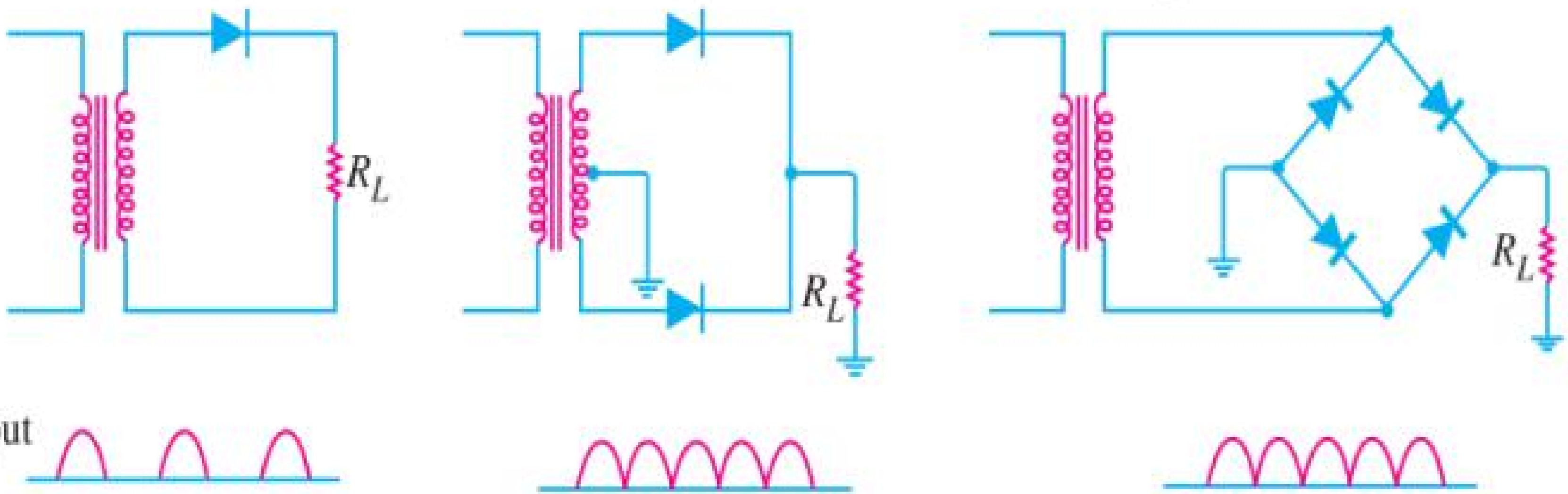
Filters

1. Capacitor Filter
2. Inductor Filter or Choke Filter
3. LC Filter or L-section Filter
4. CLC Filter or π-Filter

Rectifier type : Half-wave | Full-wave Centre-tap | Bridge Rectifier

Schematic diagram:

Typical output waveform:



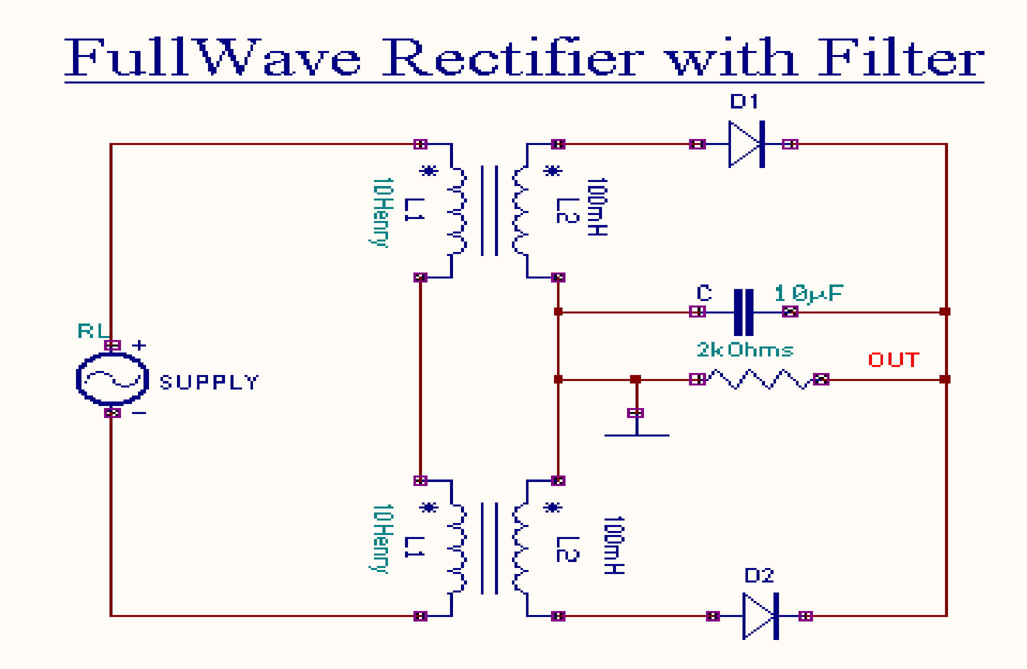
S. No.	Particulars	Half-wave	Centre-tap	Bridge type
1	No. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2 f_{in}$	$2 f_{in}$
6	Peak inverse voltage	V_m	$2 V_m$	V_m

Comparison

Sr. No.	Parameter	Half wave	Full wave	Bridge
1.	Number of diodes	1	2	4
2.	Average D.C. current (I_{DC})	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
3.	Average D.C. voltage (E_{DC})	$\frac{E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$	$\frac{2E_{sm}}{\pi}$
4.	R.M.S. current (I_{RMS})	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
5.	D.C. power output (P_{DC})	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4}{\pi^2} I_m^2 R_L$	$\frac{4}{\pi^2} I_m^2 R_L$
6.	A.C. power input (P_{AC})	$\frac{I_m^2 (R_L + R_f + R_s)}{4}$	$\frac{I_m^2 (R_f + R_s + R_L)}{2}$	$\frac{I_m^2 (2R_f + R_s + R_L)}{2}$
7.	Maximum rectifier efficiency (η)	40.6 %	81.2 %	81.2 %
8.	Ripple factor (γ)	1.21	0.482	0.482
9.	Maximum load current (I_m)	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + R_f + R_L}$	$\frac{E_{sm}}{R_s + 2R_f + R_L}$
10.	PIV rating of diode	E_{sm}	$2\ E_{sm}$	E_{sm}
11.	Ripple frequency	50 Hz	100 Hz	100 Hz
12.	T.U.F.	0.287	0.693	0.812

Rectifier with Filter

The output of the Full Wave Rectifier contains both ac and dc components. A majority of the applications, which cannot tolerate a high value ripple, necessitates further processing of the rectified output. The undesirable ac components i. e. the ripple, can be minimized using filters.

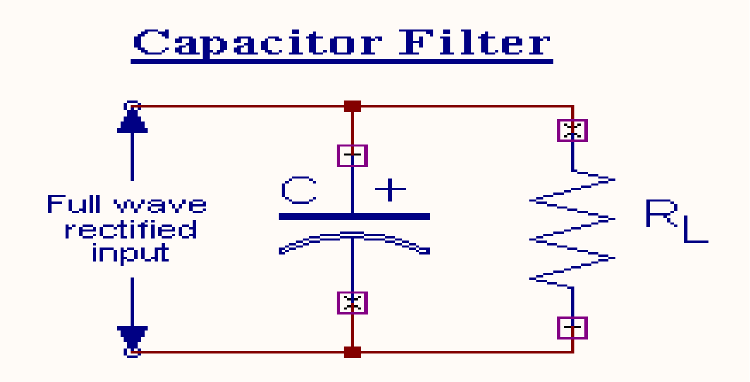


The output of the rectifier is fed as input to the filter. The output of the filter is not a perfect dc, but it also contains small ac components.

Some important filters are

1. Capacitor Filter
2. Inductor Filter
3. LC Filter
4. CLC or π Filter

Capacitor Filter



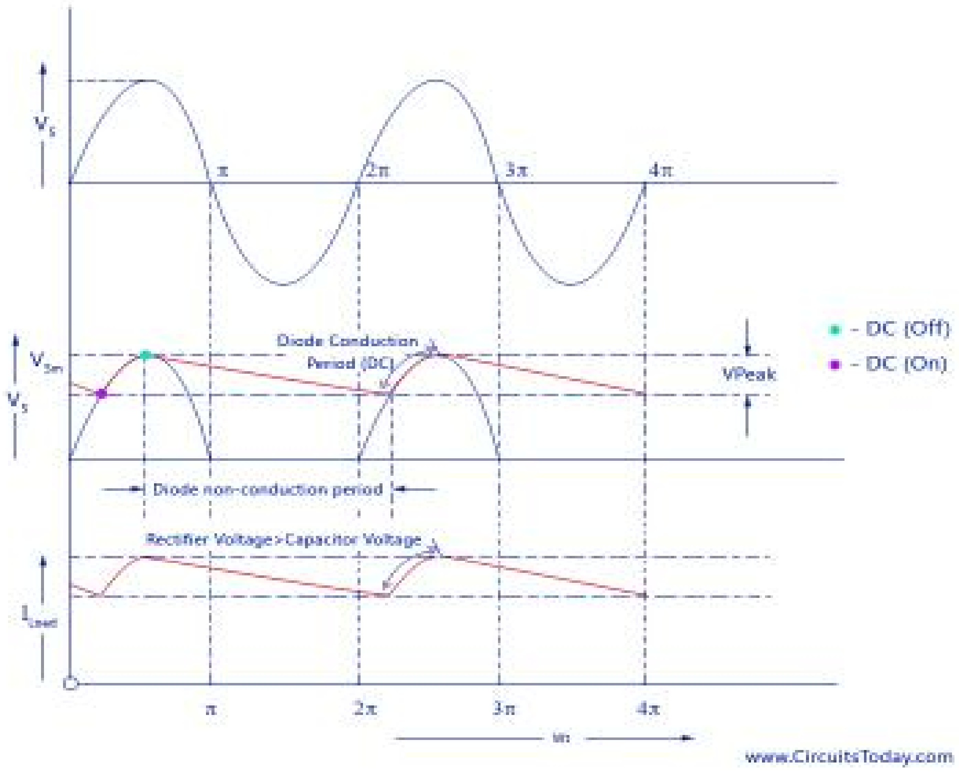
A capacitor filter connected directly across the load is shown above. The property of a capacitor is that it allows ac component and blocks dc component. The operation of the capacitor filter is to short the ripple to ground but leave the dc to appear at output when it is connected across the pulsating dc voltage.

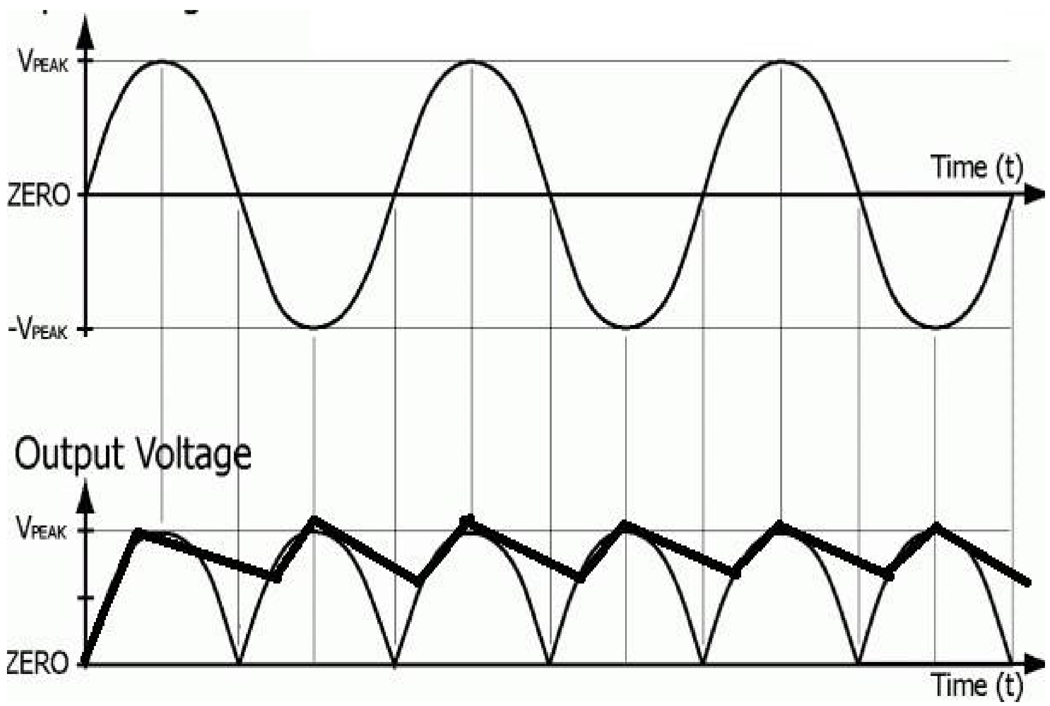
Working: During the positive half cycle, the capacitor charges upto the peak vale of the transformer secondary voltage, V_m and Capacitor will discharge through R_L slowly until the transformer secondary voltage again increase to a value greater than the capacitor voltage.

The diode conducts for a period, which depends on the capacitor voltage. The diode will conduct when the transformer secondary voltage becomes more than the diode voltage. This is called the cut in voltage.

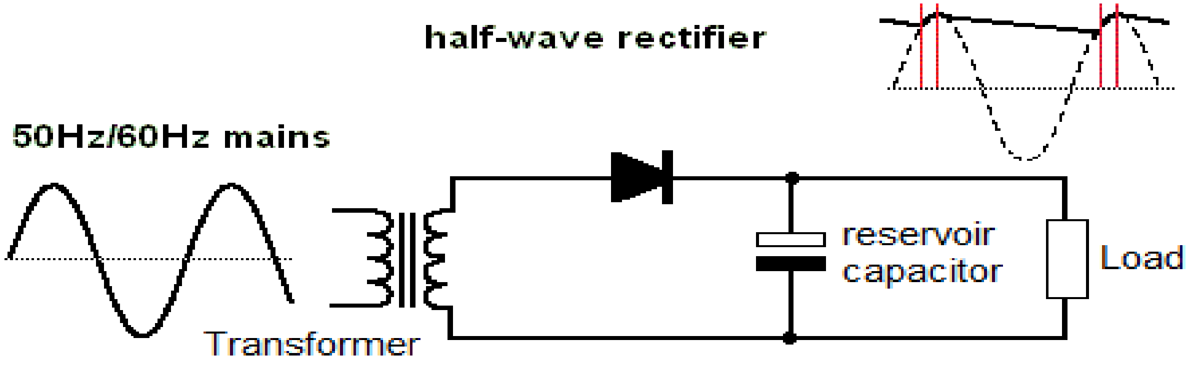
The diode stops conducting when the transformer voltage becomes less than the diode voltage. This is called cut out voltage.

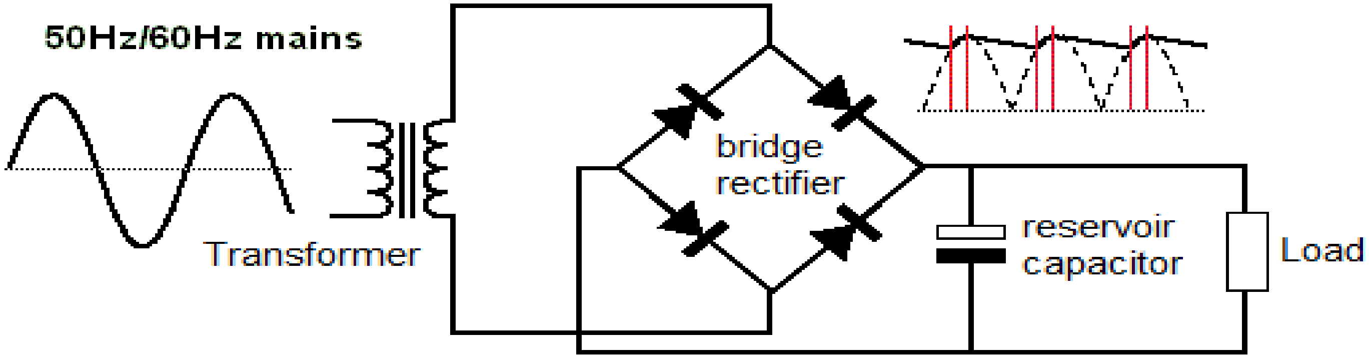
Half wave Rectifier with Capacitor Filter - Waveform





Capacitor filter for Half wave and Full wave Rectifier



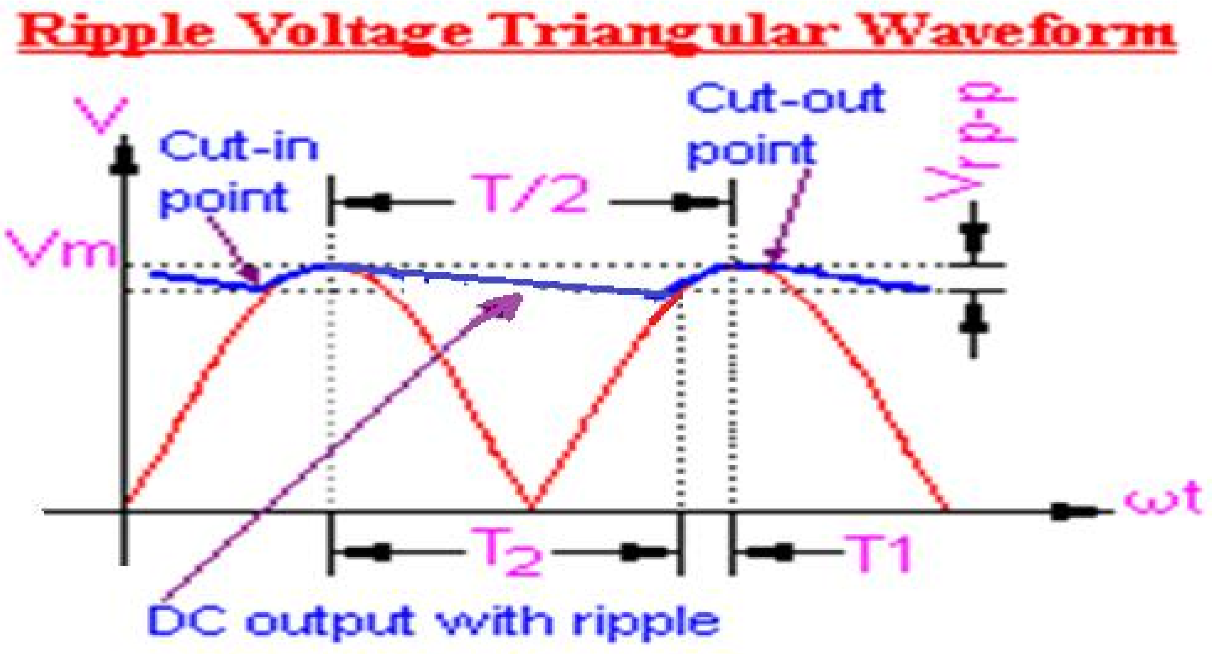


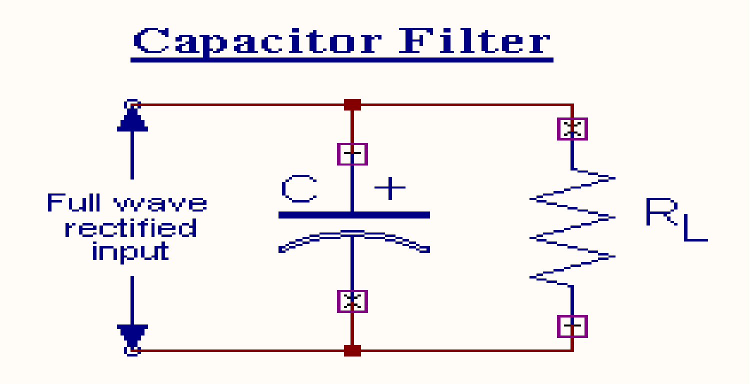
full-wave (bridge) rectifier

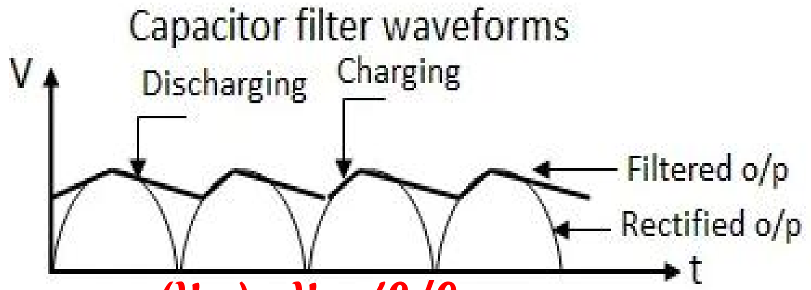
Referring to the figure below, with slight approximation the ripple voltage can be assumed as triangular. From the cut-in point to the cut-out point, whatever charge the capacitor acquires is equal to the charge the capacitor has lost during the period of non-conduction, i. e. , from cut-out point to the next cut-in point.

The charge it has acquired $= V_{r\,p-p} \times C$

The charge it has lost is $= I_{d.c.} \times T_2$







$(V_{rms}) = V_{(p-p)}/2\sqrt{3}$

$$\therefore V_{r\,p-p} \times C = I_{d.c.} \times T_2$$

If the value of the capacitor is fairly large, or the value of the load resistance is very large, then it can be assumed that the time T_2 is equal to half, the periodic time of the waveform.

In case of full wave rectifier $T_2 = \frac{T}{2} = \frac{1}{2f}$, then $V_{r\,p-p} = \frac{I_{d.c.}}{2fC}$ **CxV = Q = IxT**

From the above assumptions, the ripple waveform will be triangular and its rms value is given by

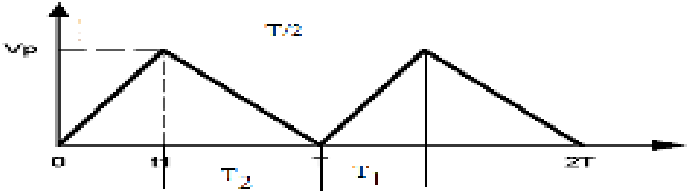
$$V_{r(rms)} = \frac{V_{r\,(P-P)}}{2\sqrt{3}} = \frac{I_{dc}}{2fC} \times \frac{1}{2\sqrt{3}} = \frac{I_{dc}}{4\sqrt{3}\,fC}$$

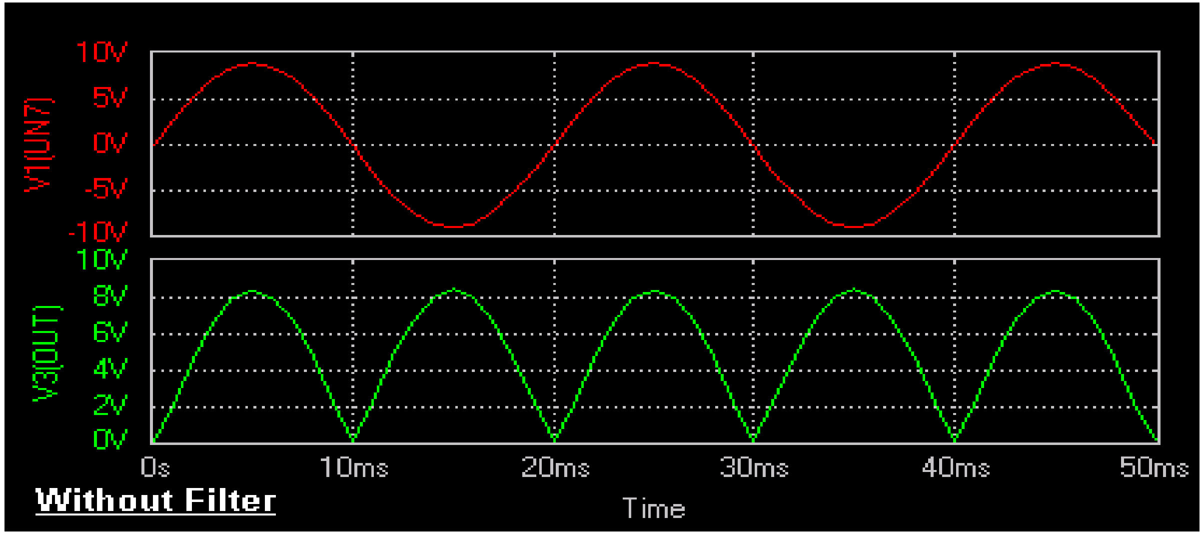
$$V_{r\,rms} = \frac{I_{d.c.}}{4\sqrt{3}f\,C} = \frac{V_{d.c.}}{4\sqrt{3}f\,C\,R_L},\ \because I_{d.c.} = \frac{V_{d.c.}}{R_L} \qquad \therefore Ripple, \gamma = \frac{V_{r\,rms}}{V_{d.c.}} = \frac{1}{4\sqrt{3}f\,C\,R_L},\ \because I_{d.c.} = \frac{V_{d.c.}}{R_L}$$

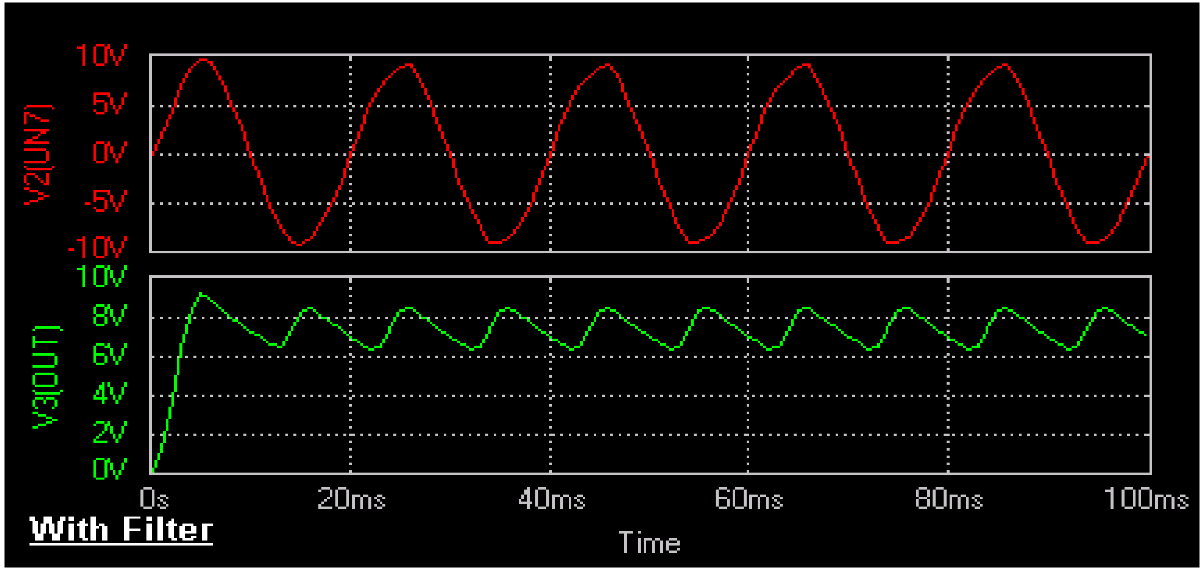
The ripple may be decreased by increasing C or R_L (both) with a resulting increase in the dc. output voltage.

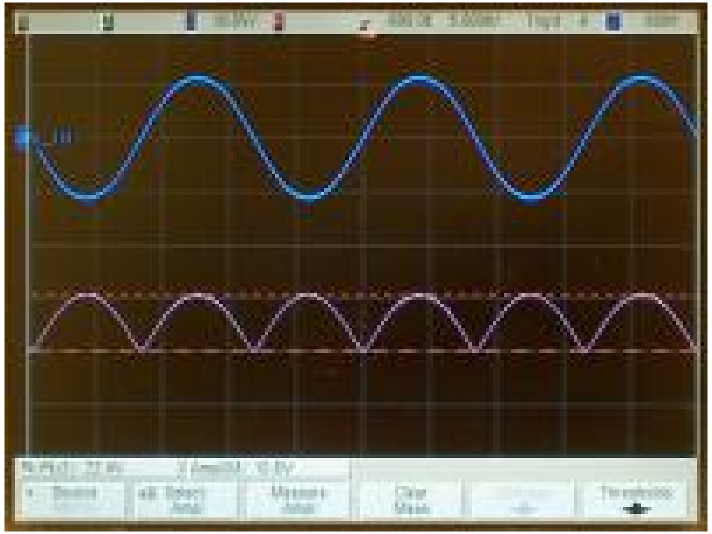
For half wave rectifier $T_2 \approx T = \frac{1}{f}$ **hence,** $V_{r(rms)} = \frac{I_{dc}}{fC} \times \frac{1}{2\sqrt{3}} = \frac{I_{dc}}{2\sqrt{3}\,fC}$

and $\gamma = \frac{1}{2\sqrt{3}\,fCR_L}$



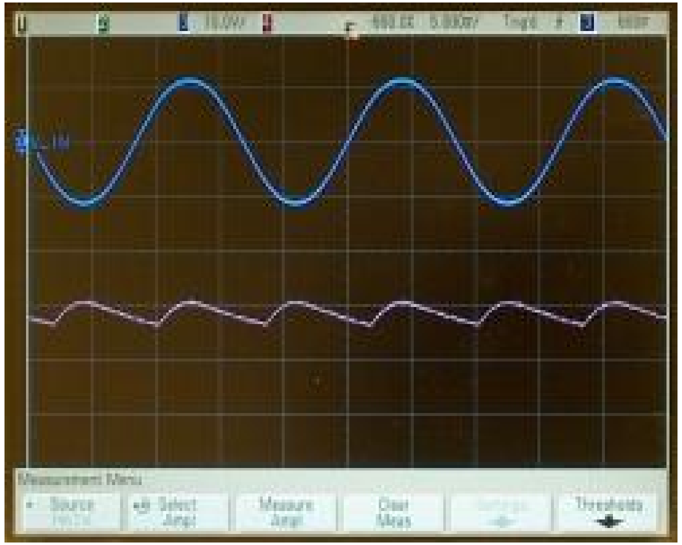

10V
5V
0V
-5V
-10V
V1(UN7)
10V
8V
6V
4V
2V
0V
V3(OUT)
0s
10ms
20ms
30ms
40ms
50ms
Without Filter
Time


10V
5V
0V
-5V
-10V
V2(UN7)
10V
8V
6V
4V
2V
0V
V3(OUT)
0s
20ms
40ms
60ms
80ms
100ms
With Filter
Time



Full wave O/P without filter

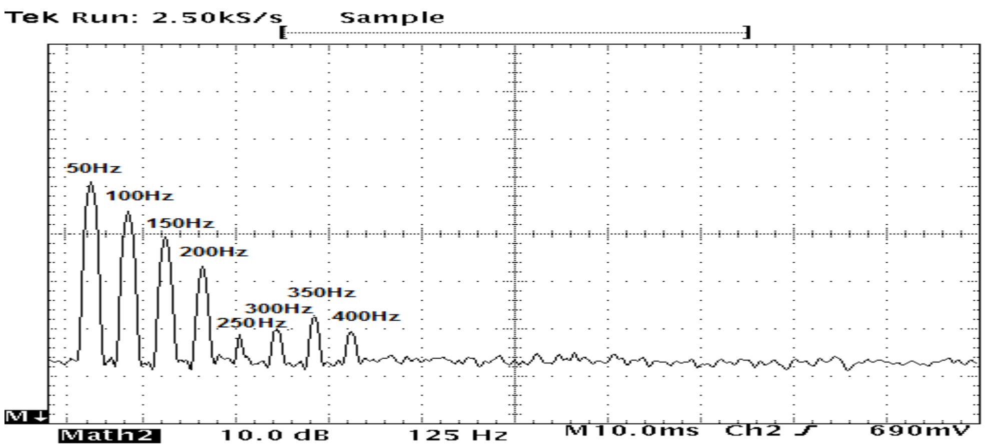
0. 01 μF

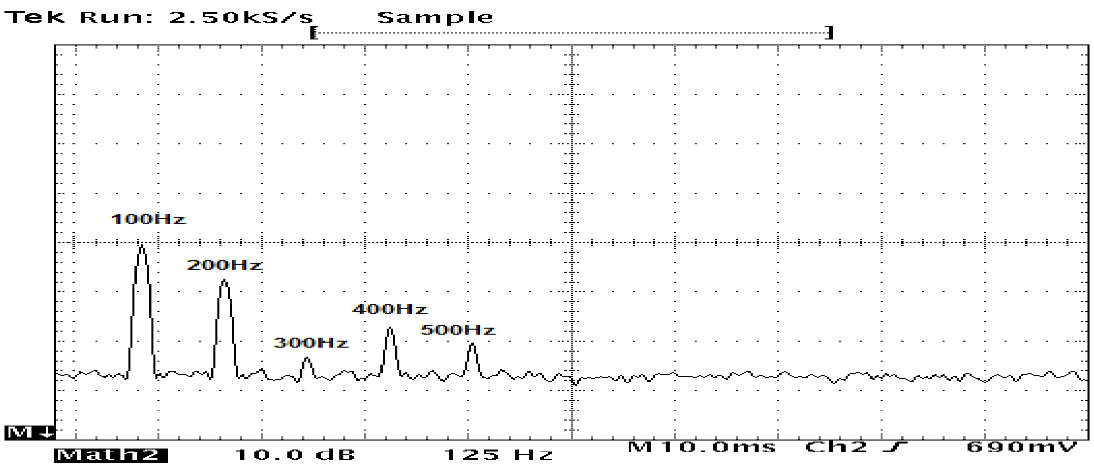


0. 1μF

10μF

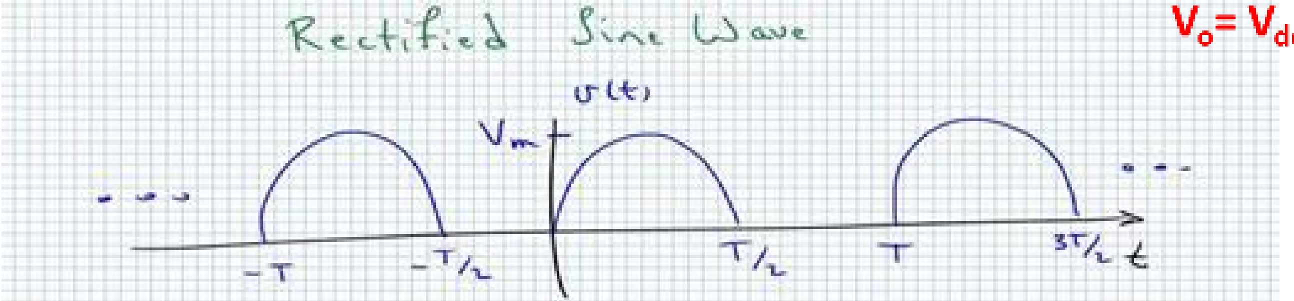
Harmonics in Half wave and Full wave rectifier





The Fourier series of the output voltage is given by:

$$V_o = V_{dc} + \sum_{n=1}^{N}(a_n \sin n\theta + b_n \cos n\theta)$$



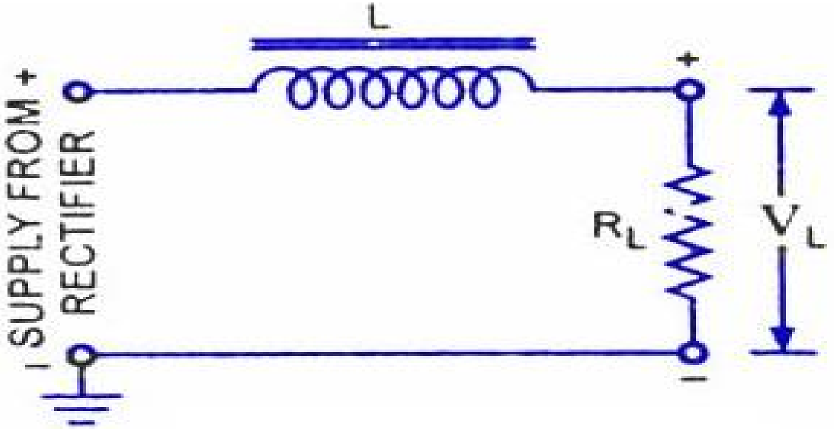
$$v(t) = \frac{V_m}{\pi} + \frac{V_m}{2}\sin(\omega_0 t) - \sum_{n=2,4,6}^{\infty} \frac{2V_m}{\pi(n^2-1)}\cos(n\omega_0 t)$$

$$\left(\omega_0 = \frac{2\pi}{T}\right)$$

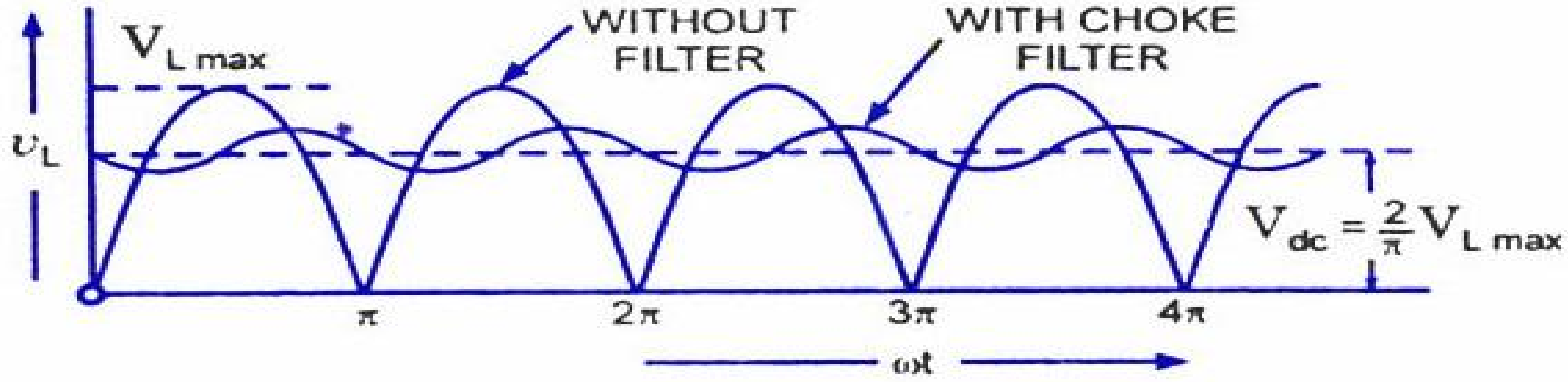
The Fourier series for the output voltage, V_o, is given as

$$V_0(t) = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos(2wt) - \frac{4V_m}{15\pi} - \cdots$$

Full Wave Rectifier with Series Inductor Filter



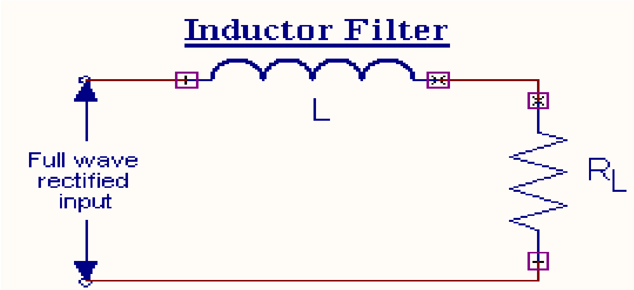
Circuit Diagram



Output Voltage Waveforms www.CircuitsToday.com

Inductor Filter

The figure shows an inductor filter. When the output of the rectifier passes through an inductor, it blocks the ac component and allows only the dc component to reach the load.



To analyze this filter for full wave, the Fourier series can be written as

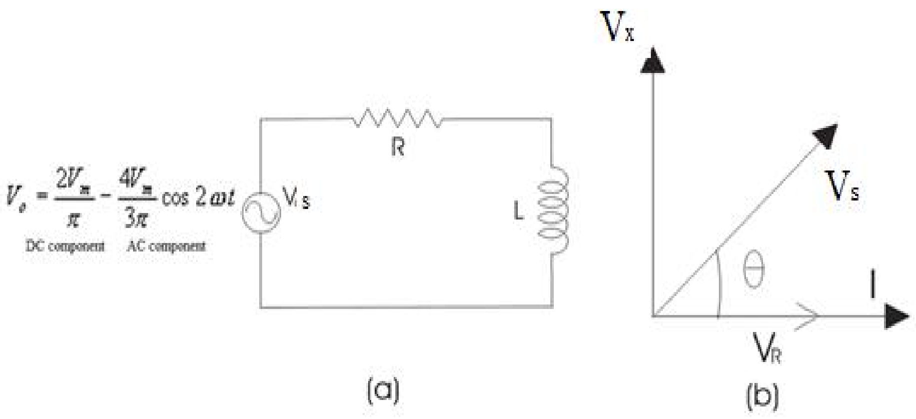
$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{\pi}\left[\frac{1}{3}\cos 2\omega t + \frac{1}{15}\cos 4\omega t + \frac{1}{35}\cos 6\omega t + \cdots\right]$$

(Assuming that the third and higher hormonic terms contribute little output, the output voltage is)

$$V_o = \underbrace{\frac{2V_m}{\pi}}_{\text{DC component}} - \underbrace{\frac{4V_m}{3\pi}\cos 2\omega t}_{\text{AC component}}$$

The diode, choke and transformer resistances can be neglected since they are very small compared with R_L. Therefore the dc component of current

$$I_m = \frac{V_m}{R_L}$$

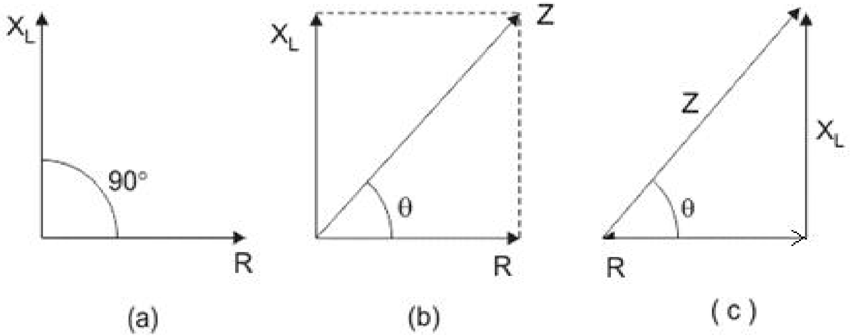


The impedance of series combination of L and R_L at 2ω is

$$Z = \sqrt{R_L^2 + (2\omega L)^2} = \sqrt{R_L^2 + 4\omega^2 L^2}$$

Therefore for the ac component,

$$I_m = \frac{V_m}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$



Therefore, the resulting current i is given by,

$$i = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\pi}\frac{\cos(2\omega t - \varphi)}{\sqrt{R_L^2 + 4\omega^2 L^2}} \quad \text{where} \quad \varphi = \tan^{-1}\left(\frac{2\omega L}{R_L}\right)$$

$\theta = \tan^{-1}(X_L / R)$.

$X_L = 2\pi \times 2f \times L$ ohms. $(f_{out} = 2 f_{in})$

is . This is slightly less than $\gamma = \frac{2}{3\sqrt{2}} = 0.471$

The ripple factor which can be defined as the ratio of the rms value of the ripple to the dc value of the wave, is

$$\gamma = \frac{\dfrac{4V_m}{3\pi\sqrt{2}\sqrt{R_L^2 + 4\omega^2 L^2}}}{\dfrac{2V_m}{\pi R_L}} = \frac{2}{3\sqrt{2}} \frac{1}{\sqrt{1 + \dfrac{4\omega^2 L^2}{R_L^2}}}$$

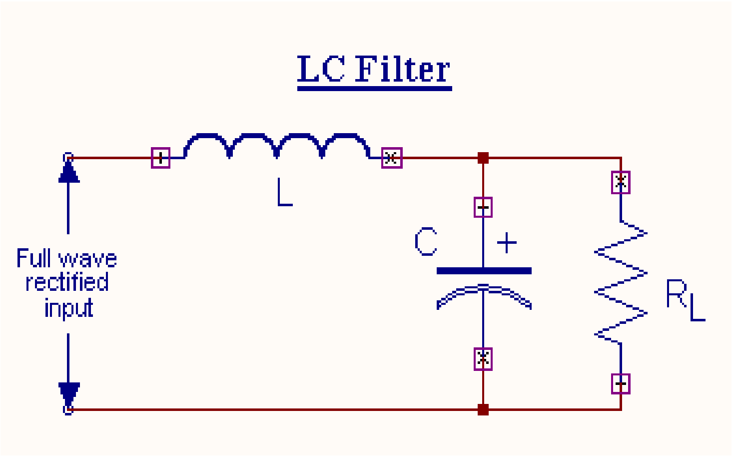
$$\frac{4\omega^2 L^2}{R_L^2} >> 1$$

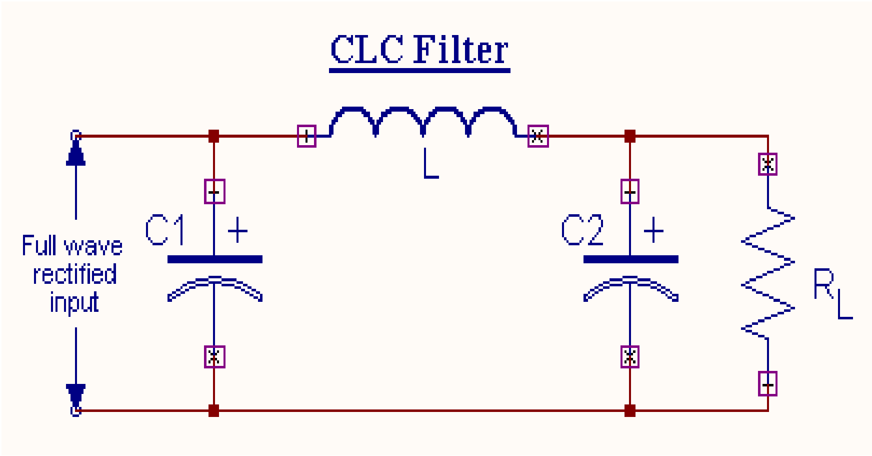
then a simplified expression for γ is $\gamma = \dfrac{R_L}{3\sqrt{2}\,\omega L}$

In case, the load resistance is infinity i. e. , the output is an open circuit, then the ripple factor is

$$\gamma = \frac{2}{3\sqrt{2}} = 0.471$$

The value of ripple factor for full wave rectifieris 0. 482. The difference being attributable to the omission of higher harmonics as mentioned. It is clear that the inductor filter should only be used where R_L is consistently small.





$$\gamma = \frac{V_{r,rms}}{V_{dc}} = \frac{\sqrt{2}}{3} \cdot \frac{X_C}{X_L} = \frac{\sqrt{2}}{3} \cdot \frac{1}{4\omega^2 CL} \quad \because X_C = \frac{1}{2\omega C} \quad \& \quad X_L = 2\omega L$$

$$\gamma = \sqrt{2}\,\frac{X_{C1}}{R_L} \cdot \frac{X_{C2}}{X_L}$$

Ripple Factor in L-Section Filter

$$I_{ac\,rms} = \frac{4V_{L\,max}}{3\pi\sqrt{2}\,X_L} = \frac{\sqrt{2}}{3}\frac{V_{dc}}{X_L}$$

($X_L >> R_L$, Hence current will be decided by X_L and $\frac{2V_m}{\pi} = V_{dc}$)

AC Voltage across the load (the ripple voltage) is equal to voltage across the capacitor. Thus,

$$V_{ac\,rms} = I_{ac\,rms}\,X_c = \frac{\sqrt{2}}{3}V_{dc}\frac{X_C}{X_L}$$

Where, $X_c = \frac{1}{2\omega C}$ *is the reactance of the capacitor at the second harmonic frequency.*

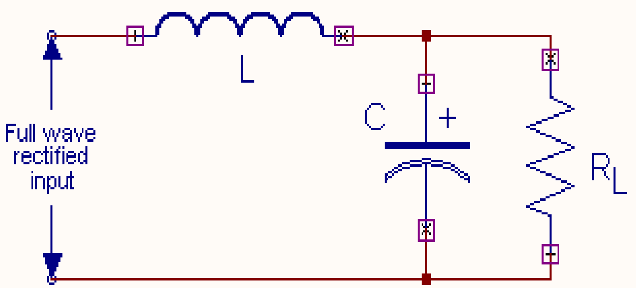
$$\text{Ripple factor, } \gamma = \frac{V_{ac\,rms}}{V_{dc}}$$

$$= \frac{\sqrt{2}}{3}\frac{X_C}{X_L} = \frac{\sqrt{2}}{3}\frac{1}{2\omega C}\frac{1}{2\omega L}$$

$$= \frac{1}{6\omega^2 LC\sqrt{2}}$$

$$V_o = \underbrace{\frac{2V_m}{\pi}}_{\text{DC component}} - \underbrace{\frac{4V_m}{3\pi}\cos 2\omega t}_{\text{AC component}}$$

LC Filter



The expression for voltage for Pi filter is given in below equation:-

$V_r = \frac{I_{dc}}{2fC}$ **For triangular wave fourier series is written as** $v_0 = V_{dc} - \frac{V_{p-p}}{\pi}\left(\sin 2\omega t - \frac{\sin 4\omega t}{2} + \frac{\sin 6\omega t}{3} - \ldots\right)$

Here $V_r = V_{p-p}$

In the case of Pi filter $C = C_1$

The RMS value of output voltage is given as:-

$$V_{ac\,rms} = \frac{V_r}{\pi\sqrt{2}} = \frac{1}{\pi\sqrt{2}}\frac{I_{dc}}{2fC_1} = I_{dc}X_{C1}\sqrt{2}$$

Here $X_{C1} = \frac{1}{2\omega C_1} = \frac{1}{4\pi f C_1}$*, reactance of input capacitor* C_1 *at second harmonic frequency.*

Now $V_{ac\,rms}$ *is applied to* $L -$ *section so the ripple voltage can be obtained by multiplying* X_{C2}/X_L *i.e.*

$$V'_{ac\,rms} = V_{ac\,rms} \times \frac{X_{C2}}{X_L} = \sqrt{2}I_{dc}X_{C1} \times \frac{X_{C2}}{X_L}$$

Now the ripple factor,

$$\gamma = \frac{V'_{ac\,rms}}{V_{dc}} = \frac{I_{dc}X_{C1}X_{C2}\sqrt{2}}{V_{dc}X_L} = \frac{I_{dc}X_{C1}X_{C2}\sqrt{2}}{I_{dc}R_LX_L} = \frac{X_{C1}X_{C2}\sqrt{2}}{R_LX_L}$$

$$\gamma = \frac{\sqrt{2}}{R_L}\frac{1}{2\omega C_1}\frac{1}{2\omega C_2}\frac{1}{2\omega L} = \frac{\sqrt{2}}{8\omega^3 C_1C_2LR_L}$$

Comparison of Filters

Parameter	Capacitor / C Filter	Choke input /L filter	LC filter	π / (CLC) type filter
Place of filter	Across the load	In series with the load	Across the load	Across the load
Useful in	Reducing ripple in load voltage	Reducing ripple in load current	Reducing ripple in load current	Reducing ripple in load voltage
Lowest ripple in the load voltage	No load or light loads	Heavy loads	All loads	No load or light loads
Suitable for	Light load applications	Heavy load applications	Light as well as heavy loads	All loads
Surge current through diodes	Very high and must be controlled	Low and need not to be controlled	Low and need not to be controlled	Low
Expression for ripple factor	$RF= 1/4\sqrt{3}fCR$	$RF=R/3\sqrt{2}\infty L$	$RF=R/6\sqrt{2}\infty^2 LC$	$RF=1/2\sqrt{3}/(\infty^2 LC_1C_2R_L)$
Size of filter	Small and compact	Bulky	Bulky	Bulky
Cost	Lowest	Moderate	Higher	Highest
Voltage regulation	Poor	Moderate	Good	Very good
Applications	Cell charger, small eliminators	High current dc power supplies	Dc power supplies	Dc power supplies

Q1. In a shunt capacitor filter, the mechanism that helps the removal of ripples is _________
a) The current passing through the capacitor
b) The property of capacitor to store electrical energy
c) The voltage variations produced by shunting the capacitor
d) Uniform charge flow through the rectifier

Q2. The cut-in point of a capacitor filter is _________
a) The instant at which the conduction starts
b) The instant at which the conduction stops
c) The time after which the output is not filtered
d) The time during which the output is perfectly filtered

Q3. The rectifier current is a short duration pulses which cause the diode to act as a _________
a) Voltage regulator b) Mixer c) Switch d) Oscillator

(Ans: c, Explanation: The diode permits charge to flow in capacitor when the transformer voltage exceeds the capacitor voltage. It disconnects the power source when the transformer voltage falls below that of a capacitor.)

Q4. A half wave rectifier, operated from a 50Hz supply uses a 1000μF capacitance connected in parallel to the load of rectifier. What will be the minimum value of load resistance that can be connected across the capacitor if the ripple% not exceeds 5?
a) 114.87Ω b) 167.98Ω c) 115.47Ω d) 451.35Ω

Answer: c Explanation: For a half wave filter,
$\gamma = 1/2\sqrt{3}\, fCR_L = 1/2\sqrt{3}*50*10^{-3}*R_L$ or $R_L = 10^3/5\sqrt{3} = 115.47\Omega$.

Q5. A 100μF capacitor when used as a filter has 15V ac across it with a load resistor of 2.5KΩ. If the filter is the full wave and supply frequency is 50Hz, what is the percentage of ripple frequency in the output?
a) 2.456% b) 1.154% c) 3.785% d) 3.675%

Ans: For a full wave rectifier, $\gamma = 1/4\sqrt{3} \times fCR_L = 1/4\sqrt{3}*50*10^{-3}*2.5 = 0.01154$. ripple= 1.154%.

Q6. A full wave rectifier uses a capacitor filter with 500μF capacitor and provides a load current of 200mA at 8% ripple. Calculate the dc voltage.
a) 15.56V b) 20.43V c) 11.98V d) 14.43V

Ans: The ripple factor $\gamma = 1 / 4\sqrt{3} \times f\ C\ R_L = I_{dc} / 4\sqrt{3} \times f\ C\ R_L \times I_{dc} = I_{dc} / 4\sqrt{3} \times f\ C \times V_{DC}$

$V_{DC} = 200 \times 10^{-3} / 4\sqrt{3} \times 50 \times 500 \times 8 = 14.43$.

Q7. The charge (q) lost by the capacitor during the discharge time for shunt capacitor filter.
a) $I_{DC}*T$ b) I_{DC}/T c) $I_{DC}*2T$ d) $I_{DC}/2T$

Q8. Which of the following are true about capacitor filter?
a) It is also called as capacitor output filter b) It is electrolytic c) It is connected in parallel to load
d) It helps in storing the magnetic energy

Q9. The rms ripple voltage (V_{rms}) of a shunt filter is proportional to__________
a) $I_{DC}/2\sqrt{3}$ b) $I_{DC}2\sqrt{3}$ c) $I_{DC}/\sqrt{3}$ d) $I_{DC}\sqrt{3}$

Ans: The ripple waveform will be triangular in nature and depends on peak to peak value.

Q10. A shunt capacitor of value 500μF fed rectifier circuit. The dc voltage is 14.43V. The dc current flowing is 200mA. It is operating at a frequency of 50Hz. What will be the value of peak rectified voltage?
a) 18.67V b) 16.43V c) 15.98V d) 11.43V Ans:
We know, $V_m = V_{dc} + I_{dc}/4fC = 14.43 + \{200/(200*500)\}10^3 = 14.43 + 2 = 16.43V$.

Q1. What is the effect of an inductor filter on a multi frequency signal?

a) Dampens the AC signal b) Dampens the DC signal

c) To reduce ripples d) To change the current (a)

Q2. The ripple factor (Υ) of inductor filter is__________

a) $\Upsilon = R_L 3/\sqrt{2}\omega L$ b) $\Upsilon = R_L/3\sqrt{2}\omega L$

c) $\Upsilon = R_L 3\sqrt{2}/\omega L$ d) $\Upsilon = R_L 3/\sqrt{2}\omega L$

(b)

Q3. A full wave rectifier with a load resistance of 5KΩ uses an inductor of 15 henry. The peak value of applied voltage is 250V and the frequency is 50 cycles per second. Calculate the dc load current.

a) 0. 7mA b) 17mA c) 10. 6mA d) 20mA (c)

Ans: For a rectifier with an inductor filter, $V_{DC} = 2V_m/\pi$, $I_{dc} = V_{DC}/R_L = 2V_m/R_L\pi$

$I_{DC} = 2*250/(3.14*15*103) = 10.6mA.$

Q4. A dc voltage of 380V with a peak ripple voltage not exceeding 7V is required to supply a 500Ω load. Find out the inductance required.

a) 10. 8 Henry b) 30. 7 Henry c) 28. 8 Henry d) 15. 4 Henry (c)

(Hint: Peak value of ripple voltage =7v. RMS value of ripple voltage = $V_m/\sqrt{2}$ or $V_{RMS} = 7/1.414$)

- Ans: Given the ripple voltage peak is 7V. So, $7 = 1.414V_{RMS}$ $\Upsilon = V_{RMS}/V_{DC} = 4.95/380 = 0.0130$. $\Upsilon = 1/3\sqrt{2}(R_L/\omega L)$ or $L = R_L/0.013 \times 2\pi f \times 3\sqrt{2}$ So, L=28. 8 Henry.

Q5. The output voltage VDC for a rectifier with inductor filter is given by__________

a) $(2V_m/\pi)-I_{DC}R$ b) $(2V_m/\pi)+I_{DC}R$

c) $(2V_m\pi)-I_{DC}R$ d) $(2V_m\pi)+I_{DC}R$ (a)

(R is the resistance offered by inductor and secondary winding of transformer)

Q6. A full wave rectifier with a load resistance of 5KΩ uses an inductor filter of 15henry. The peak value of applied voltage is 250V and the frequency is 50 cycles per second. Calculate the ripple factor (Y).

a) 0.1 b) 0. 25 c) 0. 5 d) 0. 4

Ans: $Y = R_L/3\sqrt{2}\,(2\pi f\,L) = 5000/3\times\sqrt{2}\times 2\times 3.14\times 50\times 15 = 0.25$

Q7. The inductor filter should be used when RL is consistently small because__________

a) Effective filtering takes place when load current is high

b) Effective filtering takes place when load current is low

c) Current lags behind voltage d) Current leads voltage (a)

Answer the following

Q1. The input source to a full wave rectifier is of form Vm*sin(2*pi*50*t). The load ripple frequency in Hz is_____________

Q2. The input source to a full wave bridge rectifier is of form Vm*sin(wt). The input source (as per Indian standards) has a tolerance band of 20%. The peak inverse voltage seen by the rectifier diodes is_____________

Q3. In a capacitor filter rectifier circuit, lower the capacitance value, ______ will be the ripple factor

Q4. In a capacitor filter rectifier circuit, higher the capacitance value, _________ will be the peak current drawn by diodes from the input source.

Q5. For a rectifier capacitor filter circuit, the value of the capacitance for a given load is ________ proportional to the ripple amplitude.

Application of Diode as Wave Shaping

Clippers and Clampers

Clippers

Clipping circuit: A wave shaping circuit which controls the shape of the output waveform by removing or clipping a portion of the applied wave.

- Half wave rectifier is the simplest example. (It clips negative half cycle).
- Also referred as voltage limiters/ amplitude selectors/ slicers.
- Applications:
  - In radio receivers for communication circuits.
  - In radars, digital computers and other electronic systems.
  - Generation for different waveforms such as trapezoidal, or square waves.
  - Helps in processing the picture signals in television transmitters.
  - In television receivers for separating the synchronising signals from composite picture signals

Types of clippers

- According to non- linear devices used:
  - Diode clippers and Transistor clippers
- According to biasing
  - Biased clippers and Unbiased clippers.
- According to level of clipping
  - Positive clippers, Negative clippers and combination clippers

Application of Diode for Wave Shaping

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Types of clippers

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THUMB RULE

Action of biasing on diode

- When diode is forward biased, it acts as a closed switch (ON state).
- When diode is reverse biased, it acts as a open switch (OFF state).

Clippers

- ***Clippers***
  - ***Series Clippers***
  - ***Parallel Clippers***

Clippers

Further Classification:

- **Parallel Clippers**
  - **Unbiased Parallel Clippers**
  - **Biased Parallel Clippers**

Clippers

Further Classification (Cont..) :

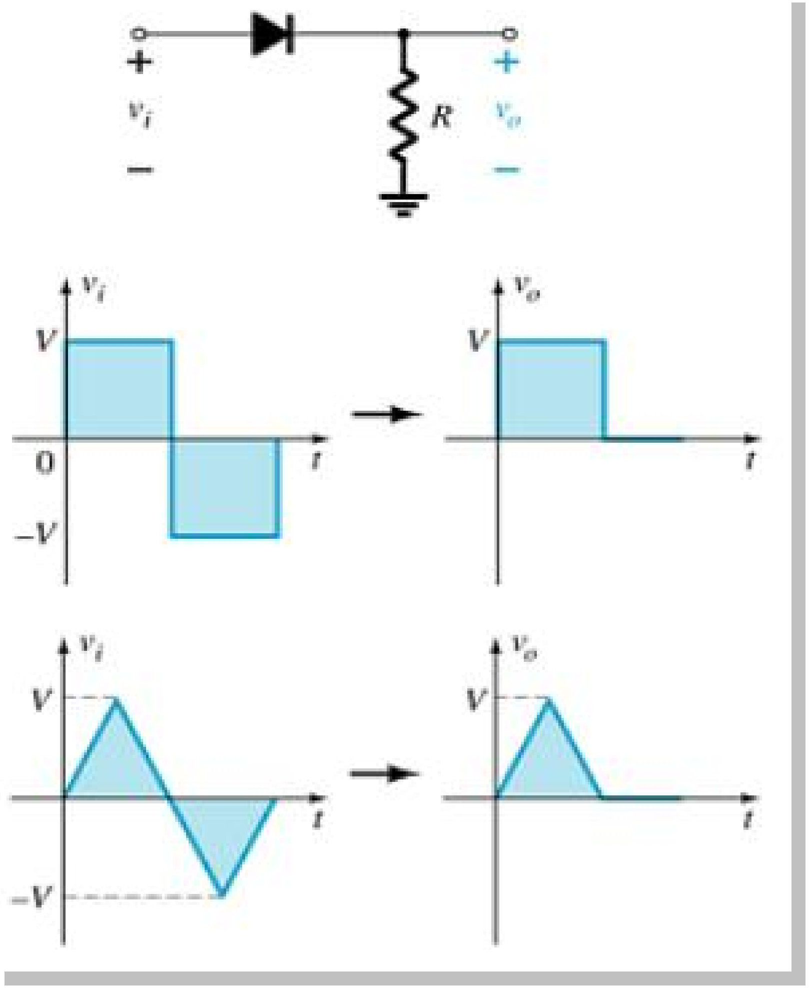
- ***Series Clippers***
  - ***Unbiased Series Clippers***
  - ***Biased Series Clippers***

Diode Clippers

1. Series Clippers

The diode is in series of Load (Resistance) in a **series clipper and** "clips" any input voltage that does not make the diode forward bias:

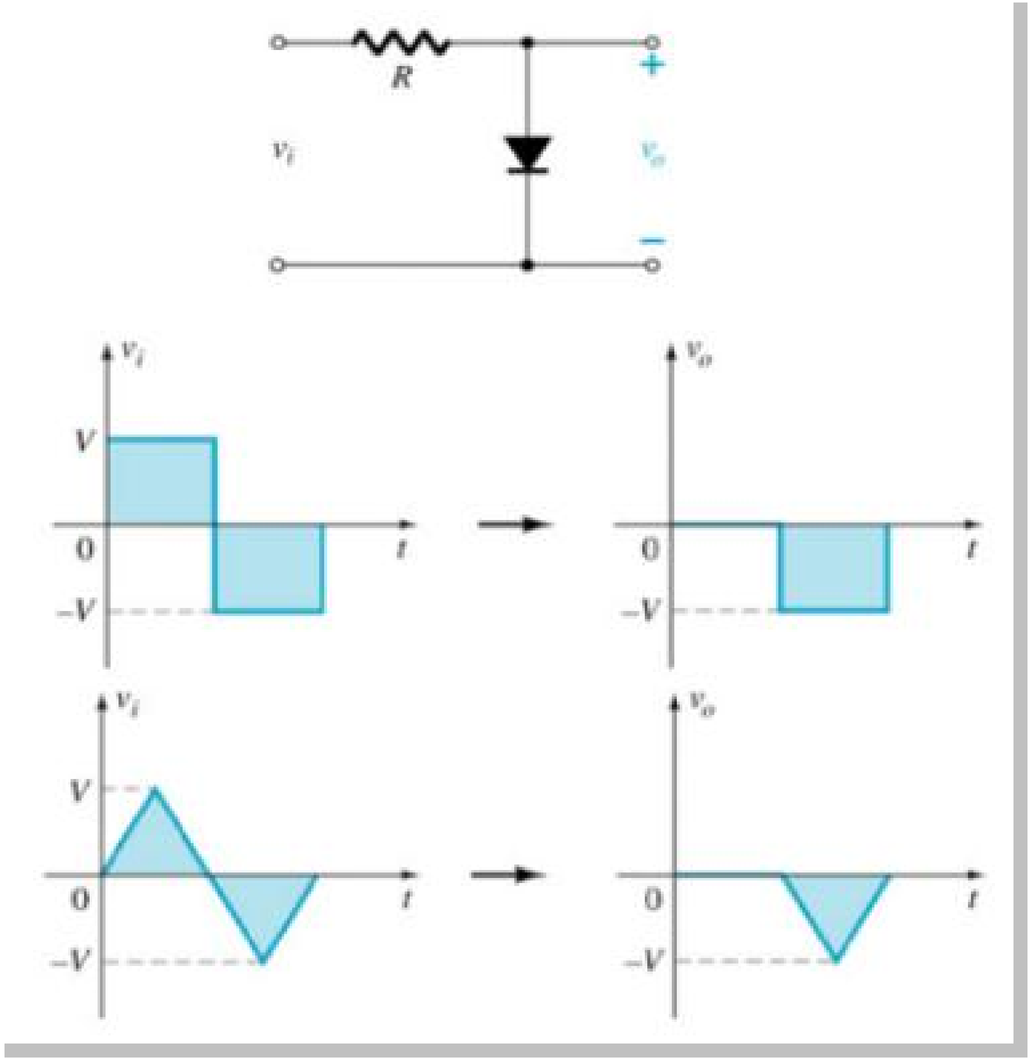
- A reverse-biasing polarity output is zero.
- A forward-biasing polarity less than 0.7 V (for a silicon diode)



Parallel or shunt Clippers

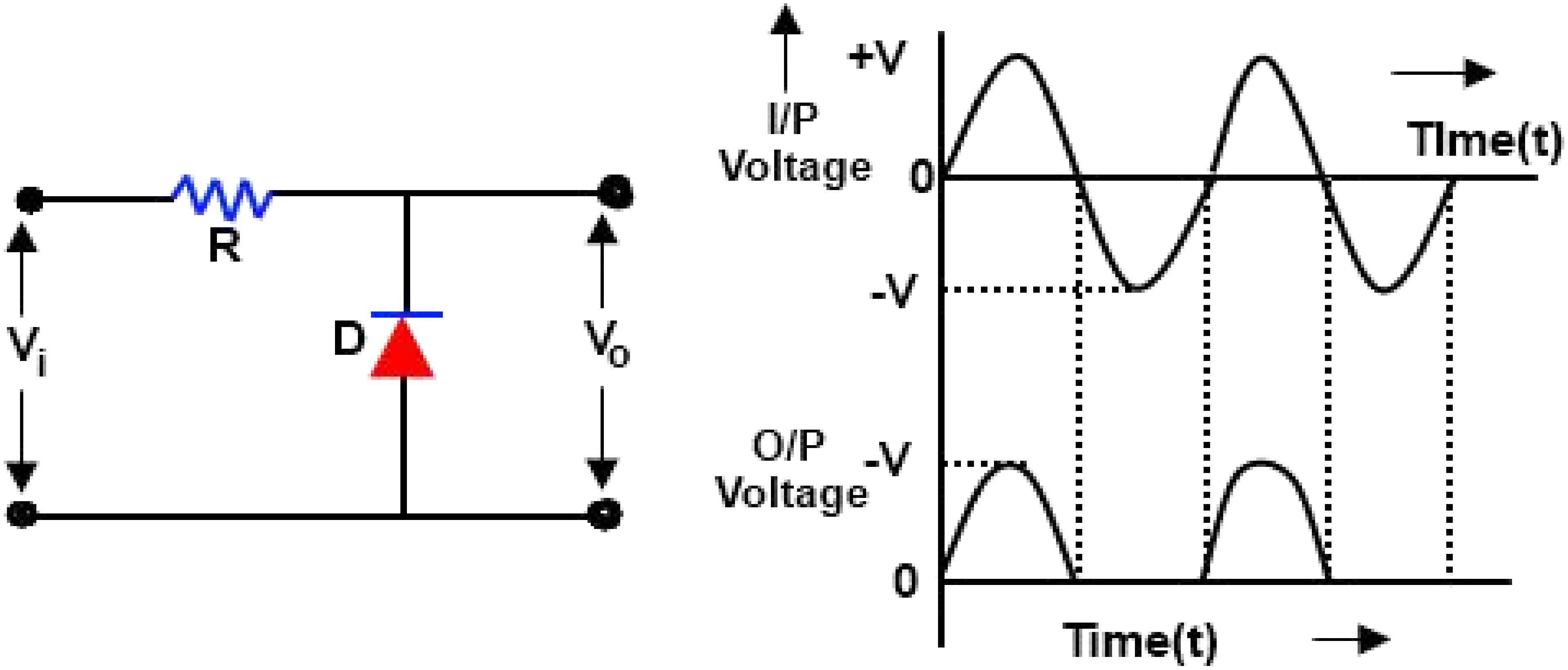
The diode is connected in a parallel clipper to output and circuit "clips" any input voltage that forward bias it.

DC biasing can be added in series with the diode to change the clipping level.



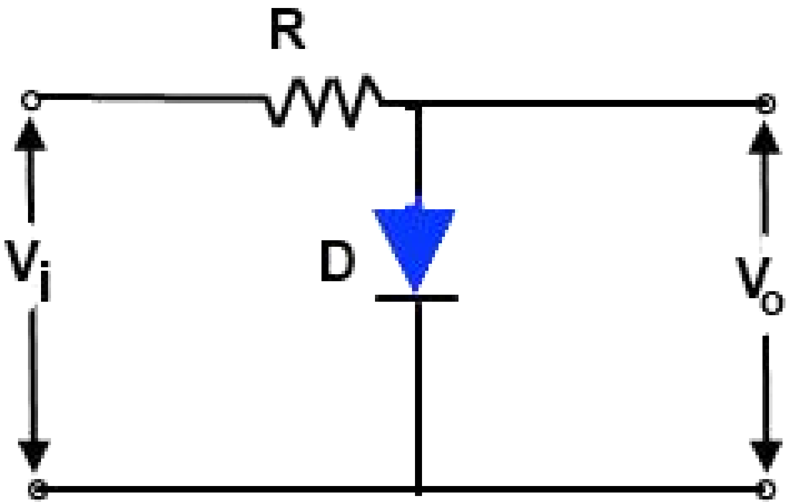
Shunt Clipper (Negative shunt Clipper)

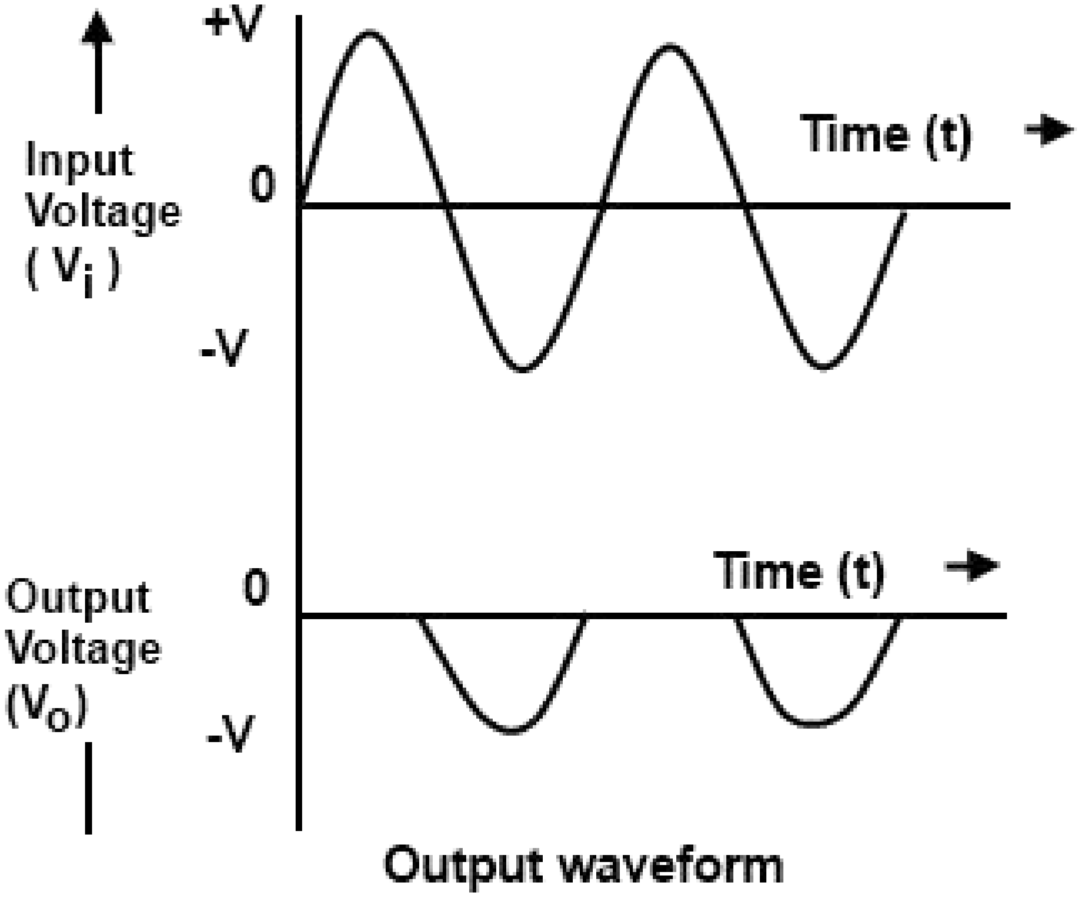
Output follows input when diode is OFF



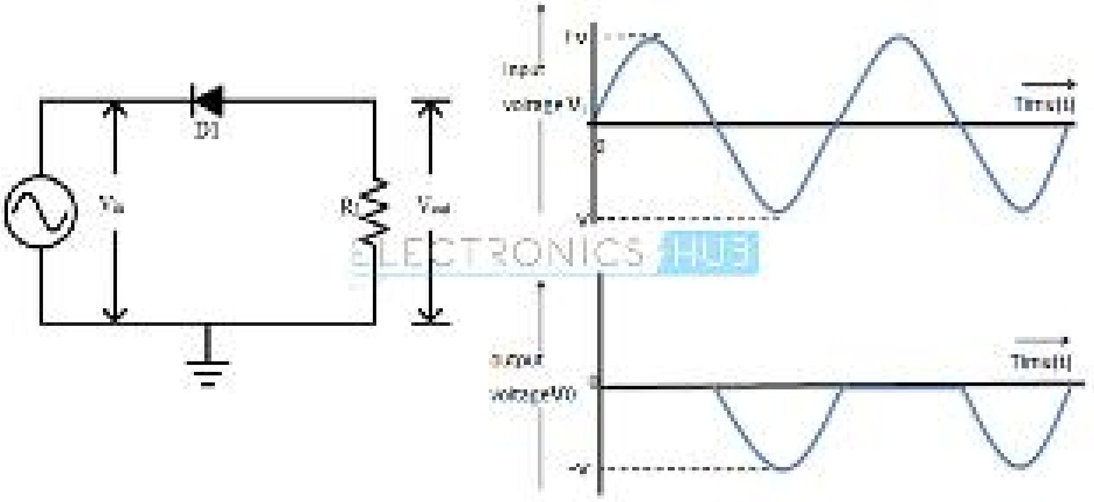
(a) (b)

Positive Shunt Clipper(Positive shunt Clipper)
Output follows input when diode is OFF



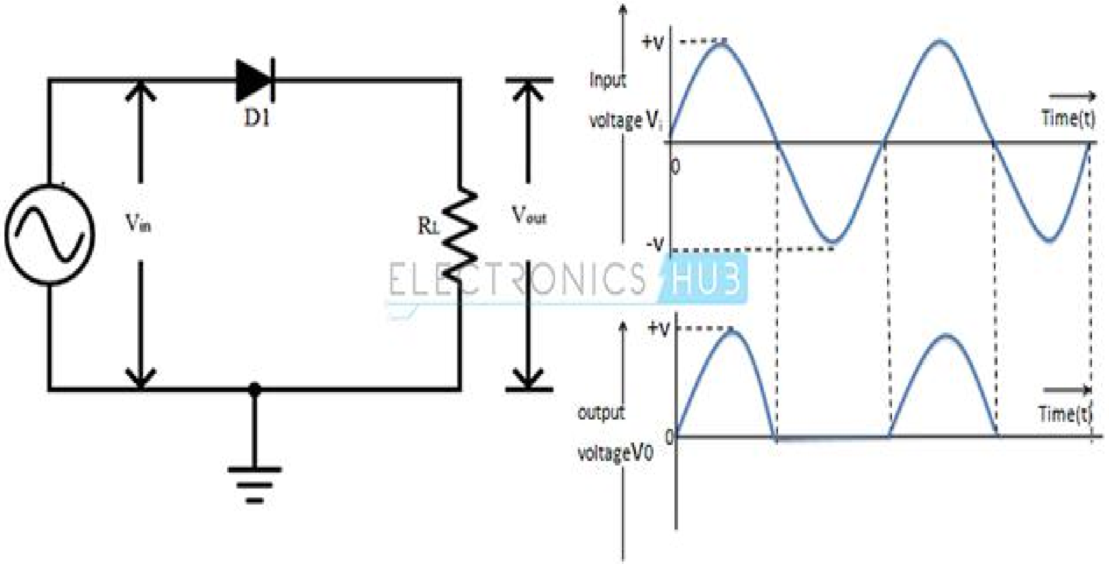


Series Positive Clipper



Cathode is connected to the power supply and anode is maintained at ground potential.
•**During Positive Half Cycle**: *Output voltage (V_0) = 0 Volts*
•**During Negative Half Cycle**: *Output voltage (V_0) = (V_{in} – V_d) Volts*
Where V_d is the Diode Threshold Voltage.

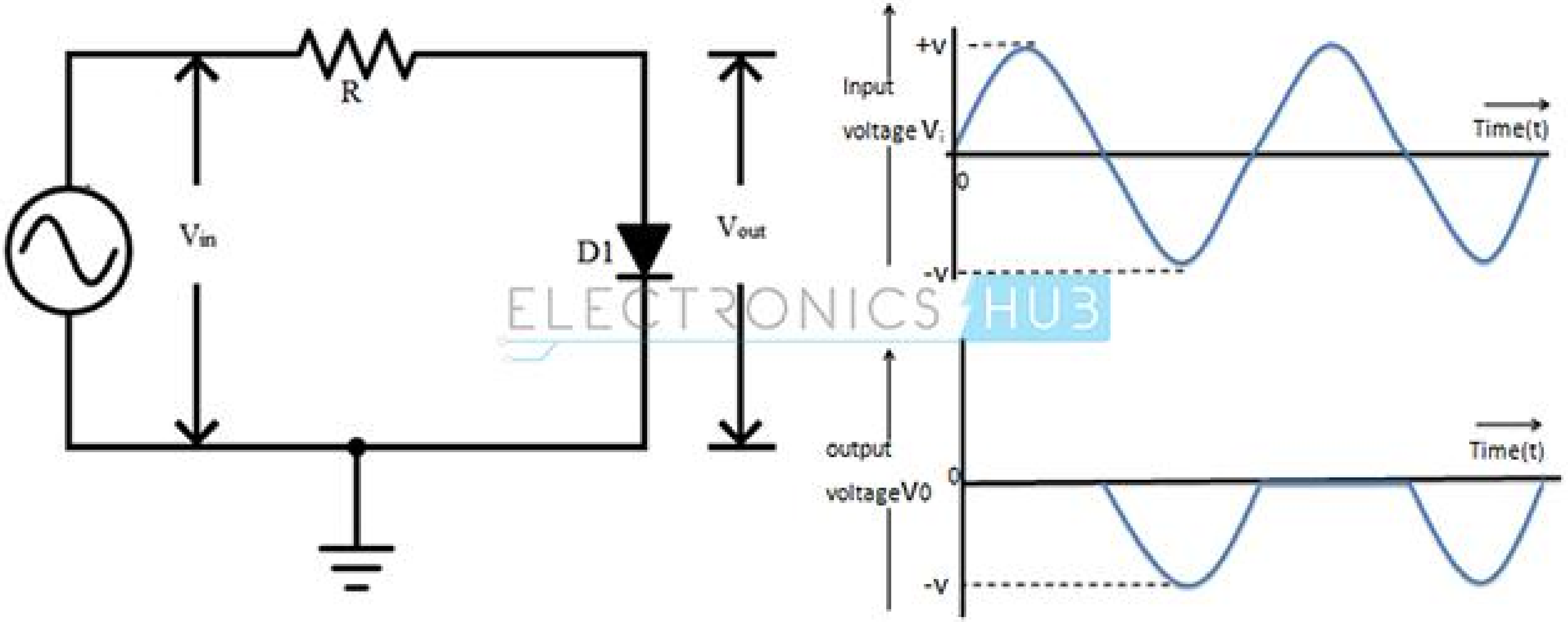
Series Negative Clipper



Anode is connected to the power supply and the cathode is maintained at ground potential.

- **During Positive Half Cycle**: Output voltage (V_0) = (V_{in} – V_d) Volts
- **During Negative Half Cycle**: Output voltage (V_0) = 0 Volts

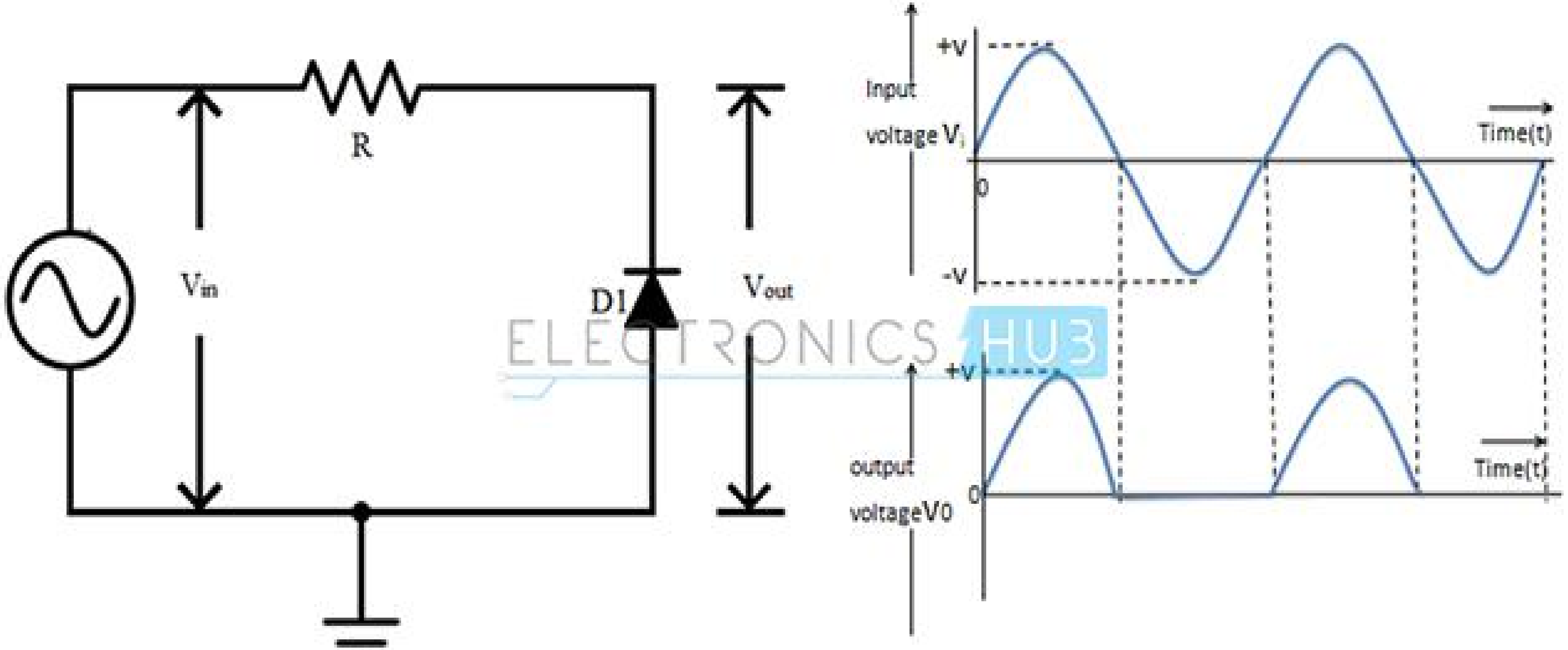
Shunt Positive Clipper



Anode is connected to the the power supply through a resistor R and the cathode is at ground potential.

- **During Positive Half Cycle:** *Output voltage (V_0) = V_d Volts = 0.7 V*
- **During Negative Half Cycle:** *Output voltage (V_0) = V_{in} Volts*

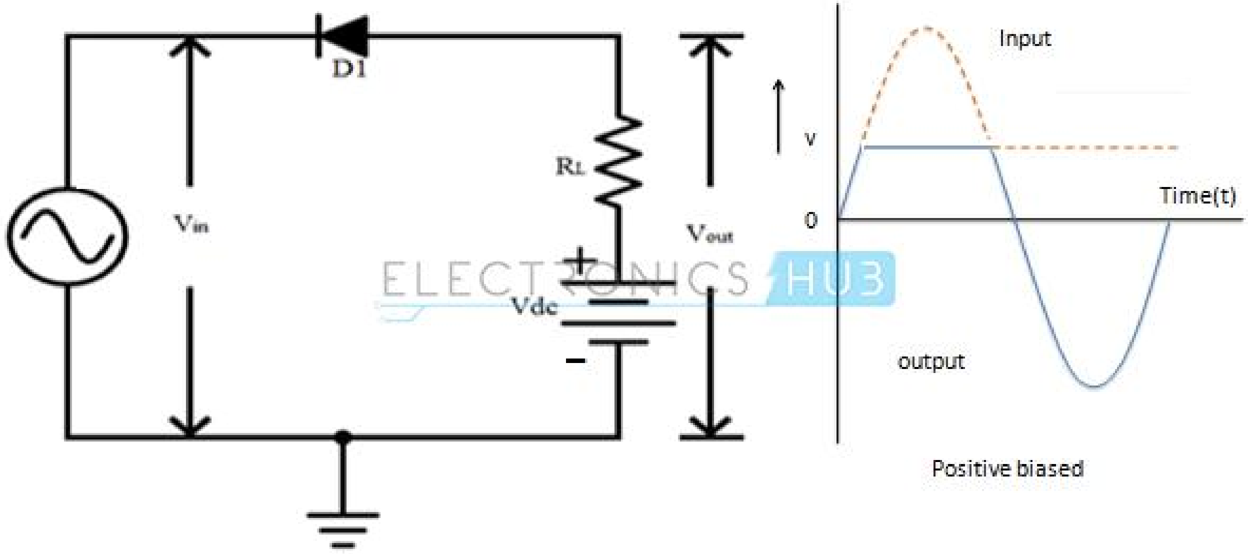
Shunt Negative Clipper



Cathode is connected to the power supply through a resistor R and anode is maintained at ground potential.

- ***During Positive Half Cycle:*** *Output voltage* (V_0) = V_{in} *Volts*
- ***During Negative Half Cycle:*** *Output voltage* (V_0) = – V_d *Volts* = –0. 7 V.

Series Positive Clipper with Positive Bias Voltage



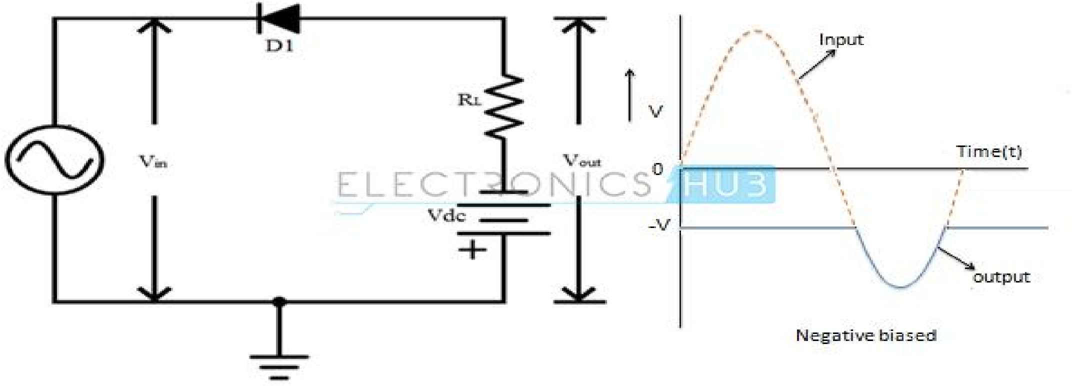
Positive Half Cycle: Cathode is connected to the positive supply and the anode is maintained at positive bias potential.

- When $V_{in} < V_d + V_{dc}$, Output Voltage $(V_0) = (V_{in} - V_d)$ Volts
- When $V_{in} > V_d + V_{dc}$, Output Voltage $(V_0) = + V_{dc}$ Volts

Negative Half Cycle: Cathode is connected to the negative supply and anode is maintained at positive bias potential.

- Output voltage $(V_0) = (V_{in} + V_d)$

Series Positive Clipper with Negative Bias Voltage



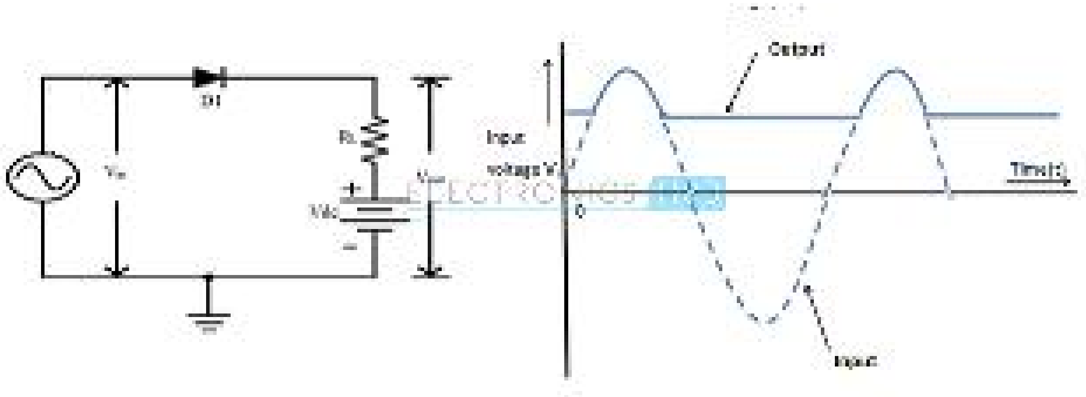
Positive Half Cycle: Cathode is connected to the positive supply and the anode is maintained at negative bias potential.

- Output Voltage (V_0) = $-V_{dc}$ Volts

Negative Half Cycle: Cathode is connected to the negative supply and anode is maintained at negative bias potential.

- When $V_{in} < V_d + V_{dc}$, Output Voltage (V_0) = $-V_{dc}$ Volts.
- When $V_{in} > V_d + V_{dc}$, Output Voltage (V_0) = ($V_{in} - V_d$) Volts.

Series Negative Clipper with Positive Bias Voltage



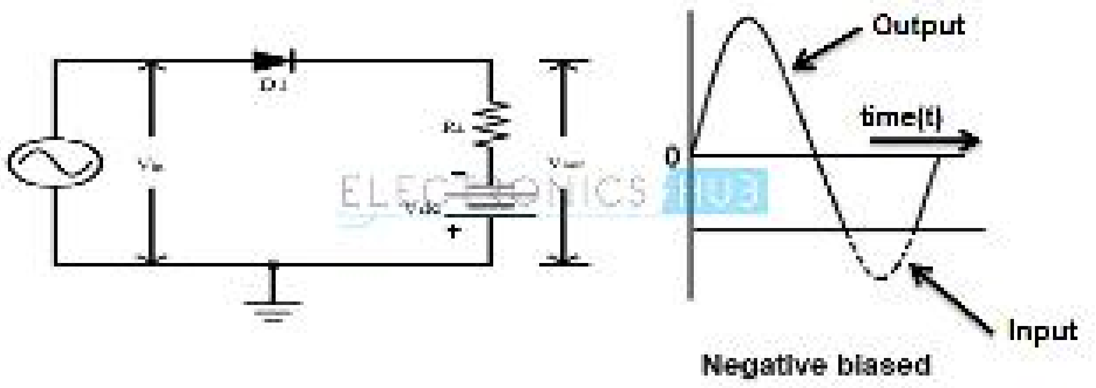
Positive Half Cycle: *In this case the anode is connected to the positive supply and the cathode is maintained at positive bias potential.*

- When $V_{in} < V_d + V_{dc}$, Output Voltage $(V_0) = V_{dc}$ Volts
- When $V_{in} > V_d + V_{dc}$, Output Voltage $(V_0) = (V_{in} - V_d)$ Volts

Negative Half Cycle: *In this case the anode is connected to the negative supply and the cathode is maintained at positive bias potential.*

- Output Voltage $(V_0) = + V_{dc}$ Volts

Series Negative Clipper with Negative Bias Voltage Connected in Parallel



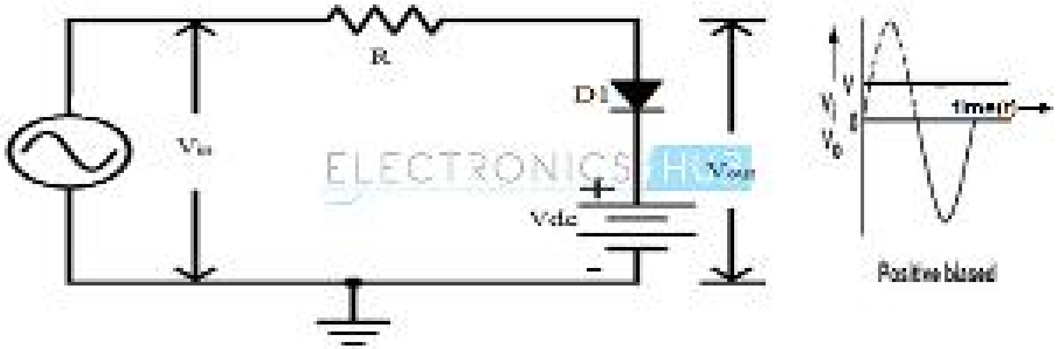
Positive Half Cycle: *In this circuit the anode is connected to the positive supply and the cathode is maintained at negative bias potential.*

- *When $V_{in} < V_d + V_{dc}$, Output Voltage (V_0) = (V_{in} + V_d) Volts*
- *When $V_{in} > V_d + V_{dc}$, Output Voltage (V_0) = + V_{dc} Volts*

Negative Half Cycle: *In this circuit the anode is connected to the negative supply and the cathode is maintained at negative bias potential.*

- *Output Voltage (V_0) = (V_{in} + V_d) Volts*

Shunt Positive Clipper with Positive Shunt Bias Voltage



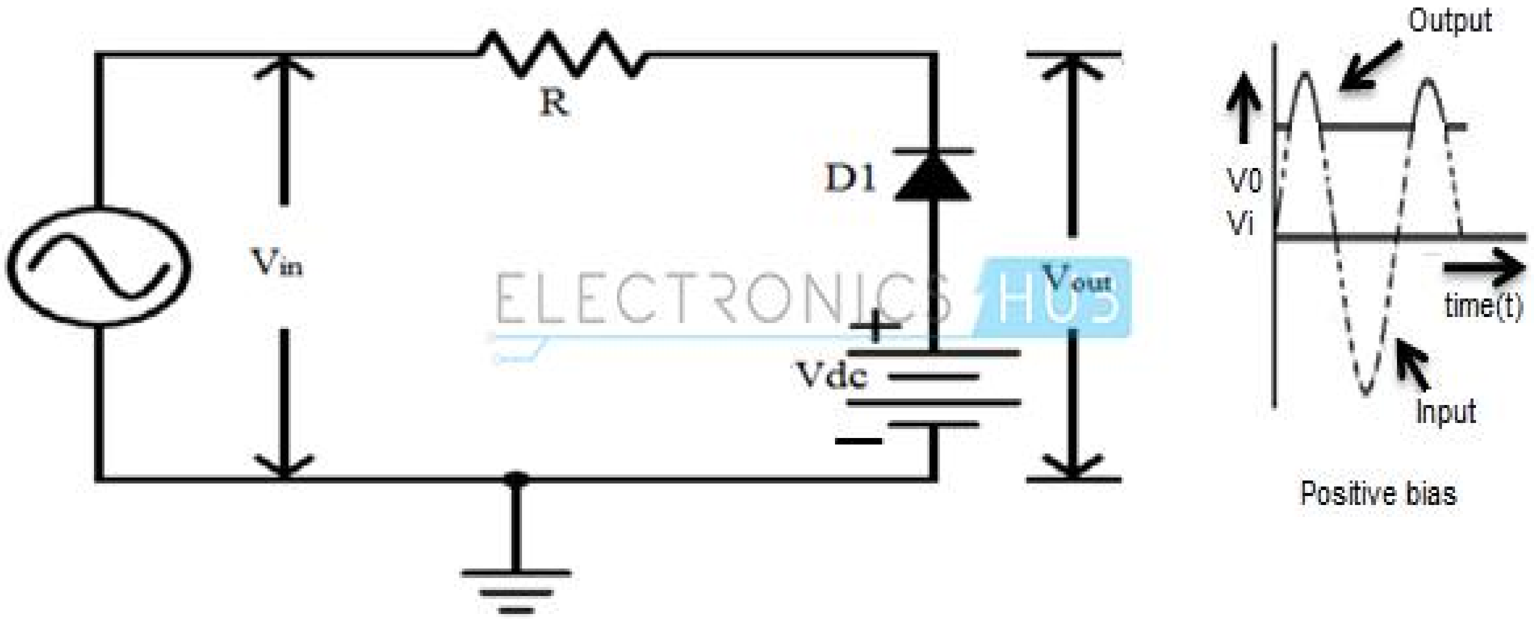
Positive Half Cycle: In this circuit, anode is connected to the positive supply and the cathode is maintained at positive bias potential.

- When $V_{in} < V_d + V_{dc}$, Output Voltage (V_0) = V_{in} Volts
- When $V_{in} > V_d + V_{dc}$, Output Voltage (V_0) = ($V_d + V_{dc}$) Volts

Negative Half Cycle: In this circuit, anode is connected to the negative supply and the cathode is maintained at positive bias potential.

- Output voltage (V_0) = V_{in} Volts

Shunt Negative Clipper with Positive Bias Voltage



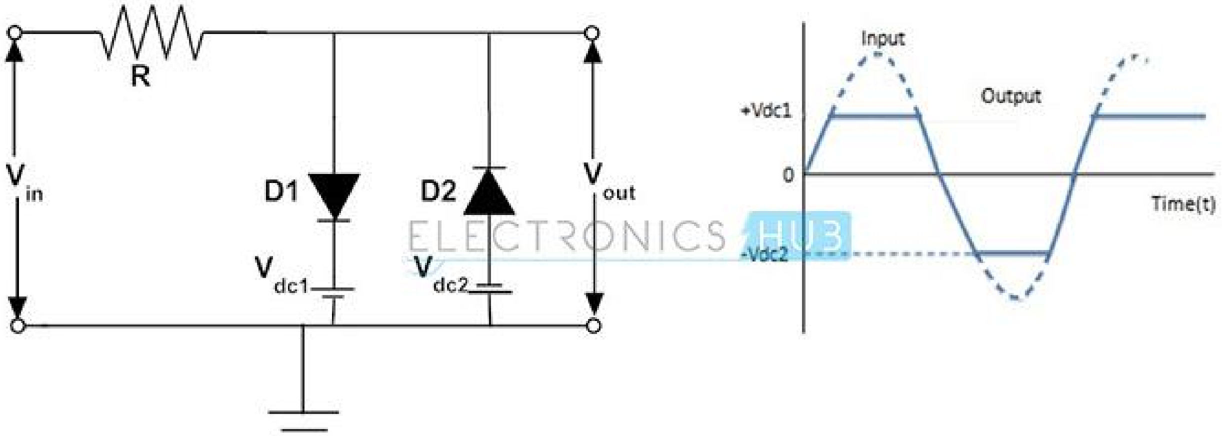
Positive Half Cycle: Cathode is connected to the positive supply and the anode is maintained at positive bias potential.

- When $V_{in} < V_{dc} - V_d$, Output voltage $(V_0) = V_{dc}$ Volts
- When $V_{in} > V_{dc} - V_d$, Output voltage $(V_0) = V_{in}$ Volts

Negative Half Cycle: Cathode is connected to the negative supply and anode is maintained at positive bias potential.

- Output voltage $(V_0) = (V_{dc} - V_d)$ Volts

Clipping Both Half Wave Cycles

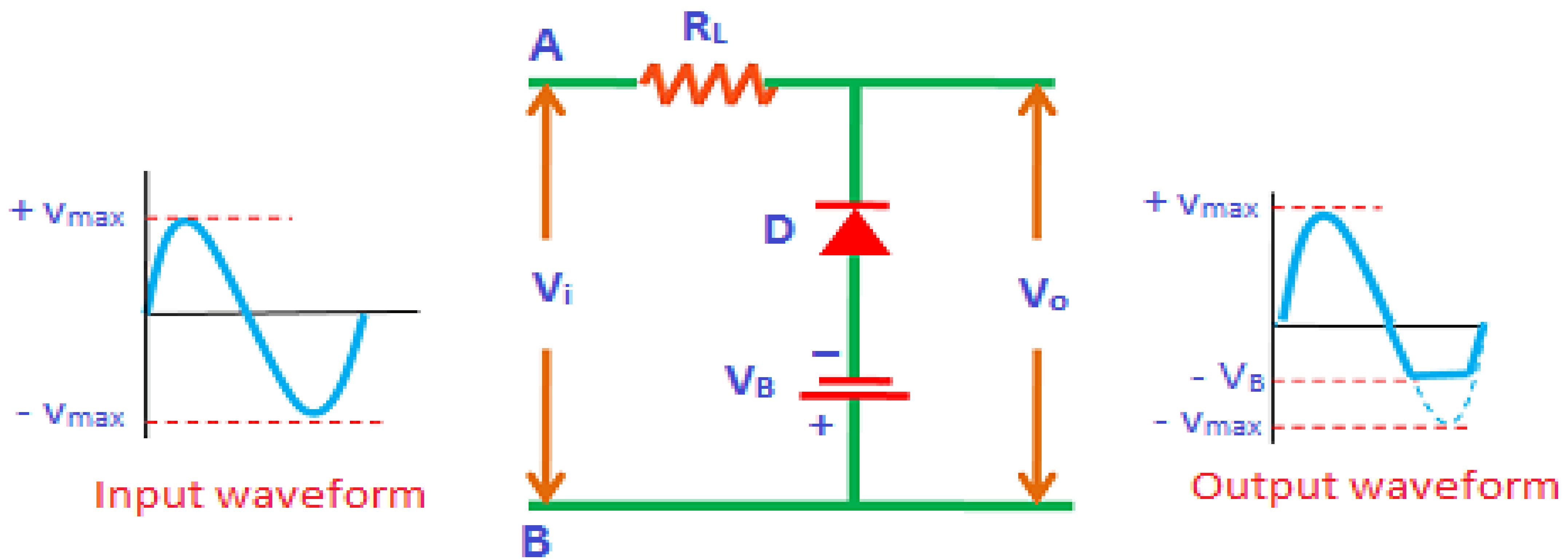


Positive Half Cycle: In this cycle, cathode of first diode D1 is maintained at $+V_{dc1}$ and its anode observes a variable positive voltage. Similarly anode of diode D2 is maintained at $-V_{dc2}$ and its cathode observes a variable positive voltage. The diode D2 will be completely reverse biased during the whole positive half cycle.

- When $V_{in} < V_{dc1} + V_{d1}$ – Diodes D1 & D2 are reverse biased, Output voltage $(V_0) = V_{in}$ Volts.
- When $V_{in} > V_{dc1} + V_{d1}$ – Diode D1 will be forward biased and D2 will be reverse biased, Output voltage $(V_0) = (V_{dc1} + V_{d1})$ Volts

Negative Half Cycle: In this cycle, cathode of diode D1 is maintained at $+V_{dc1}$ and its anode observes a variable negative voltage. Similarly anode of diode D2 is maintained at $-V_{dc2}$ and its cathode observes a variable negative voltage. The diode D1 will be completely reverse biased during the whole negative half cycle.

- When $V_{in} < V_{dc2} + V_{d2}$ – Diodes D1 & D2 are reverse biased, Output voltage (V_0) = Vin Volts.
- When $V_{in} > V_{dc2} + V_{d2}$ – Diode D2 will be forward biased and D1 will be reverse biased, Output voltage $(V_0) = (-V_{dc2} - V_{d2})$ Volts

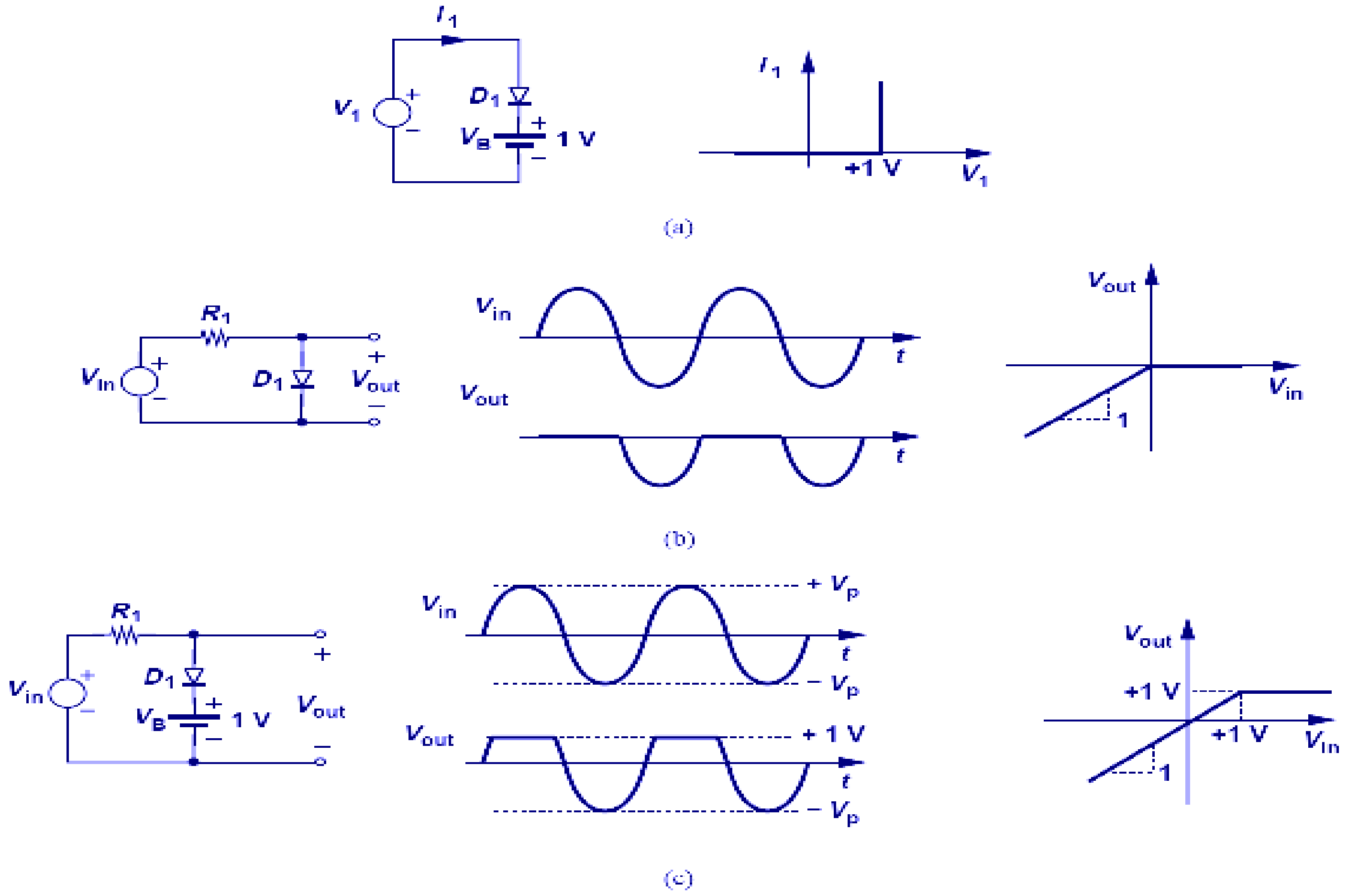


Shunt negative clipper with negative bias

Physics and Radio-Electronics

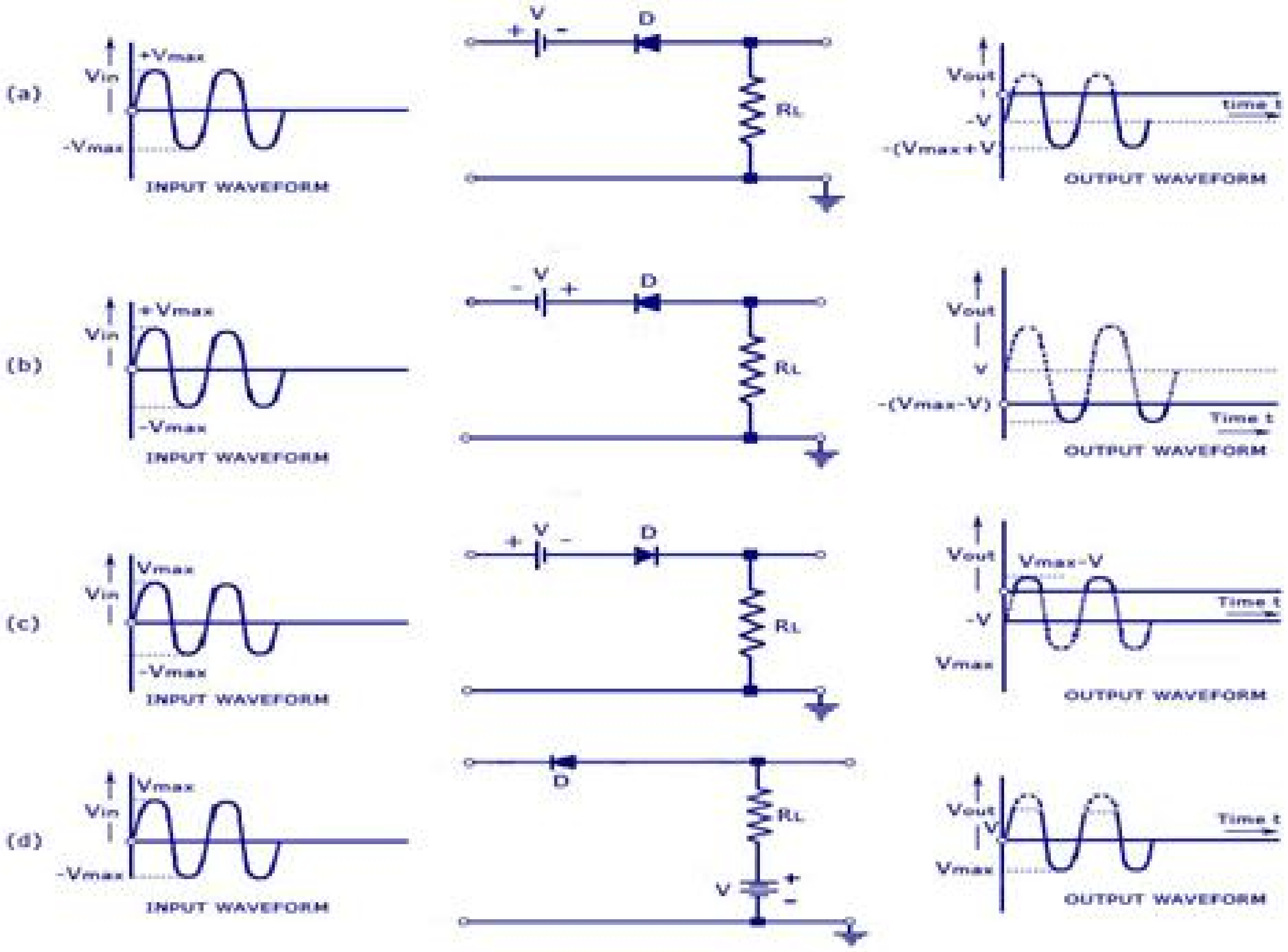
Transfer Function

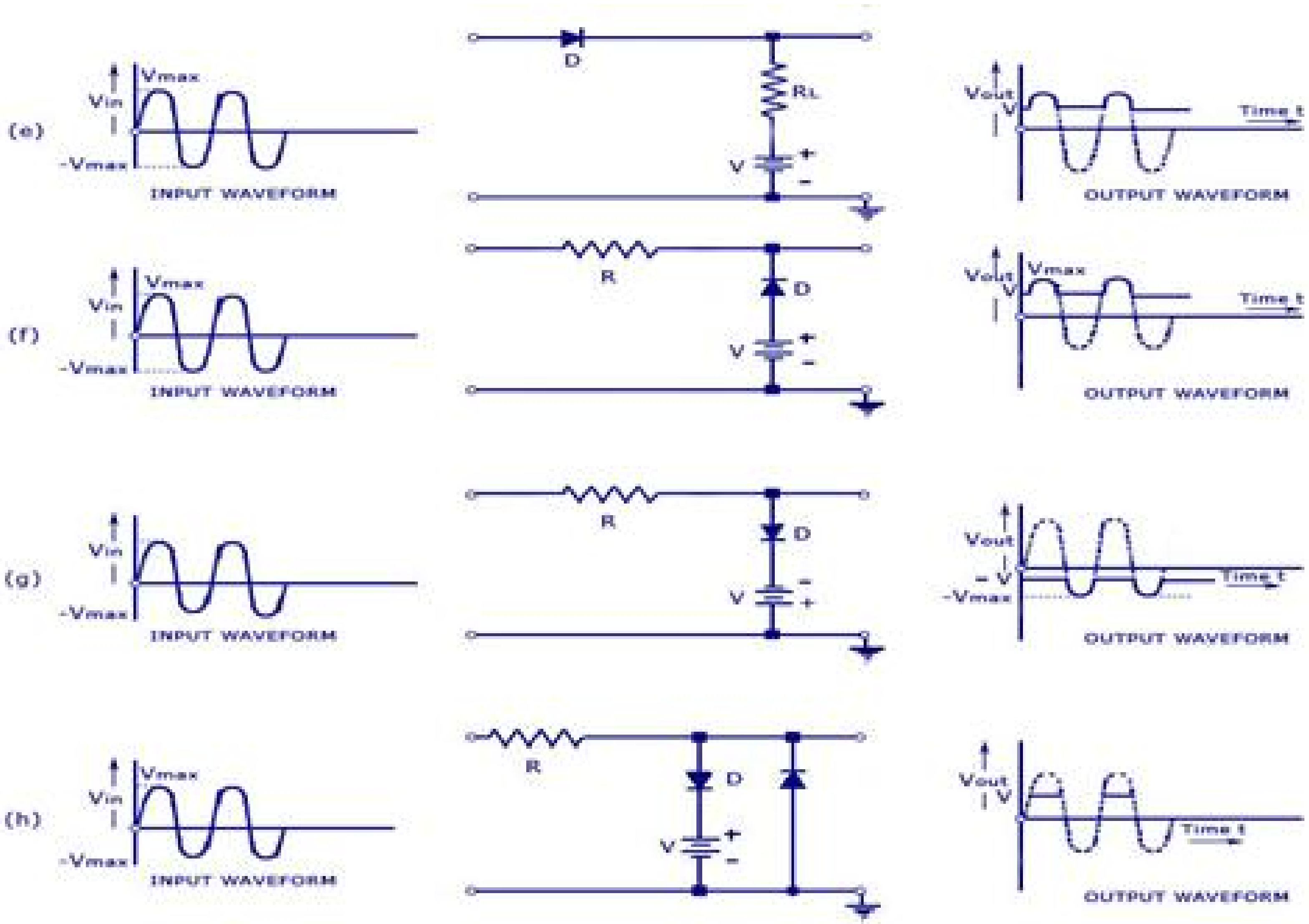
Diode's application： Limiter



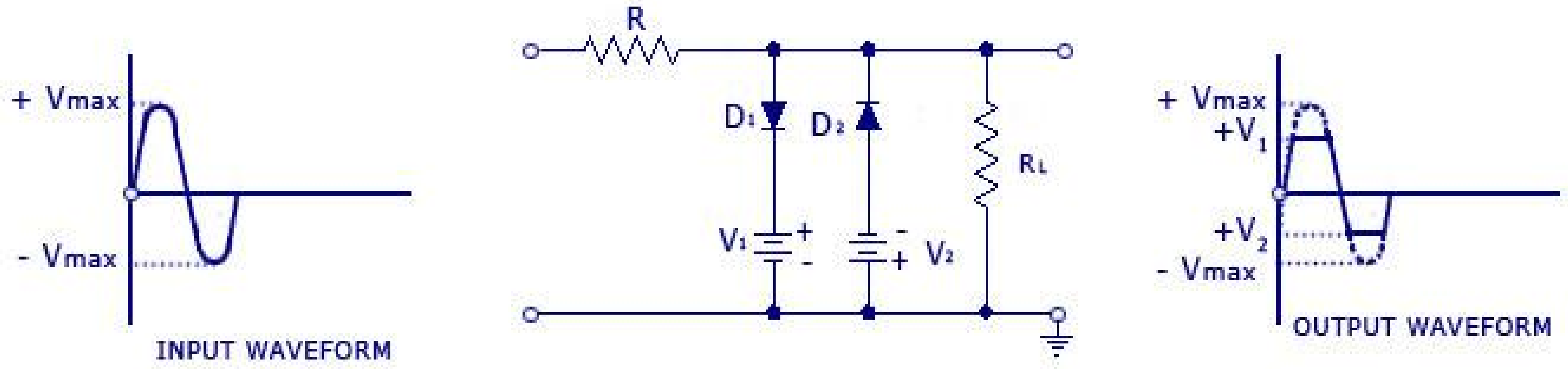
- The purpose of a limiter is to force the output to remain below certain value.
- In a), the addition of a 1 V battery forces the diode to turn on after V_1 has become greater than 1 V.

Different Clipping Circuits




(e)
Vmax
Vin
-Vmax
INPUT WAVEFORM
D
RL
V
+
-
Vout
V
Time t
OUTPUT WAVEFORM
(f)
Vmax
Vin
-Vmax
INPUT WAVEFORM
R
D
V
+
-
Vout
Vmax
V
Time t
OUTPUT WAVEFORM
(g)
Vin
-Vmax
INPUT WAVEFORM
R
D
V
-
+
Vout
- V
-Vmax
Time t
OUTPUT WAVEFORM
(h)
Vmax
Vin
-Vmax
INPUT WAVEFORM
R
D
V
+
-
Vout
V
Time t
OUTPUT WAVEFORM

COMBINATION CLIPPER



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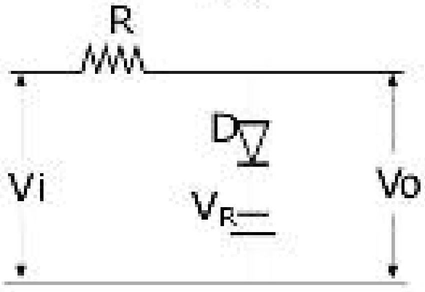
Positive Shunt clipping with negative reference voltage

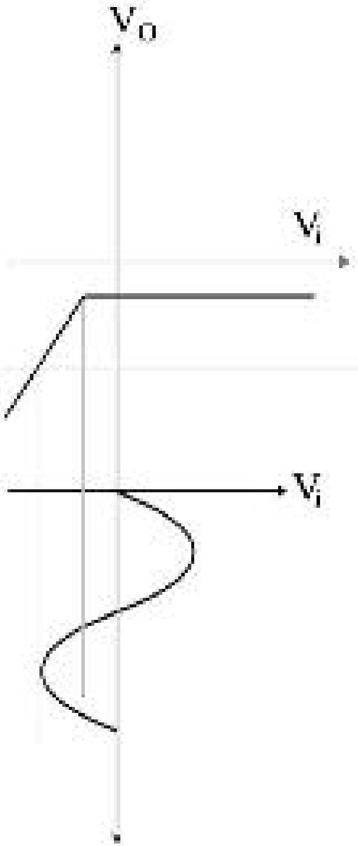


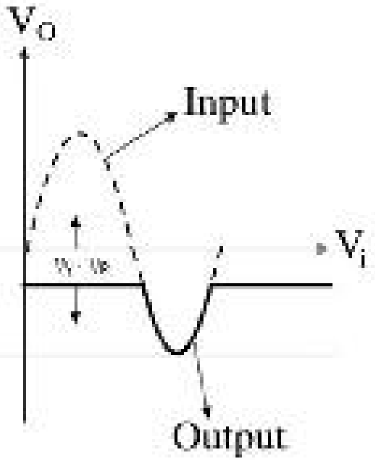
Transfer characteristics equation:

$V_i > V_\gamma - V_R$ D – ON $V_O = V_\gamma - V_R$

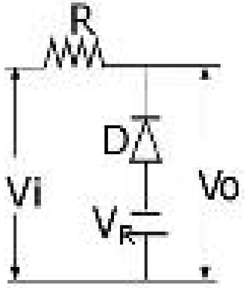
$V_i < V_\gamma - V_R$ D – OFF

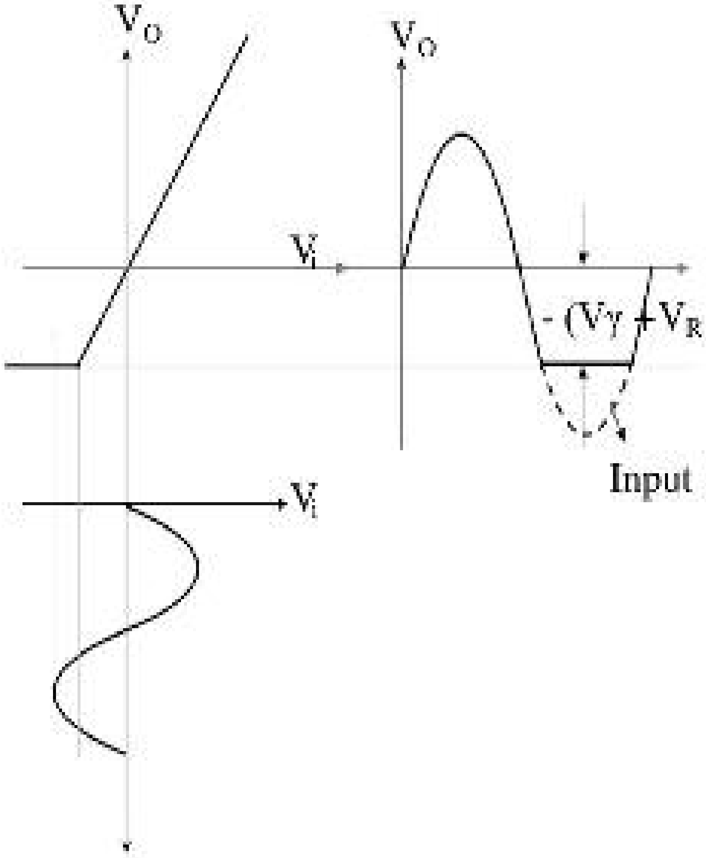
$V_O = V_i$





Negative Shunt clipping with negative reference voltage





<u>Transfer characteristic equations:</u>

$V_i < -(V\gamma + V_R)$ D – ON $V_O = -(V\gamma + V_R)$

$V_i < -(V\gamma + V_R)$ D – OFF $V_O = V_i$

Clampers

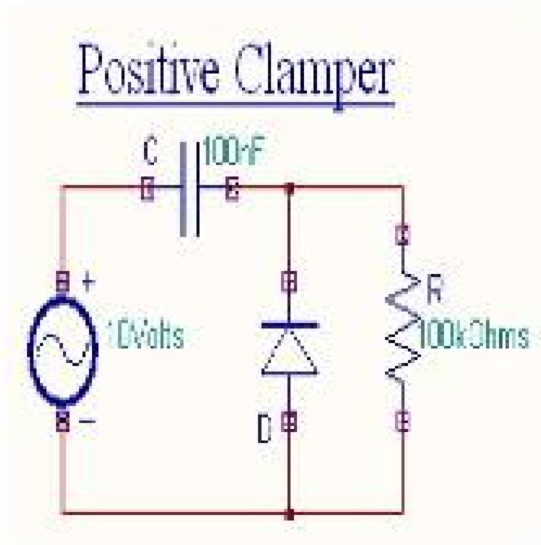
A Clamper circuit can be defined as the circuit that consists of a diode, a resistor and a capacitor that shifts the waveform to a desired DC level without changing the actual appearance of the applied signal.

- Positive Clamper Circuit
- A Clamping circuit restores the DC level. When a negative peak of the signal is raised above to the zero level, then the signal is said to be **positively clamped**.
- A Positive Clamper circuit is one that consists of a diode, a resistor and a capacitor and that shifts the output signal to the positive portion of the input signal.

Diode :- Clamper

Positive Clamper

The circuit for a positive clamper is shown in the figure. During the negative half cycle of the input signal, the diode conducts and acts like a short circuit. The output voltage $V_o \Rightarrow 0$ volts . The capacitor is charged to the peak value of input voltage V_m, and it behaves like a battery. During the positive half of the input signal, the diode does not conduct and acts as an open circuit. Hence the output voltage $V_o \Rightarrow V_m + V_m$ This gives a positively clamped voltage.



$V_o \Rightarrow V_m + V_m = 2 V_m$

Basic Clamper Circuite

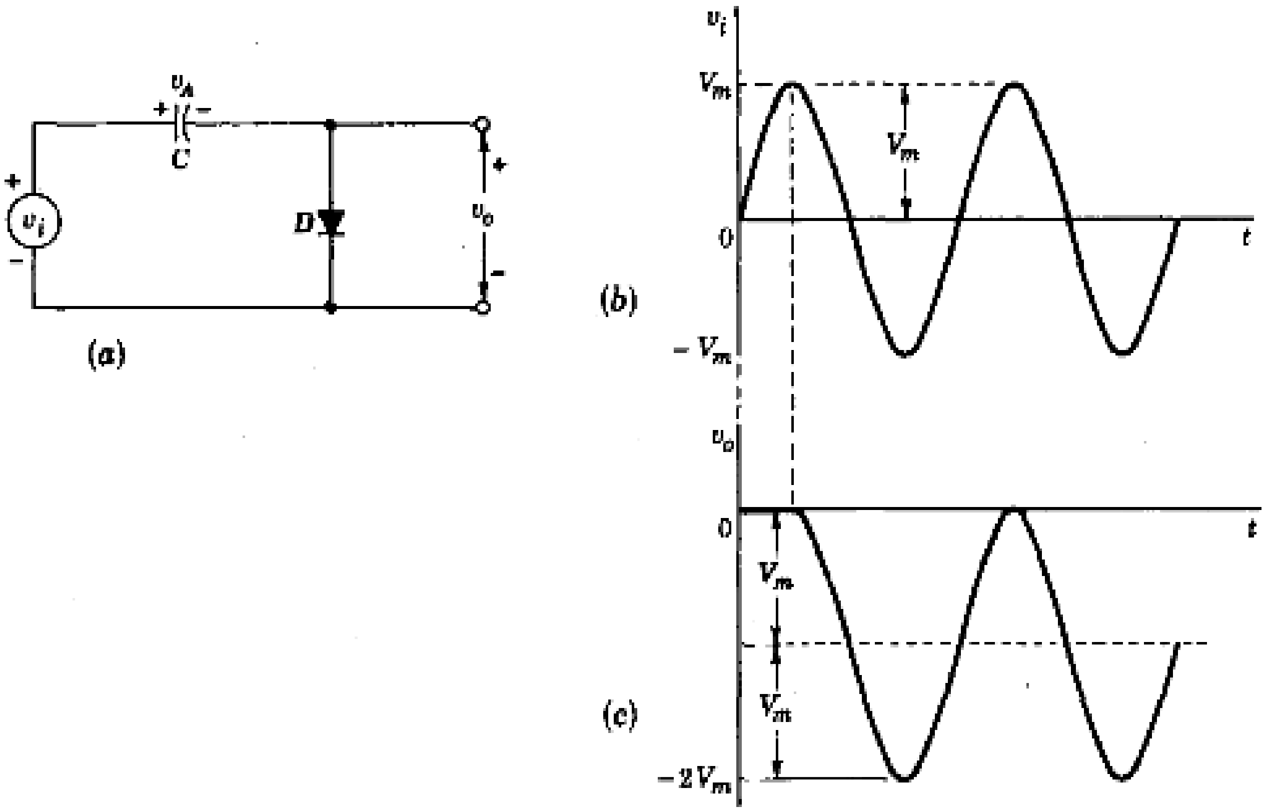


Fig. 8-1 (a) The basic circuit of a d-c restorer; (b) a sinusoidal signal is applied at $t = 0$; (c) the output waveform.

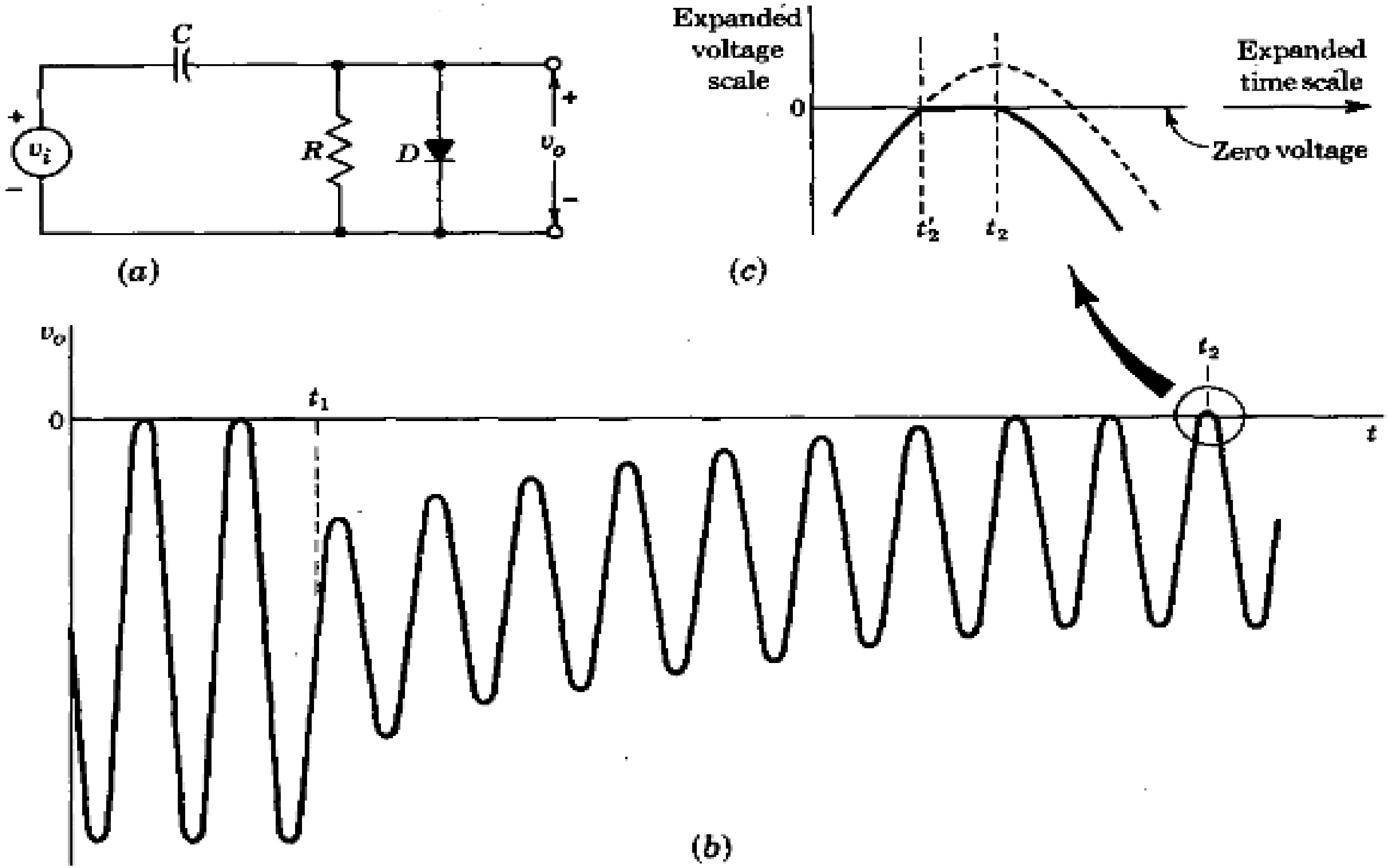
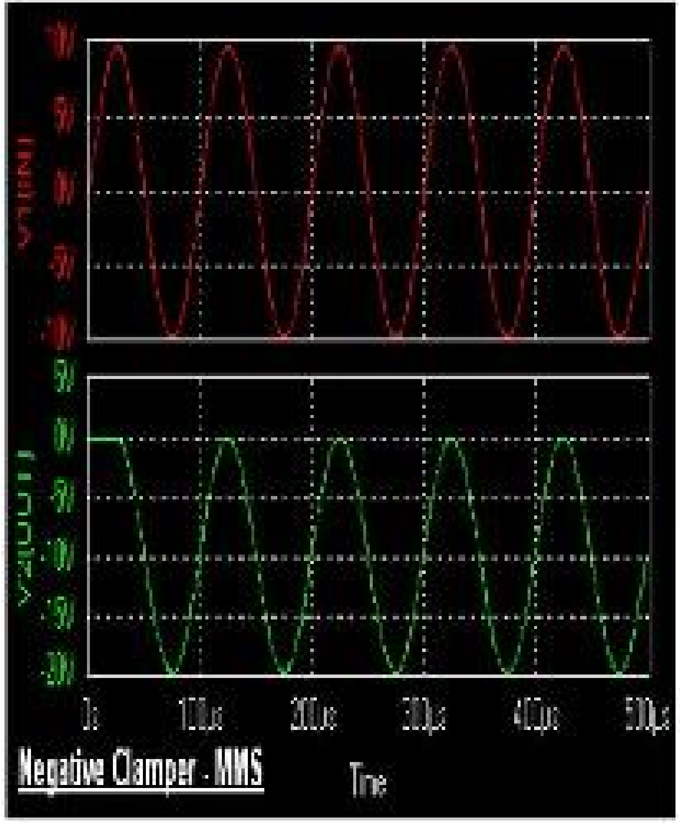
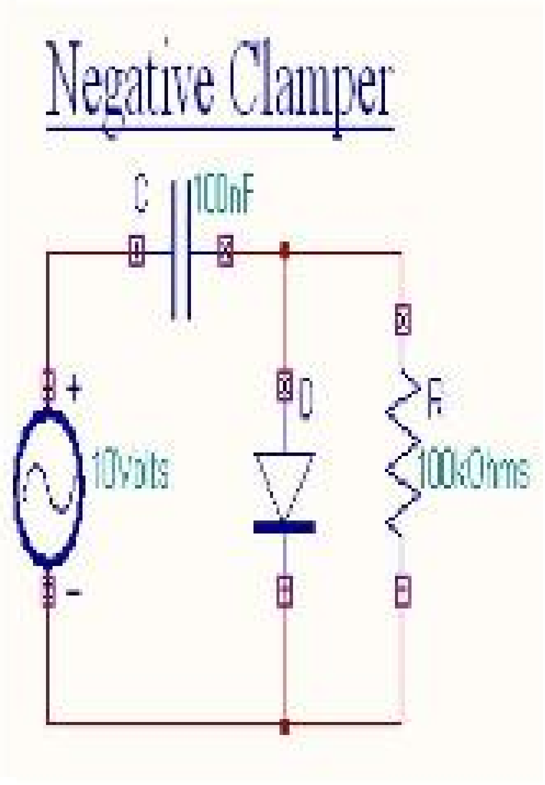
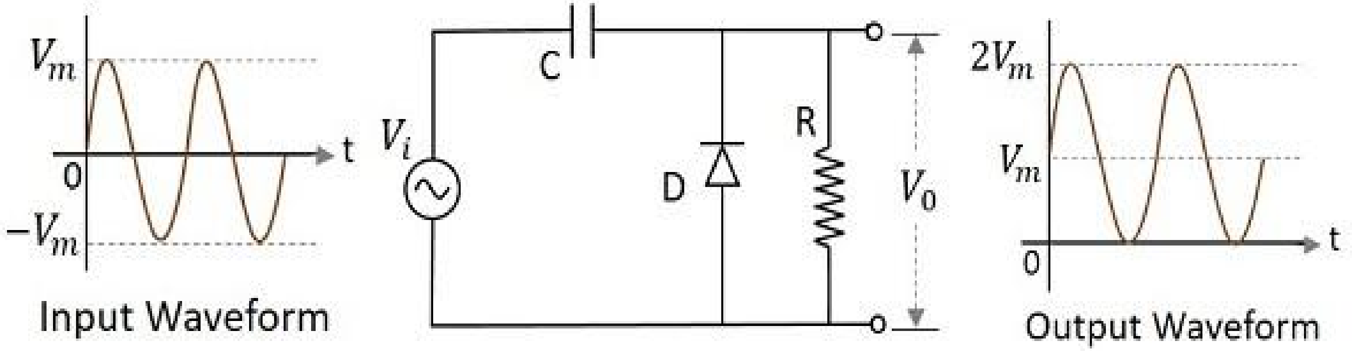


Fig. 8-2 (*a*) The clamping circuit is completed through the inclusion of a resistor which permits the capacitor to discharge. (*b*) At time $t = t_1$ the amplitude of the input signal is abruptly reduced. Output waveform shows approach to steady state. (*c*) The details of the waveform v_o at the first positive peak which would cross the zero-voltage axis at t_2' if the diode were absent.


Negative Clamper - MMS
Time


Negative Clamper
C
100nF
D
R
10Volts
100kOhms

Positive Clamper Circuit

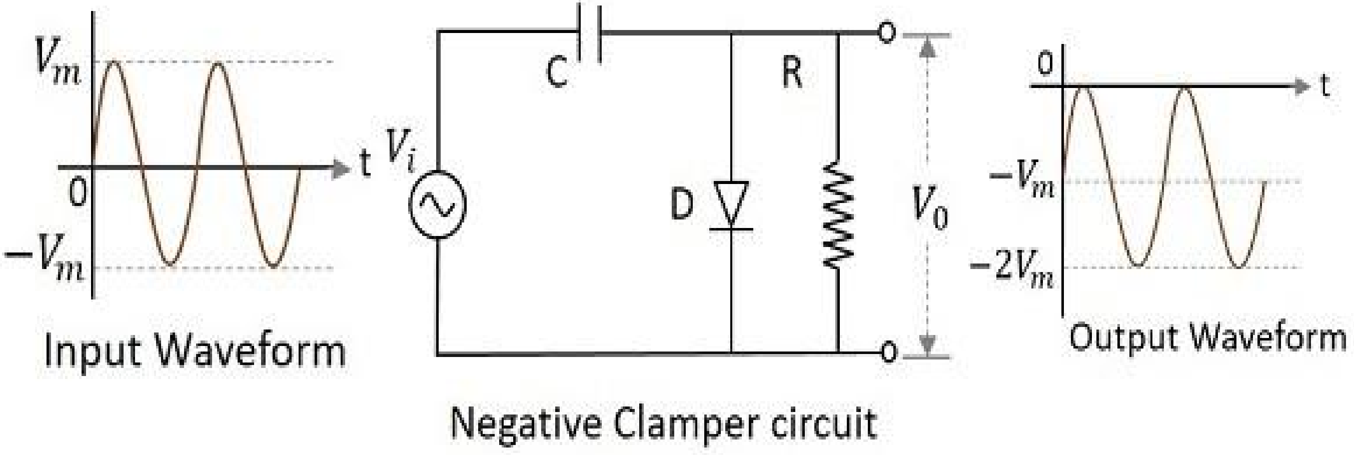


Positive Clamper circuit

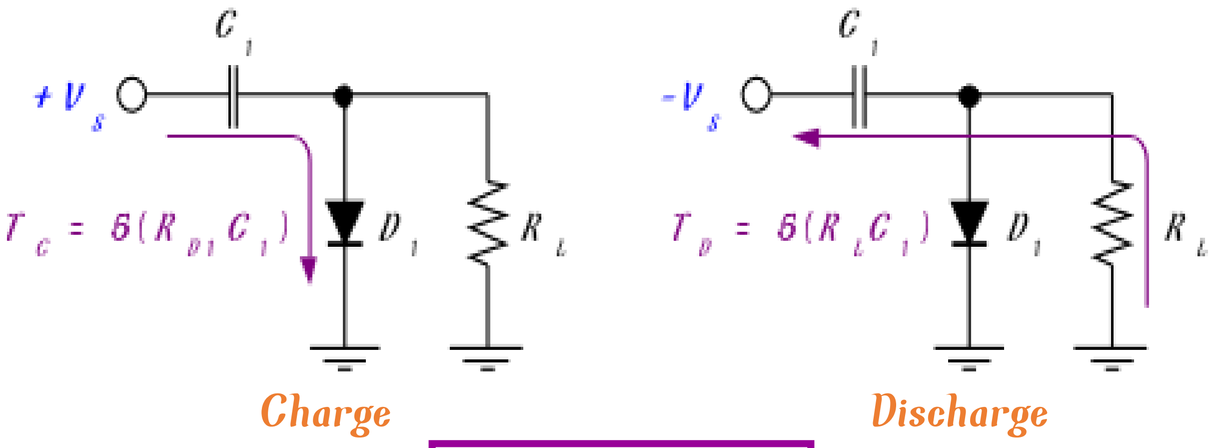
$$V_0 = V_i + V_m$$

Negative Clamper

A Negative Clamper circuit is one that consists of a diode, a resistor and a capacitor and that shifts the output signal to the negative portion of the input signal. The figure below explains the construction of a negative clamper circuit.



Clamper operation.



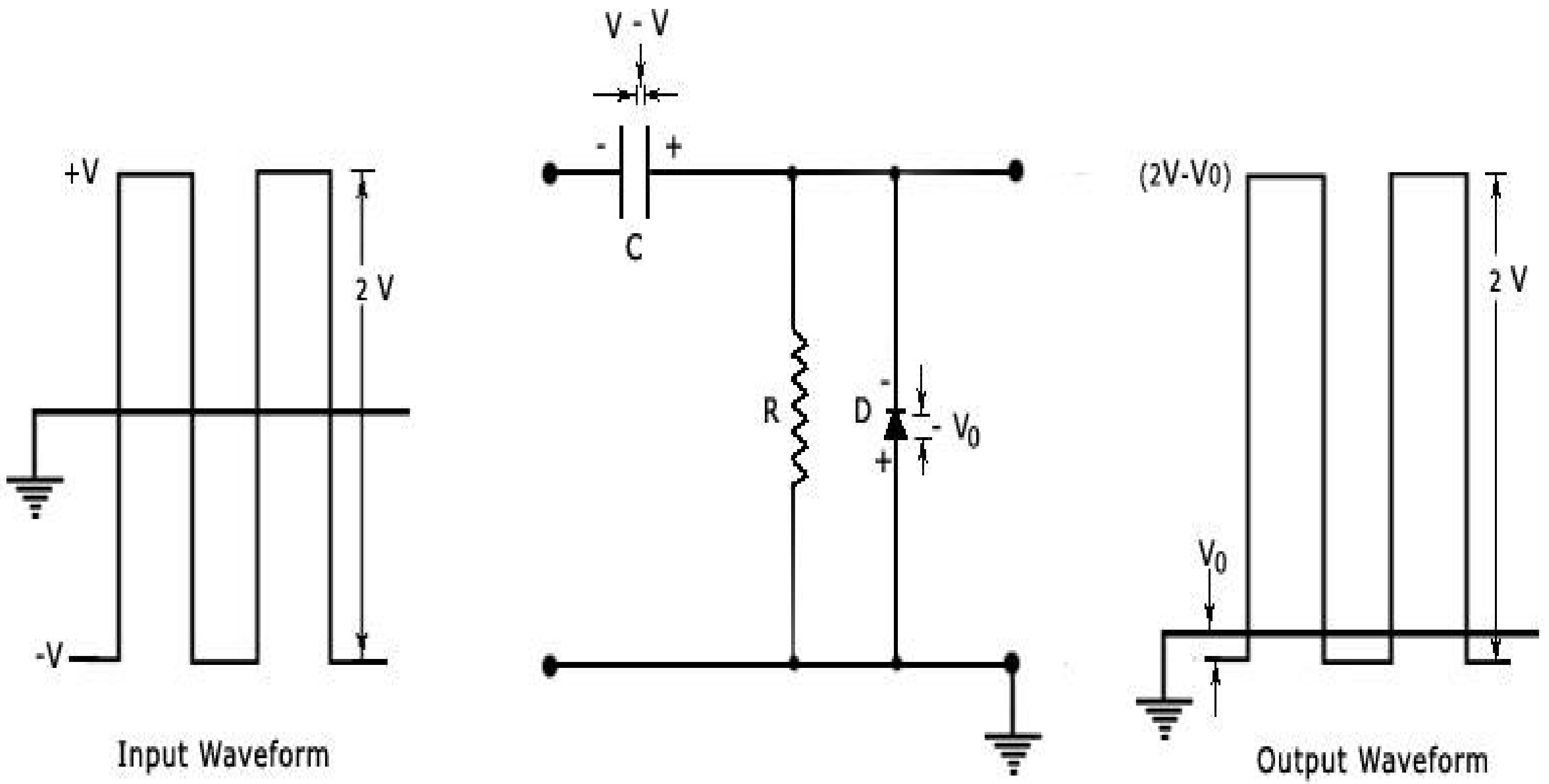
$$\boxed{T_C \ll T_D}$$

Determine the capacitor charge and discharge times for the circuit represented in above Fig. Assume that the forward resistance of the diode (R_{D1}) is 10 Ω, R_L = 10kΩ, and C_1 = 1μF.

$$T_C = 5(R_{D1}C_1) = 5(10\,\Omega \times 1\,\mu F) = 50\,\mu s$$

$$T_D = 5(R_LC_1) = 5(10\,k\Omega \times 1\,\mu F) = 50\,ms$$

Positive Clamper



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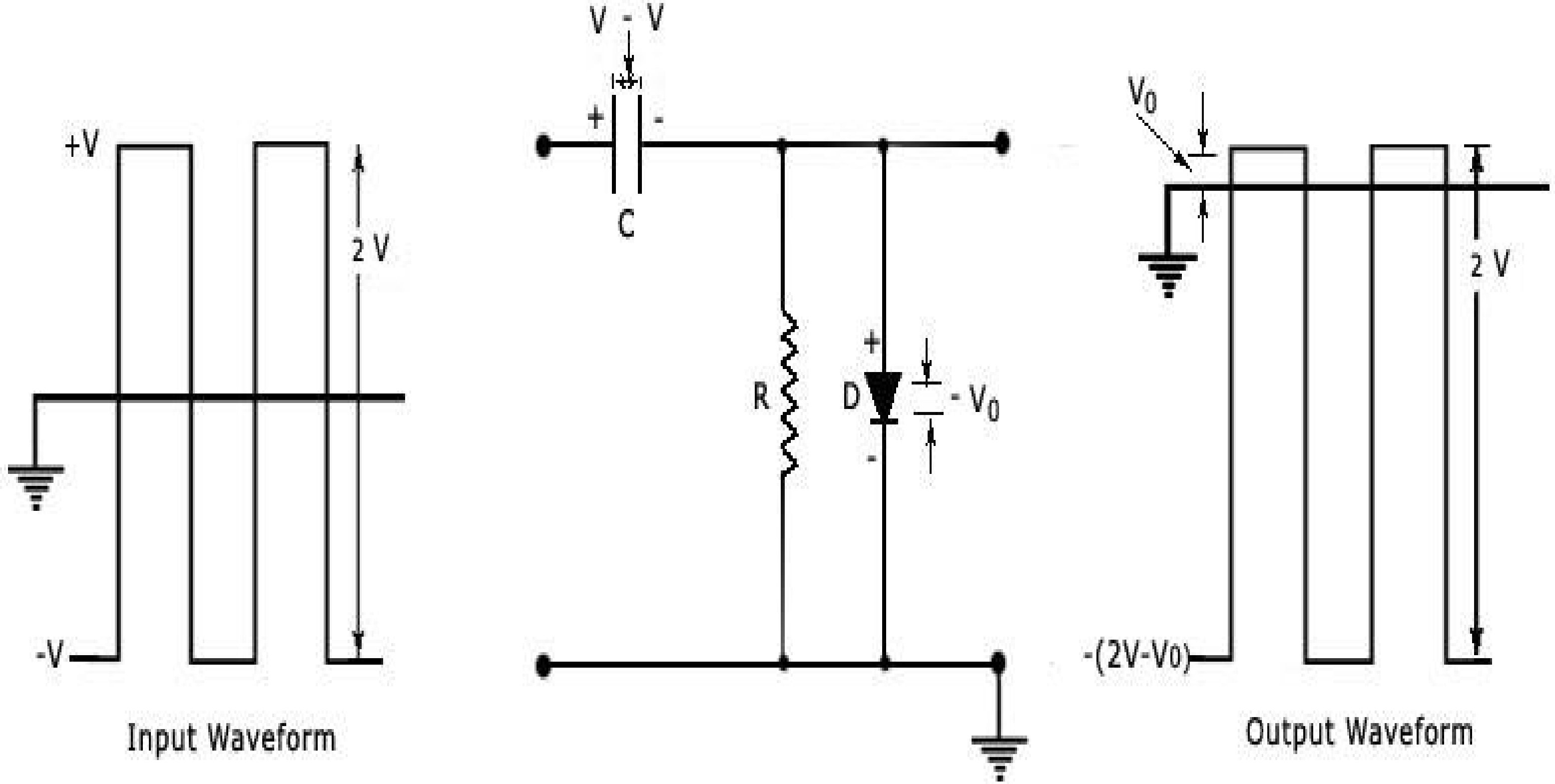
Negative Clamper



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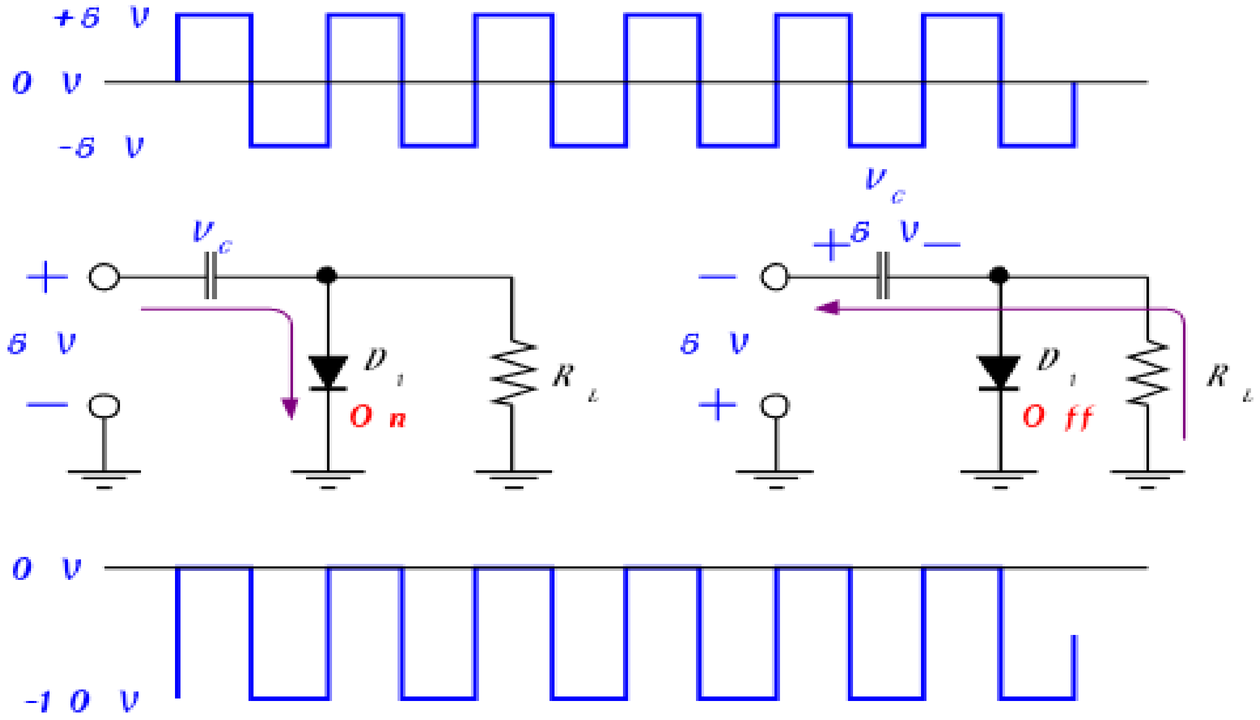
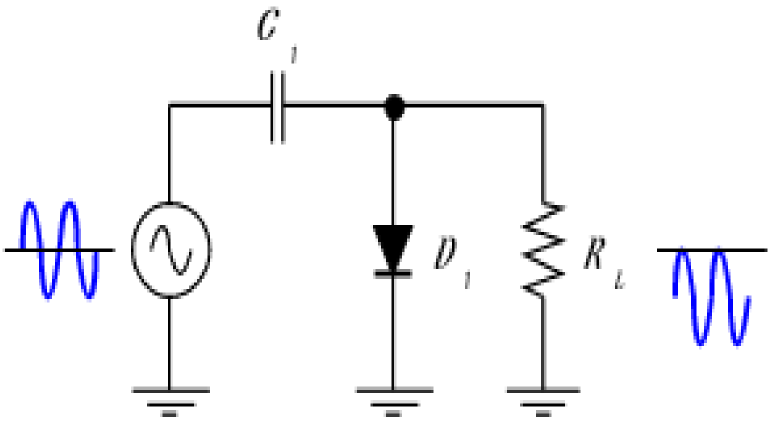
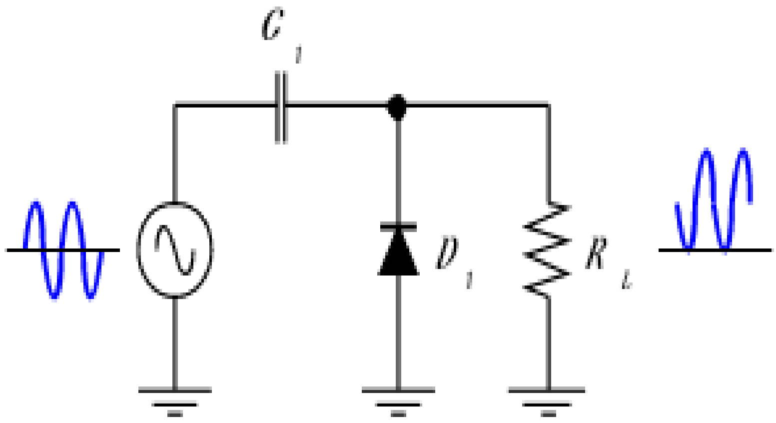
Clamper operation.



Clamper circuits.



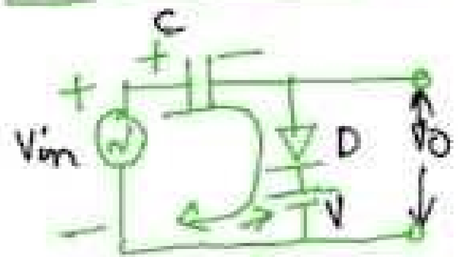


Negative clamper

Positive clamper

Negative Clamper with Biased Voltage

Biased clamper



Applying KVL

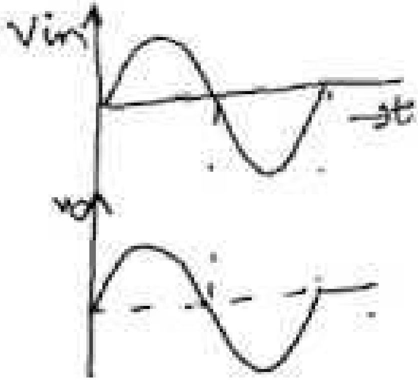
$V_{in} - V_C - V_{ref} = 0 \Rightarrow V_{in} - V_C - V = 0$

$\therefore V_C = V_{in} - V$

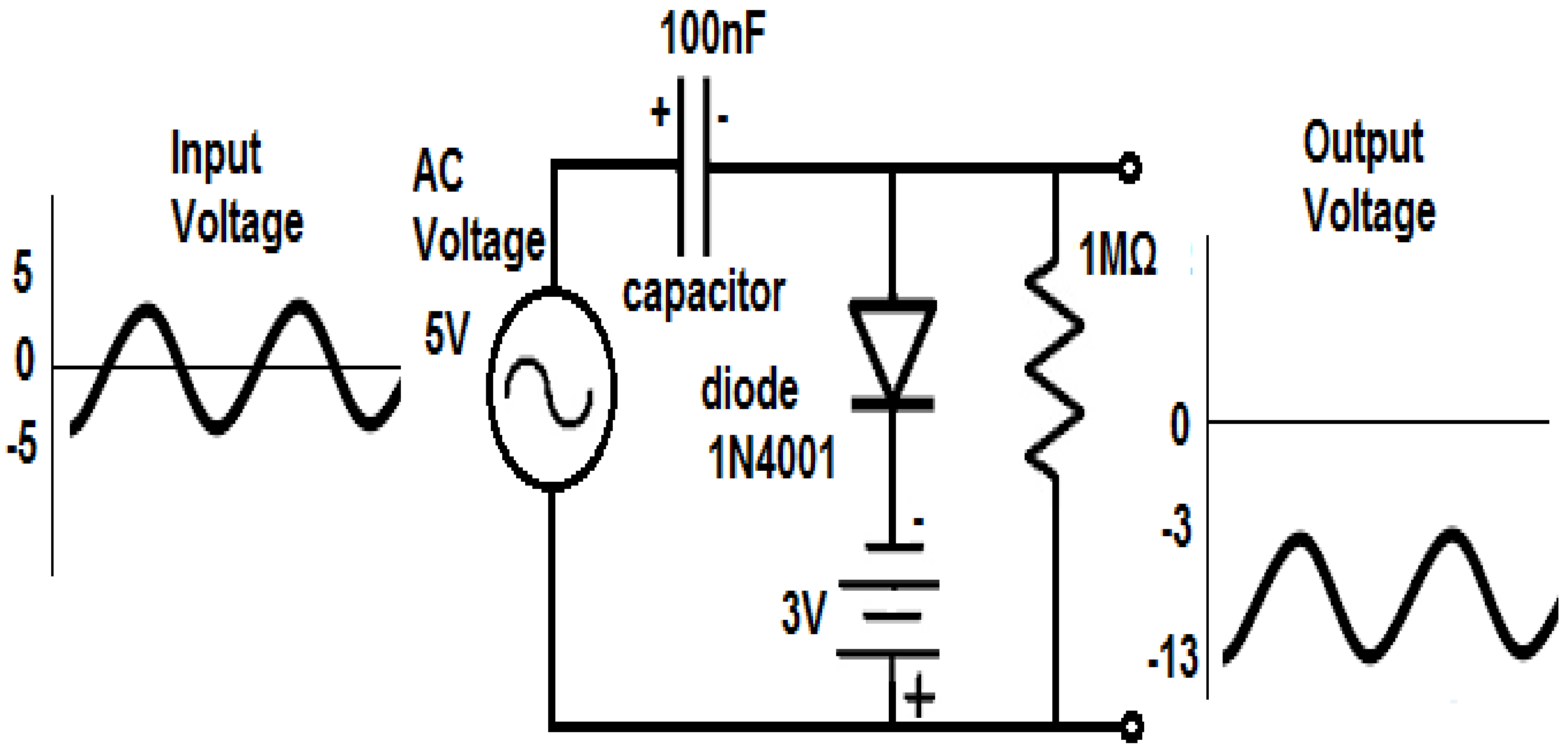
$= V_m - V \quad$ — (1)

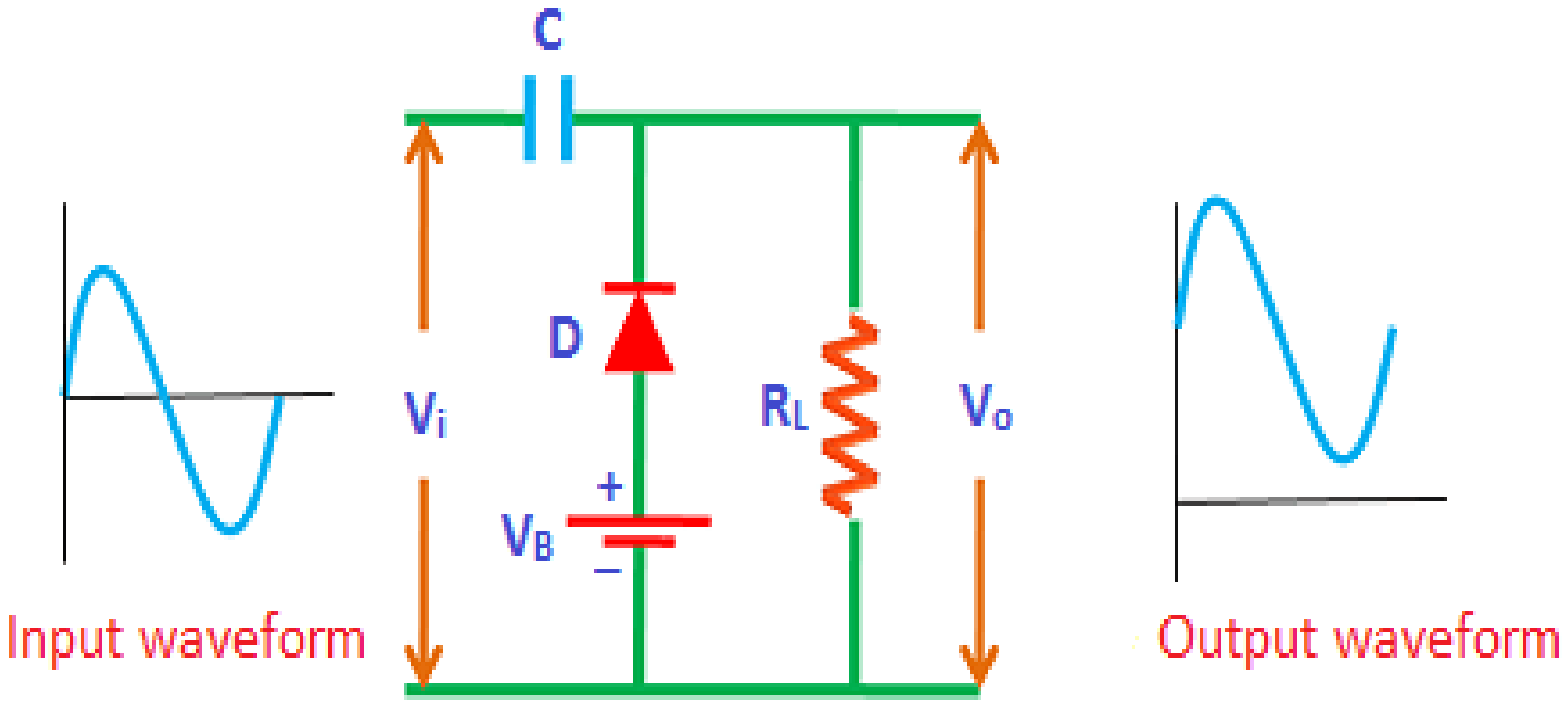
$V_{in} - V_C - V_O = 0$

$\therefore V_O = V_{in} - V_C$



Negative Clamper with Biased Voltage

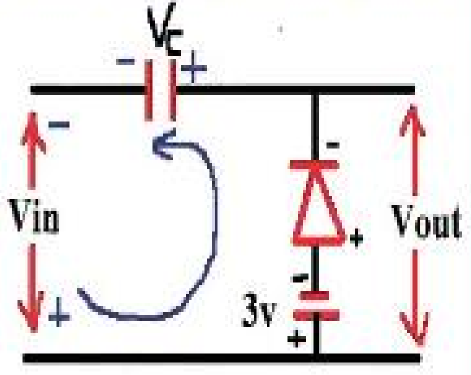




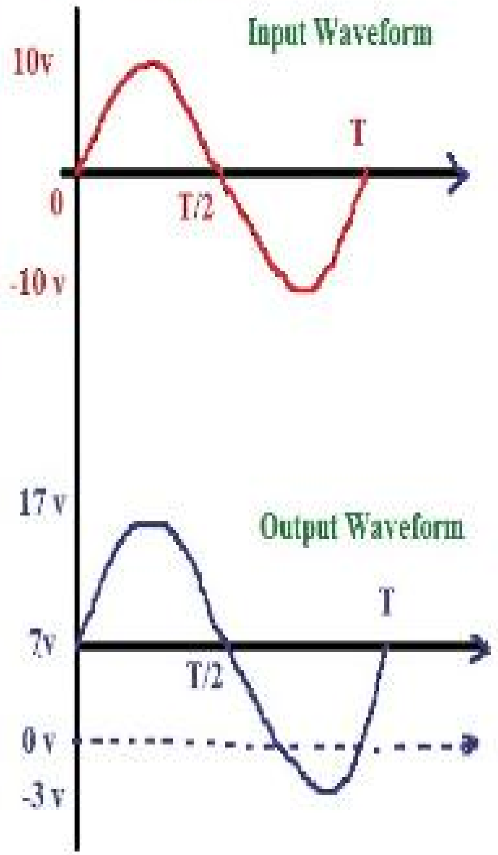
Positive clamper with positive bias

Physics and Radio-Electronics

Biased Clamper: Example 2



Direct Method:



Vrify using KVL:

Find The charge across capacitor, Apply 1st negative cycle:

Apply Kvl for Vc:

$V_{in} - 3 - V_c = 0$

$V_c = V_{in} - 3 = 10 - 3 = 7v$ — (1)

Apply Kvl for O/P

$V_{in} + V_c - V_o = 0$

$V_o = V_{in} + V_c$ — (2)

O/P for positive half cycle

$V_o = 10 + 7 = 17V$ — (3)

O/P for Negative half cycle

$V_o = -10 + 7 = -3V$ — (4)

O/P for the origin

$V_o = 0 + 7 = 7V$ — (5)

Points to remember

- Start the analysis of clamping network, by considering that part of the input signal that will forward bias the diode.
- During the period that the diode is in the "ON" state, assume that capacitor will charge up instantaneously to a voltage level determined by the network.
- Assume that during the period when the diode is in "OFF" state, capacitor will hold on its established voltage level.
- Keep in mind the general rule, that Total swing of total output = Swing of input signal

Clamping Circit Theorem

The clamping circuit theorem states that under steady-state conditions, for any input waveform, the ratio of the area under the output voltage curve in the forward direction to that in the reverse direction is equal to the ratio R_f/R or

$$\frac{A_f}{A_r} = \frac{R_f}{R}$$

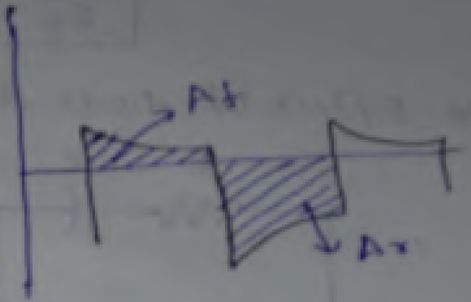
$$\frac{A_f}{A_r} = \frac{R_f}{R}$$

Clamping Circuit Theorem

Clamping circuit theorem:

→ It states that "the ratio of area under the output voltage curve in forward direction to that in reverse direction is equal to R_f/R"

$$\frac{A_f}{A_r} = \frac{R_f}{R}$$



→ $0 < t < T_1$, the diode is forward bias. Hence the capacitor will charge through the current i_f.

→ The charge gained by the capacitor is

$$Q_g = \int_0^{T_1} i_f(t)\,dt$$

$$Q_g = \int_0^{T_1} \frac{V_f(t)}{R_f}\,dt$$

$$= \frac{1}{R_f}\int_0^{T_1} V_f(t)\,dt$$

$$Q_g = \frac{A_f}{R_f}$$

→ Over the interval $T_1 < t < T_1 + T_2$, the diode is reverse bias hence the capacitor will discharge through the current i_r

→ The charge lost by the capacitor is

$$Q_l = \int_{T_1}^{T_1+T_2} i_r(t)\,dt$$

$$Q_l = \int_{T_1}^{T_1+T_2} \frac{V_r(t)}{R}\,dt$$

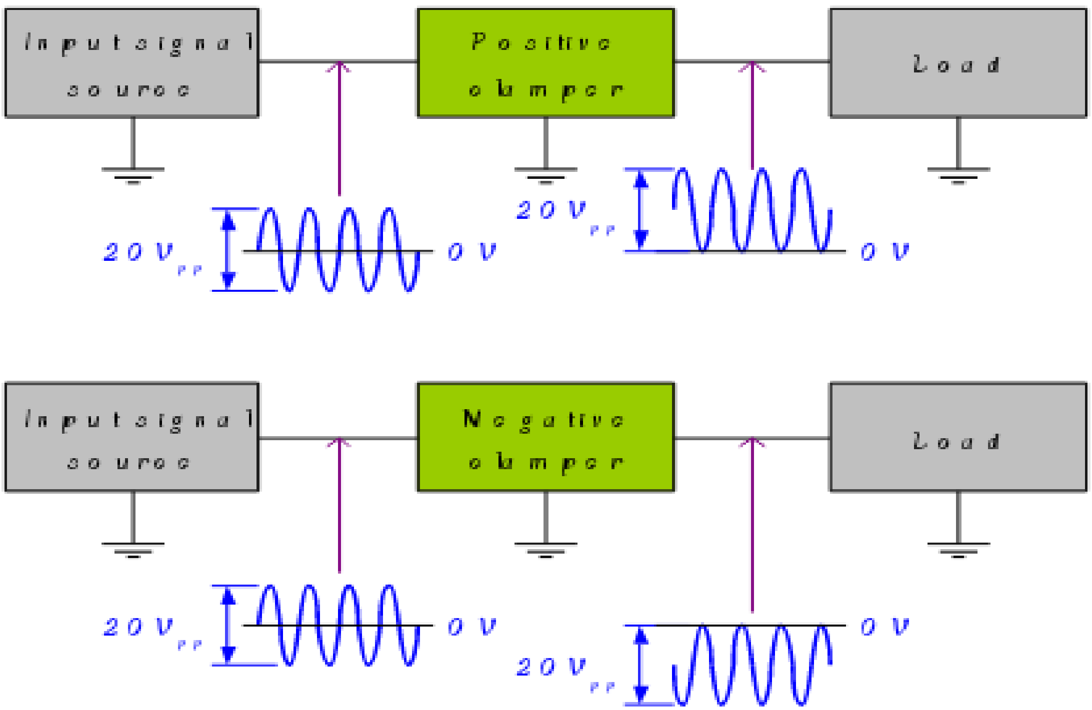
$$= \frac{1}{R}\int_{T_1}^{T_1+T_2} V_r(t)\,dt$$

Under steady state condition, charge gained must be equal to charge lost $Q_g = Q_l$

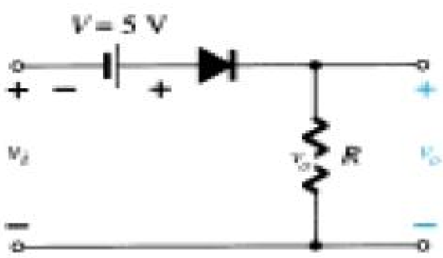
$$\frac{A_f}{A_r} = \frac{R_f}{R}$$

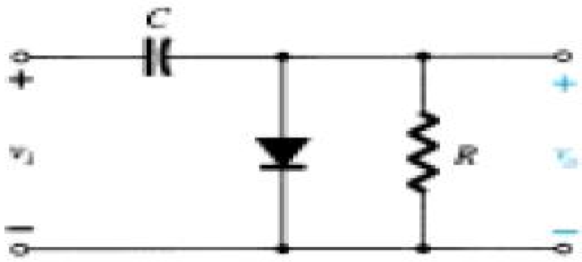
hence Clamper circuit theorem is prooved.

Clampers (DC restorers).

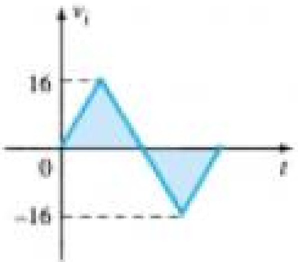


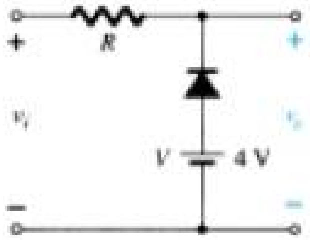
Give name of the circuit



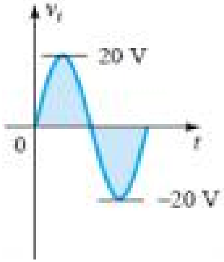


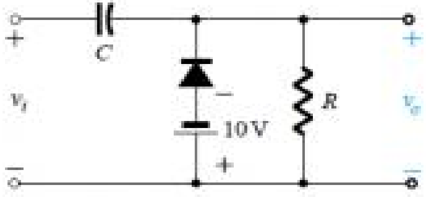
For the given input waveform to the given circuit, what is the peak value of the output waveform?





For the given circuit and input waveform, the peak value of the output is equal to.





Thank You