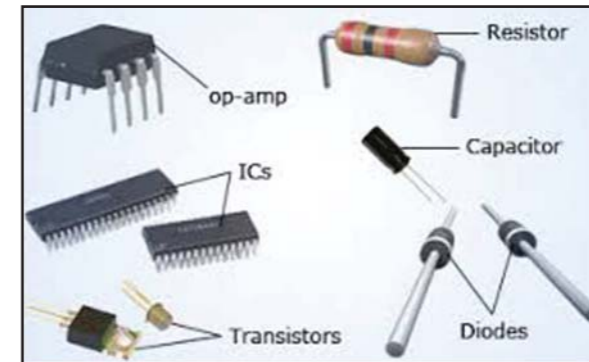


Electronic Device and Circuit



Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

Phone : 5639122/6634373/6635046/6630088
Website : www.moecdc.gov.np

**Technical and Vocational Stream
Learning Resource Material**

**Electronic Device and Circuit
(Grade 10)**

**Secondary Level
Computer Engineering**



Government of Nepal
Ministry of Education, Science and Technology
Curriculum Development Centre
Sanothimi, Bhaktapur

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Preface

The curriculum and curricular materials have been developed and revised on a regular basis with the aim of making education objective-oriented, practical, relevant and job oriented. It is necessary to instill the feelings of nationalism, national integrity and democratic spirit in students and equip them with morality, discipline and self-reliance, creativity and thoughtfulness. It is essential to develop in them the linguistic and mathematical skills, knowledge of science, information and communication technology, environment, health and population and life skills. It is also necessary to bring in them the feeling of preserving and promoting arts and aesthetics, humanistic norms, values and ideals. It has become the need of the present time to make them aware of respect for ethnicity, gender, disabilities, languages, religions, cultures, regional diversity, human rights and social values so as to make them capable of playing the role of responsible citizens with applied technical and vocational knowledge and skills. This Learning Resource Material for Computer Engineering has been developed in line with the Secondary Level Computer Engineering Curriculum with an aim to facilitate the students in their study and learning on the subject by incorporating the recommendations and feedback obtained from various schools, workshops and seminars, interaction programs attended by teachers, students and parents.

In bringing out the learning resource material in this form, the contribution of the Director General of CDC Dr. Lekhnath Poudel, Dr. Tankanath Sharma, Dr. Sanjib Prasad Pandey, Bishnuraj Bhandari, Sankar Kumar Yadav, Anup Bhujju, Trimandir Prajapati is highly acknowledged. The book is written by Satyaram Suwal, Rajendra Lakhe and Tej Prasad Dhamala and the subject matter of the book was edited by Badrinath Timalina and Khilanath Dhamala. CDC extends sincere thanks to all those who have contributed in developing this book in this form.

This book is a supplementary learning resource material for students and teachers. In addition they have to make use of other relevant materials to ensure all the learning outcomes set in the curriculum. The teachers, students and all other stakeholders are expected to make constructive comments and suggestions to make it a more useful learning resource material.

Table of Contents

Unit - 1	
Introduction to Electronic Component	1
Learning outcomes:	1
Introduction to matter, molecule and atom	1
Properties of Matter	2
What is a molecule?	4
Charge, Electric quantity and Electric Current	6
Potential difference and electromotive force	7
Introduction to direct current and alternating current	11
Basic parameter of alternating current	12
Types of Periodic Waveform	13
Average Value of a Non-sinusoidal Waveform	15
Review on Ohm's Law and Kirchoff's voltage and current laws	17
Unit - 2	
Introduction to Passive Component	21
Learning outcomes:	21
Introduction to Passive component:	21
Capacitors, their construction, types, characteristics and color code	24
Types of capacitor:	25
Capacitors Circuits: Capacitors in Series	26
Color code of Capacitor:	29
Inductors, their construction, types, characteristics and color code	30
List of practical lab for the passive component (Each lab required 2 hours)	34
Unit - 3	
Semiconductor	45
Learning Outcomes	45
Energy level	46
Band theory in solids	47
Classification of materials based on forbidden gap	49
Introduction to semiconductor	57
Atomic structure of silicon and germanium	58
Atomic structure of silicon	58
Atomic structure of germanium	59
Holes	60
Intrinsic semiconductor	62
Types of impurities	66
P-N Junction	73
APN Junction Diode	73
Junction Diode Symbol and Static I-V Characteristics.	74
Reverse Biased PN Junction Diode	75

Increase in the Depletion Layer due to Reverse Bias	76
Reverse Characteristics Curve for a Junction Diode	76
Forward Biased PN Junction Diode	77
Forward Characteristics Curve for a Junction Diode	77
Reduction in the Depletion Layer due to Forward Bias	78
Biasing of P-N junction diode	80
Reverse Break down	81
Zener Breakdown(Diode)	82
Characteristics of Zener Diode	82
Unit 4	
Power Supplies	96
Learning Outcomes:	96
Full wave rectifier	98
Voltage Regulation:	108
UNIT-5	
Bipolar Junction Transistors	120
5.1 Explain the Types of transistors with working principles, circuit characteristics and applications	120
5.2 Transistor circuit configuration:	127
5.3 Transistor as a Switch – Cutoff and Saturation	131
Unit-6	
Special Purpose Transistors	134
Learning outcomes:	134
Device operation	137
Programmable UJT (PUT).	138
UNIT-7	
Field Effect Transistors	141
Learning Outcomes:	141
7.1 Field effect transistors	141
7.2 Types and working principles, characteristics and applications of Field effect transistors.	144
7.3 Difference between Depletion MOSFET and Enhancement MOSFET	158

UNIT - 1

Introduction to Electronic Component

Learning outcomes:

After completion of this lesson, students will be able to:

- Define matter, molecule, atom and its properties
- To explain about potential difference and electromotive force(EMF)
- To explain about direct current, alternating current and basic parameters of alternating current
- To explain about Ohm's law and Kirchhoff's law

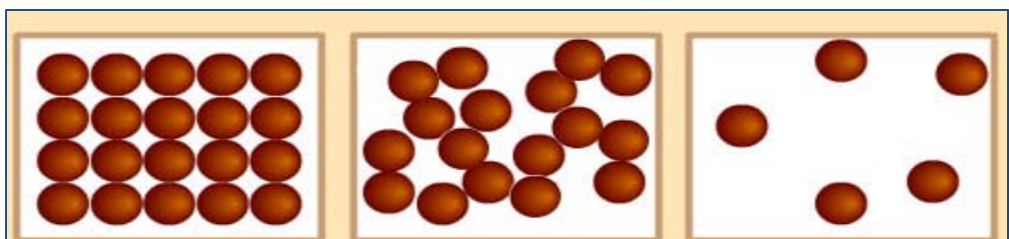
Lesson - 1

Introduction to matter, molecule and atom

Introduction to matter

Any substances, such as a solid, liquid or gas that has weight (mass) and occupies space are called as matter. For anything to occupy space, it must have volume. Based on this, we can say that everything on earth that has weight and takes up some space can be called as matters. Ultimately, everything on earth is matter.

All the matters like Solids, liquids and gases are made up of very tiny stuff that the naked eye cannot see, called atoms, molecules and/or ions. The picture below shows how the tiny stuffs are arranged in a matter.



Molecules in Solid

Molecules in Liquid

Molecules in Gas

Properties of Matter

Physical properties:

The measurement of mass and other characteristics that can be seen without changing how that object looks are its physical properties. When we look at a book, we know that it is a book because of its shape, size, color etc. Color, shape, size, volume, mass and density are some physical properties of matter.

Density is the mass of a substance per unit volume. It is an important physical property of matter. Volume is the amount of space an object occupies.it

Chemical properties:

These are properties that can only be observed by changing the identity of the substance. A piece of paper burns and turns to ash. The chemical properties have been changed.

Types of matter

There are three types of matters:

- Solid
- Liquid
- Gas

Solid

The hard substances that we see around us are solids. They are hard because of their molecules are packed in very high density. Examples include book, pen, apple, a piece of wood, plastic etc. They are all solids at room temperature. They can exist in different sizes, shapes and forms.

Think of ice cubes as an example. They are solids when frozen. They change into liquid when temperature is above zero degree.

Characteristic of particles (molecules) in a solid.

- The particles are close together (that's why they cannot be compressed).
- The particles cannot move freely from place to place (this is why they have a fixed shape).
- The particles are arranged in a regular, distinct pattern.

- The particles are held together by strong forces called bonds (This is why solids do not flow like water. Their particles are only able to vibrate in their position and cannot move from place to place.)
- The particles can vibrate in a fixed position

Different solids behave slightly differently because they have different properties such as ‘STRENGTH’. This makes solids useful for different things. Look at a pencil eraser—it is solid, but can slightly change shape because the strength of its bonds is slightly weaker than that in a piece of diamond.

Liquid

The particles in liquids are not as closely bonded, arranged and fixed in place as in solids. The particles in liquid can flow freely and can mix with particles from other liquids. Liquids have their atoms close together, so they are not very easy to compress.

Liquids, unlike gases are pulled by gravity to the bottom of the container in which it is kept. They take the shape of the container. You can pour a volume of liquid from one container to the other, it can change shape but the volume remains same.

Characteristics of particles in liquid

- The particles are close together, but not as packed as in solids.
- Particles are arranged in a random way.
- Move around each other (They flow and take the shape of their container because their particles can move over each other)
- The bonds in a liquid are strong enough to keep the particles close together, but weak enough to let them move around each other.

Gas

Gas is everywhere, and it is around us. The air around us is a kind of gas. The atmosphere surrounding the earth is a gas too. Helium, Oxygen, Carbon dioxide and water vapor are all examples of gas.

The particles in gases are very different from that of solids and liquids. In gases, the particles are far apart from each other and arranged in a random way. The particles also move quickly in all directions. Gases can fill up any container of any shape and

size. Gases can be compressed. When gas is compressed, the gas molecules move from an area of high pressure to low pressure.

The table below is a great guide to the relationship between solids, liquids and gases:

	Solid	Liquid	Gas
Arrangement of molecules	Close to each other	Not so close as in solid	Wide apart
Movement of molecules	Less movement, it is in the form of vibration	Molecules can move freely around each other	Fast movement in random direction
Strength of bond between molecules	Very strong bonding	Weak bonding	Very loose bonding
example	Brick	Water	Water vapor

What is a molecule?

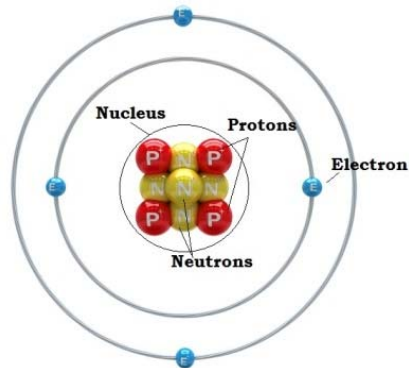
A molecule is the smallest particle in a chemical element or compound that has the chemical properties of that element or compound. Molecules are made up of atoms that are held together by chemical bonds. These bonds form as a result of the sharing or exchange of electrons among atoms.

Molecules are always in motion. In solids and liquids, they are packed tightly together. In a solid, the motion of the molecules can be expressed as rapid vibration. In a liquid, the molecules can move freely among each other. In a gas, the density of molecules is generally less than in a liquid or solid of the same chemical compound, and they move even more freely than in a liquid. For a specific compound in a given state (solid, liquid, or gas), the speed of molecular motion increases as the absolute temperature increases.

Atom

Atoms are the basic units of matter and the defining structure of elements. Atoms are made up of three particles: protons, neutrons and electrons.

Protons and neutrons are heavier than electrons and reside in the center of the atom, which is called the nucleus. Electrons are extremely lightweight and exist in a cloud orbiting the nucleus.



Adding a proton to an atom makes a new element, while adding a neutron makes an isotope, or heavier version, of that atom.

Nucleus

The nucleus was discovered in 1911, but its parts were not identified until 1932. Virtually all the mass of the atom resides in the nucleus. The nucleus is held together by the "strong force," one of the four basic forces in nature.

Protons

Protons are positively charged particles found within atomic nuclei. They were discovered by Ernest Rutherford in experiments conducted between 1911 and 1919.

The number of protons in an atom defines what element it is. For example, Hydrogen atoms have one and oxygen atoms have eight protons. The number of protons in an atom is referred to as the atomic number of that element

Electrons

Electrons have a negative charge and are electrically attracted to the positively charged protons. Electrons surround the atomic nucleus in pathways called orbital. The inner orbital surrounding the atom are spherical but the outer orbital are much more complicated.

Neutrons

Neutrons are uncharged particles found within atomic nuclei. A neutron's mass is slightly larger than that of a proton. Neutrons were discovered by James Chadwick in 1932.

Isotopes

The number of neutrons in a nucleus determines the isotope of that element. For example, hydrogen has three known isotopes: protium, deuterium and tritium. Protium, symbolized as ^1H , is just ordinary hydrogen; it has one proton and one electron and no neutrons. Deuterium (D or ^2H) has one proton, one electron and one neutron. Tritium (T or ^3H) has one proton, one electron and two neutrons.

Lesson - 2

Charge, Electric quantity and Electric Current

Definition of Electric Charge

Electric charge is the physical property of matter that causes it to experience a force when placed in an electromagnetic field.

There are two types of electric charges: positive and negative. Like charges repel and unlike attract. An object is negatively charged if it has an excess of electrons, and is otherwise positively charged or uncharged.

The SI derived unit of electric charge is the coulomb (C).

Protons and electrons carry charges of $\pm 1.602 \times 10^{-19}$ C. Every accumulation of charge is an even multiple of this number, and fractional charges cannot exist.

Electric charge is a conserved quantity. That means it cannot be created or destroyed, and the net amount of electric charge in the universe remains same. Positive and negative charges can neutralize each other, or neutral particles can split to form positively and negatively charged pairs of particles, but the net amount of charge always remains the same.

Electric current

An electric current is a flow of charge, and in a wire this will be a flow of electrons. We need two things for an electric current to flow:

1. Something to transfer energy to the electrons, such as a battery or power pack
2. A complete path for the electrons to flow through (an electric circuit)

Lesson - 3

Potential difference and electromotive force

Potential difference (pd)

The difference in electric potential between two points in an electric field, the work that has to be done in transferring unit positive charge from one point to the other is called as potential difference. It is measured in volts.

Electromotive force (emf)

The force that makes electrons move to produce an electric current. Electro motive force is supplied by a power source, such as a battery or dynamo. It is measured in volts.

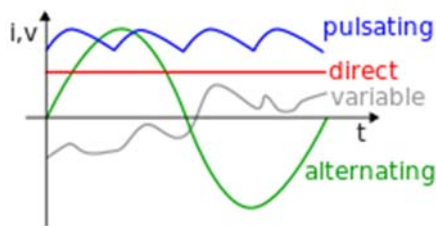
The difference in the potential energies of a cathode and anode immersed in the same solution of electrolytes or connected in another manner.

Difference between potential difference and electromotive force

Electromotive force	Potential Difference
The potential difference between the two terminals of a cell is called electromotive force in an open circuit.	Bringing a unit positive charge from one point to another point in a circuit is called potential difference between two points
Electromotive force transmits current both inside and outside the cell.	Potential difference current transfers between any two points in the circuit.
Electromotive force emf is the cause.	Potential difference is the result.
Electromotive force is always greater than potential difference.	Potential difference is always less than electromotive force.

Electromotive force creates potential difference in entire circuit.	Potential difference takes place between any two points in the circuit.
Electromotive force does not depend on the resistance of the circuit.	Potential difference of two points depends on the resistance of those points.
Electromotive force remains constant.	It does not remain constant.
The part of the circuit where electrical energy is created from any other energy then that part contains the source of Electromotive force.	Potential difference exists in the part of the circuit where electrical potential energy is transformed into another form of energy
Electromotive force is concept of time varying electric and magnetic field.	Potential difference is the concept of static field.

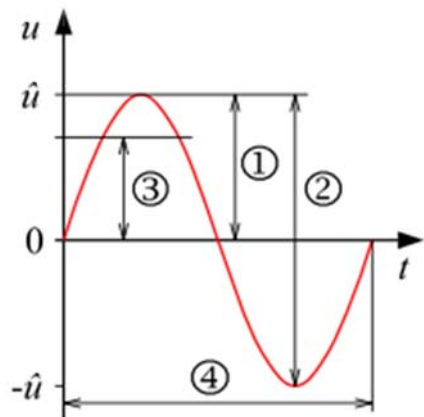
Alternating current:



Alternating current (green curve). The horizontal axis measures time; the vertical, current or voltage.

Alternating current (AC), is an electric current in which the flow of electric charge periodically reverses direction, whereas in direct current (DC, also dc), the flow of electric charge is only in one direction. The abbreviations AC and DC are often used to mean simply alternating and direct, as when they modify current or voltage

Mathematics of AC voltage



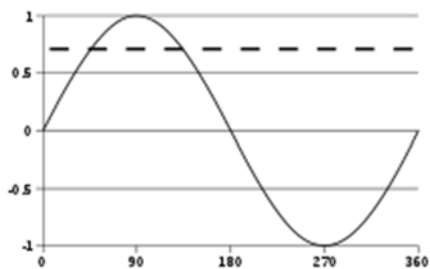
A sinusoidal alternating voltage.

1 = peak, also amplitude,

2 = peak-to-peak,

3 = effective value,

4 = Period



A sine wave, over one cycle (360°). The dashed line represents the root mean square (RMS) value at about 0.707

Alternating currents are accompanied (or caused) by alternating voltages. An AC voltage v can be described mathematically as a function of time by the following equation:

$$v(t) = V_{\text{peak}} \cdot \sin(\omega t),$$

where

- V_{peak} is the peak voltage (unit: volt),
- ω is the angular frequency (unit: radians per second)
- The angular frequency is related to the physical frequency, f (unit = hertz), which represents the number of cycles per second, by the equation $\omega = 2\pi f$.
- t is the time (unit: second).

The peak-to-peak value of an AC voltage is defined as the difference between its positive peak and its negative peak. Since the maximum value of $\sin(x)$ is +1 and the minimum value is -1, an AC voltage swings between $+V_{\text{peak}}$ and $-V_{\text{peak}}$.

The peak-to-peak voltage, usually written as V_{PP} or $V_{\text{P-P}}$, is therefore $V_{\text{peak}} - (-V_{\text{peak}}) = 2V_{\text{peak}}$.

Root mean square voltage

For a sinusoidal voltage:

$$\begin{aligned} V_{\text{rms}} &= \sqrt{\frac{1}{T} \int_0^T [V_{pk} \sin(\omega t + \phi)]^2 dt} \\ &= V_{pk} \sqrt{\frac{1}{2T} \int_0^T [1 - \cos(2\omega t + 2\phi)] dt} \\ &= V_{pk} \sqrt{\frac{1}{2T} \int_0^T dt} \\ &= \frac{V_{pk}}{\sqrt{2}} \end{aligned}$$

The factor $\sqrt{2}$ is called the crest factor, which varies for different waveforms.

- For a triangle waveform centered about zero

$$V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{3}}.$$

- For a square waveform centered about zero

$$V_{\text{rms}} = V_{\text{peak}}.$$

- For an arbitrary periodic waveform $v(t)$ of period T :

$$V_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T [v(t)]^2 dt}.$$

Lesson - 4

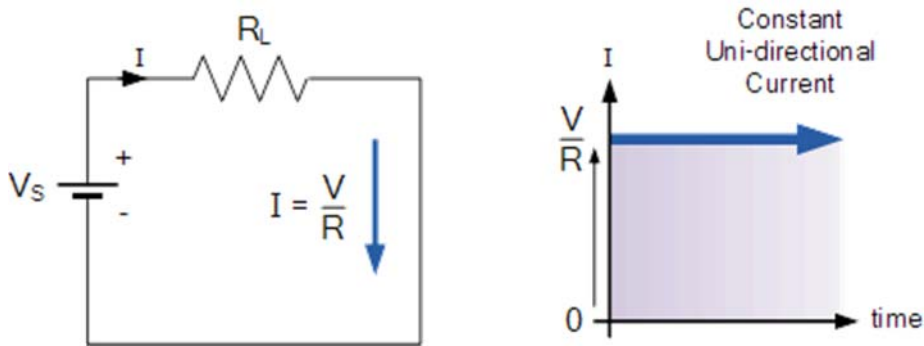
Introduction to direct current and alternating current

Top of Form

Direct Current or D.C. as it is more commonly called, is a form of current or voltage that flows around an electrical circuit in one direction only, making it a “Uni-directional” supply. Generally, both DC currents and voltages are produced by power supplies, batteries, dynamos and solar cells to name a few. A DC voltage or current has a fixed magnitude (amplitude) and a definite direction associated with it. For example, +12V represents 12 volts in the positive direction, or -5V represents 5 volts in the negative direction.

We also know that DC power supplies do not change their value with regards to time, they are a constant value flowing in a continuous steady state direction. In other words, DC maintains the same value for all times and a constant uni-directional DC supply never changes or becomes negative unless its connections are physically reversed. An example of a simple DC or direct current circuit is shown below.

DC Circuit and Waveform



An alternating function or **AC Waveform** on the other hand is defined as one that varies in both magnitude and direction in more or less an even manner with respect to time making it a “Bi-directional” waveform. An AC function can represent either a power source or a signal source with the shape of an *AC waveform* generally following that of a mathematical sinusoid as defined by:- $A(t) = A_{max} \times \sin(2\pi ft)$.

Lesson -5

Basic parameter of alternating current

The term AC or Alternating Current, generally refers to a time-varying waveform with the most common of all being called a **Sinusoid** better known as a **Sinusoidal Waveform**. Sinusoidal waveforms are more generally called by their short description as **Sine Waves**. Sine waves are by far one of the most important types of AC waveform used in electrical engineering.

The shape obtained by plotting the instantaneous ordinate values of either voltage or current against time is called an **AC Waveform**. An AC waveform is constantly changing its polarity every half cycle alternating between a positive maximum value and a negative maximum value respectively with regards to time with a common example of this being the domestic mains voltage supply we use in our homes.

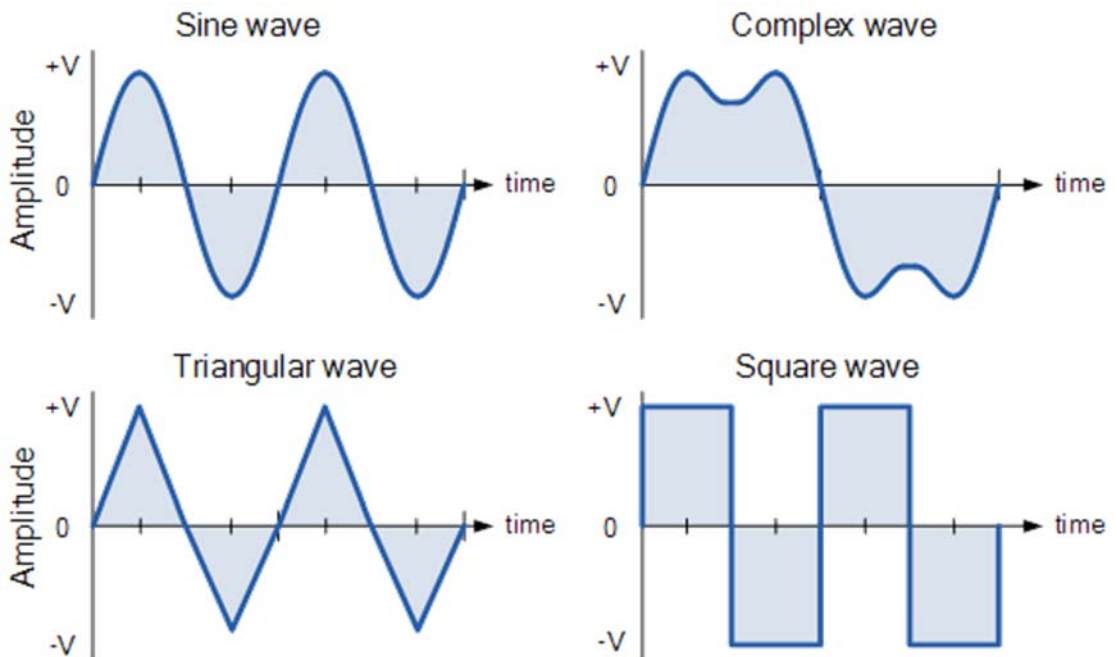
Alternating voltages and currents can not be stored in batteries or cells like direct current (DC) can, it is much easier and cheaper to generate these quantities using alternators or waveform generators when they are needed. The type and shape of an

AC waveform depends upon the generator or device producing them, but all AC waveforms consist of a zero voltage line that divides the waveform into two symmetrical halves. The main characteristics of an **AC Waveform** are defined as:

AC Waveform Characteristics

- The Period, (T) is the length of time in seconds that the waveform takes to repeat itself from start to finish. This can also be called the *Periodic Time* of the waveform for sine waves, or the *Pulse Width* for square waves.
- The Frequency, (f) is the number of times the waveform repeats itself within a one second time period. Frequency is the reciprocal of the time period, ($f = 1/T$) with the unit of frequency being the *Hertz*, (Hz).
- The Amplitude (A) is the magnitude or intensity of the signal waveform measured in volts or amps.

Types of Periodic Waveform



The time taken for an **AC Waveform** to complete one full pattern from its positive half to its negative half and back to its zero baseline again is called a **Cycle** and one

complete cycle contains both a positive half-cycle and a negative half-cycle. The time taken by the waveform to complete one full cycle is called the **Periodic Time** of the waveform, and is given the symbol “T”.

The number of complete cycles that are produced within one second (cycles/second) is called the **Frequency**, symbol f of the alternating waveform. Frequency is measured in Hertz, (Hz) named after the German physicist Heinrich Hertz.

Then we can see that a relationship exists between cycles (oscillations), periodic time and frequency (cycles per second), so if there are f number of cycles in one second, each individual cycle must take $1/f$ seconds to complete.

Relationship Between Frequency and Periodic Time

$$\text{Frequency, } (f) = \frac{1}{\text{Periodic Time}} = \frac{1}{T} \text{ Hertz}$$

or

$$\text{Periodic Time, } (T) = \frac{1}{\text{Frequency}} = \frac{1}{f} \text{ seconds}$$

Amplitude of an AC Waveform

Another important parameter of the AC waveform is Amplitude, better known as its Maximum or Peak value represented by the terms, V_{max} for voltage or I_{max} for current.

The peak value is the greatest value of either voltage or current that the waveform reaches during each half cycle measured from the zero baseline. Unlike a DC voltage or current which has a steady state that can be measured or calculated using Ohm’s Law, an alternating quantity is constantly changing its value over time.

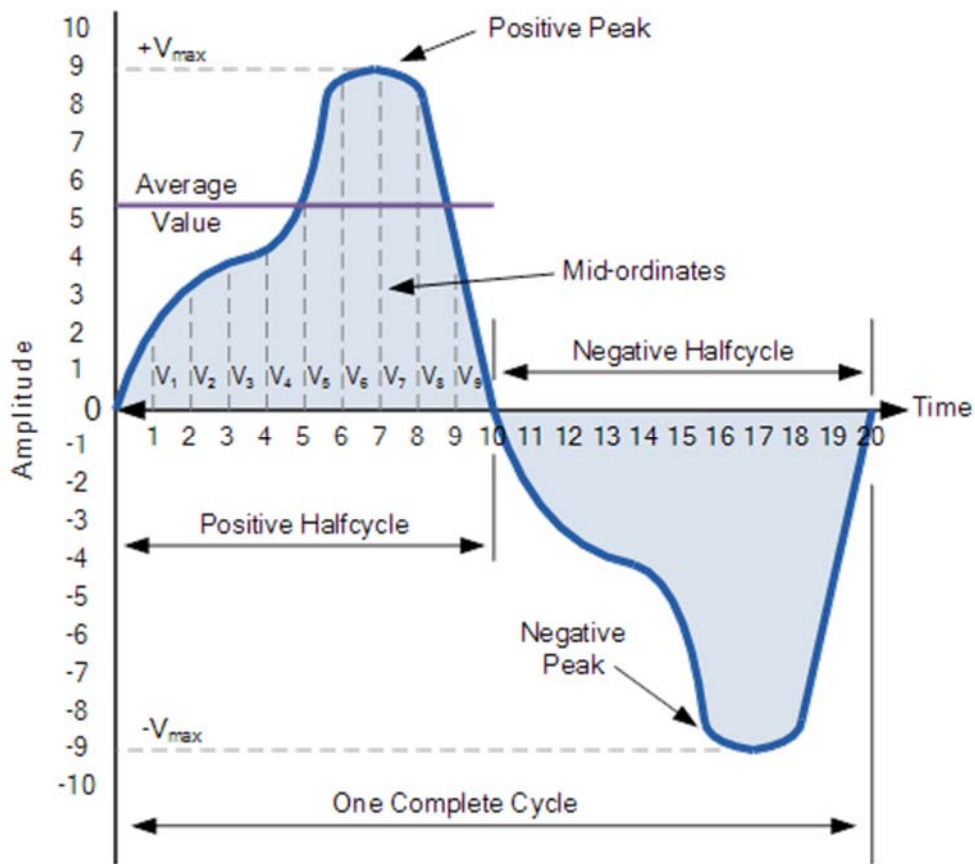
For pure sinusoidal waveforms this peak value will always be the same for both half cycles ($+V_m = -V_m$) but for non-sinusoidal or complex waveforms the maximum peak value can be very different for each half cycle. Sometimes, alternating waveforms are given a *peak-to-peak*, V_{p-p} value and this is simply the distance or

the sum in voltage between the maximum peak value, $+V_{max}$ and the minimum peak value, $-V_{max}$ during one complete cycle.

The Average Value of an AC Waveform

The average or mean value of a continuous DC voltage will always be equal to its maximum peak value as a DC voltage is constant. This average value will only change if the duty cycle of the DC voltage changes. In a pure sine wave if the average value is calculated over the full cycle, the average value would be equal to zero as the positive and negative halves will cancel each other out. So the average or mean value of an AC waveform is calculated or measured over a half cycle only and this is shown below.

Average Value of a Non-sinusoidal Waveform



Average Value of an AC Waveform

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

Where: n equals the actual number of mid-ordinates used.

For a pure sinusoidal waveform this average or mean value will always be equal to $0.637 \times V_{\text{max}}$ and this relationship also holds true for average values of current.

The RMS Value of an AC Waveform

The average value of an AC waveform is NOT the same value as that for a DC waveforms average value. This is because the AC waveform is constantly changing with time and the heating effect given by the formula ($P = I^2.R$), will also be changing producing a positive power consumption. The equivalent average value for an alternating current system that provides the same power to the load as a DC equivalent circuit is called the “effective value”.

This effective power in an alternating current system is therefore equal to: ($I^2.R.\text{Average}$). As power is proportional to current squared, the effective current, I will be equal to $\sqrt{I^2 \text{ Ave}}$. Therefore, the effective current in an AC system is called the Root Mean Squared or R.M.S. value and RMS values are the DC equivalent values that provide the same power to the load.

The effective or RMS value of an alternating current is measured in terms of the direct current value that produces the same heating effect in the same value resistance. The RMS value for any AC waveform can be found from the following modified average value formula.

RMS Value of an AC Waveform

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

Where: n equals the number of mid-ordinates.

For a pure sinusoidal waveform this effective or R.M.S. value will always be equal to $1/\sqrt{2} \times V_{\text{max}}$ which is equal to $0.707 \times V_{\text{max}}$ and this relationship holds true for RMS values of current. The RMS value for a sinusoidal waveform is always greater than the average value except for a rectangular waveform. In this case the heating effect remains constant so the average and the RMS values will be the same.

Lesson - 6

Review on Ohm's Law and Kirchhoff's voltage and current laws

Ohm's law



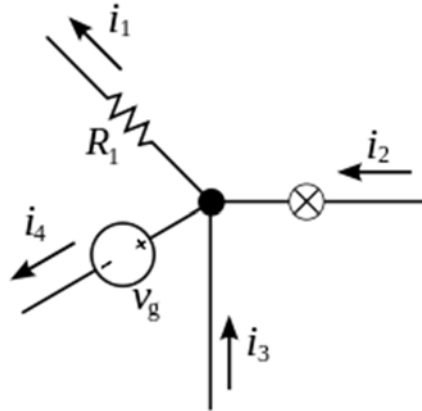
V, I, and R, the parameters of Ohm's law.

Ohm's law states that the current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship:

$$I = \frac{V}{R},$$

where I is the current through the conductor in units of amperes, V is the voltage measured *across* the conductor in units of volts, and R is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the R in this relation is constant, independent of the current.

Kirchhoff's Current Law (KCL)



The current entering any junction is equal to the current leaving that junction. $i_2 + i_3 = i_1 + i_4$

This law is also called Kirchhoff's first law, Kirchhoff's point rule, or Kirchhoff's junction rule (or nodal rule).

The principle of conservation of electric charge implies that:

At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

or equivalently

The algebraic sum of currents in a network of conductors meeting at a point is zero.

Recalling that current is a signed (positive or negative) quantity reflecting direction towards or away from a node, this principle can be stated as:

$$\sum_{k=1}^n I_k = 0$$

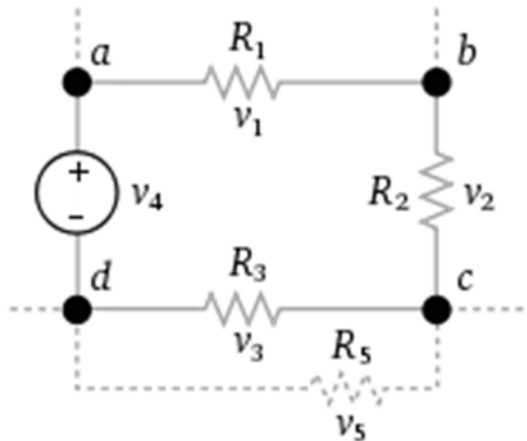
n is the total number of branches with currents flowing towards or away from the node.

This formula is valid for complex currents:

$$\sum_{k=1}^n \tilde{I}_k = 0$$

The law is based on the conservation of charge whereby the charge (measured in coulombs) is the product of the current (in amperes) and the time (in seconds).

Kirchhoff's Voltage Law (KVL)



The sum of all the voltages around a loop is equal to zero.
 $v_1 + v_2 + v_3 - v_4 = 0$

This law is also called Kirchhoff's second law, Kirchhoff's loop (or mesh) rule, and Kirchhoff's second rule.

The principle of conservation of energy implies that

The directed sum of the electrical potential differences (voltage) around any closed network is zero, or:

More simply, the sum of the emfs in any closed loop is equivalent to the sum of the potential drops in that loop, or:

The algebraic sum of the products of the resistances of the conductors and the currents in them in a closed loop is equal to the total emf available in that loop.

Similarly to KCL, it can be stated as:

$$\sum_{k=1}^n V_k = 0$$

Here, n is the total number of voltages measured. The voltages may also be complex:

$$\sum_{k=1}^n \tilde{V}_k = 0$$

This law is based on the conservation of energy whereby voltage is defined as the energy per unit charge. The total amount of energy gained per unit charge must be equal to the amount of energy lost per unit charge, as energy and charge are both conserved.

Teaching Tips:

1. Give the examples that are found in the surrounding environment.
2. Use the Charts as far as possible to explain the content.
3. Assign the homework at the end of every class from the chapter so far covered during that class.
4. Conduct group discussions after finishing one lesson.

References and Resources :

- Introduction to Electrical Engineering, Valery Vodovozov
- Principles of physics-II ,Ayam Publication Pvt.Ltd
- Electronic Principles, Alberto Malvino/David Bates,

<http://www.pbs.org/>

<https://www.boundless.com>

<http://www.physicsclassroom.com>

<http://www.electronics-tutorials.ws/>

UNIT - 2

Introduction to Passive Component

Learning outcomes:

- After completion of this lesson, students will be able to:
- Define resistor, their characteristics and color code
- To explain about capacitor, construction of capacitor, color code and their characteristic.

To explain about inductor, construction of inductors, color code and their characteristic

Lesson - 1

Introduction to Passive component:

Those component which cannot provide power gain (voltage and current) to the circuit is known as passive component. For example: capacitor, resistor and inductor.

1. Resistor:

- ▶ It is a passive two terminal electrical component that implement electrical resistance as a circuit element. Resistance is the property of the substance which opposes the flow of an electric current through it. It is symbolized by 'R'. It is measure in ohm (Ω).

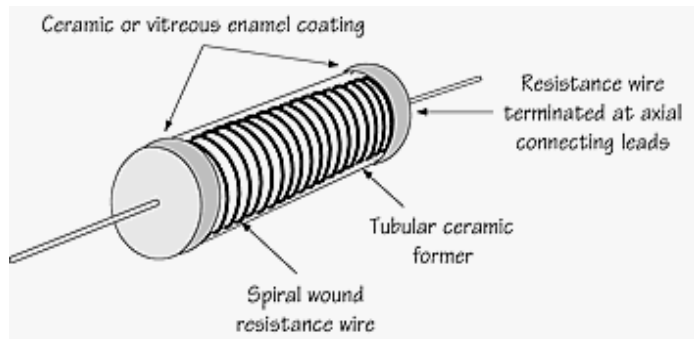
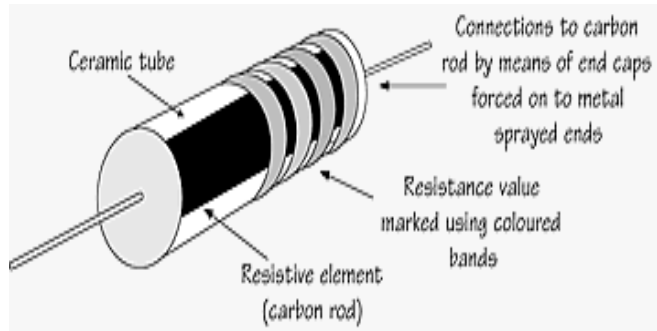
On the basis of operating condition resistor can be classified into two categories:

- ▶ Fixed resistor
- ▶ Variable resistor



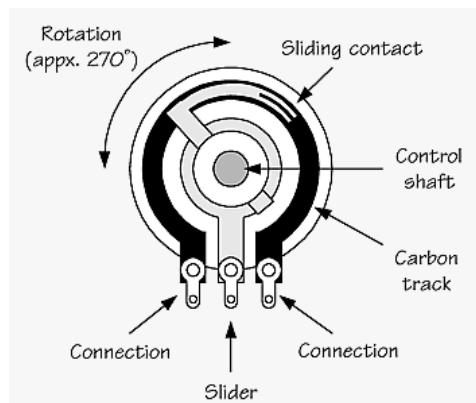
Fig: Symbol of resistor

The simple form of a carbon resistor consists of a tubular rod of carbon enclosed in an insulating ceramic tube. The value of resistance and the tolerance is usually marked on the surface of the component using coloured bands. Values from 10 ohm to 1 M ohm are typical.



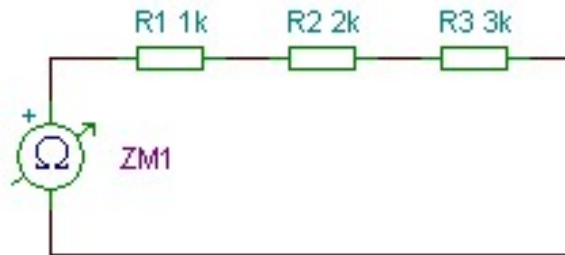
Variable resistor

The simple variable resistor consists of a circular carbon track fitted with a sliding metal contact driven by a rotary control shaft. With three terminals (two fixed connections at the extreme ends of the track and one connection to the slider) a component of this type is more correctly known as a potentiometer. Values from 1k ohm to 1 M ohm are typical.



Resistor circuit:

Resistors in Series



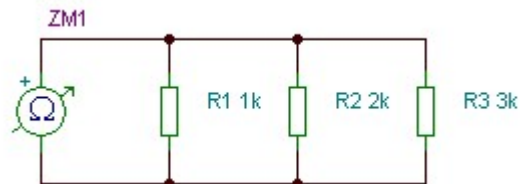
When two resistors are connected in series, the same current flows in each of them and the effective resistance of the circuit will always be greater than any one of the two resistors taken alone. The effective resistance of a circuit with two resistors (R_1 and R_2) connected in series is simply the sum of the two resistance values. Thus the effective resistance, R , of the circuit will be given by:

$$\text{(Effective resistance)} R = R_1 + R_2$$

Similarly, where three resistors (R_1 , R_2 , and R_3) are connected in series, the effective resistance of the combined circuit will be given by:

$$\text{(Effective resistance)} R = R_1 + R_2 + R_3$$

Resistors in Parallel



When two resistors are connected in parallel, the same voltage appears across each of them and the effective resistance of the circuit will always be less than any one of the two resistors taken alone. The effective resistance, R , of a circuit with two resistors, R_1 and R_2 , connected in parallel is given by:

$$1 / R = 1 / R_1 + 1 / R_2$$

Similarly, where three resistors (R_1 , R_2 , and R_3) are connected in parallel, the effective resistance of the combined circuit will be given by:

$$1 / R = 1 / R_1 + 1 / R_2 + 1 / R_3$$

In the case of two resistors, the formula can be more conveniently re-arranged as follows:

$$R = (R_1 \times R_2) / (R_1 + R_2)$$

This can be remembered as "product over sum".

Resistor Color Code

Carbon and metal oxide resistors are normally marked with color codes which indicate their value and tolerance. Two methods of color coding are in common use, one involves four colored bands while the other uses five colored bands.

digits		multiplier	tolerance	digits			multiplier	tolerance
band 1	band 2	band 3	band 4	band 1	band 2	band 3	band 4	band
black 0	black 1	black 1	1% brown	black 0	black 1	black 0	black 1	1% brown
brown 1	brown 1	brown 10	2% red	brown 1	brown 1	brown 1	brown 10	2% red
red 2	red 2	red 100	5% gold	red 2	red 2	red 2	red 100	5% gold
orange 3	orange 3	orange 1 000	10% silver	orange 3	orange 3	orange 3	orange 1 000	10% silver
yellow 4	yellow 4	yellow 10 000		yellow 4	yellow 4	yellow 4	yellow 10 000	
green 5	green 5	green 100 000		green 5	green 5	green 5	green 100 000	
blue 6	blue 6	blue 1 000 000		blue 6	blue 6	blue 6	blue 1 000 000	
violet 7	violet 7			violet 7	violet 7	violet 7		
grey 8	grey 8	0.1 gold		grey 8	grey 8	grey 8	0.1 gold	
white 9	white 9	0.01 silver		white 9	white 9	white 9	0.01 silver	

4 band resistors

5 band resistors

Lesson - 2

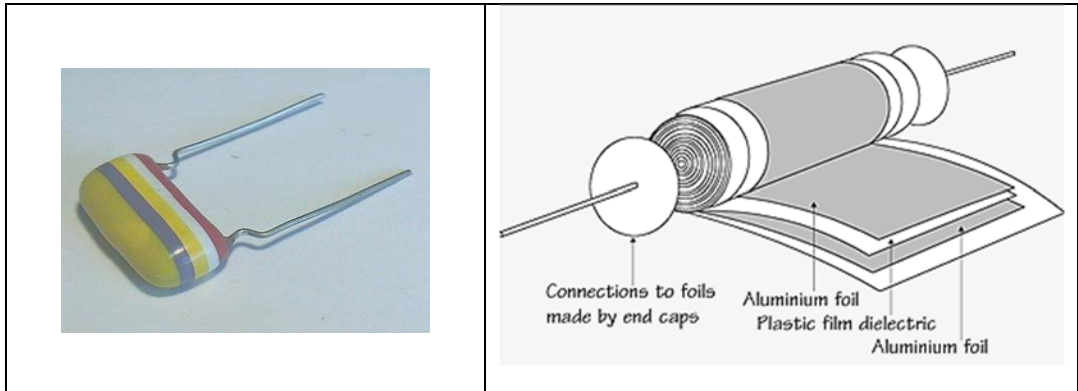
Capacitors, their construction, types, characteristics and color code

Capacitor:

It is a passive two terminal electrical component used to store energy (electrical) in an electric field that is it store electron or electrical energy and release them whenever required.

Capacitance is a measure of capacitor ability to store charge and is measure in Farad(F).

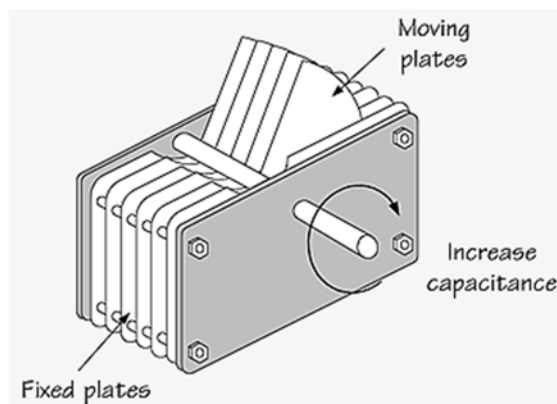
Capacitor Construction



Types of capacitor:

Solid-dielectric capacitor

This common form of solid-dielectric capacitor consists of two aluminum foils separated by a thin insulating plastic film. The entire assembly is then rolled into a tube. The capacitor is then plastic dipped in order to provide insulation and sealing against moisture. Values from $100\text{pF}(10^{-12})$ to $100\text{nF}(10^{-9})$ are typical.



Variable capacitor

This simple variable capacitor consists of sets of fixed and moving plates that are meshed with one another. The moving plates are driven by a rotary control shaft and the dielectric material between the plates is air. Values of $10\text{pF}(10^{-12})$ to $500\text{pF}(10^{-9})$ are typical.

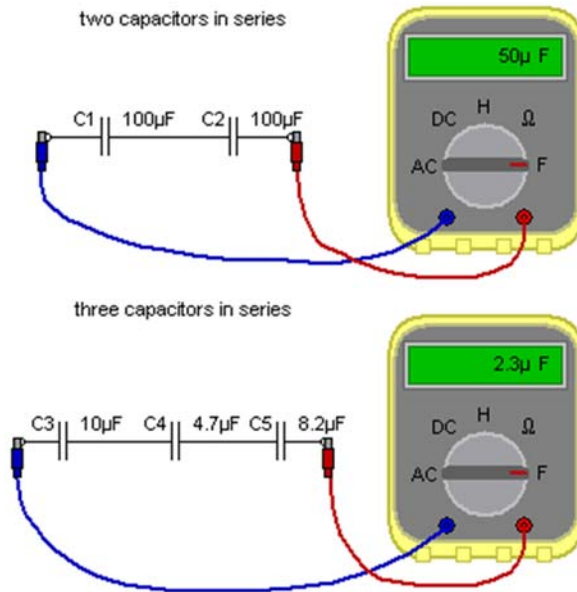
By keeping one plate (or set of plates) fixed and moving the other plate (or set of plates), a capacitor can be made variable. The dielectric material separating the plates can either be air or plastic (the latter tend to be more compact). Typical values for variable capacitors tend to range from about 25pF(10-12) to 500pF(10-12) . These components are commonly used for tuning radio receivers.



Ganged variable capacitors, in which two or three capacitors are linked together by a common control shaft, are used to simultaneously tune several tuned circuits within a radio receiver.

Finally, you may also encounter various forms of preset capacitor that are used to make occasional adjustments (e.g. for precisely calibrating the frequency of an oscillator). Various types are available including solid-dielectric and air-spaced types.

Capacitors Circuits: Capacitors in Series



When two capacitors are connected in series, the same charge is present on each of them and the effective capacitance of the circuit will always be less than any one of the two capacitors taken alone. The effective capacitance, C , of a circuit with two capacitors, C_1 and C_2 , connected in series is given by:

$$1 / C = 1 / C_1 + 1 / C_2$$

Similarly, where three capacitors (C_1 , C_2 , and C_3) are connected in series, the effective capacitance of the combined circuit will be given by:

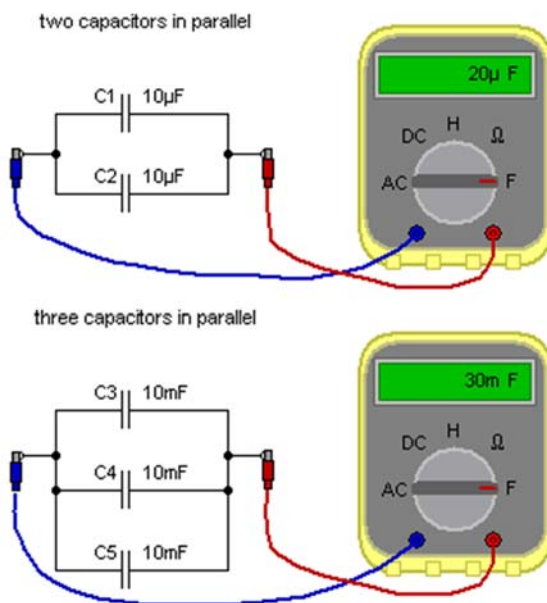
$$1 / C = 1 / C_1 + 1 / C_2 + 1 / C_3$$

In the case of two capacitors, the formula can be more conveniently re-arranged as follows:

$$C = (C_1 \times C_2) / (C_1 + C_2)$$

This can be remembered as "product over sum".

Capacitors in Parallel



When two capacitors are connected in parallel, the same potential difference appears across them and the effective capacitance of the circuit will always be greater than any one of the two capacitors taken alone. The effective capacitance of a circuit with two capacitors (C_1 and C_2) connected in parallel is simply the sum of the two capacitance values. Thus the effective capacitance of the circuit will be given by:

$$C = C_1 + C_2$$

Similarly, where three capacitors (C_1 , C_2 , and C_3) are connected in parallel, the effective capacitance of the combined circuit will be given by:

$$C = C_1 + C_2 + C_3$$

Hence, two capacitors are connected in parallel, the same potential difference appears across them and the effective capacitance of the circuit will always be greater than any one of the two capacitors taken alone. The effective capacitance of a circuit with two capacitors (C_1 and C_2) connected in parallel is simply the sum of the two capacitance values. Thus the effective capacitance of the circuit will be given by:

$$C = C_1 + C_2$$

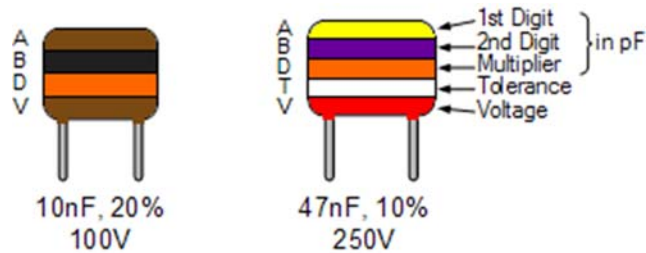
Similarly, where three capacitors (C_1 , C_2 , and C_3) are connected in parallel, the effective capacitance of the combined circuit will be given by:

$$C = C_1 + C_2 + C_3$$

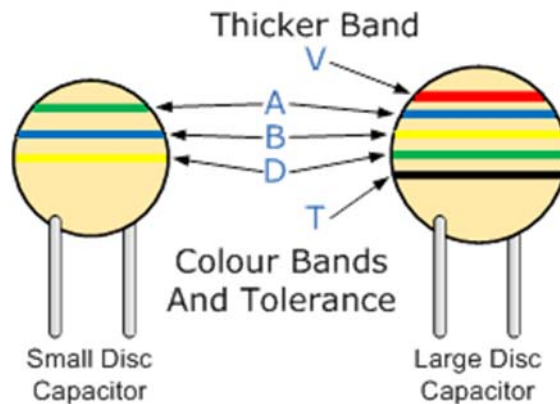
Color code of Capacitor:

Band Colour	Digit A	Digit B	Multiplier D	Tolerance (T) > 10pf	Tolerance (T) < 10pf	Temperature Coefficient (TC)
Black	0	0	x1	± 20%	± 2.0pF	
Brown	1	1	x10	± 1%	± 0.1pF	-33×10 ⁻⁶
Red	2	2	x100	± 2%	± 0.25pF	-75×10 ⁻⁶
Orange	3	3	x1,000	± 3%		-150×10 ⁻⁶
Yellow	4	4	x10,000	± 4%		-220×10 ⁻⁶
Green	5	5	x100,000	± 5%	± 0.5pF	-330×10 ⁻⁶
Blue	6	6	x1,000,000			-470×10 ⁻⁶
Violet	7	7				-750×10 ⁻⁶
Grey	8	8	x0.01	+80%,-20%		
White	9	9	x0.1	± 10%	± 1.0pF	
Gold			x0.1	± 5%		
Silver			x0.01	± 10%		

Metalised Polyester Capacitor



Disc & Ceramic Capacitor



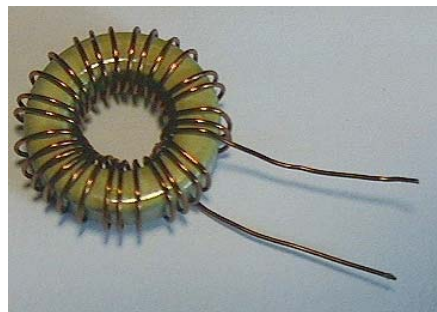
Lesson - 3

Inductors, their construction, types, characteristics and color code

Inductors:

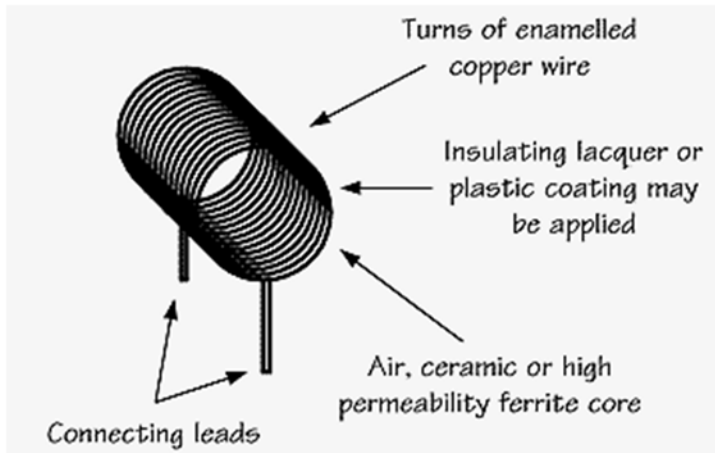
An inductor is an electrical passive component which opposes changes in current by means of energy store in the form of magnetic field.

Inductors provide us with a means of storing electrical energy in the form of a magnetic field measure by its inductance (L) and its unit is Henries (H). Typical applications include chokes, filters, and frequency selective circuits. The electrical characteristics of an



inductor are determined by a number of factors including the material of the core (if any), the number of turns, and the physical dimensions of the coil.

Inductor Construction

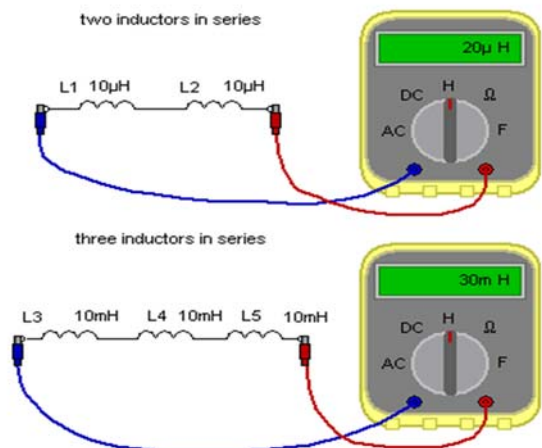


Simple Inductor

The simple form of an inductor consists of a length of insulated (enameled) copper wire spiral wound. The winding may either be self-supporting with an air core or wound onto a ceramic or high-permeability ferrite core. Values from 100 nH to 100 μ H are typical. Larger value inductors often use ferrite pot cores which provide a closed magnetic circuit with no air gaps.

Inductors in Series

When two inductors are connected in series, the same current flows in each of them and the effective inductance of the circuit will always be greater than any one of the two inductors taken alone. The effective inductance of a circuit with two inductors (L_1 and L_2) connected in series is simply the sum of the two inductance values.



Thus the effective inductance, L , of the circuit will be given by:

$$L = L_1 + L_2$$

Similarly, where three inductors (L_1 , L_2 , and L_3) are connected in series, the effective inductance of the combined circuit will be given by:

$$L = L_1 + L_2 + L_3$$

Inductors in Parallel

When two inductors are connected in parallel, the same voltage appears across each of them and the effective inductance of the circuit will always be less than any one of the two inductors taken alone. The effective inductance, L , of a circuit with two inductors, L_1 and L_2 , connected in parallel is given by:

$$1 / L = 1 / L_1 + 1 / L_2$$

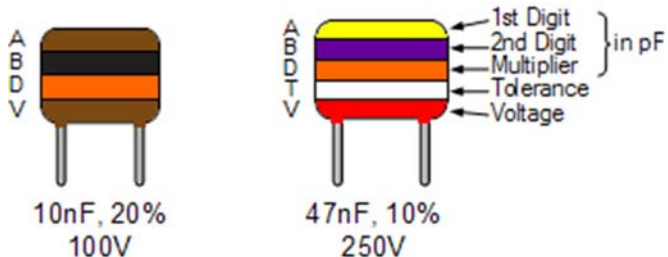
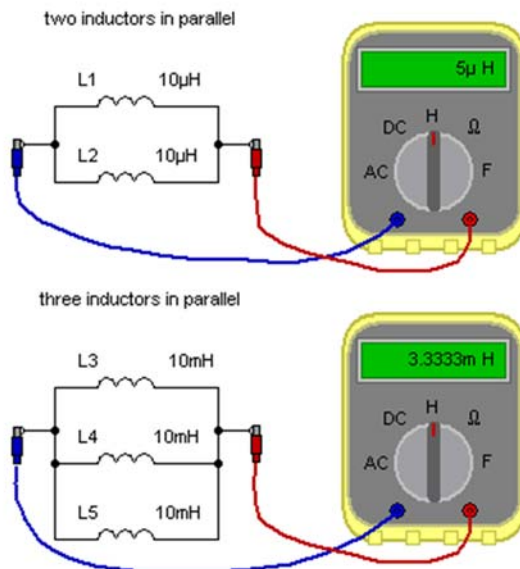
Similarly, where three inductors (L_1 , L_2 , and L_3) are connected in parallel, the effective inductance of the combined circuit will be given by:

$$1 / L = 1 / L_1 + 1 / L_2 + 1 / L_3$$

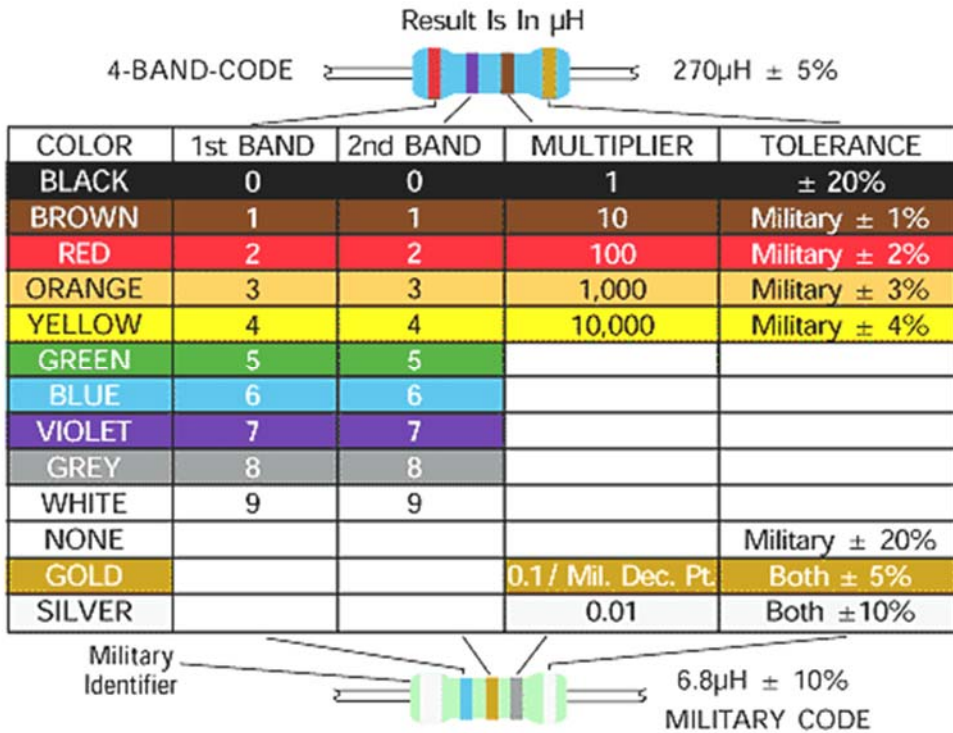
In the case of two inductors, the formula can be more conveniently re-arranged as follows:

$$L = (L_1 \times L_2) / (L_1 + L_2)$$

This is similar to the product over sum used for resistors in parallel and capacitors in series.



Color code of Inductor



Instruction for teacher

1. Give the practical examples found at their home and surrounding.
2. Use the Charts as far as possible to explain the content.
3. Assign the homework at the end of every class from the chapter so far covered during that class.
4. Conduct group discussions after finishing one lesson.

References and Resources:

<http://www.elektropage.com>

<http://www.rapidtables.com/electric/capacitor.htm>

<http://whatis.techtarget.com>

- ▶ Principles of physics-II, Ayam Publication Pvt.Ltd
- ▶ Electronic Principles, Alberto Malvino/David Bates,

List of practical lab for the passive component

(Each lab required 2 hours)

LAB NO.1: TO MEASURE RESISTANCE OF DIFFERENT RANGE OF RESISTORS USING COLOR CODE.

LAB NO2: TO MEASURE RESISTANCE OF DIFFERENT RANGE OF RESISTOR USING DIGITAL MULTIMETER.

LAB NO3: TO MEASURE EQUIVALENT RESISTANCE OF SERIES CONNECTION.

LAB NO4: TO MEASURE EQUIVALENT RESISTANCE OF PARALLEL CONNECTION.

Lab NO 5: TO MEASURE CAPACITANCE OF DIFFERENT RANGE OF CAPACITOR USING COLOR CODE.

LAB NO6: TO MEASURE EQUIVALENT CAPACITANCE OF SERIES CONNECTION.

LAB NO7: TO MEASURE EQUIVALENT CAPACITANCE OF PARALLEL CONNECTION.

Lab NO 8: TO MEASURE INDUCTANCE OF DIFFERENT RANGE OF INDUCTOR USING COLOR CODE.

LAB NO9: TO MEASURE EQUIVALENT INDUCTANCE OF SERIES CONNECTION.

LAB NO10: TO MEASURE EQUIVALENT INDUCTANCE OF PARALLEL CONNECTION.

LAB NO.1: TO MEASURE RESISTANCE OF DIFFERENT RANGE OF RESISTORS USING COLOR CODE.

a) Apparatus required:

- ▶ Resistor of different ranges
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

b) Theory:

- ▶ Resistor

- ▶ Knowledge about table of color code for up to 4 bands.

c) Procedure:

- i. Collect all the required resistor having different color code.
- ii. Calculate the resistance of given resistor according to color code table.

d) Calculation:

e) Conclusion:

LAB NO 2: TO MEASURE RESISTANCE OF DIFFERENT RANGE OF RESISTOR USING DIGITAL MULTIMETER.

1. Apparatus required:

- ▶ Resistor of different range
- ▶ Digital multimeter
- ▶ Connecting wire
- ▶ Breadboard

2. Theory:

- ▶ Resistor

- ▶ Knowledge of multimeter

- ▶ Use of multimeter to measure resistance

3. Procedure:

- i. Collect all the required resistor of different ranges
- ii. Connect RED cord of multimeter to one terminal of resistor and BLACK cord to another terminal of the resistor.
- iii. Set the multimeter tuner to the symbol to Ω indicator.
- iv. Read the values from the Multimeter display panel.

4. Result and Conclusion:

LAB NO3: TO MEASURE EQUIVALENT RESISTANCE OF SERIES CONNECTION.

1. Apparatus required:

- ▶ Resistor of different range
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

2. Theory:

- ▶ Resistor (series connection)

$$R=R_1+R_2+\dots\dots+R_n$$

- ▶ Knowledge of multimeter
- ▶ Use of multimeter to measure resistance



Resistor in series

3. Procedure:

- i. Collect all the required resistor of different ranges
- ii. Connect any two or more resistor in series pattern.
- iii. Connect RED cord of multimeter to one end of the series circuit of resistor and BLACK cord to another end of the circuit of the resistor.
- iv. Set the multimeter tuner to the symbol to Ω indicator.
- v. Read the values from the Multimeter display panel.

4. Conclusion:

LAB NO4: TO MEASURE EQUIVALENT RESISTANCE OF PARALLEL CONNECTION.

1. Apparatus required:

- ▶ Resistor of different range
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

2. Theory:

- ▶ Resistor (series connection)

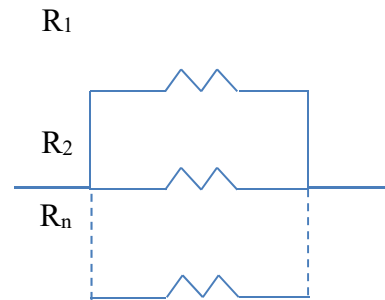
$$1/R = 1/R_1 + 1/R_2 + \dots + 1/R_n$$

Resistor in parallel

- ▶ Knowledge of multimeter
- ▶ Use of multimeter to measure resistance

3. Procedure:

- vi. Collect all the required resistor of different ranges
- vii. Connect any two or more resistor in parallel pattern.
- viii. Connect RED cord of multimeter to one end of the parallel circuit of resistor and BLACK cord to another end of the circuit of the resistor.
- ix. Set the multimeter tuner to the symbol to Ω indicator.
- x. Read the values from the Multimeter display panel.



4. Result and Conclusion:

Lab NO 5: TO MEASURE CAPACITANCE OF DIFFERENT RANGE OF CAPACITOR USING COLOR CODE.

a. Apparatus required:

- ▶ Capacitor of different ranges
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

b. Theory:

- ▶ Capacitor

- ▶ Knowledge about table of color code for up to 4 bands.

c. Procedure:

- i. Collect all the required capacitor having different color code.
- ii. Calculate the capacitance of given capacitor according to color code table.

d. Calculation:

e. Conclusion:

LAB NO6: TO MEASURE EQUIVALENT CAPACITANCE OF SERIES CONNECTION.

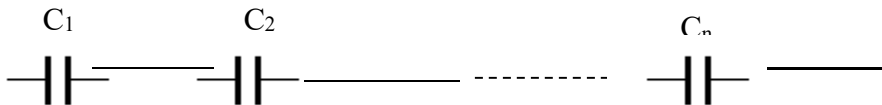
1. Apparatus required:

- ▶ Capacitor of different range
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

2. Theory:

- Capacitor (series connection)

$$1/C=1/C_1+1/C_2+\dots\dots\dots+1/C_n$$



Capacitor in series connection

3. Procedure:

- i. Collect all the required capacitor of different ranges
- ii. Connect any two or more capacitor in series pattern.
- iii. Calculate the equivalent capacitance of given circuit.

4. Conclusion:

LAB NO7: TO MEASURE EQUIVALENT CAPACITANCE OF PARALLEL CONNECTION.

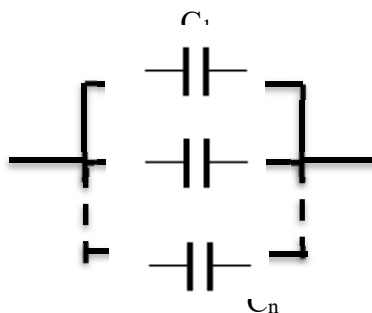
1. Apparatus required:

- ▶ Capacitor of different range
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

2. Theory:

- ▶ Capacitor (Parallel connection)

$$C=C_1+C_2+\dots\dots+C_n$$



3. Procedure:

- Collect all the required capacitor of different ranges
- Connect any two or more capacitor in parallel pattern.
- Calculate the equivalent capacitance of the given circuit.

4. Result and Conclusion:

Lab NO 8: TO MEASURE INDUCTANCE OF DIFFERENT RANGE OF INDUCTOR USING COLOR CODE.

a. Apparatus required:

- ▶ Inductor of different ranges
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

b. Theory:

- ▶ Inductor

- ▶ Knowledge about table of color code for up to 4 bands.

c. Procedure:

- i. Collect all the required Inductor having different color code.
- ii. Calculate the inductance of given Inductor according to color code table.

d. Calculation:

e. Conclusion:

LAB NO9: TO MEASURE EQUIVALENT INDUCTANCE OF SERIES CONNECTION.

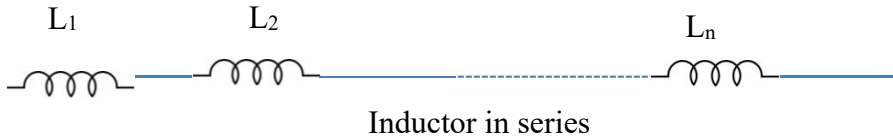
1. Apparatus required:

- ▶ Inductor of different range
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)

2. Theory:

- ▶ Inductor (series connection)

$$L=L_1+L_2+\dots\dots+L_n$$



3. Procedure:

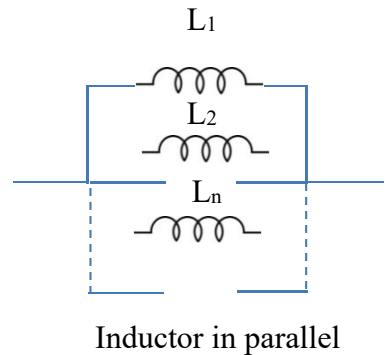
- Collect all the required inductor of different ranges
- Connect any two or more inductor in series pattern.
- Calculate the equivalent inductance of given circuit.

4. Conclusion:

LAB NO10: TO MEASURE EQUIVALENT INDUCTANCE OF PARALLEL CONNECTION.

1. Apparatus required:

- ▶ Inductor of different range
- ▶ Connecting wire
- ▶ Breadboard
- ▶ Multimeter (digital)
- ▶ Theory:
- ▶ Inductor (Parallel connection)
- ▶ $1/L=1/L_1+1/L_2+\dots\dots+1/L_n$



2. Procedure:

- i. Collect all the required inductor of different ranges
- ii. Connect any two or more inductor in parallel pattern.
- iii. Calculate the equivalent inductance of the given circuit.

3. Result and Conclusion:

UNIT - 3

Semiconductor

Learning Outcomes

- Understand crystalline structure, Energy levels, energy bands and conduction of electrons and holes.
- Understand the concept of doping, P and N type material, majority and minority carrier.
- Explain characteristic of Germanium and Silicon material.
- Explain the conditions that exist at the pn junction of an unbiased diode, a forward-biased diode, and a reverse-biased diode.
- Describe the types of breakdown current (Avalanche and Zener breakdown)

Lesson - 1

The solids are characterized by a definite shape as well as a definite volume. Depending upon the nature and arrangement of atoms or molecules, solids are broadly classified into following two categories

- i) Crystalline solids
- ii) Amorphous (non- crystalline or glassy) solids.

Crystalline solids

A crystal or crystalline solid is a solid material whose constituents, such as atoms, molecules or ions, are arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions. In addition, macroscopic single crystals are usually identifiable by their geometrical shape, consisting of flat faces with specific, characteristic orientations.

Crystalline solids possess the following characteristics

1. The atoms and molecules are arranged in a definite order, giving them a definite geometrical form.
2. They exhibit long range order.

3. They are bound by flat surface.
4. They have homogeneous composition
5. They have sharp melting point and boiling point
6. They are anisotropic.
7. All the bonds in the crystalline solids are equally strong.

Examples of large crystals include snowflakes, diamonds, and table salt. Most inorganic solids are not crystals but poly crystals, i.e. many microscopic crystals fused together into a single solid. Examples of poly crystals include most metals, rocks, ceramics, and ice. A third category of solids is amorphous solids, where the atoms have no periodic structure whatsoever. Examples of amorphous solids include glass, wax, and many plastics.

Amorphous Solids

Amorphous solids are those solids in which the atoms are not arranged in regular geometrical pattern Ordinary glass, sulphur, plastics etc are examples of amorphous solids. Amorphous solids possess the following characteristics:

1. They do not possess characteristic geometrical shapes.
2. Atoms or molecules of amorphous solids are arranged in irregular ways.
3. They exhibit short range order.
4. Their composition may not be homogeneous.
5. They are isotropic, so they have same physical properties in all direction.
6. They do not have sharp melting point.
7. Bonds between different atoms are not identical.

Lesson - 2

Energy level

An atom of a matter consists of some definite number of electrons and the electrons are moving in various orbits around the nucleus. The first orbit has the least energy and the outer most orbits has the greatest energy. The first orbit is the first energy level, the second orbit is called the second energy level and so on.

If various energy levels of an isolated atom are drawn in one dimensional graph, the graph obtained is called the energy level diagram. The positions of orbits and their energy levels are shown respectively in the figure.

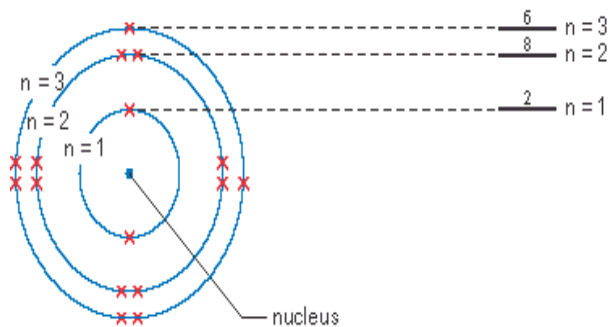


Fig (a)

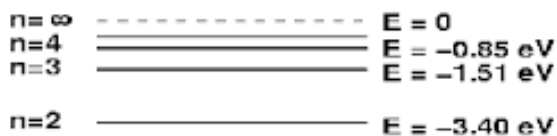


fig (b)



Lesson - 3

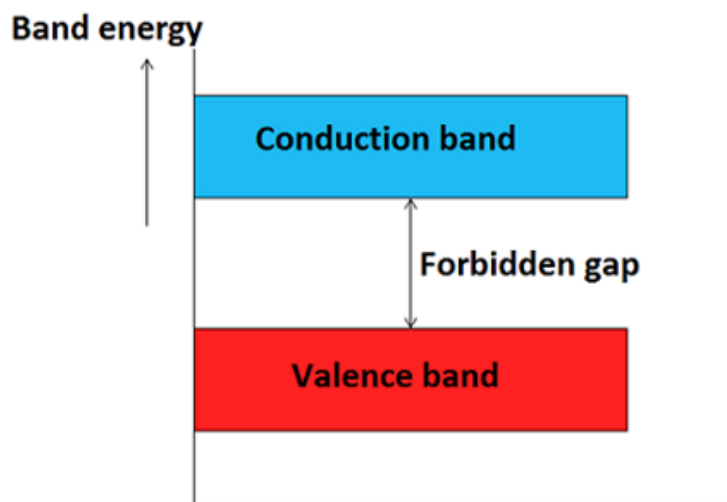
Band theory in solids

In a single isolated atom, the electrons in each orbit have definite energy associated with it. But in case of solids all the atoms are close to each other, so the energy levels of outermost orbit electrons are affected by the neighboring atoms.

When two single or isolated atoms are bring close to each other then the outermost orbit electrons of two atoms are interact or shared with each other. i.e, the electrons in the outermost orbit of one atom experience a attractive force from the nearest or

neighboring atomic nucleus. Due to this the energies of the electrons will not be in same level, the energy levels of electrons are changed to a value which is higher or lower than that of the original energy level of the electron. The electrons in same orbit exhibit different energy levels. The grouping of these different energy levels is called energy band. However, the energy levels of inner orbit electrons are not much affected by the presence of neighboring atoms. Important energy bands in solids: there are number of energy bands in solids but three of them are very important. These three energy bands are important to understand the behavior of solids. These energy bands are

- Valence band
- Conduction band
- Forbidden band or forbidden gap



Valence band

The energy band which is formed by grouping the range of energy levels of the valence electrons or outermost orbit electrons is called as valence band. Valence band is present below the conduction band as shown in figure. Electrons in the valence band have lower energy than the electrons in conduction band. The electrons present in the valence band are loosely bound to the nucleus of atom.

Conduction band

The energy band which is formed by grouping the range of energy levels of the free electrons is called as conduction band. Generally, the conduction band is empty but when external energy is applied the electrons in the valence band jumps in to the conduction band and becomes free electrons. Electrons in the conduction band have higher energy than the electrons in valence band. The conduction band electrons are not bound to the nucleus of atom.

Forbidden gap

The energy gap which is present between the valence band and conduction band by separating these two energy bands is called as forbidden band or forbidden gap. In solids, electrons cannot stay in forbidden gap because there is no allowed energy state in this region. Forbidden gap is the major factor for determining the electrical conductivity of a solid. The classification of materials as insulators, conductors and semiconductors is mainly depends on forbidden gap. The energy associated with forbidden band is called energy gap and it is measured in unit electron volt (eV).

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

The applied external energy in the form of heat or light must be equal to to the forbidden gap in order to push an electron from valence band to the conduction band.

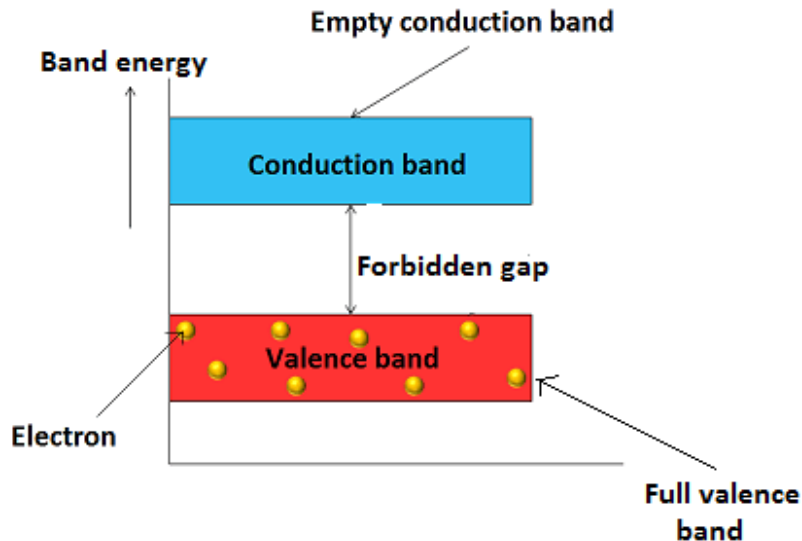
Lesson - 4

Classification of materials based on forbidden gap

Forbidden gap plays a major role for determining the electrical conductivity of material. Based on the forbidden gap materials are classified in to three types, they are

- Insulators
- Conductors
- semiconductors
- Insulators

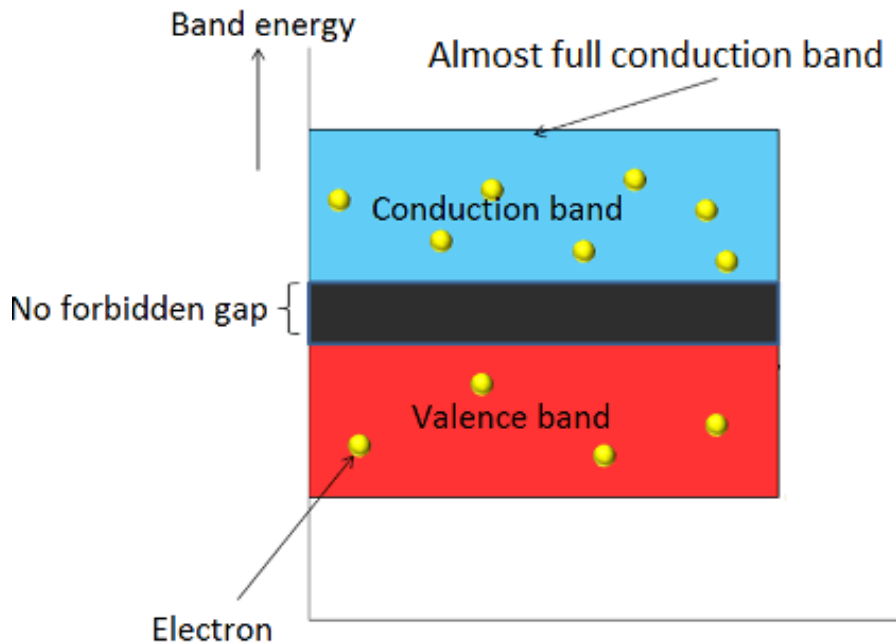
The material which does not allow the flow of electric current through them are called as insulators. Insulators are also called as poor conductors of electricity.



Normally, in insulators the valence band is fully occupied with electrons due to sharing of outer most orbit electrons with the neighboring atoms. Whereas conduction band is empty, i.e, no electrons are present in conduction band. The forbidden gap between the valence band and conduction band is very large in insulators. The energy gap of insulator is approximately equal to 15 electron volts (eV). The electrons in valence band cannot move because they are locked up between the atoms. In order move the valence band electrons in to conduction band large amount of external energy is applied which is equal to the forbidden gap. But in insulators, this is practically impossible to move the valence band electrons in to conduction band. Rubber, wood, diamond, plastic are some examples of insulators. Insulators such as plastics are used for coating of electrical wires. These insulators prevent the flow of electricity to unwanted points and protect us from electric shocks.

Conductors

The materials which easily allow the flow of electric current through them are called as conductors. Metals such as copper, silver, iron, aluminum etc. are good conductors of electricity.

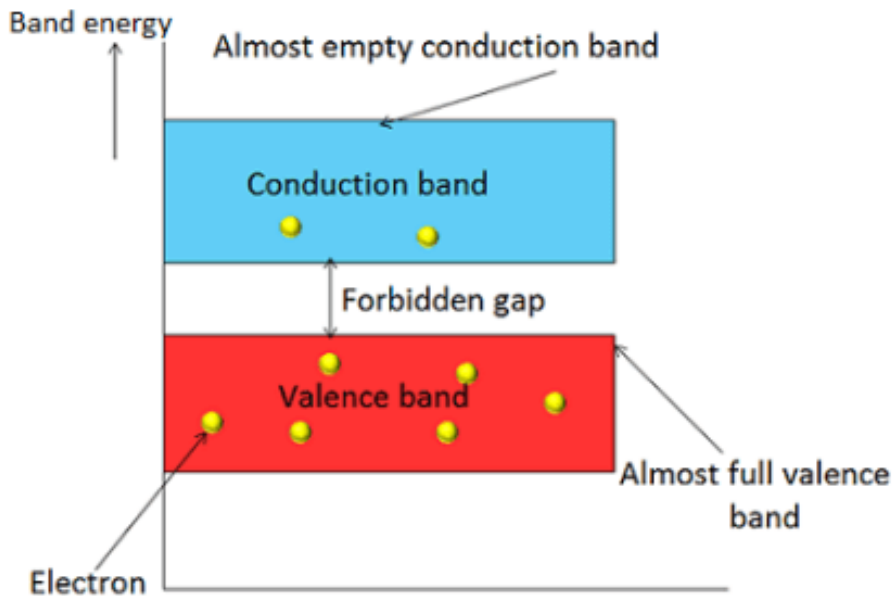


In a conductor, valence band and conduction band overlap each other as shown in figure. Therefore, there is no forbidden gap in a conductor. A small amount of applied external energy provides enough energy for the valence band electrons to move in to conduction band. Therefore, more number of valence band electrons can easily moves in to the conduction band. When valence band electrons move to conduction band they becomes free electrons. The electrons present in the conduction band are not attached to the nucleus of atom.

In conductors, large numbers of electrons are present in conduction band at room temperature, i.e, conduction band is almost full with electrons. Whereas valence band is partially occupied with electrons. The electrons present in the conduction band moves freely by carrying the electric current from one point to other.

Semiconductors

The material which has electrical conductivity between that of a conductor and an insulator is called as semiconductor. Silicon, germanium and graphite are some examples of semiconductors.



In semiconductors, the forbidden gap between valence band and conduction band is very small. It has a forbidden gap of about 1 electron volt (eV). At low temperature, the valence band is completely occupied with electrons and conduction band is empty because the electron in the valence band does not have enough energy to move in to conduction band. Therefore, semiconductor behaves as an insulator at low temperature. However, at room temperature some of the electrons in valence band gains enough energy in the form of heat and moves in to conduction band.

When the temperature is goes on increasing, the number of valence band electrons moving in to conduction band is also increases. This shows that electrical conductivity of the semiconductor increases with increase in temperature. I.e. a semiconductor has negative temperature co-efficient of resistance. The resistance of semiconductor decreases with increase in temperature.

Fermi Energy

- The highest energy level occupied by an electron in the energy band at zero Kelvin (0 K) is called Fermi level, and corresponding energy is called Fermi energy. Therefore, at 0K all the states below Fermi level are occupied by

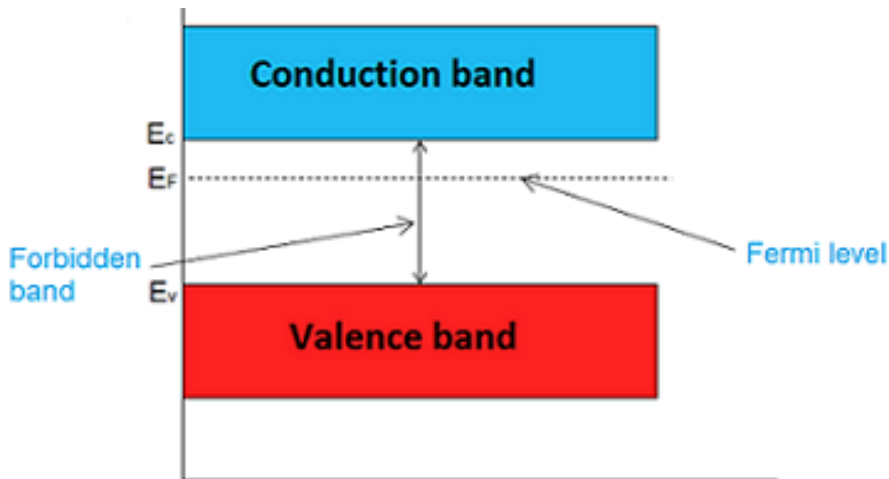
electrons and all the states above the Fermi level are empty. In pure germanium the Fermi level is about half way in the forbidden gap. When we add pentavalent impurity in the pure Ge or Si, the Fermi level in forbidden gap shifts very close to conduction band when we add a trivalent impurity in the pure semiconductor Ge or Si, the Fermi level in the forbidden gap shifts very close to valence band.

Fermi level in extrinsic semiconductor

In extrinsic semiconductor, the number of electrons in the conduction band and the number of holes in the valence band are not equal. Hence, the probability of occupation of energy levels in conduction band and valence band are not equal. Therefore, the Fermi level for the extrinsic semiconductor lies close to the conduction or valence band.

Fermi level in n-type semiconductor

In n-type semiconductor pentavalent impurity is added. Each pentavalent impurity donates a free electron. The addition of pentavalent impurity creates large number of free electrons in the conduction band.



At room temperature, the number of electrons in the conduction band is greater than the number of holes in the valence band. Hence, the probability of occupation of energy levels by the electrons in the conduction band is greater than the probability of occupation of energy levels by the holes in the valence band. This probability of occupation of energy levels is represented in terms of Fermi level. Therefore, the Fermi level in the n-type semiconductor lies close to the conduction band.

The Fermi level for n-type semiconductor is given as

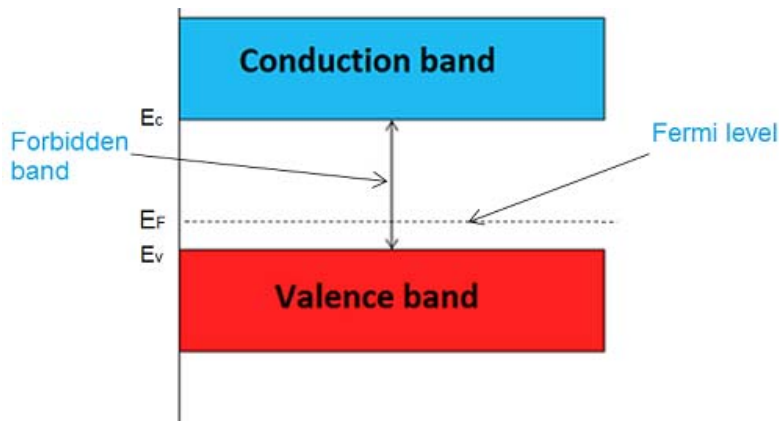
$$E_F = E_C - K_B T \log \frac{N_C}{N_D}$$

Where E_F is the Fermi level.

- ▶ E_C is the conduction band.
- ▶ K_B is the Boltzmann constant.
- ▶ T is the absolute temperature.
- ▶ N_C is the effective density of states in the conduction band.
- ▶ N_D is the concentration of donor atoms.

Fermi level in p-type semiconductor

In p-type semiconductor trivalent impurity is added. Each trivalent impurity creates a hole in the valence band and ready to accept an electron. The addition of trivalent impurity creates large number of holes in the valence band.



At room temperature, the number of holes in the valence band is greater than the number of electrons in the conduction band. Hence, the probability of occupation of energy levels by the holes in the valence band is greater than the probability of occupation of energy levels by the electrons in the conduction band. This probability of occupation of energy levels is represented in terms of Fermi level. Therefore, the Fermi level in the p-type semiconductor lies close to the valence band.

The Fermi level for p-type semiconductor is given as

$$E_F = E_V + K_B T \log \frac{N_V}{N_A}$$

Where

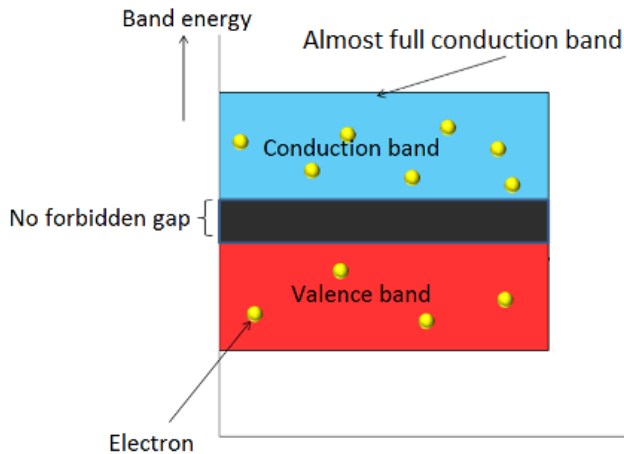
N_V is the effective density of states in the valence band.

N_A is the concentration of acceptor atoms.

- ▶ E_F is the Fermi level.
- ▶ E_V is the Valence band.
- ▶ K_B is the Boltzmann constant.
- ▶ T is the absolute temperature.

Heat effect on conductors

Conductors are the materials that easily allow the flow of electrons or electric current through them. In a conductor, no forbidden gap is present between the valence band and the conduction band. Hence, the valence electrons can easily jump into the conduction band.



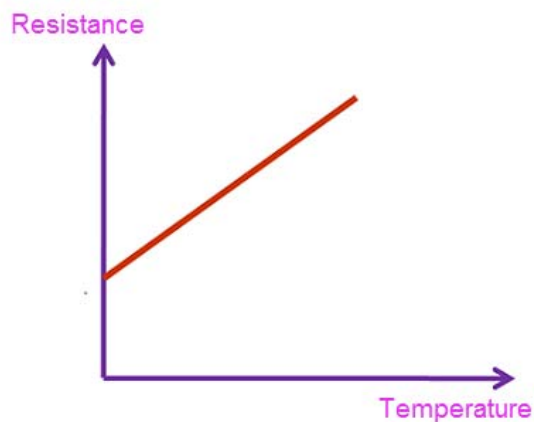
When a small amount of external energy in the form of heat is applied to the conductor, the valence band electrons or the valence electrons gain enough energy to break the bonding with the parent atom and they jump into the conduction band. The electrons that are present in the conduction band are not attached to the parent atom. Hence, the electrons present in the conduction band move freely from one

place to another place within the conductor. The electrons present in the conduction band are called as free electrons. These free electrons carry the electric charge or electric current with them while moving from one place to another place within the conductor.

In conductors, even at low temperature, a small number of free electrons are present, whereas at room temperature, a large number of free electrons are present in the conduction band.

When the heat energy is applied to the conductor, the atoms start vibrating at fixed positions and the free electrons moving in the conduction band will collide with these atoms. Due to this collision, the free electrons will lose their kinetic energy by transferring their kinetic energy to the atoms with which they collide.

After collision with the atoms, the free electrons again start moving in other direction and again the free electrons collide with another atom. This will result in loss of kinetic energy of the free electrons. Likewise, the free electrons will collide with the atoms repeatedly. This causes a reduction in the flow of free electrons that carry the electric current or electric cha



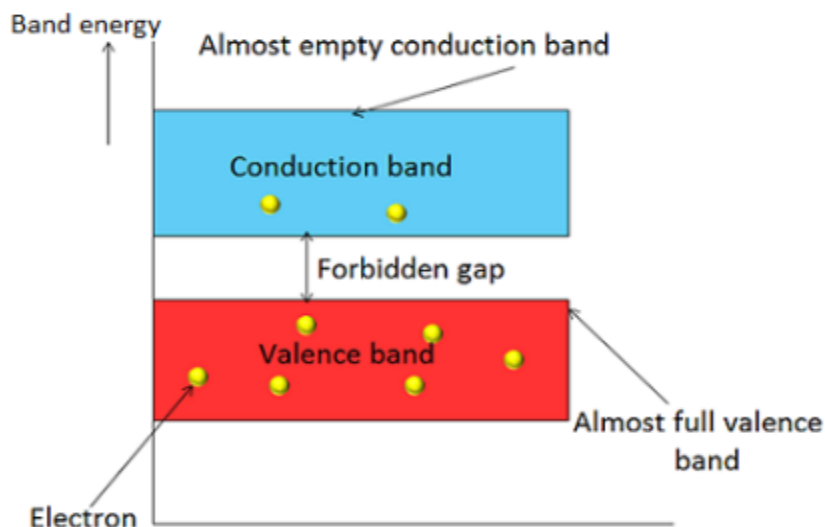
The concept of collisions of free electrons with the atoms in the conductor can be easily understood with a simple example. Let us consider a Track running (hurdling) game of 100 meters in which 10 athletes are participating. In this Track running (hurdling) game, for each player 20 hurdles are placed in a series over the running track. The participants have to reach the destination by overcoming the hurdles.

When the athletes start running by increasing their speed, they gain the kinetic energy. When the 10 athletes collide with the first hurdle, they lose their kinetic energy and transfer the kinetic energy to the hurdle. After a collision with the first hurdle, the athletes again start running by increasing their speed (kinetic energy). If the athletes again collide at the second hurdle, they again lose their kinetic energy. Likewise, the athletes collide with the hurdles repeatedly. This results in reduction in the speed of athletes. Here, the free electrons act as 10 athletes that always try to move from one place to another place whereas the vibrating atoms at fixed positions act as hurdles that oppose the flow of free electrons. Reduction in current flow means increase in resistance. Hence, the resistance of a conductor increases with the increase in the temperature (heat). Therefore, conductors have a positive temperature coefficient.

Lesson 5

Introduction to semiconductor

The material which has electrical conductivity between that of a conductor and that of an insulator is called a semiconductor. Silicon, germanium, and graphite are some examples of semiconductors. Semiconductors are the foundation of modern electronics, including transistors, Light-Emitting diodes, solar cells, etc.



In semiconductors, the forbidden gap between valence band and conduction band is very small. It has a forbidden gap of about 1 electron volt (eV). At low temperature, the valence band is completely occupied with electrons and conduction band is empty because the electrons in the valence band do not have enough energy to move in to conduction band. Therefore, semiconductor behaves as an insulator at low temperature. However, at room temperature some of the electrons in valence band gains enough energy in the form of heat and moves in to conduction band. When the valence electrons move in to conduction band they becomes free electrons. These electrons are not attached to the nucleus of a atom, So they moves freely.

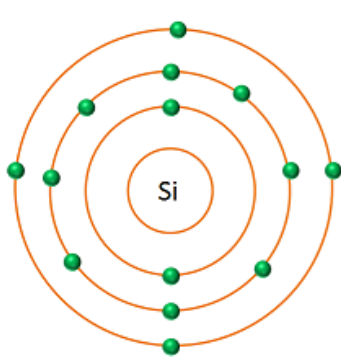
The conduction band electrons are responsible for electrical conductivity. The measure of ability to conduct electric current is called as electrical conductivity. When the temperature is goes on increasing, the number of valence band electrons moving in to conduction band is also increases. This shows that electrical conductivity of the semiconductor increases with increase in temperature. i.e. a semiconductor has negative temperature co-efficient of resistance. The resistance of semiconductor decreases with increase in temperature. In semiconductors, electric current is carried by two types of charge carriers they are electrons and holes.

Atomic structure of silicon and germanium

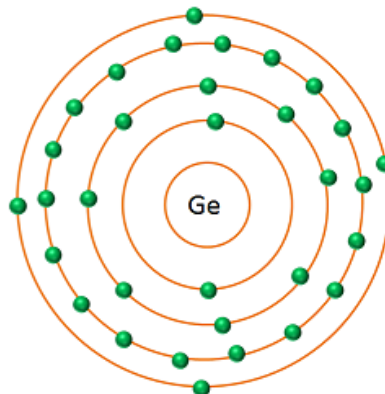
The atomic structure of intrinsic semiconductor materials like silicon and germanium is as follows.

Atomic structure of silicon

Silicon is a substance consisting of atoms which all have the same number of protons. The atomic number of silicon is 14 i.e. 14 protons. The number of protons in the nucleus of an atom is called atomic number. Silicon atom has 14 electrons (two electrons in first orbit, eight electrons in second orbit and 4 electrons in the outermost orbit).



Silicon



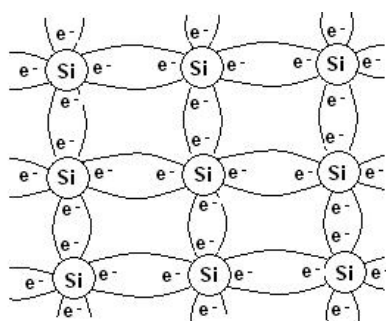
Germanium

Atomic structure of germanium

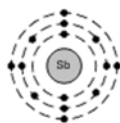
Germanium is a substance consisting of atoms which all have the same number of protons. The atomic number of germanium is 32 i.e. 32 protons. The number of protons in the nucleus of atom is called atomic number. Germanium has 32 electrons (2 electrons in first orbit, 8 electrons in second orbit, 18 electrons in third orbit and 4 electrons in the outermost orbit).

Chemical bond in semiconductor

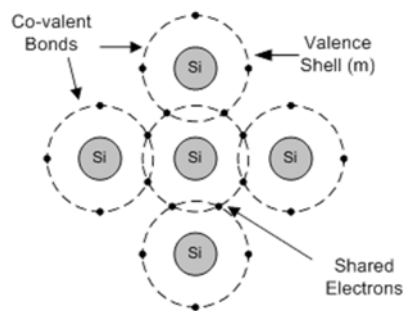
The elements which do not have free electrons and have small forbidden energy gap are the elements having four valence electrons. For example, Si, Ge, C etc. Of course, there are a lot of semiconducting substances, but the most suitable for our purpose are Silicon (Si) and Germanium (Ge).



A Silicon Atom, Atomic number = 14



Silicon atom showing 4 electrons in its outer valence shell (m)



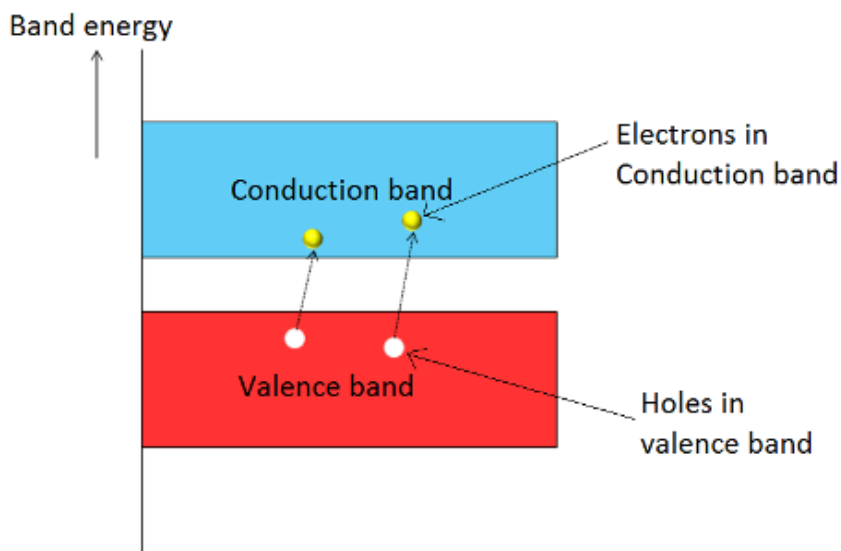
Silicon Crystal Lattice

The chemical bonds between such tetravalent atoms are called the covalent bonds. In covalent bonds, the atoms share their electrons among themselves in order to form an octet-an electron shell having 8 electrons in it. When a shell has 8 electrons in it, it is stable. Therefore, in a semiconductor material, which is tetravalent, an atom shares its four electrons with electrons of four surrounding atoms and completes its shell thus forming four covalent bonds. For example, in Si and Ge, each Si (or Ge) atom shares its four electrons with four electrons of four surrounding Si (or Ge) atoms, thus forming four covalent bond.

Lesson - 6

Holes

When an electron jumps from a covalent bond, it leaves a vacancy there. An electron from a neighboring atom can move into this vacancy, leaving the neighbor with new vacancy. This vacancy is called a hole which can travel through the material and serves as additional current carrier. In a pure semiconductor such as silicon, the numbers of holes in the valence band are equal to the number of electrons in conduction band. When an electric field is applied, they move in opposite directions to each other. So, a hole in a valence band acts as a positively charged particle although the moving charges in that band are electrons.



Classification of semiconductors :-

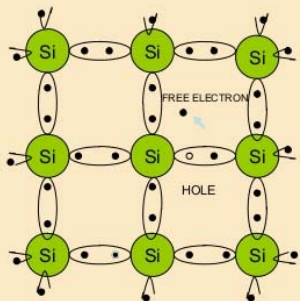
Semiconductors are classified into two types.

(i) Intrinsic semiconductors (ii) Extrinsic semiconductors

Intrinsic semiconductor :-

A semi-conductor in an extremely pure form is known as an intrinsic semiconductor. In an Intrinsic semiconductor, even at room temperature, hole-electron are created. When electric field is applied across an intrinsic semiconductor, the current conduction takes place by two process, namely by free electrons and holes. Free electrons are produced due to the breaking up of co-valent bonds by thermal energy. At the same time holes are created in the co-valent bond itself. When electric field is applied across the semiconductors material, electrons will move towards the positive terminal of supply, holes will move towards negative terminal of the supply. Thus current conduction inside this intrinsic semiconductor material is due to movement of holes & electrons. But the current in the external wire is only because of electrons. Since while applying electric field, holes are attracted towards negative terminal. There one new electron is introduced. This electron will combine with the hole, thus cancelling them. At the same time electrons are moving towards positive terminal, while leaving from this intrinsic material it leaves a hole. Again this holes are attracted towards negative terminal.

Intrinsic Semiconductor



- Semiconductor in pure form is known as Intrinsic Semiconductor.
- Ex. Pure Germanium, Pure Silicon.
- At room temp. no of electrons equal to no. of holes.

Fig 1.

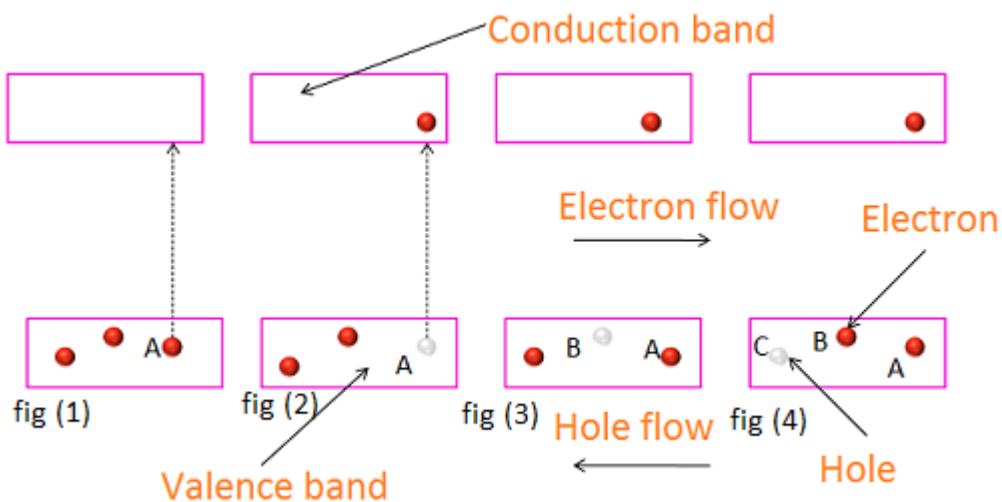
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Intrinsic semiconductor

Electron and hole current

In conductors current is caused by only motion of electrons but in semiconductors current is caused by both electrons in conduction band and holes in valence band. Current that is caused by electron motion is called electron current and current that is caused by hole motion is called hole current. Electron is a negative charge carrier whereas hole is a positive charge carrier. At absolute zero temperature intrinsic semiconductor behaves as insulator. However, at room temperature the electrons present in the outermost orbit absorb thermal energy. When the outermost orbit electrons get enough energy then they will break bonding with the nucleus of atom and jump into conduction band. The electrons present in conduction band are not attached to the nucleus of an atom so they are free to move.

When the valence electron moves from valence band to the conduction band a vacancy is created in the valence band where electron left. Such vacancy is called hole.



Let's take an example, as shown in fig there are three atoms atom A, atom B and atom C. At room temperature valence electron in an atom A gains enough energy and jumps into conduction band as shown in fig (1). When it jumps into conduction band a hole (vacancy) is created in the valence band at atom A as shown in fig (2). Then the neighboring electron from atom B moves to atom A to fill the hole at atom

A. This creates a hole at atom B as shown in fig (3). Similarly neighboring electron from atom C moves to atom B to fill the hole at atom B. This creates a hole at atom C as shown in fig (4). Likewise electrons moves from left side to right side and holes moves from right to left side.

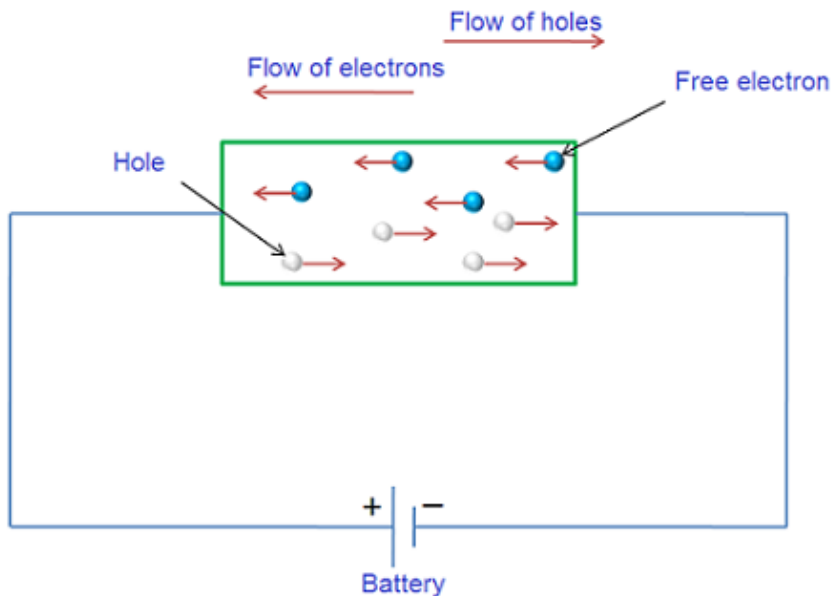
Charge carriers in intrinsic semiconductor

The semiconductors that are in pure form are called intrinsic semiconductors. In intrinsic semiconductor the total number of negative charge carriers (free electrons) is equal to the total number of positive charge carriers (holes or vacancy).

Total negative charge carriers = Total positive charge carriers

Conduction in intrinsic semiconductor

The process of conduction in intrinsic semiconductor is shown in below fig. In the below fig, an intrinsic semiconductor is connected to a battery. Here, positive terminal of battery is connected to one side and negative terminal of the battery is connected to other side. As we know like charges repel each other and opposite charges attract each other. In the similar way negative charge carriers (electrons) are attracted towards the positive terminal of battery and positive charge carriers (holes) attracted towards the negative terminal of battery.



Electrons will experience a attractive force from the positive terminal, so they move towards the positive terminal of the battery by carrying the electric current. Similarly holes will experience a attractive force from the negative terminal, so they moves towards the negative terminal of the battery by carrying the electric current. Thus, in a semiconductor electric current is carried by both electrons and holes.

In intrinsic semiconductor the number of free electrons in conduction band is equal to the number of holes in valence band. The current caused by electrons and holes is equal in magnitude.

The total current in intrinsic semiconductor is the sum of hole and electron current.

Total current = Electron current + Hole current

$$I = I_{\text{hole}} + I_{\text{electron}}$$

Doping a Semiconductor

One way to increase conductivity of a semiconductor is by doping. This means adding impurity atoms to an intrinsic crystal to alter its electrical conductivity. A doped semiconductor is called an extrinsic semiconductor.

Increasing the Free Electrons

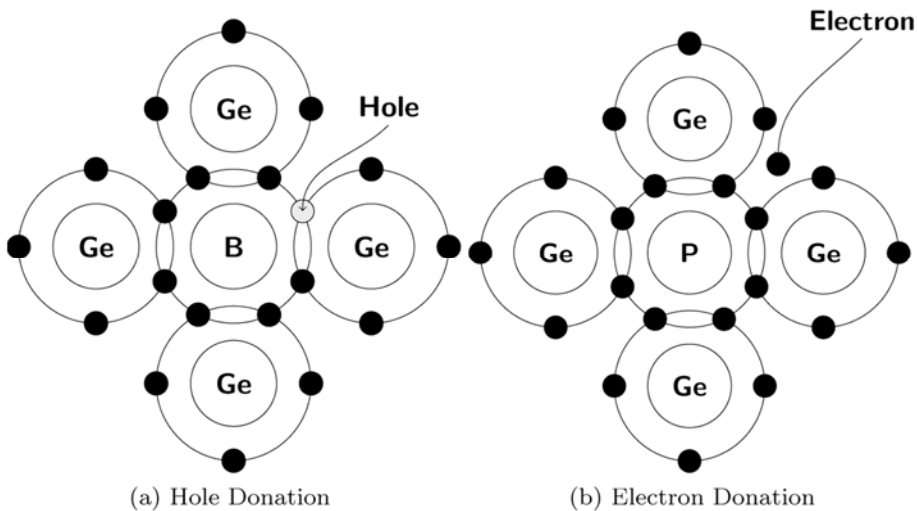
How does a manufacturer dope a silicon crystal? The first step is to melt a pure silicon crystal. This breaks the covalent bonds and changes the silicon from a solid to a liquid. To increase the number of free electrons, *pentavalent atoms* are added to the molten silicon. Pentavalent atoms have five electrons in the valence orbit. Examples of pentavalent atoms include arsenic, antimony, and phosphorus. Because these materials *will donate an extra electron* to the silicon crystal, they are often referred to as *donor impurities*. Figure 2-8a shows how the doped silicon crystal appears after it cools down and re-forms its solid crystal structure. A pentavalent atom is in the center, surrounded by four silicon atoms. As before, the neighboring atoms share an electron with the central atom. But this time, there is an extra electron left over. Remember that each pentavalent atom has five valence electrons. Since only eight electrons can fit into the valence orbit, the extra electron remains in a larger orbit. In other words, it is a free electron.

Each pentavalent or donor atom in a silicon crystal produces one free electron. This is how a manufacturer controls the conductivity of a doped semiconductor. The more impurity that is added, the greater the conductivity. In this way, a semiconductor may be lightly or heavily doped. A lightly doped semiconductor has a high resistance, whereas a heavily doped semiconductor has a low resistance.

Increasing the Number of Holes

How can we dope a pure silicon crystal to get an excess of holes? By using a *trivalent impurity*, one whose atoms have only three valence electrons. Examples include aluminum, boron, and gallium. Figure 2-8b shows a trivalent atom in the center. It is surrounded by four silicon atoms, each sharing one of its valence electrons. Since the trivalent atom originally had only three valence electrons and each neighbor shares one electron, only seven electrons are in the valence orbit. This means that a hole exists in the valence orbit of each trivalent atom. A trivalent atom is also called an *acceptor atom* because each hole it contributes can accept a free electron during

Recombination



Extrinsic semiconductor :-

The current conduction capability of intrinsic semiconductor is very low at room temperature. So we can not use it in electric devices. Hence the current conduction capability must be increased. This can be achieved by adding impurities to the

intrinsic semiconductor. So that it become impure semiconductor or extrinsic semiconductor.

The process of adding impurity is known as doping. The amount & type of impurities have to be closely controlled during the preparation of extrinsic semiconductor. Generally, for 10⁸ atoms of semiconductor, one impurity atom is added. The purpose of adding impurity is to increase either the number of free electrons or holes in the semiconductor crystal. If the pentavalent impurity is added to the semiconductor, a large number of free electrons are produced in the semiconductor. On the other hand if the trivalent impurity is added, it introduces a large number of holes.

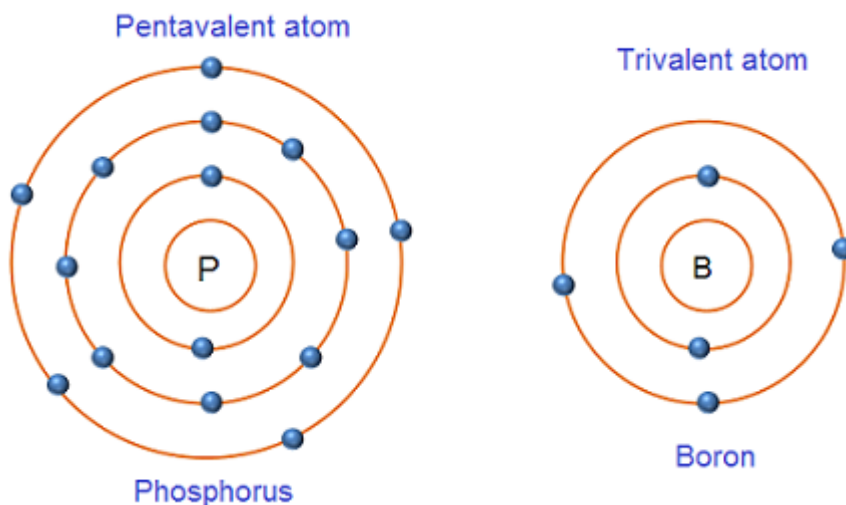
Lesson - 7

Types of impurities

Two types of impurities are added to the semiconductor. They are pentavalent and trivalent impurities.

Pentavalent impurities

Pentavalent impurity atoms have 5 valence electrons. The various examples of pentavalent impurity atoms include Phosphorus (P), Arsenic (As), Antimony (Sb), etc. The atomic structure of pentavalent atom (phosphorus) and trivalent atom (boron) is shown in below fig.



Phosphorus is a substance consisting of atoms which all have the same number of protons. The atomic number of phosphorus is 15 i.e. 15 protons. The number of protons in the nucleus of an atom is called atomic number. Phosphorus atom has 15 electrons (2 electrons in first orbit, 8 electrons in second orbit and 5 electrons in the outermost orbit).

Trivalent impurities

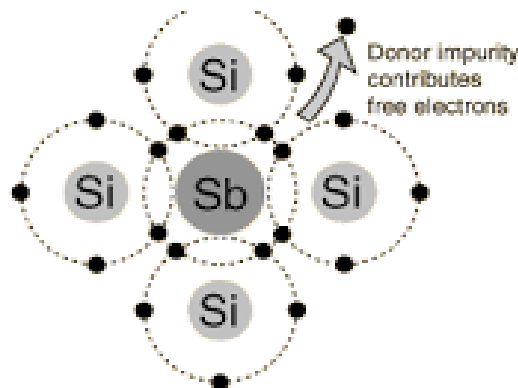
Trivalent impurity atoms have 3 valence electrons. The various examples of trivalent impurities include Boron (B), Gallium (G), Indium(In), Aluminium (Al).

Boron is a substance consisting of atoms which all have the same number of protons. The atomic number of boron is 5 i.e. 5 protons. Boron atom has 5 electrons (2 electrons in first orbit and 3 electrons in the outermost orbit).

On the basis of impurity atoms added to a pure semiconductor, the extrinsic semiconductors are divided into two categories : N-type extrinsic semiconductor and p-type extrinsic semiconductor.

N-type semiconductor

A N-type semiconductor is formed when a pentavalent impurity like Arsenic, Phosphorus and antimony is added to pure silicon, germanium crystal. Let us suppose antimony atoms(Sb) are added to pure silicon. In doing so, four electrons out of the five valence electrons of an antimony atom form covalent bonds with four surrounding silicon atoms as shown in figure. As a result, the fifth electron of antimony is superfluous and hence is loosely bounded with it like its other four valence electrons, this electron can be excited very easily to conduction band by the application of electric field or thermal energy. By introducing one Sb atom in silicon crystal, a conduction electron is obtained. In this way, desired number of free electrons can be obtained in the conduction band of a pure semiconductor crystal by introducing calculated number of pentavalent impurity atoms.

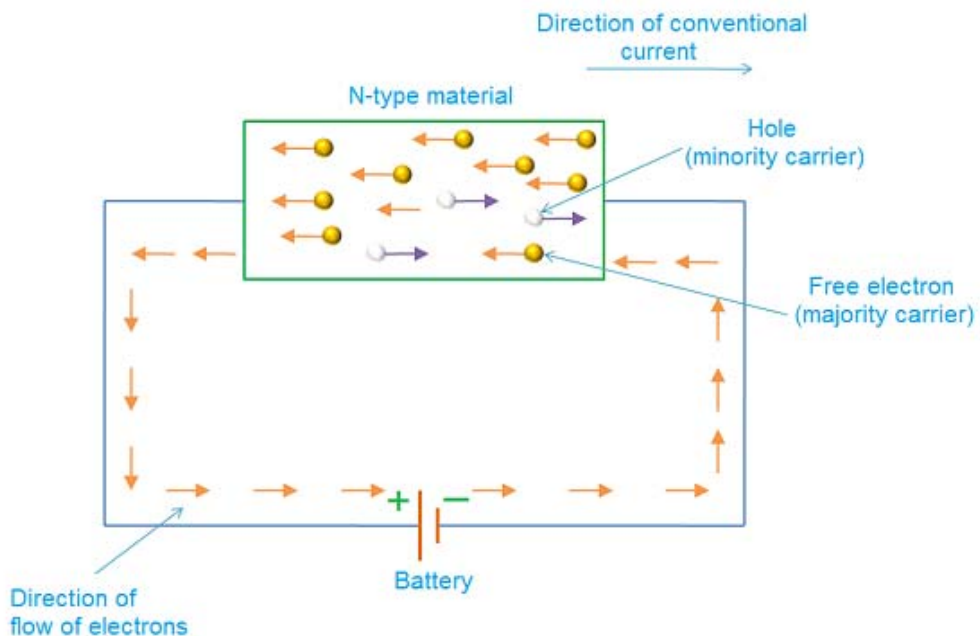


Charge on n-type semiconductor

So many people think that n-type semiconductor has large number of free electrons. So, the total electric charge of n-type semiconductor is negative. But this assumption is wrong. Even though n-type semiconductor has large number of free electrons, but these free electrons is given by the pentavalent atoms that are electrically neutral. Therefore, the total electric charge of n-type semiconductor is also neutral.

Conduction in n-type semiconductor

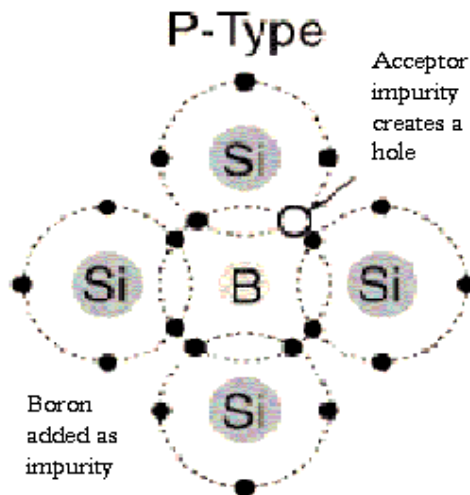
Let us consider an n-type semiconductor as shown in below figure. When voltage is applied to n-type semiconductor; the free electrons moves towards positive terminal of applied voltage. Similarly holes moves towards negative terminal of applied voltage.



In n-type semiconductor, the population of free electrons is more whereas the population of holes is less. Hence in n-type semiconductor free electrons are called majority carriers and holes are called minority carriers. Therefore, in a n-type semiconductor conduction is mainly because of motion of free electrons.

P- type semiconductor

A p-type semiconductor is formed when a trivalent impurity atom like Boron, Aluminium, and Gallium is added to pure silicon or germanium crystal. Let us suppose that some Boron (B) atoms are added to a pure silicon crystal. In doing so, a boron atom tends to form four covalent bonds with four covalents bonds with four surrounding silicon atoms as shown in fig. However, having only three valance electrons, the Boron atom can form only three complete covalent bonds and the fourth covalent bond is incomplete. An electron space (vacancy) is left in the fourth bond. This gives rise to a hole. By introducing a trivalent atom in the pure semiconductor, a hole is created. In thisway, a desired number of holes can be created in a pure semiconductor crystal by doping a calculated number of trivalent impurity atoms.

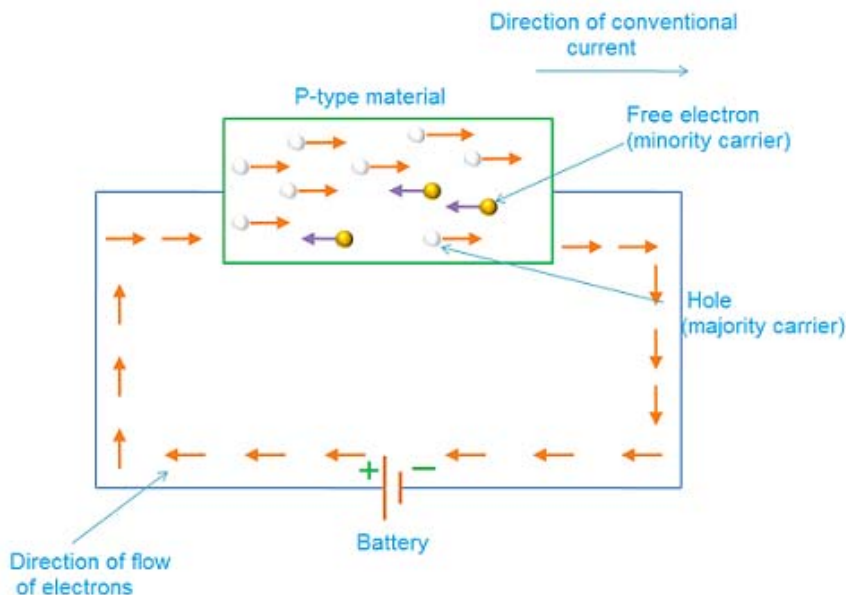


Charge on p-type semiconductor

So many people think that p-type semiconductor has large number of holes and current conduction is mainly due to these holes. So, the total electric charge of p-type semiconductor is positive. But this assumption is wrong. Even though p-type semiconductor has large number of holes, but these holes is provided by the trivalent atoms that are electrically neutral. Therefore, the total electric charge of p-type semiconductor is also neutral.

Conduction in p-type semiconductor

Let us consider a p-type semiconductor as shown in below figure. When voltage is applied to p-type semiconductor; the holes in valence band moves towards negative terminal of applied voltage. Similarly free electrons move towards positive terminal of applied voltage.



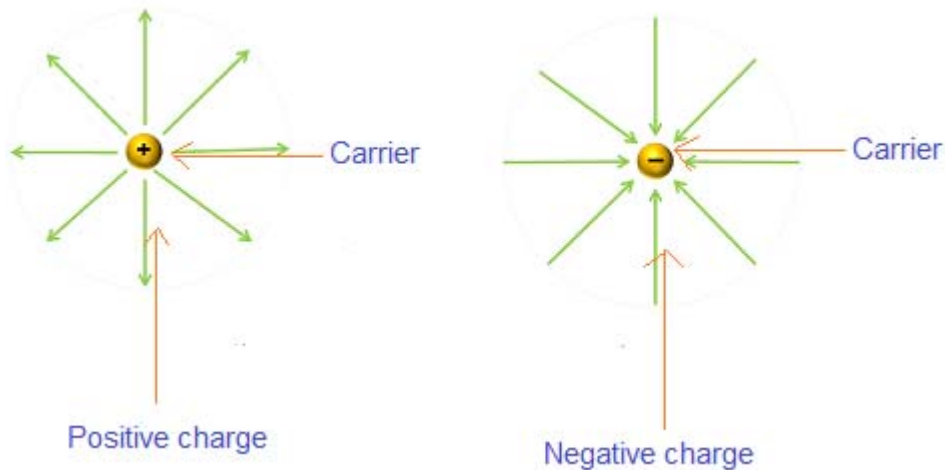
In p-type semiconductor, the population of holes in valence band is more, whereas the population of free electrons in conduction band is less. So, current conduction is mainly because of holes in valence band. Free electrons in conduction band constitute little current. Hence in p-type semiconductor, holes are called majority carriers and free electrons are called minority carriers.

charge carriers

Generally, carrier refers to any object that carry another object from one place to another place. Let us take example; People use vehicles such as buses, trains, airplanes, etc. to travel from one place to another place. Here, the vehicles act as carriers that carry people from one place to another place. In the similar way, particles such as free electrons and holes carry the charge or electric current from one place to another place.

Negative charge carriers

The negative charge carriers such as free electrons are the charge carriers that carry negative charge with them while moving from one place to another place. Free electrons are the electrons that are detached from the parent atom and moves freely from one place to another place.



Positive charge carriers

The positive charge carriers such as holes are the charge carriers that carry positive charge with them while moving from one place to another place. Holes are the vacancies in valence band that moves from one place to another place within the valence band.

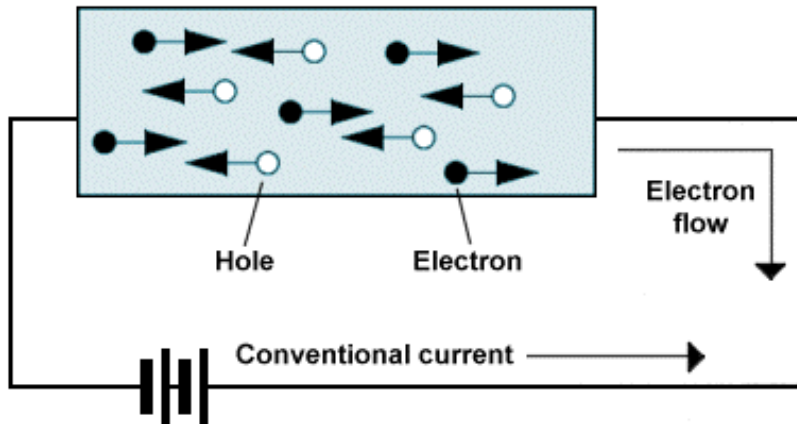
Majority and minority charge carriers definition

The charge carriers that are present in large quantity are called majority charge carriers. The majority charge carriers carry most of the electric charge or electric current in the semiconductor. Hence, majority charge carriers are mainly responsible for electric current flow in the semiconductor. The charge carriers that are present in small quantity are called minority charge carriers. The minority charge carriers carry very small amount of electric charge or electric current in the semiconductor.

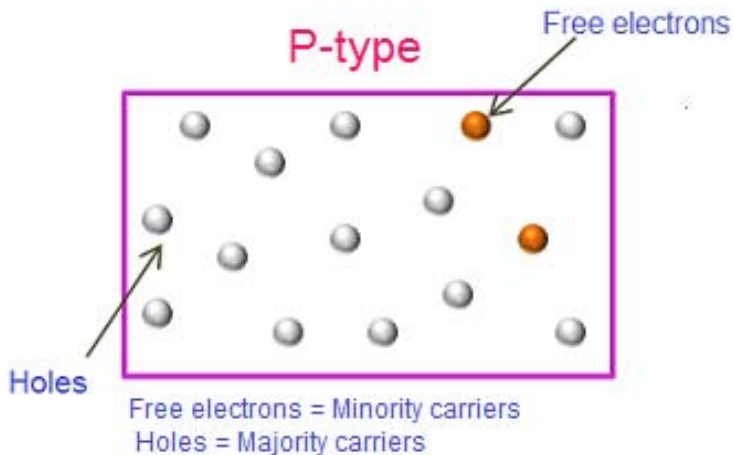
Charge carrier in P- type semiconductor

The new type of semiconductor which is obtained by doping trivalent impurity atoms with the Intrinsic semiconductor is called a P-type semiconductor. The P stands for

positive charge carrier or the hole. If P-type semiconductor is connected across a battery, the holes in the valance band will be attracted by the cathode and electrons will be attracted by the anode of the battery, thus resulting a large current to flow through the semiconductor. The major part of the total current is due to the flow of the holes in the valance band and only a fraction of it is due to the flow of the thermally generated free electron in the conduction band. Due to this reason, the holes in a P-type semiconductor are called majority charge carriers.



Total electrons < Total holes

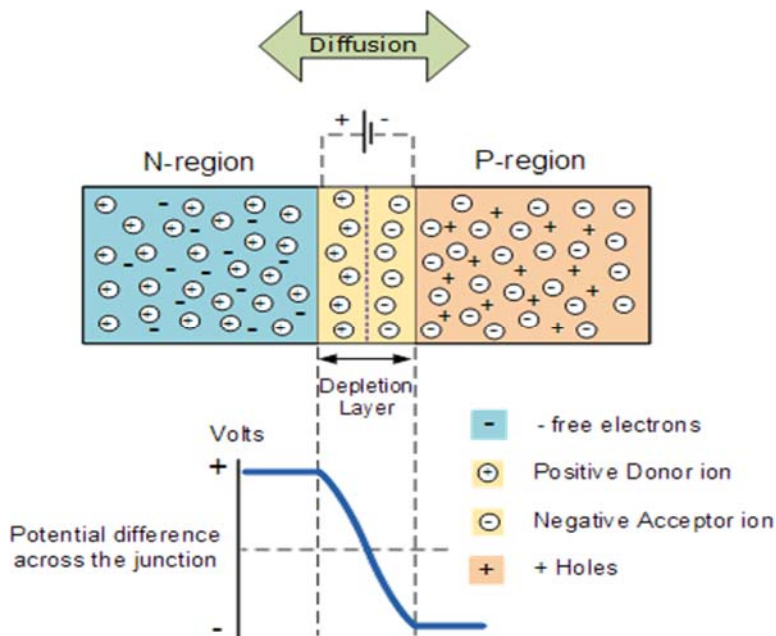


Lesson - 8

P-N Junction

When a P-type semiconductor is suitably joined to a N- type semiconductor, a junction is formed called P-N junction, and the device formed is called P-N junction diode. During the formation of a P-N junction, following two phenomena take place.

- i) A thin depletion layer (or region) is set up on both sides of the junction and is so-called because it is depleted or devoid of free charge carriers. Its width is about $1 \mu\text{m}$ (10^{-6} m)
- ii) A junction or barrier potential v_b is developed across the junction whose value is about 0.3 V for Ge and 0.7 for Si. when a P-N junction is packed as a semiconductor device, it is called a P-N junction diode.



PN Junction Diode

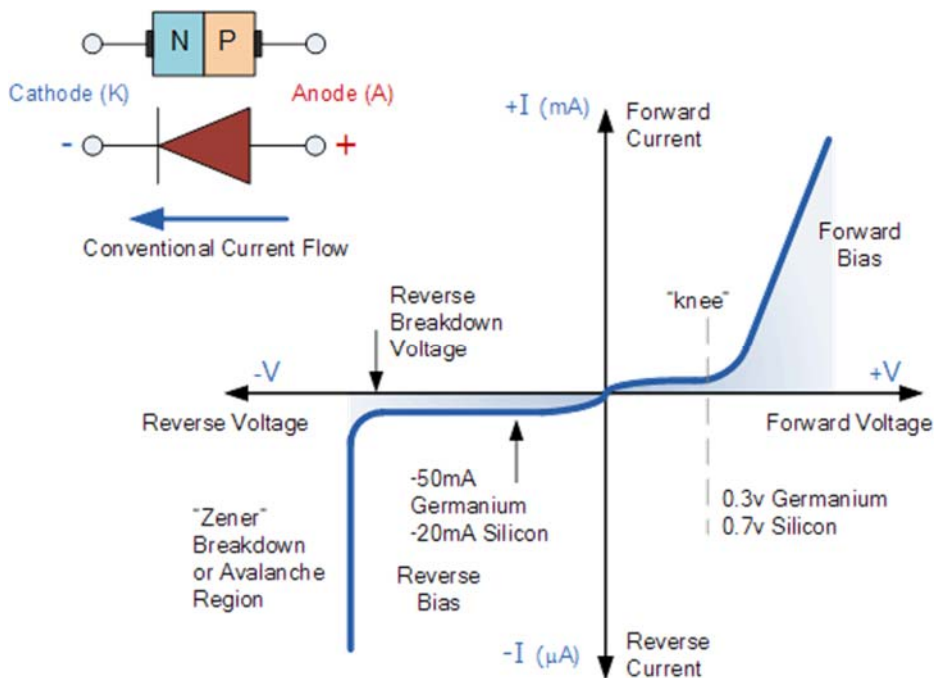
Is one of the simplest semiconductor devices around, and which has the characteristic of passing current in only one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential current-voltage (I-V) relationship and therefore we cannot describe its operation by simply using an equation such as Ohm's law.

If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.

By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking current flow through the diode.

Then the depletion layer widens with an increase in the application of a reverse voltage and narrows with an increase in the application of a forward voltage. This is due to the differences in the electrical properties on the two sides of the PN junction resulting in physical changes taking place. One of the results produces rectification as seen in the PN junction diodes static I-V (current-voltage) characteristics. Rectification is shown by an asymmetrical current flow when the polarity of bias voltage is altered as shown below.

Junction Diode Symbol and Static I-V Characteristics.



But before we can use the PN junction as a practical device or as a rectifying device we need to firstly bias the junction, ie connect a voltage potential across it. On the voltage axis above, “Reverse Bias” refers to an external voltage potential which increases the potential barrier. An external voltage which decreases the potential barrier is said to act in the “Forward Bias” direction.

There are two operating regions and three possible “biasing” conditions for the standard **Junction Diode** and these are:

- **1. Zero Bias** – No external voltage potential is applied to the PN junction diode.
- **2. Reverse Bias** – The voltage potential is connected negative, (-ve) to the P-type material and positive, (+ve) to the N-type material across the diode which has the effect of **Increasing** the PN junction diode’s width.
- **3. Forward Bias** – The voltage potential is connected positive, (+ve) to the P-type material and negative, (-ve) to the N-type material across the diode which has the effect of **Decreasing** the PN junction diodes width.

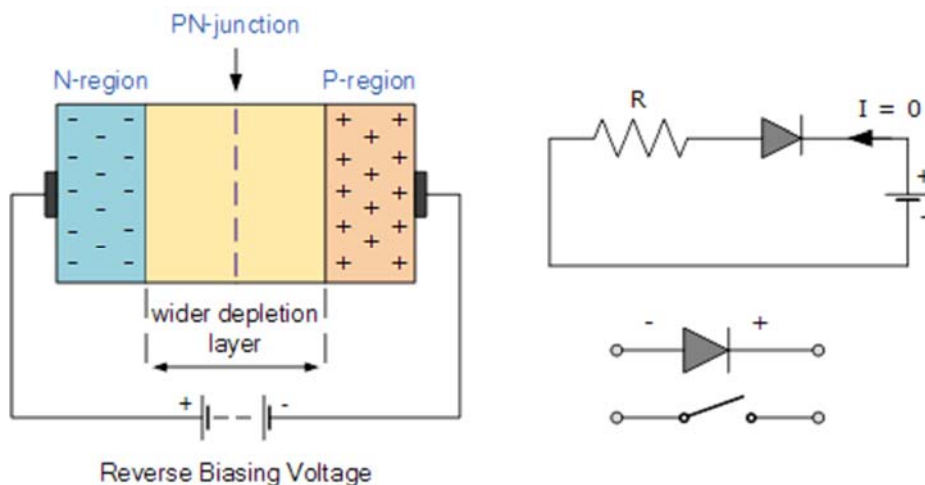
Reverse Biased PN Junction Diode

When a diode is connected in a Reverse Bias condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.

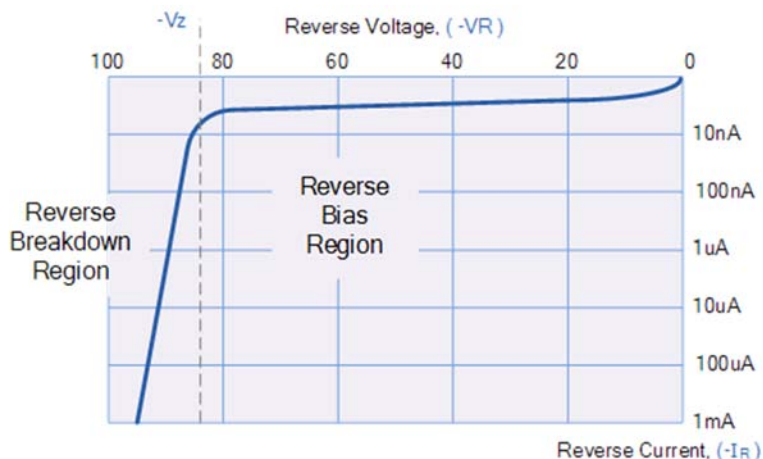
The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material.

Increase in the Depletion Layer due to Reverse Bias



This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small leakage current does flow through the junction which can be measured in micro-amperes, (μA). One final point, if the reverse bias voltage V_r applied to the diode is increased to a sufficiently high enough value, it will cause the diode's PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current, and this shown as a step downward slope in the reverse static characteristics curve below.

Reverse Characteristics Curve for a Junction Diode



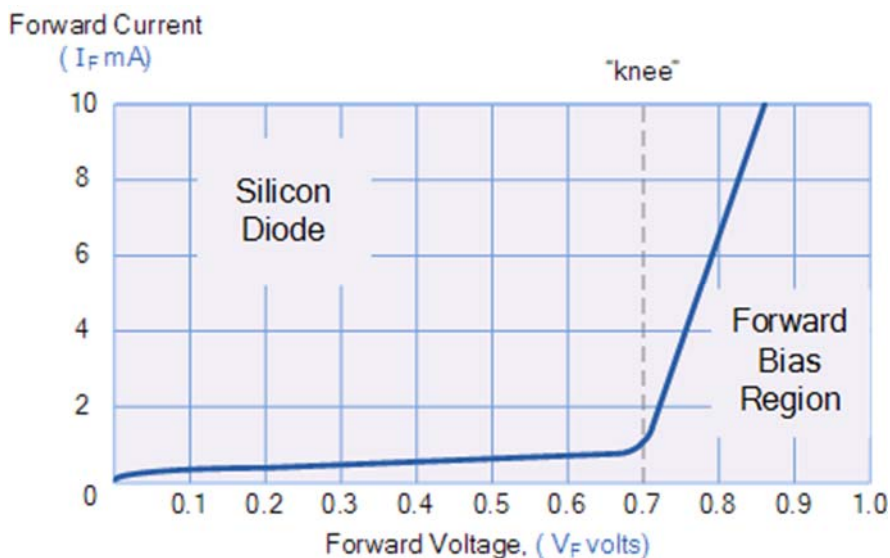
Sometimes this avalanche effect has practical applications in voltage stabilising circuits where a series limiting resistor is used with the diode to limit this reverse breakdown current to a preset maximum value thereby producing a fixed voltage output across the diode. These types of diodes are commonly known as Zener Diodes and are discussed in a later tutorial.

Forward Biased PN Junction Diode

When a diode is connected in a Forward Bias condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.

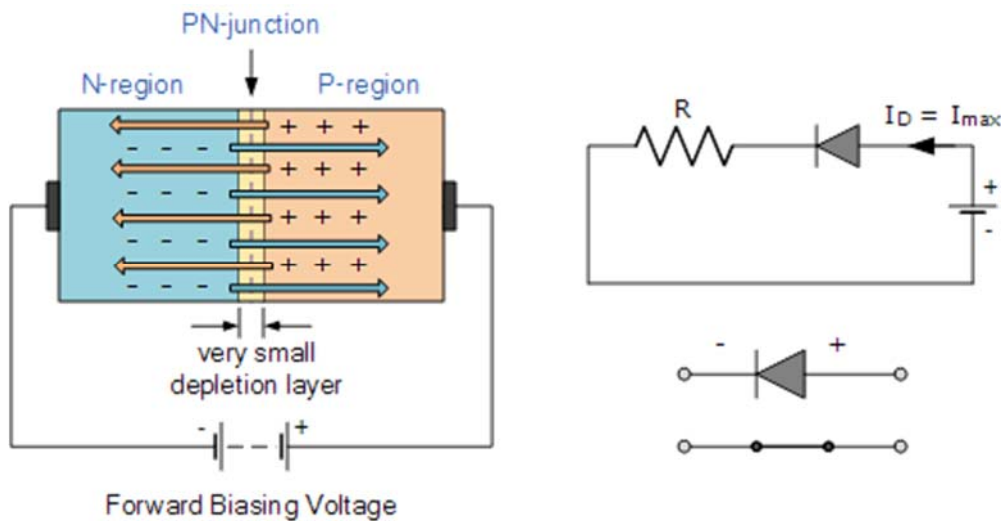
This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the “knee” on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.

Forward Characteristics Curve for a Junction Diode



The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the “knee” point.

Reduction in the Depletion Layer due to Forward Bias

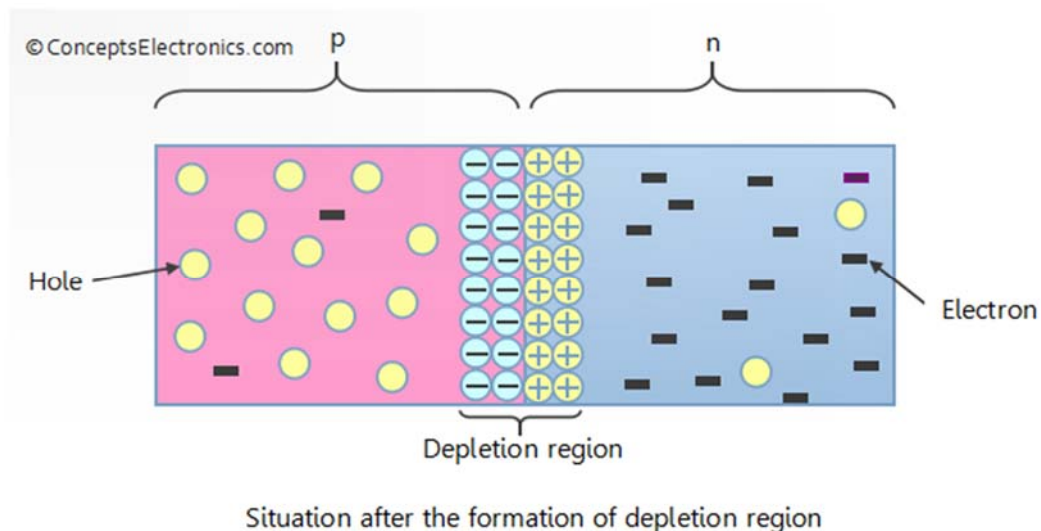


This condition represents the low resistance path through the PN junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v for germanium and approximately 0.7v for silicon junction diodes.

Since the diode can conduct “infinite” current above this knee point as it effectively becomes a short circuit, therefore resistors are used in series with the diode to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in a very quick failure of the device.

Terms Related to p-n Junction

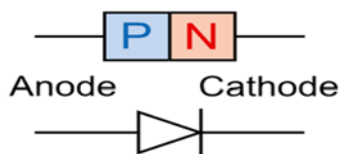
- i. Depletion Layer: At p-n junction a region is created, where there is no charge carriers. This region is called depletion layer. The width of this region is of the order of 10^{-6}m



- ii Potential Barrier : The potential difference across the depletion layer is called potential barrier. Barrier potential for Ge is 0.3 V and for Si is 0.7 V.

P-N Junction Diode

It is a device in which P- type semiconductor is in contact with an N-type semiconductor. It has two terminals namely anode and cathode. The anode refers to the P- type region and the cathode refers to N- type region as shown in fig. Its circuit symbol is as shown in fig. the arrow head shown in the circuit symbol points the direction of current flow when it is forward biased.

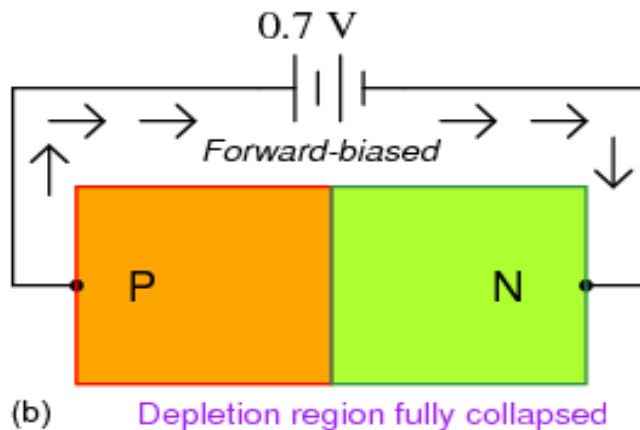


Lesson - 9

Biasing of P-N junction diode

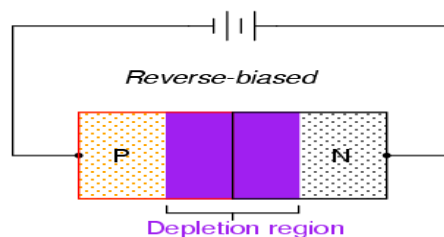
Connecting an external battery across the P-N junction diode is called the biasing of the diode. There are two types of biasing. They are:

- a) **Forward Biasing:** A diode is said to be forward biased if its P-side is connected to positive terminal and N-side to negative terminal of a battery. A forward biased diode is as shown in fig.



The following are the basic features of forward biasing.

- i. The junction offers low resistance (called forward resistance) to current.
 - ii. Depletion layer decreases.
 - iii. The current increases with increase of external potential difference. The graph between potential difference (V) and current (I) is non-linear (not obeying Ohm's Law).
- b) **Reverse Biasing:** A diode is said to be reverse biased if its P-side is connected to negative terminal and N-side is connected to positive terminal of external voltage source. A reverse biased diode is shown in fig.



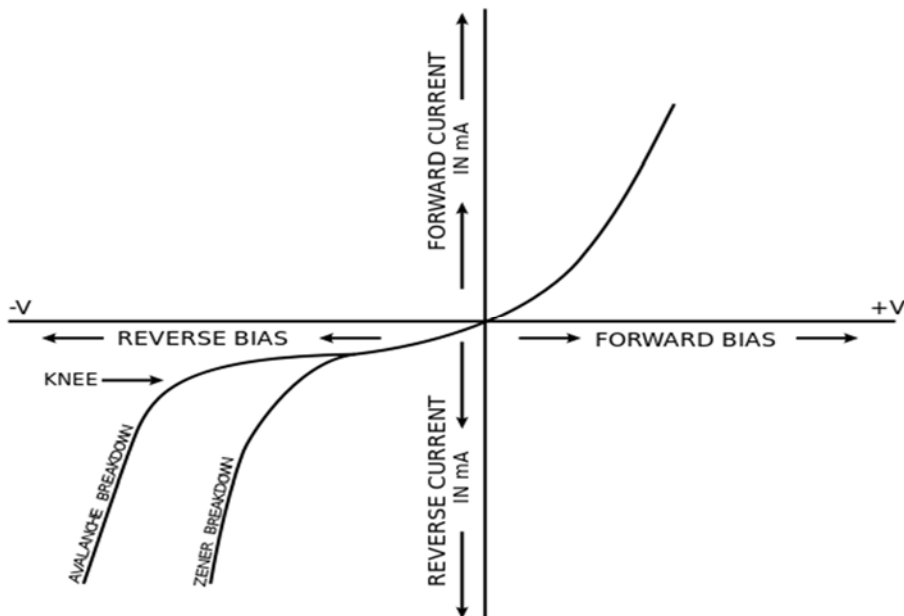
The following are the basic features of reverse biasing

- i. The potential barrier is increased.
- ii. The depletion layer increases.
- iii. The junction offers very high resistance (reverse resistance) to allow current.

Lesson - 10

Reverse Break down

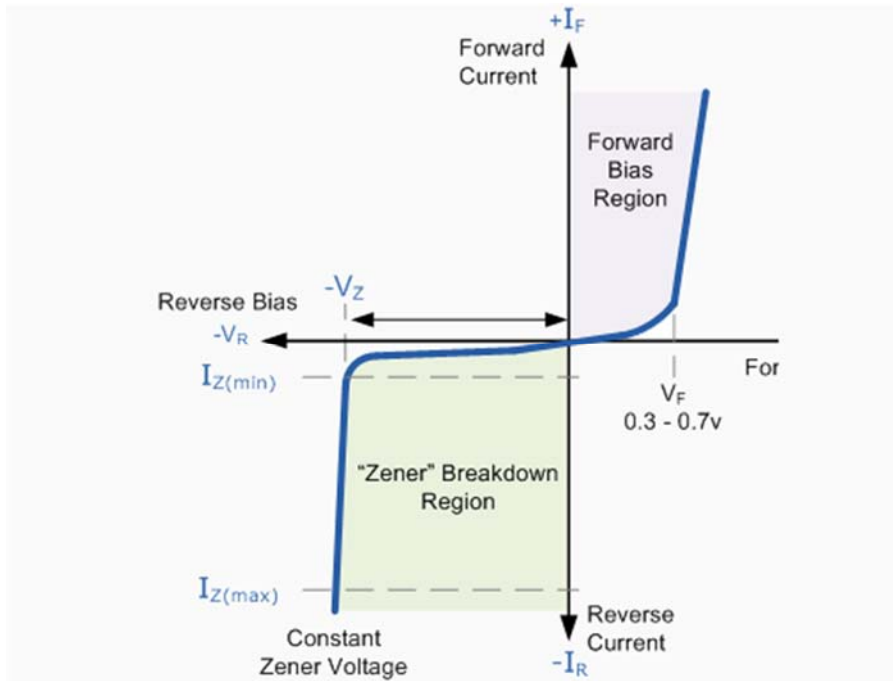
A PN junction diode allows very small amount of current when it is reverse biased. This current is due to the movement of minority charge carriers across the junction. When the reverse bias voltage is gradually increased, the reverse current through the diode increases very slowly. At a certain reverse voltage, the current rises sharply to maximum value. This voltage at which reverse current rises abruptly is called break down voltage. The following two processes cause junction break down due to increase in reverse voltage.



Lesson - 11

Zener Breakdown(Diode)

In a heavily doped junction diode the depletion region is very narrow. When the reverse voltage is increased, the electric field at the junction also increases. When this field is about 10×10^7 v/m electrons are pulled out of the covalent bond. A large number of electron hole pairs are thereby created. The reverse current rises steeply. This is zener effect or zener breakdown.



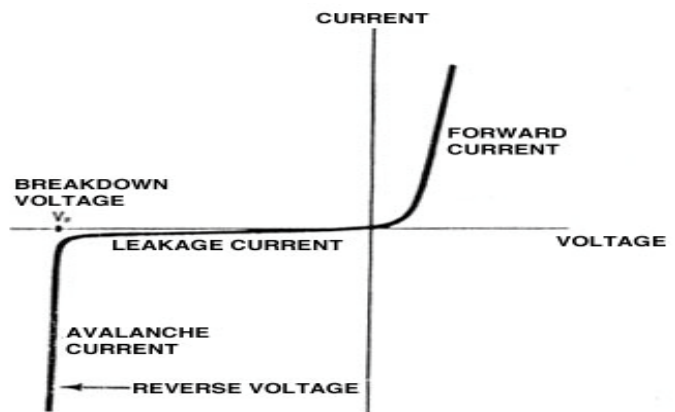
Characteristics of Zener Diode

A zener diode can operate in any of three; forward, leakage or breakdown accordingly its characteristic is shown in the above fig. In the forward region, the zener diode acts just like an ordinary diode. In the leakage region (between zero and break down), it has only a small leakage or reverse current. The zener diode has a sharp breakdown voltage (v_z) in the reverse region after which the current increase sharply and the voltage across the diode almost constant even if the current through it increased this property of the zener diode makes it as a voltage regulator.

Lesson - 12

Avalanche Breakdown

If the diode is lightly doped and the depletion layer is wide, the electric field due to the reverse voltage across the junction does not become enough to cause zener breakdown. However there are minority charge carriers in the diode which are accelerated by the electric field. When they acquire enough energy by accelerating through the electric field, they collide with the semiconductor atoms in the depletion layer. In the collision, they can break the covalent bonds and create electron-hole pairs. These newly generated electrons are accelerated in the field. When they get enough energy they collide with further atoms and breakdown further covalent bonds, thus creating further charge carriers and so on. This leads to an avalanche of charge carriers which results in a large current in the diode. This is called avalanche effect or avalanche breakdown.



Instruction for teacher

- Use the Charts as far as possible to explain the content.
- Assign the homework at the end of every class from the chapter so far covered during that class.
- Conduct group discussions after finishing one lesson.
- Use any simulation software to explain semiconductors

References and Resources :

- Principles of physics-II ,Ayam Publication Pvt.Ltd
- Electronic Principles, Alberto Malvino/David Bates,
- Basic Electronics- Solid state , B.L. Theraja
- www.allaboutcircuits.com

SEMICONDUCTOR

Lab no 1:

TOPIC: TO STUDY FORWARD CHARACTERISTIC OF PN-JUNCTION DIODE (SILICON)

Characteristic apparatus required:

- ▶ Breadboard
- ▶ Semiconductor diode
- ▶ Ammeter (10mA) - Voltmeter (0 - 3 v)
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

1. Theory:

- a. PN-Junction diode:
 - i. Forward Bias:

2. Procedure :

- a. Procedure for V-I characteristic of PN junction diode:
 - i. Make all the connect as shown in fig 1(a) using patch cords. Connection positive socket of power supply to one end of to Anode (A) of PN junction Diode and also to +ve socket of voltmeter. Connect cathode (K) of PN junction diode to +ve socket of $\mu\text{A}/\text{mA}$ meter; connect -ve socket of power supply to -ve voltmeter and to -ve of $\mu\text{A}/\text{mA}$ meter.
 - ii. Select the power supply range as well as voltmeter range to 3V and current meter to 10mA range suing SPDT switches.
 - iii. Switch ON the instrument and set the voltmeter to 0 volt.
 - iv. Increase the voltage in small steps and note down the corresponding current. Note down the observation in table no. 2(b).
 - v. Plot a graph between voltage and current as shown in fig 2(c).

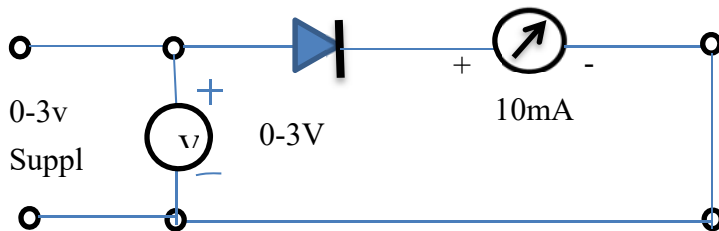


Fig.1(a)

3. Observation :

S.N.	Forward voltage	Forward current (mA)
1.		
2.		
3.		
4.		

Fig. 1(b)

4. Graph:

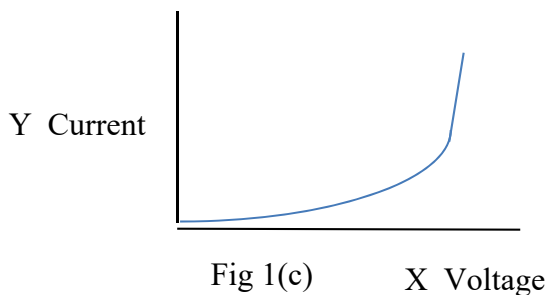


Fig 1(c)

5. Conclusion :

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SEMICONDUCTOR

Lab no 2:

TOPIC: TO STUDY REVERSE CHARACTERISTIC OF PN-JUNCTION DIODE (SILICON)

Characteristic apparatus required:

- ▶ Breadboard
- ▶ Semiconductor diode
- ▶ Ammeter (100 μ A)
- ▶ Voltmeter (0 - 30 v)
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

Specification of regulated power supply:

- ▶ Input voltage 230 +/- 10% , 50Hz

6. Theory:

a. PN-Junction diode:

i. Reverse Bias:

7. Procedure :

a. Procedure for V-I characteristic of PN junction diode:

- i. Make all the connection as shown in fig 2(a) using patch cords. Connection positive socket of power supply to one end of resistance RS, and also to positive terminal of voltmeter connect order end of resistance RS to cathode (K) of diode and anode (A) of diode to positive terminal of μ A/mA meter. Now connect -ve socket of power supply to -ve of voltmeter as well as o -ve of μ A/mA meter.
- ii. Select the power supply range as well as voltmeter range to 30V and current meter to 100 μ A ranges using SPDT switches.
- iii. Switch ON the instrument and set the voltmeter to 0 volt.

- iv. Increase the voltage in small steps and note down the corresponding current. Note down the observation in table no. 2(b).
- v. Plot a graph between voltage and current for reverse characteristics as shown in fig 2(c).

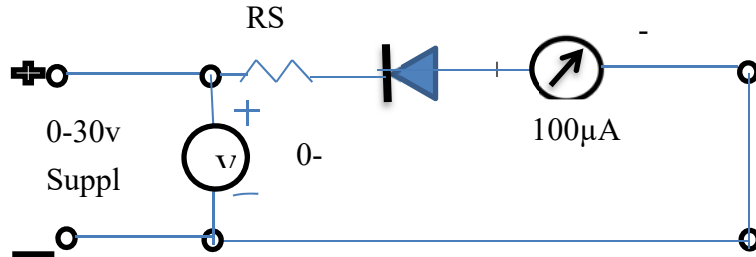


Fig .2(a)

8. Observation :

S.N.	Reverse voltage	Reverse current (μA)
1.		
2.		
3.		
4.		

Fig. 2(b)

9. Graph:

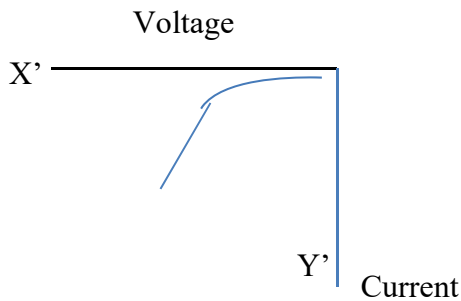


Fig 2(c)

Conclusion : -----

SEMICONDUCTOR

Lab no 3:

TOPIC: TO STUDY FORWARD CHARACTERISTIC OF PN-JUNCTION DIODE (GERMENUM)

Characteristic apparatus required:

- ▶ Breadboard
- ▶ Semiconductor diode
- ▶ Ammeter (10mA) - Voltmeter (0 - 3 v)
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

1. Theory:

- a. PN-Junction diode:
 - i. Forward Bias:

2. Procedure:

- a. Procedure for V-I characteristic of PN junction diode:
 - i. Make all the connection as shown in fig 1(a) using patch cords. Connection positive socket of power supply to one end of to Anode (A) of PN junction Diode and also to +ve socket of voltmeter,. Connect cathode (K) of PN junction diode to +ve socket of $\mu\text{A}/\text{mA}$ meter; connect -ve socket of power supply to -ve voltmeter and to -ve of $\mu\text{A}/\text{mA}$ meter.
 - ii. Select the power supply range as well as voltmeter range to 3V and current meter to 10mA range suing SPDT switches.
 - iii. Switch ON the instrument and set the voltmeter to 0 volt.
 - iv. Increase the voltage in small steps and note down the corresponding current. Note down the observation in table no. 1(b).
 - v. Plot a graph between voltage and current as shown in fig 1(c).

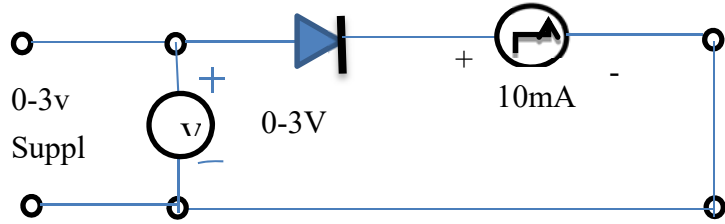


Fig .3(a)

3. Observation :

S.N.	Forward voltage	Forward current (mA)
1.		
2.		
3.		
4.		

Fig. 3(b)

4. Graph:

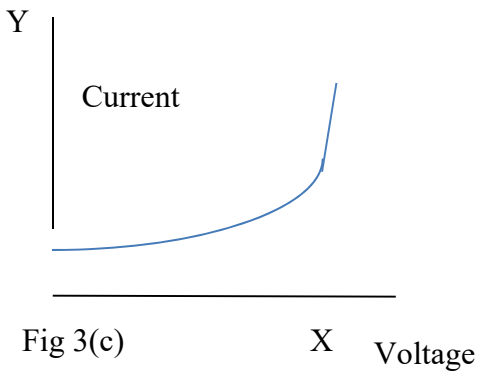


Fig 3(c)

Conclusion :

SEMICONDUCTOR

Lab no 4:

TOPIC: TO STUDY REVERSE CHARACTERISTIC OF PN-JUNCTION DIODE (GERMENIUM)

Characteristic apparatus required:

- ▶ Breadboard
- ▶ Semiconductor diode
- ▶ Ammeter (100 μ A) - Voltmeter (0 - 30 v)
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

1. Theory:

a. PN-Junction diode:

i. Reverse Bias:

2. Procedure :

a. Procedure for V-I characteristic of PN junction diode:

- i. Make all the connection as shown in fig 2(a) using patch cords. Connection positive socket of power supply to one end of resistance RS, and also to positive terminal of voltmeter connect other end of resistance RS to cathode (K) of diode and anode (A) of diode to positive terminal of μ A/mA meter. Now connect -ve socket of power supply to -ve of voltmeter as well as o -ve of μ A/mA meter.
- ii. Select the power supply range as well as voltmeter range to 30V and current meter to 100 μ A ranges using SPDT switches.
- iii. Switch ON the instrument and set the voltmeter to 0 volt.
- iv. Increase the voltage in small steps and note down the corresponding current. Note down the observation in table no. 2(b).
- v. Plot a graph between voltage and current for reverse characteristics as shown in fig 2(c).

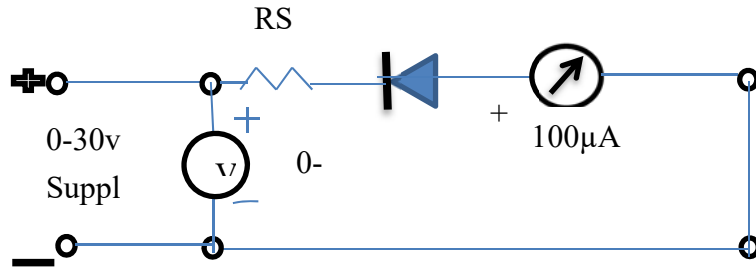


Fig .4(a)

3. Observation:

S.N.	Reverse voltage	Reverse current (μA)
1.		
2.		
3.		
4.		

Fig. 4(b)

4. Graph:

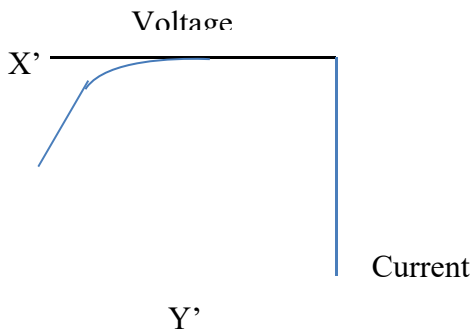


Fig 4(c)

5. Conclusion:

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SEMICONDUCTOR

Lab no 5:

TOPIC: TO STUDY FORWARD CHARACTERISTIC OF ZENER DIODE

Characteristic apparatus required:

- ▶ Breadboard
- ▶ Zener diode
- ▶ Ammeter (10mA) - Voltmeter (0 - 3 v)
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

6. Theory:

- a. Zener diode:
 - i. Forward Bias:

7. Procedure :

- a. Procedure for V-I characteristic of PN junction diode:
 - i. Make all the connection as shown in fig 5(a) using patch cords. Connect positive socket of power supply to +ve of voltmeter. And to Anode (A) of Zener Diode. Connect cathode (K) of zener diode to +ve socket of $\mu\text{A}/\text{mA}$ meter. Connect -ve socket of power supply to -ve of voltmeter and to -ve of $\mu\text{A}/\text{mA}$ meter.
 - ii. Select the power supply range as well as voltmeter range to 3V and current meter to 10mA range using SPDT switches.
 - iii. Switch ON the instrument and set the voltmeter to 0 volt.
 - iv. Increase the voltage in small steps through set volt potentiometer and note down the corresponding current. Note down the observation in table no. 5(b). As the voltage approaches to 3 v change the range of DC

power supply as well as voltmeter to 30v and further increase the voltage and note down the output current (maximum 10mA).

- v. Plot a graph between voltage and current as shown in fig 5(c).

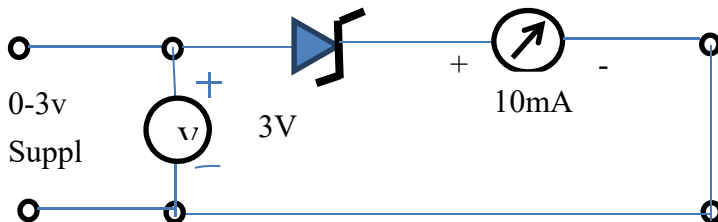


Fig .5(a)

8. Observation :

S.N.	Forward voltage	Forward current (mA)
1.		
2.		
3.		
4.		

Fig. 5(b)

9. Graph:

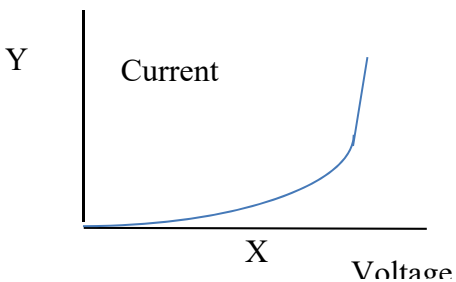


Fig 5(c)

10. Conclusion : -----

SEMICONDUCTOR

Lab no 6:

TOPIC: TO STUDY REVERSE CHARACTERISTIC OF ZENER DIODE

Characteristic apparatus required:

- ▶ Breadboard - Zener diode
- ▶ Ammeter ($100\mu\text{A}$)- Voltmeter (0 - 30 v)
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

Specification of regulated power supply:

- ▶ Input voltage 230 +/- 10% , 50Hz

11. Theory:

a. ZENER diode:

i. Reverse Bias:

12. Procedure :

- a. Procedure for V-I characteristic of Zener diode:
 - i. Make all the connection as shown in fig 6(a) using patch cords. Connect +ve socket of power supply to +ve socket of voltmeter and to cathode (k) of zener diode and anode (A) of zener diode to +ve socket of mA. Joint negative terminal of supply to -ve socket of voltmeter and -ve socket of ammeter.
 - ii. Select the power supply range as well as voltmeter range to 30V and current meter to 10mA ranges using SPDT switches.
 - iii. Switch ON the instrument using On/off toggle switch provided on the front panel.
 - iv. Increase the voltage in small steps and note down the corresponding current. Note down the observation in table no. 6(b).
 - v. Plot a graph between voltage and current for reverse characteristics as shown in fig 6 (c).

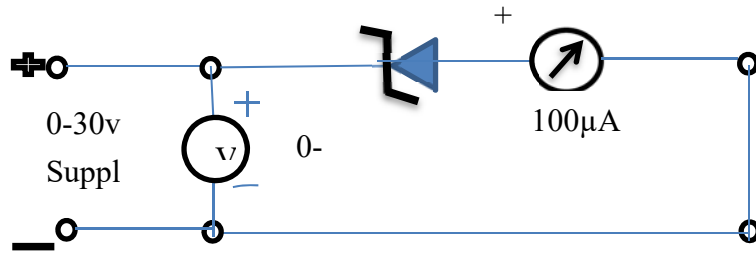


Fig .6(a)

13. Observation :

S.N.	Reverse voltage	Reverse current (μA)
1.		
2.		
3.		
4.		

Fig. 6(b)

14. Graph:

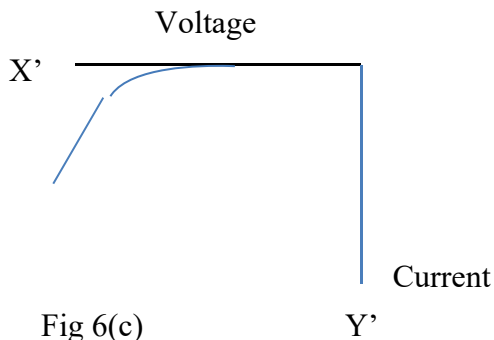


Fig 6(c)

15. Conclusion :

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UNIT 4

Power Supplies

Learning Outcomes:

After studying this chapter, student should be able to:

- Explain the basic rectifier circuits and its types, its working principle, characteristics and applications.
- Get knowledge of Zener voltage regulator circuit design with principle and calculation.

Lesson 1

4.1 Introduction:-

Generally power supply refers to a source of dc power supply that itself is operated from a source of ac power like 220-v, 50hz line (i.e. domestic –lines). This kind of power supply can also be regarded as an -ac to –dc converter because in such power supply. The ac mains as an ac-to-dc converter to the direct current.

This kind of dc power supply operated itself from an ac source consists of following three fundamental components. But it is not always necessary that all these components should be included.

- i. Rectifier converts an ac voltage to a pulsating dc voltage which allows current to flow in one direction only.
- ii. Filter circuit blocks the ac components in pulsating dc wave form. And it permits dc component (i.e. average value) only to pass through it by filtering the undesirable ac component.
- iii. Voltage regulator maintains to supply constant output voltage even under variations in load current drawn from the supply and under variations in line voltage.

4.2. Rectifier:-

Rectifier circuit is aimed to carry the rectification. Rectification is process of conversion of ac voltage or current to pulsating dc voltage or current. Diodes are main component that perform rectification in the rectifier circuit because diodes

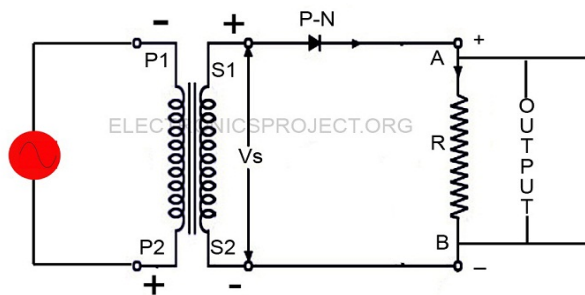
offers zero resistance when forward biased (i.e. conduct in forward biased condition) and offers infinite resistance when reverse biased (i.e. don't conduct in reverse biased condition).

Basically there are two types of rectifier.

1. Half wave rectifier
2. Full wave rectifier

Lesson 2

Half wave rectifier



Half-Wave Rectifier

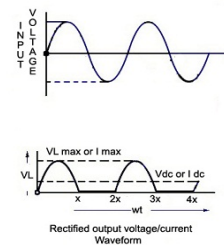


Fig: Half wave rectifier

Construction:-

Half wave rectifier circuit consist of a step down transformer which primary coil is connected to input ac voltage supply and secondary coil connected to a p-n junction diode and a load resistance (R_1) parallel to secondary coil through which output pulsating dc voltage wave form is derived as shown in figure given above.

Working Principle:-

For positive half cycle of ac, let upper end 'D' of secondary coil becomes positive and lower end 'C' becomes negative so, the diode is forward biased, According to ideal approximation of the diode, the diode offers zero resistance (i.e. behaves like switch on) so, this half of ac passes though load resistance R_1 .

For negative half cycle of ac, lower end of secondary coil 'C' is positive and upper end 'D' is negative so, the diode is reverse biased, Then, the diode offers infinite resistance (i.e. behaves like a switch off) so, this half cycle of ac is blocked to reach load resistance R_L and no output voltage can be driven in negative half of ac.

In this way, every positive half cycle of ac is conducted through load resistance and negative half cycle of ac is blocked. Thus, output is rectified pulsating half wave.

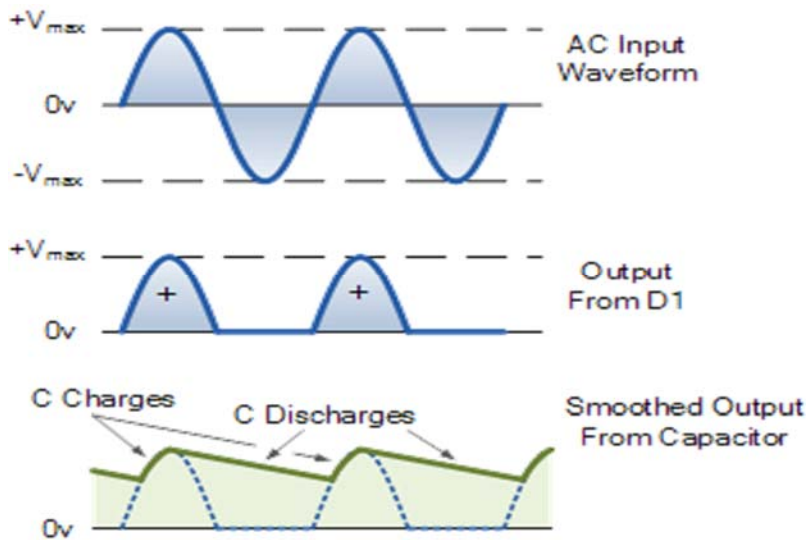


Fig:- Input and output wave-forms for half wave rectifier

Characteristics:- Thus, in half- wave rectifier we have,

Average value of current,

$$I_{dc} = I_{average} = \frac{I_0}{\pi}$$

Where, $I_0 = 2 I_{rms}$

i.e. $I_{rms} = I_0 / 2 \Rightarrow I_0 = 2 I_{rms}$

$$I_{dc} = I_{average} = \frac{I_{max}}{\pi}$$

Lesson 3

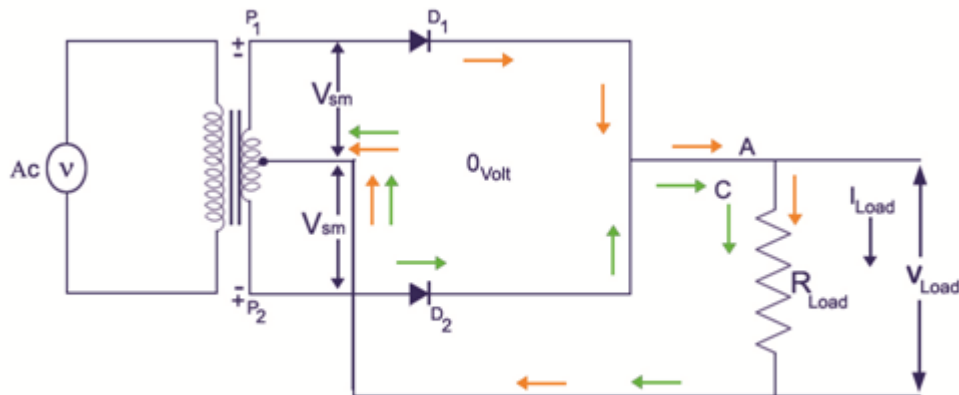
Full wave rectifier

Full rectifier, rectifies both the positive and negative half cycles of ac supply. There are two main types of full wave rectifiers they are

Central tapped full wave rectifier

Construction:

Central tapped full wave rectifier consists of two diodes connected to secondary coil of the step down transformer with p-junction. The N- junction/section are common. A load resistance R_L is connected in between N- section and the central tapped input is provided to primary coil and output is driven. Through load resistance R_L as shown in the figure below.



CENTRE - TAP FULL- WAVE RECTIFIER CIRCUIT

Fig: central tapped full wave rectifier

Working:-

Here, two diodes D_1 and D_2 are working alternatively in different half cycle of ac input.

Let, for positive half cycle upper end of secondary coil A is positive and b is negative then at that time D_1 is forward biased D_2 is reverse biased so, current flows along AD_1B XYD , as a result positive half of voltage appears across load resistance R_L . For negative half cycle upper end A is negative and B is positive then D_2 is forward biased and D_1 is reverse biased current flows along CD_2B XYD , as a result negative half of voltage appears across load resistance R_L .

Thus for both half cycles of ac, current flows through load resistance R_L

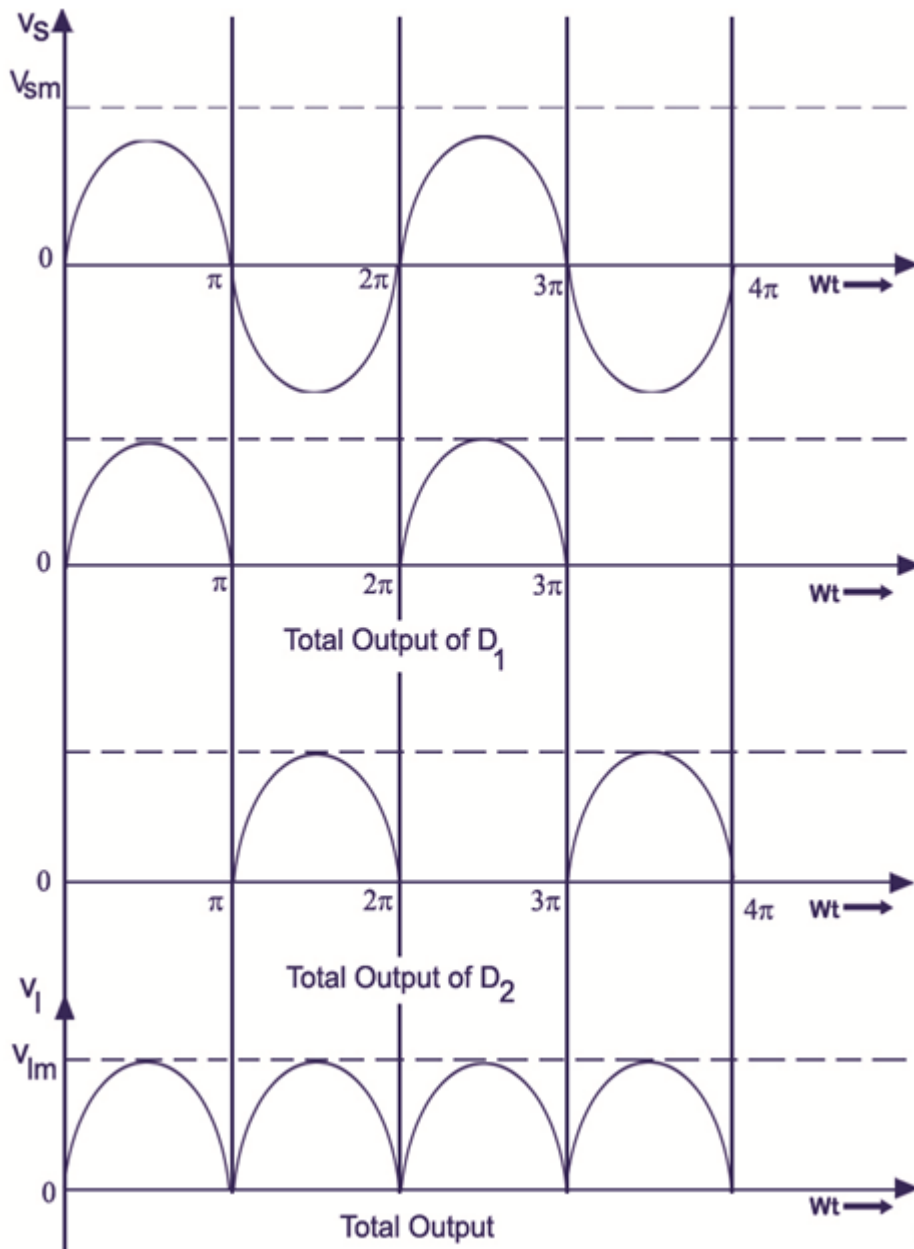


Fig: input and output voltage wave form for full wave rectifier.

Characteristics :

The average current in full wave rectifier is

$$I_{av} = I_{dc} = 2I_o = 2 I_{max}/\pi \quad [I_o = \text{maximum current}]$$

$$I_{rms} = I_o/\sqrt{2} = I_{max}/\sqrt{2}$$

Application

In central tapped rectifier there is no hysteresis loss so, it can be used for very regulated power supplies.

Lesson 4

Bridge – Rectifier

Construction: Bridge rectifier for full wave rectification consists of four diodes D_1, D_2, D_3, D_4 arranged in the form of a bridge along with a load resistor and the bridge is connected to secondary coil as shown in figure below.

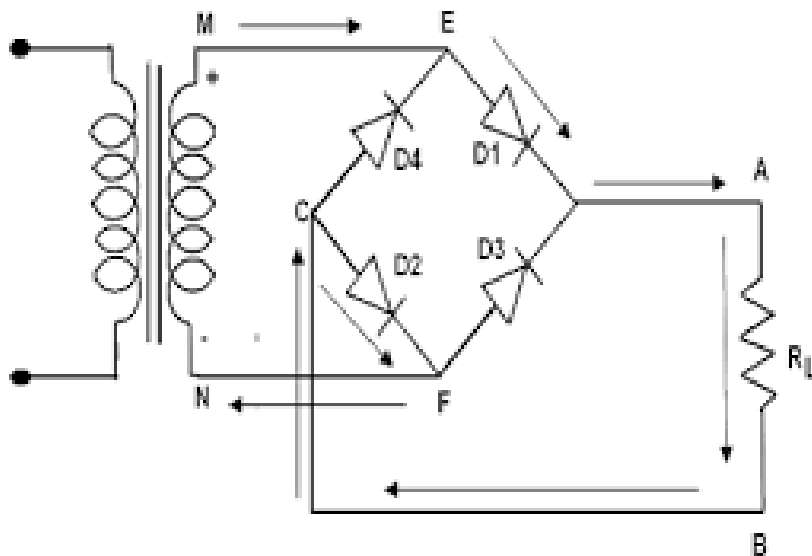


Fig. Bridge full wave rectifier

Working principle:

During positive half cycle of ac let, the upper end M of secondary coil is positive and N is negative. The diodes D_1 and D_2 are forward biased and diodes D_4 and D_3 are reverse biased. This positive half cycle of input ac flows through D_1 and D_2 along $MAD_1R_L D_2 FN$. So, current flows through load resistance R_L . For negative half

cycle of ac the end N is positive and end M is negative so diodes D4 and D3 are forward biased and D1 and D2 are reverse biased. This negative half cycles of input ac flows through R_L along NFD3R_LD4EM and as a result current flows through load resistance R_L in the same direction as in positive half cycle.

Since, in both half cycles of ac input the current flows through load resistance R_L so, it works as full wave rectifier.

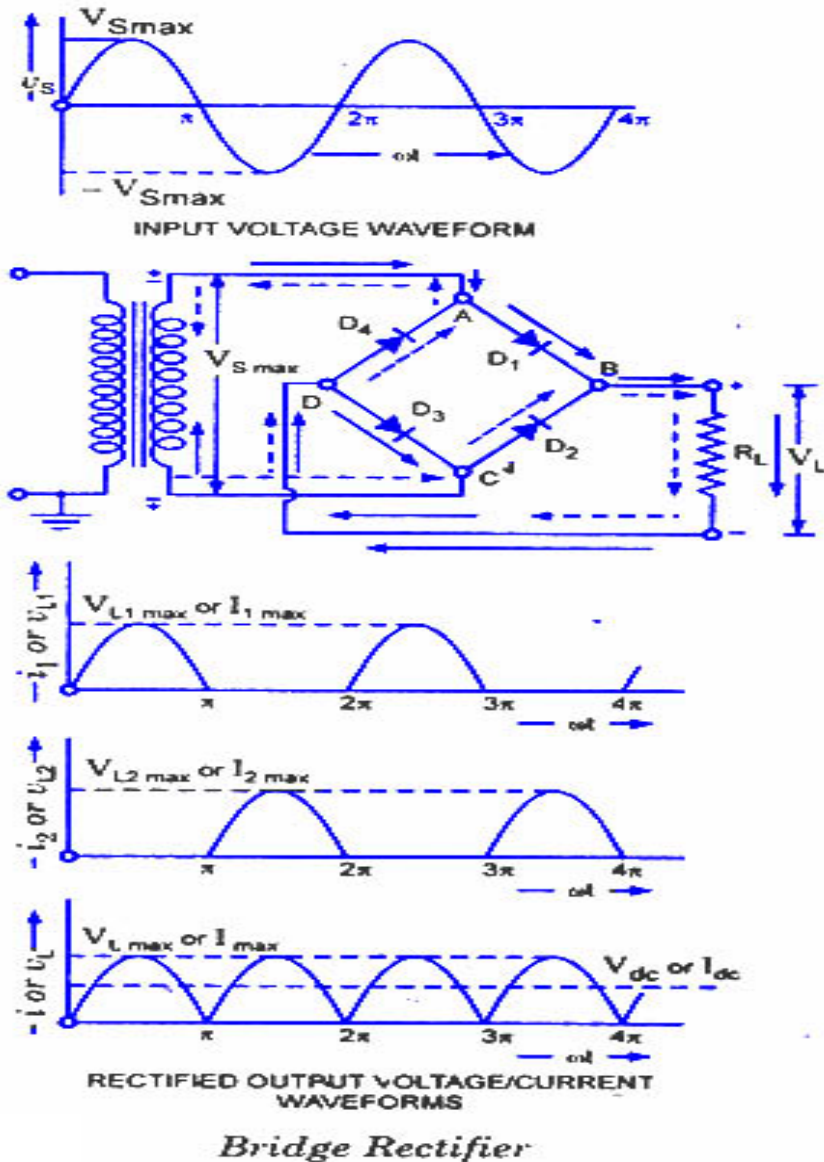


Fig. input and output waveforms for Bridge full wave rectifier

Characteristics :

The average current $I_{av} = I_{dc} = \frac{2 I_{max}}{\pi}$

$$I_{rms} = I_{max} / \sqrt{2}$$

Teaching Tips

1. Give the practical examples found at their home and surrounding.
2. Use the Charts as far as possible to explain the content.
3. Assign the homework at the end of every class from the chapter so far covered during that class.
4. Conduct group discussions after finishing one lesson.

Lab Activity

TO STUDY THE JUNCTION DIODE RECTIFIER CHARACTERISTIC - 4hrs

1. Half wave rectifier

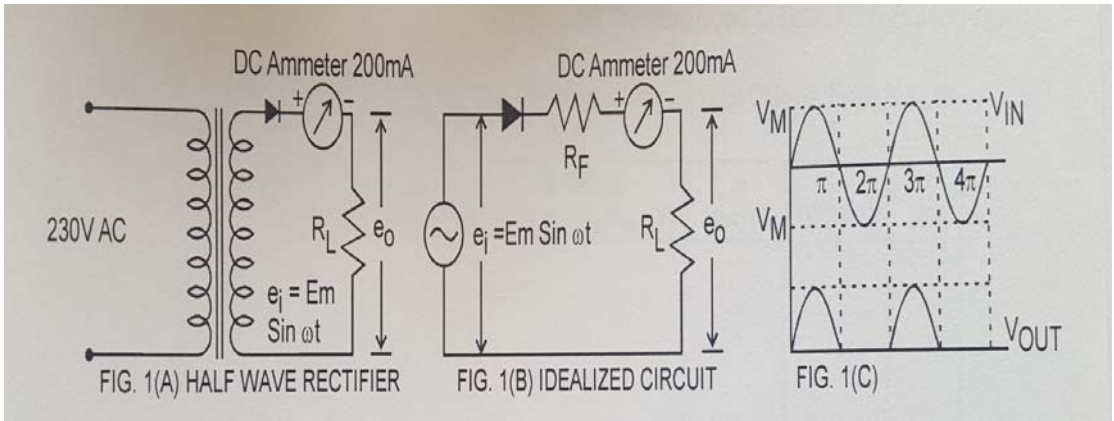
a. Apparatus required:

- ▶ Breadboard
- ▶ Semiconductor diode
- ▶ Ammeter (200mA)
- ▶ DC Voltmeter
- ▶ Transformer
- ▶ Load Resistor
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

b. Theory:

c. Procedure:

- i. Assemble the circuit as shown in the figure below.
- ii. Switch on the main supply.
- iii. Records the values in different columns of table given below for different values of load R_L .



Sr. No.	Load R_L (Ω)	Load Current I_{dc} (mA)	DC Voltage Across load e_0 (V_{dc}) (V)	E_i (rms)(V)	V_r (rms)(v)	r

d. Conclusion:

TO STUDY THE JUNCTION DIODE RECTIFIER CHARACTERISTIC - 4hrs

2. full wave rectifier (Bridge)

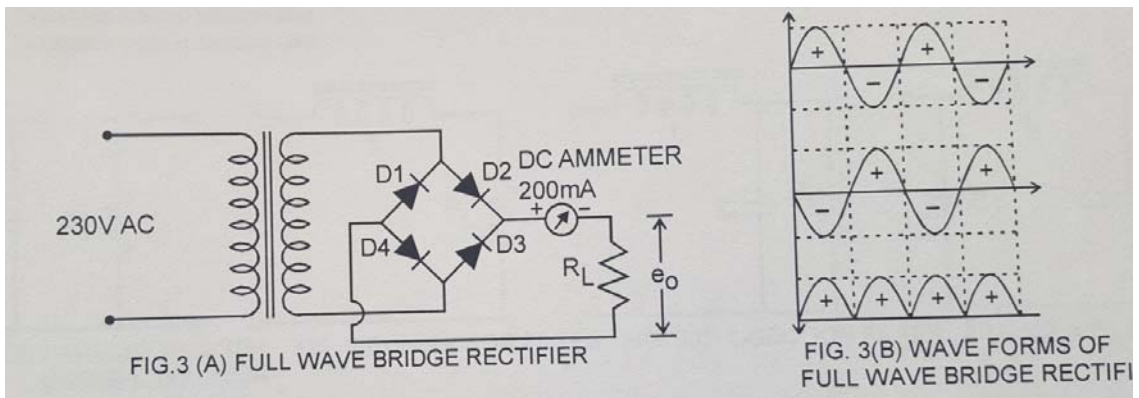
a. Apparatus required:

- ▶ Breadboard - Semiconductor diode
- ▶ Ammeter (200mA) - DC Voltmeter
- ▶ Transformer - Load Resistor
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

b. Theory:

c. Procedure:

- ▶ Assemble the circuit as shown in the figure below.
- ▶ Switch on the main supply.
- ▶ Records the values in different columns of table for different values of load R_L .



Sr. No.	Load R_L (Ω)	Load Current I_{dc} (mA)	DC Voltage Across load $e_0(V_{dc})$ (V)	e_i (rms) (V)	V_r (rms)(v)	r

d. Conclusion:

TO STUDY THE JUNCTION DIODE RECTIFIER CHARACTERISTIC - 4hrs

3. full wave rectifier (Center tap)

a. Apparatus required:

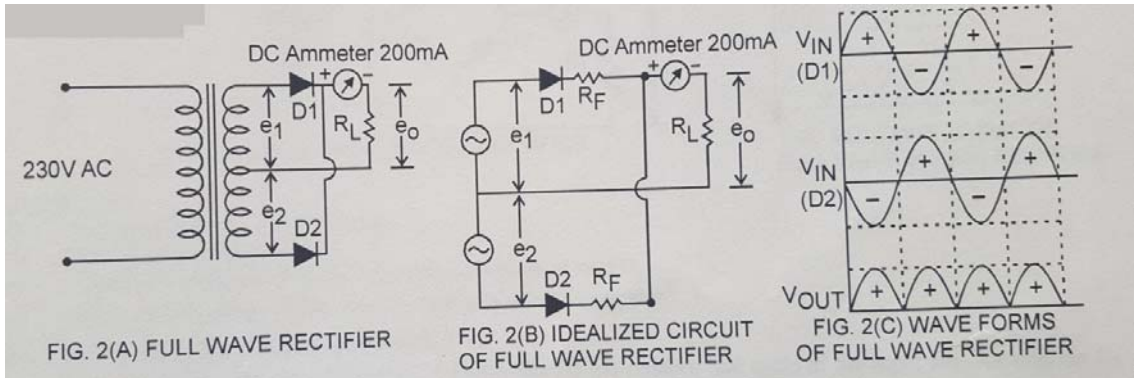
- ▶ Breadboard - Semiconductor diode
- ▶ DC Ammeter (200mA) - DC Voltmeter
- ▶ Transformer - Load Resistor
- ▶ Connecting wires
- ▶ Power Supply
- ▶ Input voltage 230 +/- 10% , 50Hz

b. Theory:

c. Procedure:

- ▶ Assemble the circuit as shown in the figure 8(a)
- ▶ Switch on the main supply.
- ▶ Records the values in different columns of table 8(b) for different values of load R_L .

Ripple factor = V_r (rms)/ V_{dc}



Sr. No.	Load $R_L (\Omega)$	Load Current $I_{dc}(mA)$	DC Voltage Across load $e_0(V_{dc}) (V)$	e_i (rms)(V)	V_r (rms)(v)	r

Conclusion:

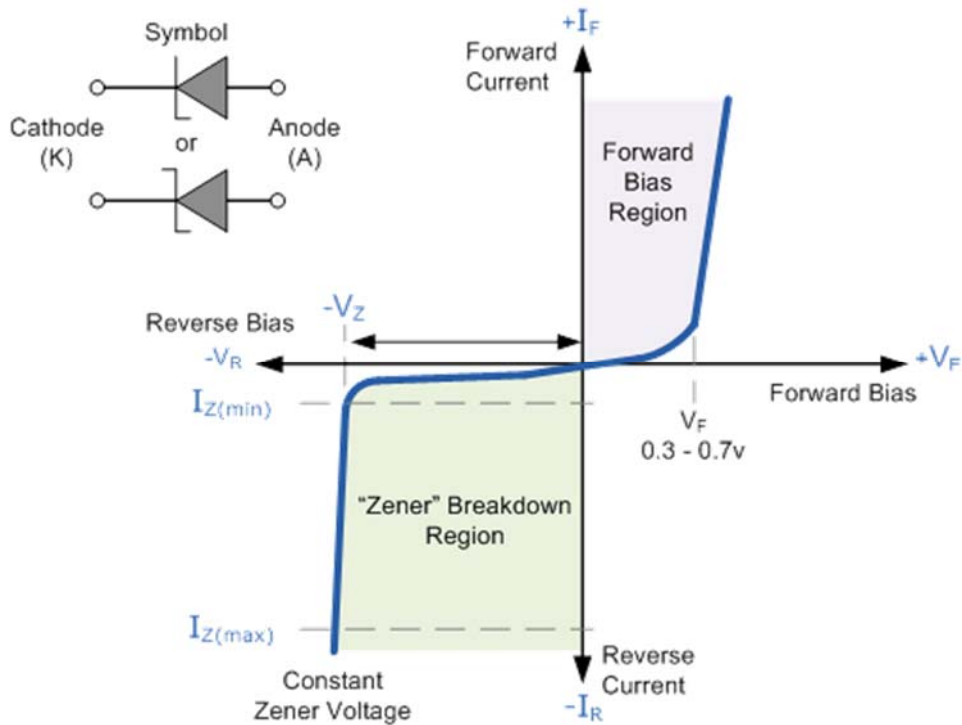
Lesson 5

4.2 Voltage Regulation:

Zener diode:

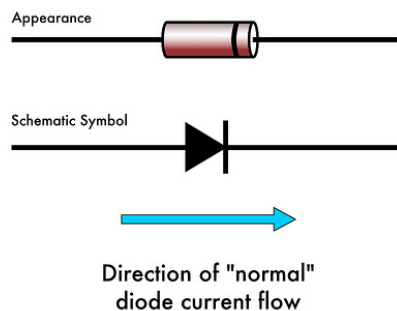
Zener diode is heavily doped pn-junction diode which works in reverse biased configuration in the breakdown region if we observed the current V_s voltage graph of zener diode we found that the diode has specific breakdown voltage called zener voltage V_z , which is as small as few volts. The vertical breakdown character represent that voltage across diode remains constant in reversed biased and current through it varies over a wide range. In this breakdown region the zener diode behaves as dynamic resistance (i.e. it resistance keeps fluctuating so as to keep voltage constant)

. So, if output is taken across the zener – diode, it is constant. Hence zener- diode can be used as a constant voltage regulator circuit, provided that it is working in breakdown region

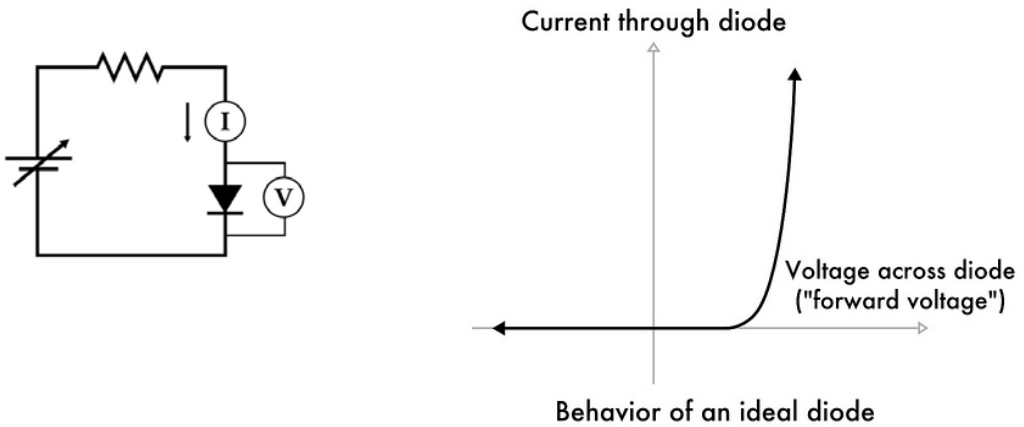


Semiconductor diodes, real and ideal

To understand how Zener diodes are different from other diodes, let's first review the properties of regular diodes. And, while there are many different types of diodes—see [here](#) for a long list—we're going to focus on so-called “normal” semiconductor diodes, most commonly constructed with a p-n silicon junction.

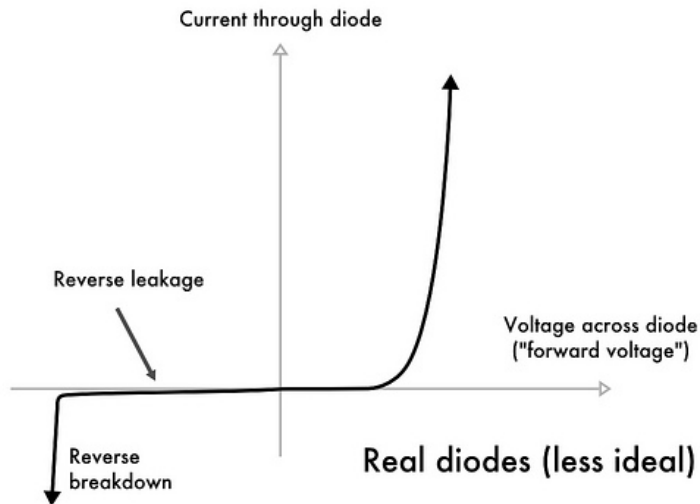


Diodes usually come in glass or plastic cylindrical packages, marked with a stripe on one side to indicate polarity. In a perfectly ideal diode, current flows in one direction only, from the anode (positive side) to the cathode (negative side) which is marked with the stripe. The schematic symbol is a triangle pointing towards a bar, where the current flows in the same direction, towards the barred (striped) end. Surface mount versions of diodes tend to follow the same labeling convention, where the cathode end is marked with a broad stripe.



If we hook up a diode in a simple circuit with a variable voltage source and a current-limiting resistor, we can measure the current I through the diode when a given voltage V is applied across it. For an ideal diode, no current at all passes when the voltage is less than zero: the diode completely prevents reverse current flow. For small positive voltage (“forward bias,” or sometimes “forward voltage”), a tiny amount of current may flow, and a very large amount of current will flow above a given threshold. The amount of current that flows is actually exponential with increasing voltage.

The threshold where an appreciable amount of current flows is typically around 0.7 V for simple semiconductor diodes, but may be as low as 0.15 V for Schottky diodes, or as high as 4 V for certain types of LEDs.

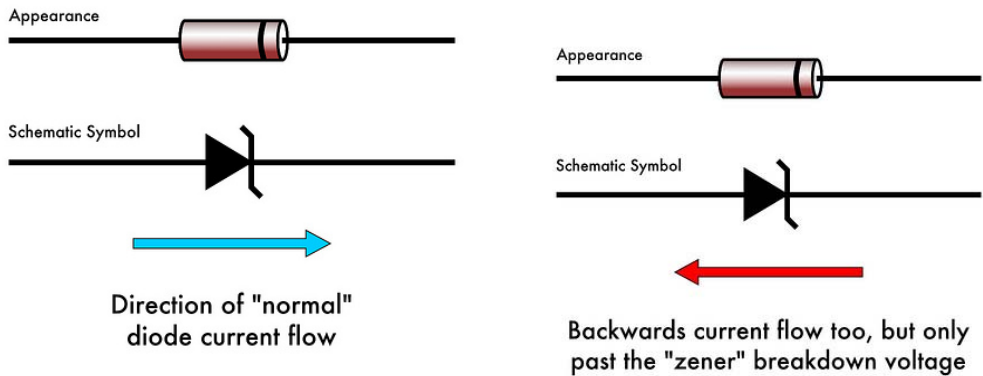


Of course, no diode is truly ideal. In real diodes, when the voltage is reversed, a very small amount of current (leakage) may flow. And, more significantly, each diode is rated for a certain maximum amount of reverse voltage. If you apply voltage more negative than that limit, the diode will undergo “reverse breakdown” and begin to conduct a significant amount of current, but *backwards* from the normal direction of diode current flow. For a regular diode, we would say that the diode has *failed* if it begins to conduct current in that direction.

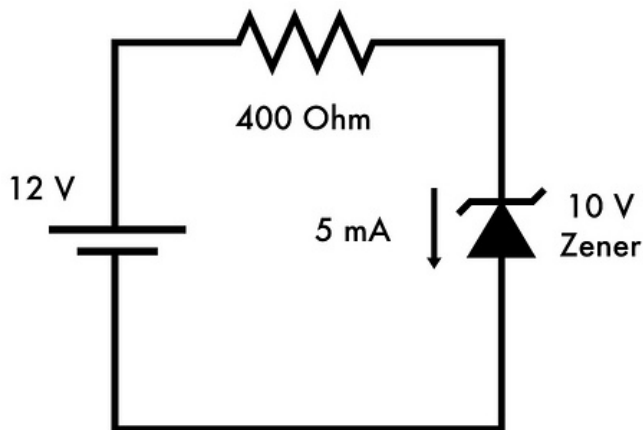
Aside: The actual physics of what happens at breakdown is quite interesting; two separate effects, the Zener effect and Avalanche breakdown both contribute to this behavior.

Zener diodes

Zener diodes are semiconductor diodes which have been manufactured to have their reverse breakdown occur at a specific, well-defined voltage (its “Zener voltage”), and that are designed such that they can be operated continuously in that breakdown mode. Commonly available Zener diodes are available with breakdown voltages (“Zener voltages”) anywhere from 1.8 to 200 V.



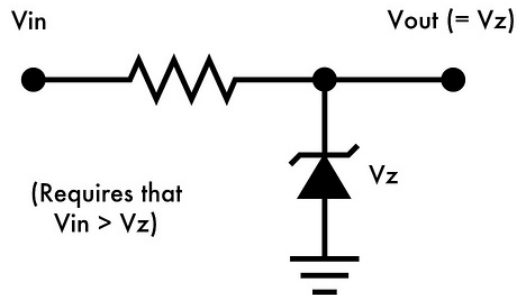
The schematic symbol for a Zener diode is shown above— it is very similar to that of a regular diode, but with bent edges on the bar. The Zener still conducts electricity in the forward direction like any other diode, but also conducts in the reverse direction, if the voltage applied is reversed and larger than the Zener breakdown voltage.



A typical application might be as above: A 10 V Zener diode (type 1N4740) is placed in series with a resistor and a fixed 12 V power supply. The resistor value is chosen such that several mA flow through it and through the Zener, keeping it in its breakdown region. In the circuit above, there is 10 V across the Zener diode, and 2 V across the resistor. With 2 V across a 400 ohm resistor, the current through that resistor (and the diode, in series) is 5 mA.

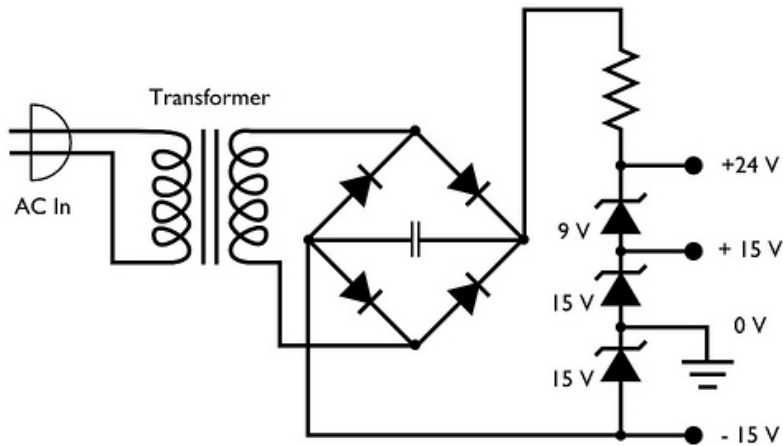
Zener voltage references

The fixed voltage property of Zener diodes makes them extremely handy as quick voltage references. The basic circuit looks like this:



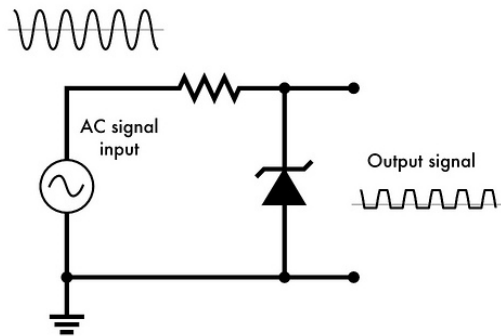
There are a couple of requirements to consider. First, the input voltage has to be higher than the Zener voltage. Second, the resistor value must be chosen such that there is always current flowing through the Zener.

Some caveats: This is not necessarily a good power supply for all purposes— the resistor limits how much current can be drawn. It is also not necessarily a precision voltage reference; the voltage will depend on the amount of current drawn. (That is to say, for the voltage to be steady, the load driven by that reference voltage must be consistent.) The voltage also depends upon the temperature. Zeners in the range 5-6 V have the best temperature stability, and there are high-precision Zener diodes (like the LM399) that include their own temperature-stabilized oven to further keep the diode temperature as steady as possible.



Taking this idea a bit further, you can actually build a full multi-rail power supply using nothing more exotic than a set of Zener diodes to generate all the voltages that are needed, provided that the current requirements are modest on the different supply voltages. The circuit above is part of a working laboratory instrument.

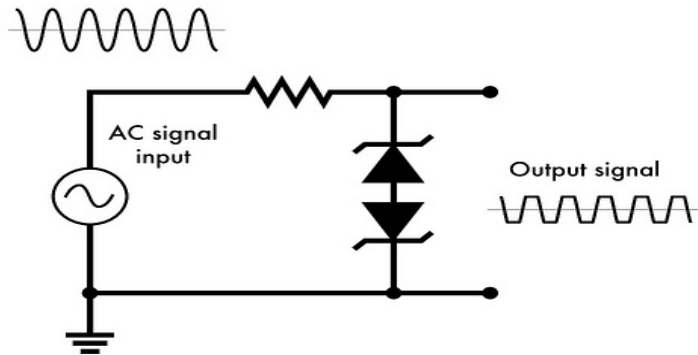
Voltage clamps: Limiting signals with Zener diodes



A varying analog signal can be constrained to a fairly narrow range of voltages with a single Zener diode. If you have a voltage that swings between $+7\text{ V}$ and -7 V , you could use a single 4 V Zener, connected to ground, to ensure that the signal does not exceed 4 V or go below -0.7 V (where the diode conducts forward to ground).

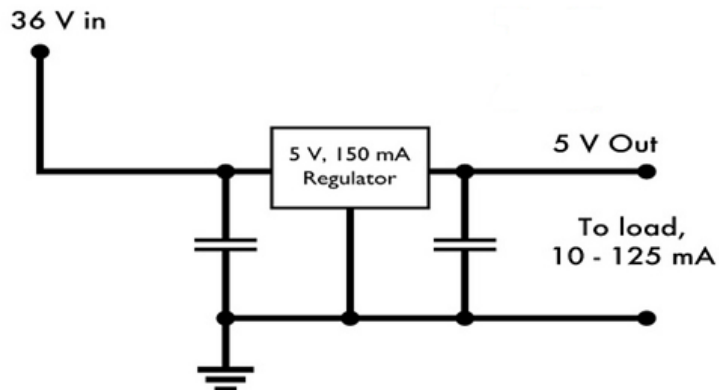
If you wanted to constrain the signal to never go negative— e.g., for input to an analog-to-digital converter that accepts signals in the $0 - 5\text{ V}$ range, you could

connect the anode of the Zener diode to a power rail at 1 V, instead of ground. Then, the output signal range would be constrained to the range of 0.3 V – 5 V.



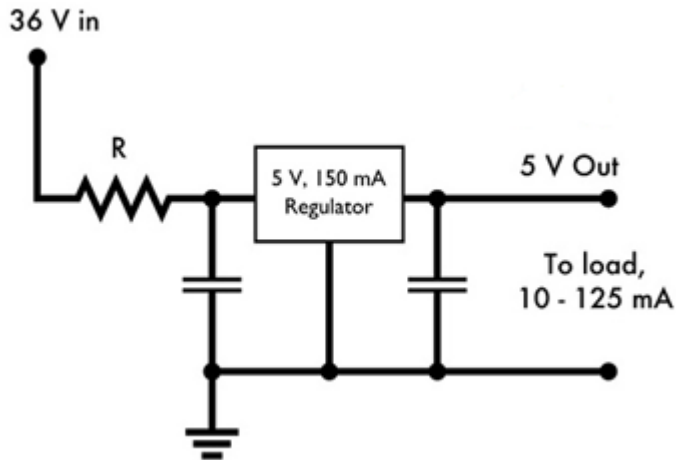
Another neat trick is to use two Zener diodes, oppositely oriented, in series. This can provide a symmetric limit on the excursion of a signal from ground, for example. This is also a common configuration for using Zener diodes as transient suppressors.

Voltage translation: Easing the load on a regulator



Here's something that doesn't work. We have a TL750L05, which is a type of 5 V output linear regulator, which can source up to 150 mA output, and its load will be variable. We need to drive it from a 36 V source. Unfortunately, the maximum input voltage of the TL750L05 is 26 V.

Let's try adding a resistor in series to drop some of that voltage:

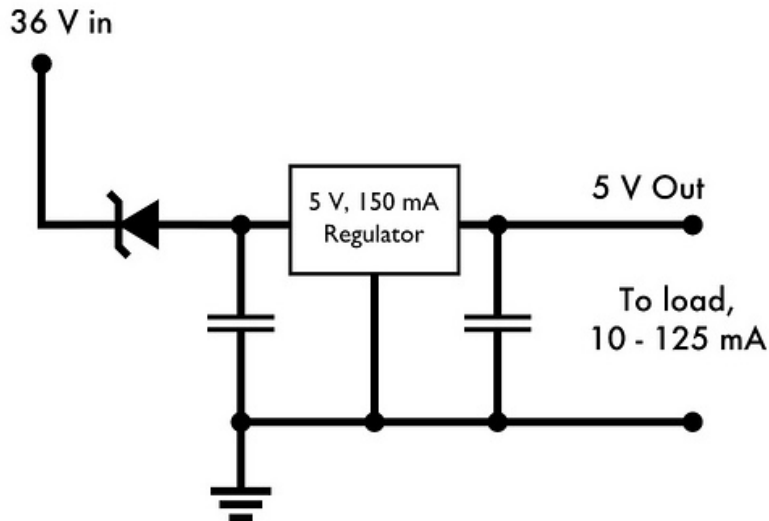


Our output load can be as high as 125 mA and as low as 10 mA. So, what value resistor will work for us?

Suppose that we assume 125 mA loads. Then to take up (say) 20 V on the resistor, $20 \text{ V} / .125 \text{ A} = 160 \text{ Ohms}$. If we use 160 ohms, that will drop only $160 \text{ Ohm} * 0.01 \text{ A} = 1.6 \text{ V}$ at 10 mA load, and $36 \text{ V} - 1.6 \text{ V}$ is still larger than 26 V. In order to be safe for the 10 mA load, we should pick a resistor that gives us at least an 11 V drop, for 25 V input to the regulator. So, $11 \text{ V} / .01 \text{ A} = 1100 \text{ Ohms}$ would be safe for the 10 mA load. But if the load increases to 125 mA, the drop across 1100 Ohms would be $V = 0.125 \text{ A} * 1100 \text{ Ohms} = 137 \text{ V}$, which means that the input to the regulator would be below 5 V, and it would cease to operate.

Clearly, there is no resistor value that you can pick that actually will work for both the low and high current cases.

Let's try again, this time with our friend, the Zener diode.

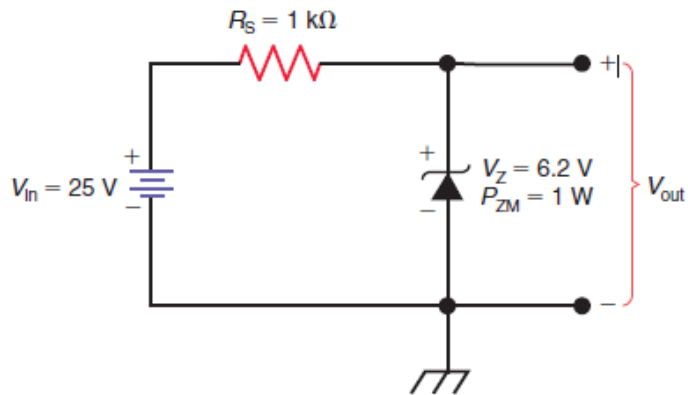


Finally, let's try using one fat 20 V Zener diode (type 1N5357BRLG), to drop some of the load. Then, the output on the anode of the Zener is just 16 V, well within the safe input range of the regulator. The 1N5357BRLG is rated for 5 W maximum. At 20 V and .125 A, the power dissipated by the Zener would be 2.5 W, so it will get warm, but we are well in the safe operating conditions of the Zener, and now the circuit will work.

Zener Diode Applications

Figure below shows an unloaded voltage regulator that uses a 6.2-V zener diode. Notice that the zener diode is reverse-biased with the positive terminal of V_{in} connected to the cathode of the zener diode through the series limiting resistor, R_S . The zener diode provides an output voltage of 6.2 V. The zener current is calculated by dividing the voltage across the series resistor, R_S , by the value of R_S . The calculations are

$$\begin{aligned}
 I_Z &= \frac{V_{in} - V_Z}{R_S} \\
 &= \frac{25 \text{ V} - 10 \text{ V}}{1 \text{ k}\Omega} \\
 &= 18.8 \text{ mA}
 \end{aligned}$$



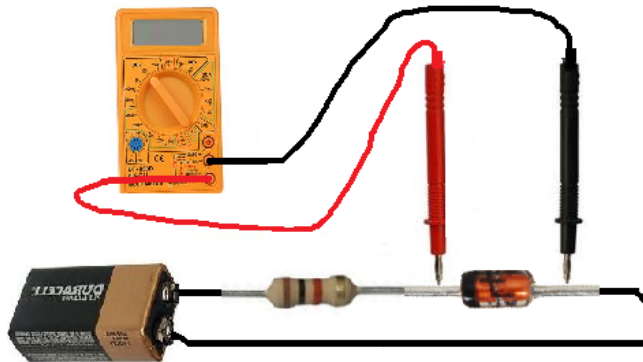
If the input voltage, V_{in} , varies, the zener current, I_Z , also varies. However, V_Z remains relatively constant. Any fluctuation in the zener voltage, V_Z , is due to the small change in the voltage drop across the zener impedance, R_Z .

Example

If $V_Z = 10\text{ V}$ in Fig. 27–26, calculate I_Z .

ANSWER The calculations are

$$\begin{aligned} I_Z &= \frac{V_{\text{in}} - V_Z}{R_S} \\ &= \frac{25\text{ V} - 10\text{ V}}{1\text{ k}\Omega} \\ &= 15\text{ mA} \end{aligned}$$



Instruction for Teacher:

- ▶ Use the Charts as far as possible to explain the content.
- ▶ Assign the homework at the end of every class from the chapter so far covered during that class.
- ▶ Conduct group discussions after finishing one lesson.
- ▶ Use any simulation software to explain semiconductors

References and Resources:

- ▶ Principles of physics-II (Ayam Publication Pvt.Ltd)
- ▶ Electronic Principles Alberto Malvino/David Bates
- ▶ Basic Electronics Solid state (B.L. Theraja)
- ▶ www.allaboutcircuits.com
- ▶ Electronic Devices and Circuits by Theodore F. Bogart

UNIT-5

Bipolar Junction Transistors

Learning Outcomes:

After completion of this chapter, Student will be able to:

- Design simple circuit using BJT
- Application and real world use of BJT

5.1 Explain the Types of transistors with working principles, circuit characteristics and applications

Introduction

A Bipolar Junction Transistor (a BJT or Bipolar Transistor) is an active semiconductor device formed by two P-N junctions whose function is amplification of an electric current. A bipolar junction transistor (BJT) is a specially constructed three terminal semiconductor device containing two p-n junctions. The basic principle involved is the use of the voltage between two terminals to control the current flowing in third terminal. In this type of transistor, the current conduction is due to both electrons and holes, which is the reason for the name bipolar.

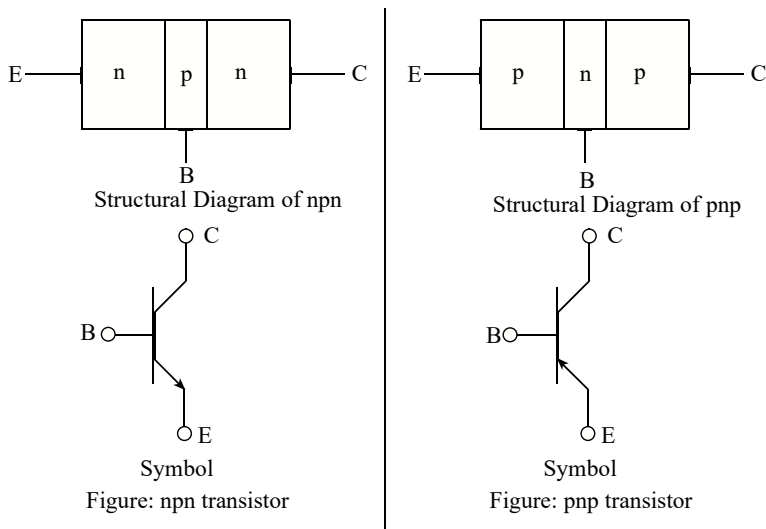
Geometry and Doping Level

A BJT has three different regions: (i) the emitter (ii) the base and (iii) the collector. The base region or the central layer is very much narrower than the outer two layers. Also, this region is much lightly doped in comparison to other two layers. The emitter region, with larger area, is the most heavily doped region while the collector region has the largest area and doping level with a value lying in between emitter and base region. The emitter is named emitter as it emits electrons or holes, while the collector collects electrons or holes. Because the outer layers i.e. emitter and collectors are heavily doped, the depletion region penetrates deeper into the base reducing the width of the base.

Two types of Bipolar Junction Transistors:

Depending upon the layers formed there are two types of transistors NPN and PNP.

In NPN transistor a thin layer of P type semiconductor is sandwiched between two thicker layers of N type semiconductors. Similarly, in PNP transistor a thin layer of N type semiconductor is sandwiched between two thick thicker layers of P type semiconductors. The structural and circuit diagram of NPN and PNP transistor are shown in following fig.



Mode

MOD	EB Junction	CB Junction
E		
Cut-off	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward
Reverse active	Reverse	Forward

The cutoff mode and saturation mode are used for making switches and logic gates. The active mode is used for making amplifiers.

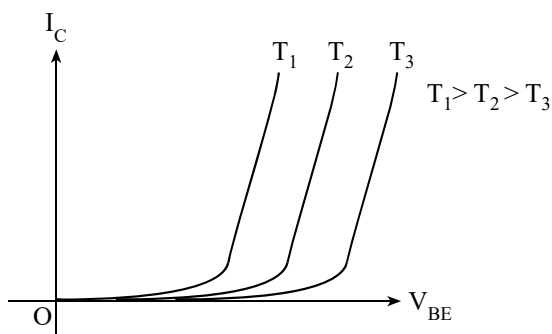
Graphical Representation of Transistor Characteristics:

Figure shows the $I_C - V_{BE}$ characteristics, which is the exponential relationship and given by

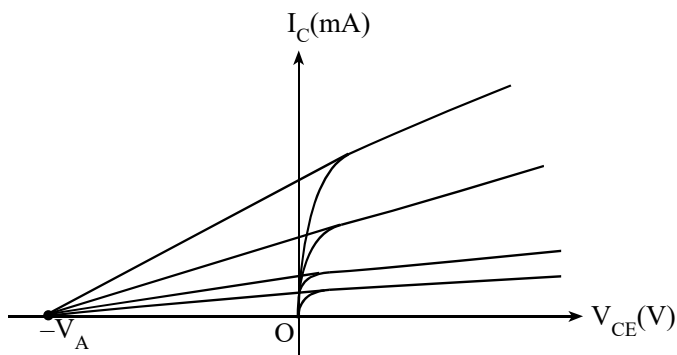
$$I_C = I_{se}^{V_{BE}/V_T}$$

It is identical to the diode i-v relationship except for the value of constant n. The $I_E - V_{BE}$ and $I_B - V_{BE}$ characteristics are also exponential but with different scale currents, I_S/α for I_E and I_S/β for I_B . For V_{BE} smaller than about 0.5 V, the current is negligibly small.

The voltage across the emitter base junction decreases by about 2 mV for each rise of 1°C in temperature, provided that the junction is operating at constant current. Temperature dependence fig is shown below:



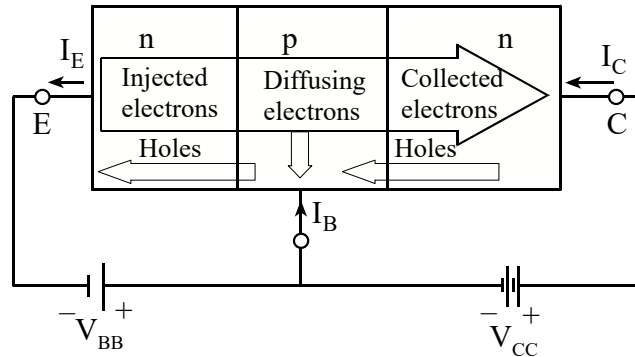
Effect of temperature on the characteristics curve



Characteristics curve of a practical BJT

The voltage V_A , a positive number, is a parameter for the particular BJT, with typical values in the range of 50 V to 100 V. It is called the Early voltage.

Operation of npn-transistor in Active mode (normal mode)



Operation of npn in Active Mode

For normal operation, base-emitter junction is forward-biased (i.e. base is more positive with respect to emitter) and the base collector junction is reverse-biased (base is less positive with respect to collector).

The forward bias at emitter-base junction reduces its barrier potential and as a result, electrons from emitter flow into base. Holes also flow from p-type base into n-type region. But, since the base region is much lightly doped than emitter, large numbers of electrons are accumulated in base region, which could not recombine with holes of base region. These electrons behave like minority charge carriers for reverse biased collector- base junction. Hence, they flow into collector region as minority carrier current. The reverse bias at the collector- base junction causes collector-base depletion layer to penetrate deeper into base region. Thus, the thin base region becomes thinner. As, a result, the electrons emitted from emitter region into base region almost immediately reaches the collector base junction where larger positive collector voltage is present, causing almost all of these electrons to cross collector-base junction and flow into collector region as collector current.

Due to this phenomenon, more than 99% of emitter current becomes collector current and very few electrons recombine with holes to give rise to base current. Some of the electrons that are diffused from emitter into base recombine with the majority carriers of the base. The external power supplies the holes lost due to recombination process.

The base current I_B constitutes the current I_{B1} due to the holes diffused from base into emitter and the current I_{B2} due to the electron hole recombination process in the base.

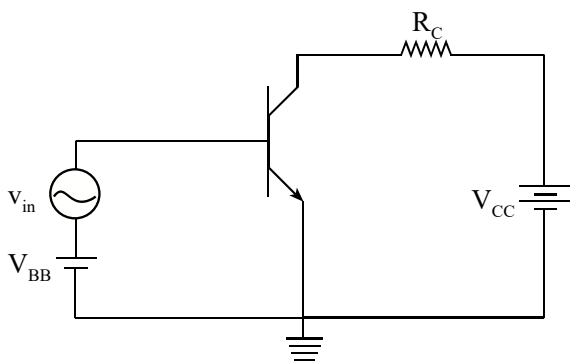
$$I_B = I_{B1} + I_{B2}$$

The direction of current is shown in fig 5.1 and it is opposite to the flow of electrons .Now from above explanation and figure we have

$$I_E = I_B + I_C$$

$$\text{or, } 100\% \text{ of } I_E = 1\% \text{ of } I_E + 99\% \text{ of } I_E$$

Transistor as an Amplifier:



Basic Common Emitter Amplifier

To operate as an amplifier a transistor must be in active region. Consider the basic common-emitter circuit given as an amplifier circuit in fig 5.4.

Here, we know that in active mode of operation I_C depends upon the magnitude of emitter current I_E (& not upon V_{CE}) which in turn depends upon the forward bias voltage V_{BE} . That mean I_C depends upon the magnitude of V_{BE} .

For the dc condition we have

$$I_C = I_{se} (V_{BE}/V_T)$$

$$I_E = ; I_B =$$

From circuit diagram we have,

$$V_C = V_{CE} = V_{CC} - I_C R_C$$

Here $V_C > V_B$ for active mode

The total instantaneous base emitter voltage v_{BE} becomes

$$v_{BE} = V_{BE} + v_{be}$$

And corresponding collector current i_c is given by

$$i_c = I_{se}^{(v_{BE}/V_T)}$$

$$\begin{aligned} I_C + i_c &= I_{se}^{((V_{BE} + v_{be})/V_T)} \\ &= I_{ce}^{(v_{be}/V_T)} \end{aligned}$$

Expanding the exponential term and neglecting higher terms we have

$$I_C + i_c \approx I_C + I_C$$

Comparing dc to dc and ac to ac quantities we have

$$I_C = I_C \text{ and}$$

$$i_c = I_C$$

$$= = g_m = \text{mutual conductance} = \text{trans-conductance}$$

$$\text{Thus } i_c = g_m v_{be}$$

Similarly, we have total base current

$$i_B = I_B + i_b = +$$

Comparing ac to ac

$$i_b = = I_C =$$

$$= = r_\pi \text{ (or } r_b)$$

r_π = base ac resistance or small signal ac input resistance between base and emitter looking into base

Also

$$r_\pi = =$$

Total emitter current

$$i_E = i_e + I_E = +$$

Comparing ac to ac quantities

$$i_e =$$

$$= r_e$$

r_e = emitter ac resistance or small signal ac resistance between base and emitter looking into emitter

Also

$$r_e =$$

$$\text{Thus } r_e = \left[\frac{V_T}{I_E} \approx 1 \right]$$

$$r_e =$$

$$r_\pi = (\beta + 1)r_e$$

For voltage gain

From figure

$$V_{CE} = V_{CC} - i_c R_C$$

$$V_{CE} + v_{ce} = V_{CC} - (i_c + I_C) R_C$$

Comparing ac to ac quantities

$$v_{ce} = -i_c R_C = -g_m v_{be} R_C$$

$$= -g_m R_C$$

Therefore voltage gain of an amplifier (A_v) = $-g_m R_C$. The negative sign indicates that the output signal voltage is 180° out of phase with respect to input ac signal voltage.

Similarly current gain (A_i)

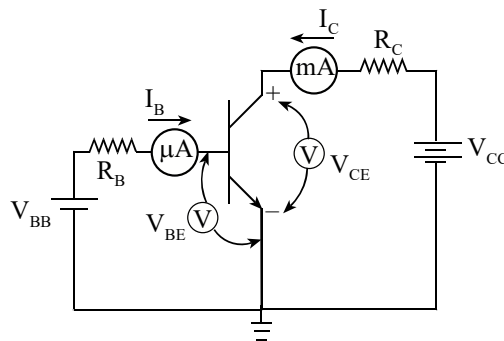
$$A_i = -g_m r_\pi = -\beta$$

5.2 Transistor circuit configuration:

Configuration simply means arrangement of input and output terminals and is related to investigating transistor behavior based on arrangement. This contains the transistor characteristics based on where the input is applied and where the output is taken from. Transistor can be configured in three ways:

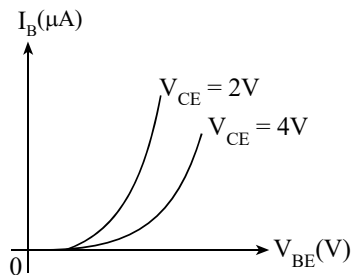
- i. Common Emitter Configuration
- ii. Common Base Configuration
- iii. Common Collector Configuration

i. Common Emitter Configuration:



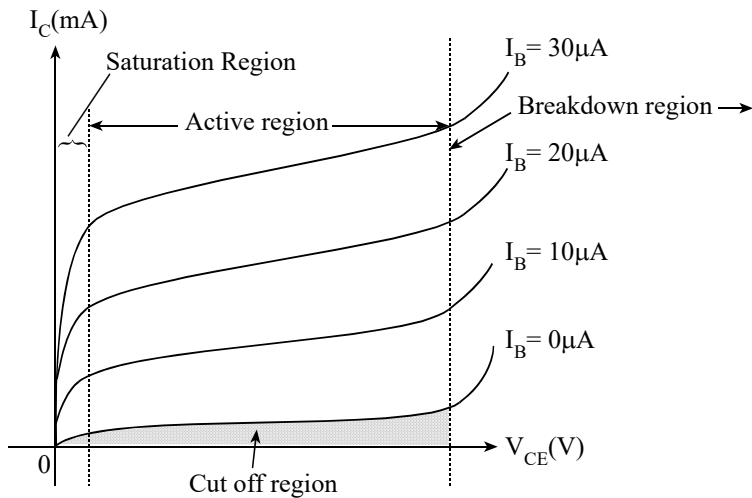
Circuit to Study Characteristics of CE Configuration

For this configuration, the input voltage is applied to the base and the output is taken at the collector and the emitter terminal is common to both input and output.



Input Characteristics

To observe input characteristics of common emitter configuration, V_{CE} is held constant, V_{BE} is set at convenient level and the corresponding I_B is recorded. The graph almost resembles with the I - V characteristic curve of forward-biased diode.

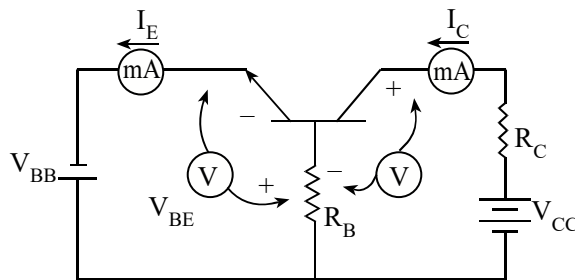


Output Characteristics

For plotting the output characteristics, I_B is maintained at several convenient levels, whereas V_{CE} is adjusted in steps and corresponding I_C are noted.

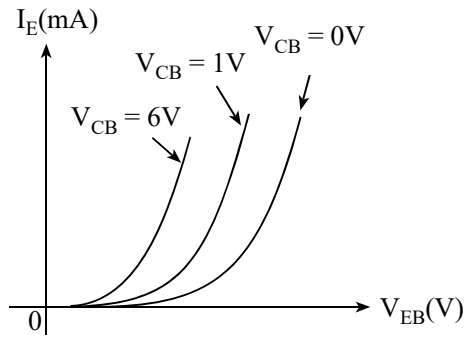
Because, I_E is not held constant, the shortening of distance between depletion regions draws more charge carriers from the emitter to collector. So, although I_B is constant, I_C increases to some extent with increasing V_{CE} causes the slope of common-emitter output characteristics. This slope is sometimes formed as early effect. On extension of slope line towards left, they meet at a point on the horizontal scale. The voltage at this point of intersection is called early voltage.

ii. Common Base Configuration



Circuit to Study Characteristics of CB Configuration

The above diagram shows that a npn transistor is configured with its base terminal common to both the input terminals and output terminals.



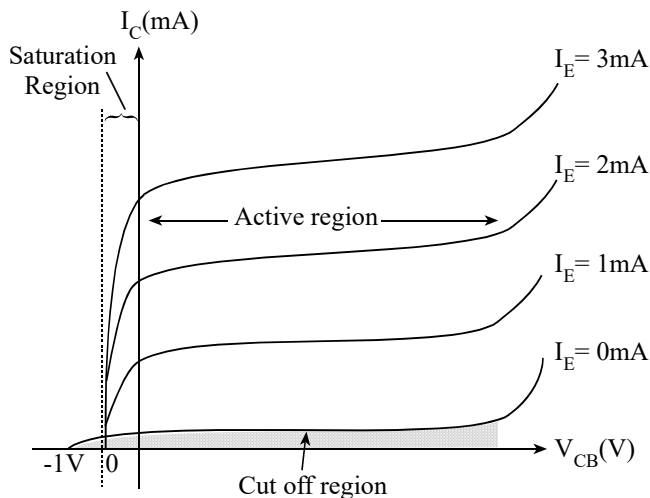
Input Characteristics

To investigate the input characteristics, the output voltage V_{CB} is kept constant and the input voltage is set at convenient levels. At each voltage level, the corresponding input current is recorded.

For a given input voltage V_{EB} , more input current flows when higher level of collector base voltage is used. This is because larger collector-base voltages cause the depletion region at the collector base junction to penetrate deeper into the base of transistor, thus shortening the distance and reducing resistance between emitter-base and collector-base depletion regions.

Current gain; $\beta = \frac{I_C}{I_E}$

Output characteristics

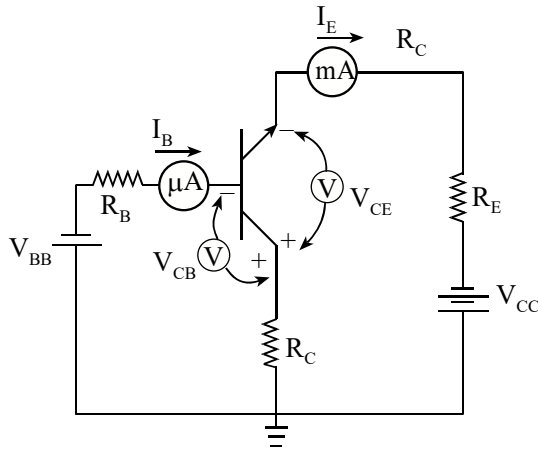


Output Characteristics

For plotting output characteristic, I_E is held constant and the corresponding I_C values are noted for V_{CB} adjusted in convenient steps.

When V_{CB} is zero, I_C still flows. This is because even when the externally applied voltage is zero, there is still a barrier voltage existing at the collector base junction and this assists flow of I_C . And, to stop the flow of charge carriers, the collector base junction has to be forward biased.

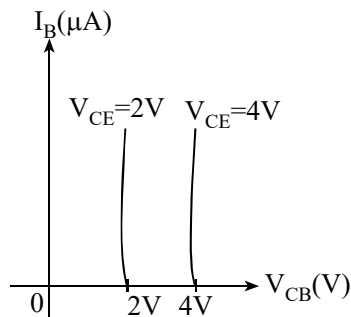
iii. Common collector configuration:



Circuit to Study Characteristics of CC Configuration

The circuit arrangement in figure above shows that the collector is common to both the input and the output terminal.

Input characteristics:

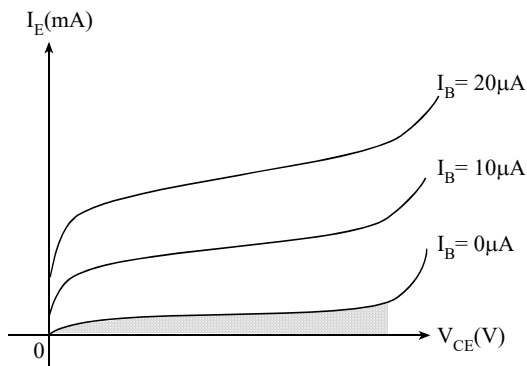


Input Characteristics

The common collector input characteristics are quite different from either common base or common-emitter configuration. The difference is due to the fact that the input voltage is largely determined by the output voltage V_{CE} . i.e.

$$V_{CE} = V_{CB} + V_{BE} \text{ and, } V_{BE} = V_{CE} - V_{CB}$$

Output characteristics:



Output Characteristics

The output characteristics are a plot of emitter current I_E Vs collector-emitter voltage V_{CE} for several constant levels of base current, I_B .

Relationship between β and β' :

We have,

From common emitter configuration,

$$\beta = \dots\dots\dots (i)$$

And, from common base configuration

$$\beta' = \dots\dots\dots (i)$$

Moreover, for a transistor,

$$I_E = I_B + I_C$$

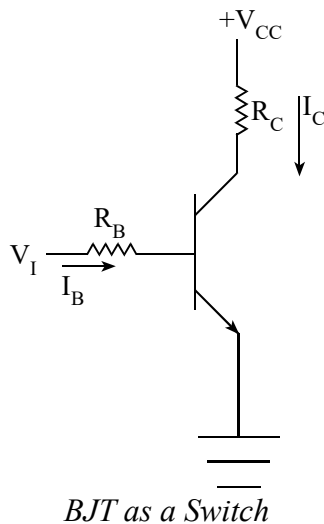
or, $\beta = + 1$

or, $\beta = + 1$ $\beta' \beta =$ and $\beta =$

5.3 Transistor as a Switch – Cutoff and Saturation

BJT can work in one of the following mode of operations:

- i. Active Mode
- ii. Cutoff mode
- iii. Saturation Mode



Out of these modes of operation the cutoff and saturation mode of operations are used to operate BJT as a switch. When transistor is in cutoff mode, it doesn't conduct any current and this mode of operation is considered as "OFF" position of switch. Now, when base emitter junction voltage will be well beyond the cut-in voltage the transistor enters into saturation mode and maximum current will flow in it. It is "ON" position.

Operation in cutoff

When base emitter junction is less than 0.5 volt, it will be in reverse biased and practically no current flows in the transistor.

$$V_{BE} < 0.5 \text{ V}; I_B = I_C = I_E = 0$$

$$\text{Therefore, } V_{out} = V_C = V_{CC}$$

Since all the currents in transistor are equal to zero the transistor is in "OFF" condition.

Operation in saturation

When $V_{BE} > 0.7 \text{ V}$ the transistor enters into active mode. The V_{BE} can be increased just by increasing the input V_I . Since emitter is directly grounded.

In active mode

$$I_B = \quad =$$

$$I_B = \quad [\text{for active mode}]$$

Also

$$V_C = V_{CC} - I_C R_C$$

The base current can be increased by increasing V_I . It is clear from above expression that collector current increases with increasing base current. When I_C increases V_C decreases. In this process if V_C will be less than V_B (0.7) then collector- base junction starts to be come forward biased and operation of transistor enters into saturation mode. In saturation mode, if I_B increases I_C also increases and V_C will decreases. This means that collector base junction of transistor becomes more and more forward biased and transistor enters into deep saturation region.

Thus in saturation mode

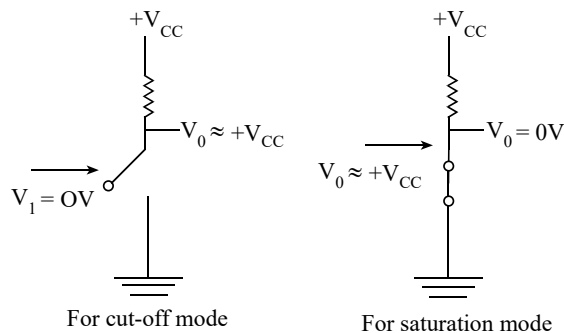
$$I_C \neq \beta I_B$$

We have

$$I_{C_{sat}} =$$

$$\beta_{forced} =$$

The equivalent circuit diagram for the described conditions can be expressed as follows:



The truth table can be constructed as:

V_I	V_O	Transistor status
0	+VCC	OFF
+VCC	0	ON

Teaching tips

1. Give the practical examples found at their home and surrounding.
2. Use the Charts as far as possible to explain the content.
3. Assign the homework at the end of every class from the chapter so far covered during that class.
4. Conduct group discussions after finishing one lesson.

UNIT - 6

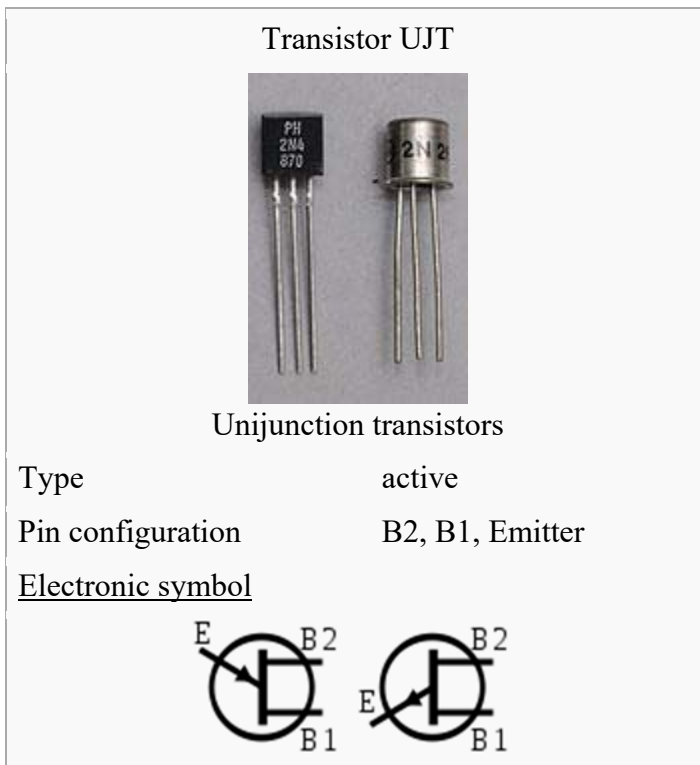
Special Purpose Transistors

Learning outcomes:

After completion of this lesson, students will be able to:

- Explain about Unijunction transistor, its characteristics and applications
- Know and explain about programmable Unijunction transistors and its characteristic

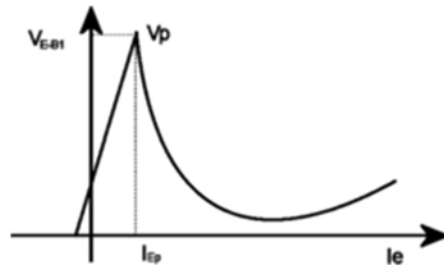
Unijunction transistor



A unijunction transistor (UJT) is a three-lead electronic semiconductor device with only one junction that acts exclusively as an electrically controlled switch.

The UJT is not used as a linear amplifier. It is used in free-running oscillators, synchronized or triggered oscillators, and pulse generation circuits at low to

moderate frequencies (hundreds of kilohertz). It is widely used in the triggering circuits for silicon controlled rectifiers. The low cost per unit, combined with its unique characteristic, have warranted its use in a wide variety of applications like oscillators, pulse generators, saw-tooth generators, triggering circuits, phase control, timing circuits, and voltage- or current-regulated supplies.[1] The original unijunction transistor types are now considered obsolete; but a later multi-layer device, the programmable unijunction transistor (PUT), is still widely available.



Graph of UJT characteristic curve, emitter-base voltage as a function of emitter current, showing current-controlled negative resistance (downward-sloping region)

There are three types of unijunction transistors:

The original unijunction transistor, or UJT, is a simple device that is essentially a bar of n-type semiconductor material into which p-type material has been diffused somewhere along its length, fixing the device parameter η (the "intrinsic stand-off ratio"). The 2N2646 model is the most commonly used version of the UJT.

The complementary unijunction transistor, or CUJT, that is a bar of p-type semiconductor material into which n-type material has been diffused somewhere along its length, defining the device parameter η . The 2N6114 model is one version of the CUJT.

The programmable unijunction transistor or PUT, is a multi-junction device that, with two external resistors, displays similar characteristics to the UJT. It is a close cousin to the thyristor and like the thyristor consists of four p-n layers. It has an anode and a cathode connected to the first and the last layer, and a gate connected to one of the inner layers. PUTs are not directly interchangeable with conventional UJTs but perform a similar function. In a proper circuit configuration with two

"programming" resistors for setting the parameter η , they behave like a conventional UJT. The 2N6027, 2N6028[2] and BRY39 models are examples of such devices.

Applications

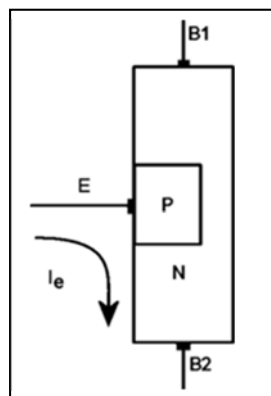
Unijunction transistor circuits were popular in hobbyist electronics circuits in the 1960s and 1970s because they allowed simple oscillators to be built using just one active device. For example, they were used for relaxation oscillators in variable-rate strobe lights. Later, as integrated circuits became more popular, oscillators such as the 555 timer IC became more commonly used.

In addition to its use as the active device in relaxation oscillators, one of the most important applications of UJTs or PUTs is to trigger thyristors (silicon controlled rectifiers (SCR), TRIAC, etc.). A DC voltage can be used to control a UJT or PUT circuit such that the "on-period" increases with an increase in the DC control voltage. This application is important for large AC current control.

UJTs can also be used to measure magnetic flux. The hall effect modulates the voltage at the PN junction. This affects the frequency of UJT relaxation oscillators. This only works with UJTs. PUTs do not exhibit this phenomenon.

The UJT has three terminals: an emitter (E) and two bases (B1 and B2) and so is sometimes known a "double-base diode". The base is formed by lightly doped n-type bar of silicon. Two ohmic contacts B1 and B2 are attached at its ends. The emitter is of p-type and it is heavily doped; this single PN junction gives the device its name. The resistance between B1 and B2 when the emitter is open-circuit is called interbase resistance. The emitter junction is usually located closer to base-2(B2) than base-1(B1) so that the device is not symmetrical, because symmetrical unit does not provide optimum electrical characteristics for most of the applications.

Construction of a UJT



Structure of a p-type UJT

If no potential difference exists between its emitter and either of its base leads, an extremely small current flows from B1 to B2. On the other hand, if an adequately

large voltage relative to its base leads, known as the 'trigger voltage', is applied to its emitter, then a very large current will flow from its emitter and join the current flowing from B1 to B2, which would create a larger B2 output current.

The schematic diagram symbol for a Unijunction transistor represents the emitter lead with an arrow, showing the direction of conventional current flow when the emitter-base junction is conducting a current. A complementary UJT would use a p-type base and an n-type emitter, and operates the same as the n-type base device but with all voltage polarities reversed.

The structure of a UJT is similar to that of an N-channel JFET, but p-type (gate) material surrounds the N-type (channel) material in a JFET, and the gate surface is larger than the emitter junction of UJT. A UJT is operated with emitter junction forward-biased while the JFET is normally operated with the gate junction reverse-biased. It is a current controlled negative resistance device.

Device operation

The device has a unique characteristic that when it is triggered, its emitter current increases regeneratively until it is restricted by emitter power supply. It exhibits a negative resistance characteristic and so it can be employed as an oscillator.

The UJT is biased with a positive voltage between the two bases. This causes a potential drop along the length of the device. When the emitter voltage is driven approximately one diode voltage above the voltage at the point where the P diffusion (emitter) is, current will begin to flow from the emitter into the base region. Because the base region is very lightly doped, the additional current (actually charges in the base region) causes conductivity modulation which reduces the resistance of the portion of the base between the emitter junction and the B2 terminal. This reduction in resistance means that the emitter junction is more forward biased, and so even more current is injected. Overall, the effect is a negative resistance at the emitter terminal. This is what makes the UJT useful, especially in simple oscillator circuits.

Programmable UJT (PUT).

Programmable unijunction transistor or PUT is a close relative of the thyristor family. It has a four layered construction just like the thyristors and have three terminals named anode(A), cathode(K) and gate(G) again like the thyristors. Yet some authors call it a programmable UJT just because its characteristics and parameters have much similarity to that of the unijunction transistor. It is called programmable because the parameters like intrinsic standoff ratio (η), peak voltage(V_p) etc can be programmed with the help of two external resistors. In a UJT, the parameters like V_p , η etc are fixed and we cannot change it. The main application of programmable UJT are relaxation oscillators, thyristor firing, pulse circuits and timing circuits. ON Semiconductor® is the only manufacturer of PUT now. 2N6027 is the most common type number and it is available in the TO-92 plastic package. The internal block diagram and circuit symbol of PUT are shown below.

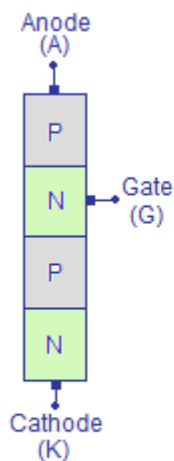


Fig 1: PUT internal block diagram

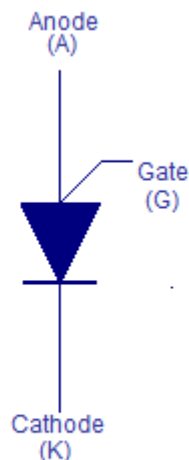


Fig 2: PUT circuit symbol

From the above figure, you can see that the PUT has a four layered construction. Topmost P-layer is called the anode (A). The N-layer next to the anode is called the gate (G). The P-layer next to the gate is left alone. The bottom most N-layer is called cathode (K). Ohmic contacts are made on the anode, cathode and gate layers for external connection.

PUT characteristics.

PUT characteristics is essentially a plot between the anode voltage V_a and anode current I_a of the PUT. The typical biasing diagram and characteristics plot of a PUT is shown below. Typically the anode of the PUT is connected to a positive voltage and the cathode is connected to the ground. The gate is connected to the junction of the two external resistor R_1 and R_2 which forms a voltage divider network. It is the value of these two resistors that determines the intrinsic standoff ratio (η) and peak voltage (V_p) of the PUT.

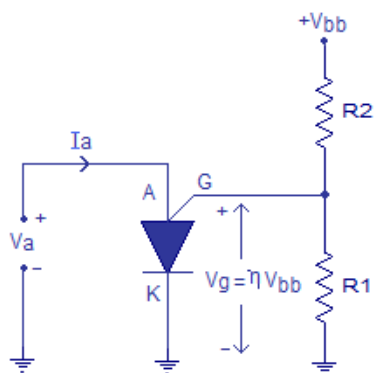


Fig 3: PUT biasing circuit

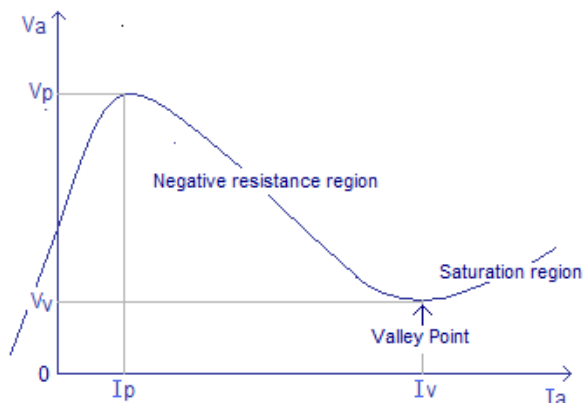


Fig 4: PUT characteristics

When the anode to cathode voltage (V_a) is increased the anode current will also get increased and the junction behaves like a typical P-N junction. But the V_a cannot be increased beyond a particular point. At this point sufficient number of charges are injected and the junction starts to saturate. Beyond this point the anode current (I_a) increases and the anode voltage (V_a) decreases. This is equal to a negative resistance scenario and this negative resistance region in the PUT characteristic is used in relaxation oscillators. When the anode voltage (V_a) is reduced to a particular level called “Valley Point”, the device becomes fully saturated and no more decrease in V_a is possible. There after the device behaves like a fully saturated P-N junction.

Peak voltage (V_p): It is the anode to cathode voltage after which the PUT jumps into the negative resistance region. The peak voltage V_p will be usually one diode drop (0.7V) plus the gate to cathode voltage (V_g). Peak voltage can be expressed using the equation:

$V_p = 0.7V + V_g = 0.7V + V_{R1} = 0.7V + \eta V_{bb}$. Where η is the intrinsic standoff ratio and V_{bb} is the total voltage across the external resistor network.

Instruction for teacher

1. Give the practical examples found at their home and surrounding.
2. Use the Charts as far as possible to explain the content.
3. Assign the homework at the end of every class from the chapter so far covered during that class.
4. Conduct group discussions after finishing one lesson.

References and Resources:

- ▶ Principles of physics-II ,Ayam Publication Pvt.Ltd
- ▶ Electronic Principles, Alberto Malvino/David Bates,

<http://www.futureelectronics.com>

<http://www.circuitstoday.com>

<http://www.electroschematics.com>

UNIT-7

Field Effect Transistors

Learning Outcomes:

After completion of this chapter, Student will be able to:

- Design simple circuit using FET
- Application and real world use of Different types of FET

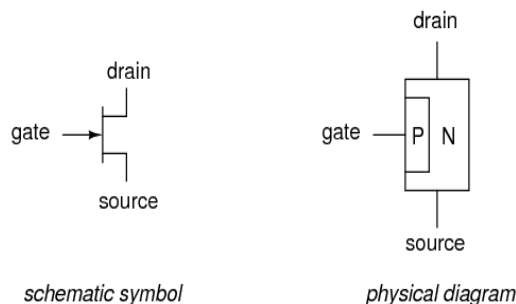
7.1 Field effect transistors

Introduction

A transistor is a linear semiconductor device that controls current with the application of a lower-power electrical signal. Transistors may be roughly grouped into two major divisions: bipolar and field-effect. In the last chapter we studied bipolar transistors, which utilize a small current to control a large current. In this chapter, we'll introduce the general concept of the field-effect transistor—a device utilizing a small voltage to control current—and then focus on one particular type: the junction field-effect transistor. In the next chapter we'll explore another type of field-effect transistor, the insulated gate variety.

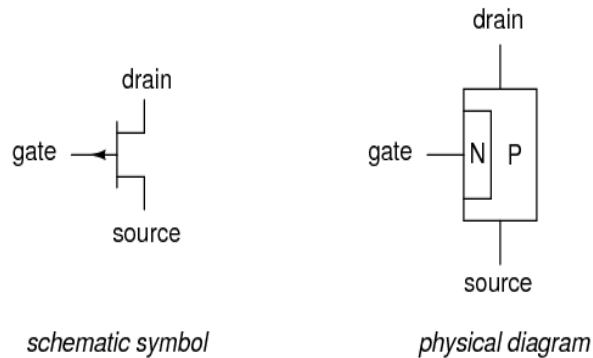
All field-effect transistors are unipolar rather than bipolar devices. That is, the main current through them is comprised either of electrons through an N-type semiconductor or holes through a P-type semiconductor. This becomes more evident when a physical diagram of the device is seen:

N-channel JFET



In a junction field-effect transistor, or JFET, the controlled current passes from source to drain, or from drain to source as the case may be. The controlling voltage is applied between the gate and source. Note how the current does not have to cross through a PN junction on its way between source and drain: the path (called a channel) is an uninterrupted block of semiconductor material. In the image just shown, this channel is an N-type semiconductor. P-type channel JFETs are also manufactured:

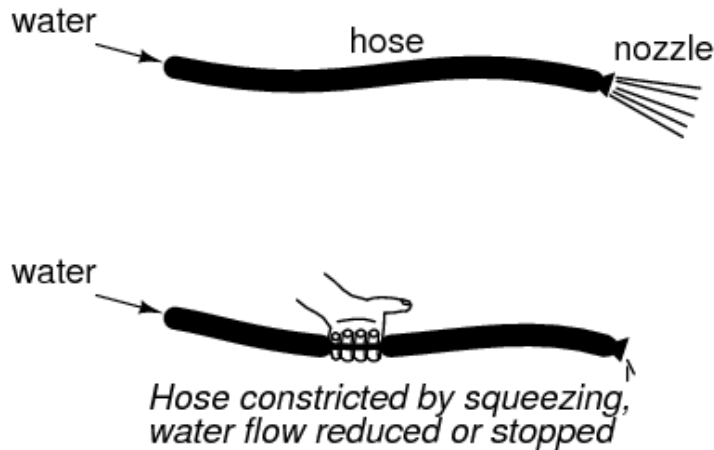
P-channel JFET



Generally, N-channel JFETs are more commonly used than P-channel. The reasons for this have to do with obscure details of semiconductor theory, which I'd rather not discuss in this chapter. As with bipolar transistors, I believe the best way to introduce field-effect transistor usage is to avoid theory whenever possible and concentrate instead on operational characteristics. The only practical difference between N- and P-channel JFETs you need to concern yourself with now is biasing of the PN junction formed between the gate material and the channel.

With no voltage applied between gate and source, the channel is a wide-open path for electrons to flow. However, if a voltage is applied between gate and source of such polarity that it reverse-biases the PN junction, the flow between source and drain connections becomes limited, or regulated, just as it was for bipolar transistors with a set amount of base current. Maximum gate-source voltage “pinches off” all current through source and drain, thus forcing the JFET into cutoff mode. This behavior is due to the depletion region of the PN junction expanding under the

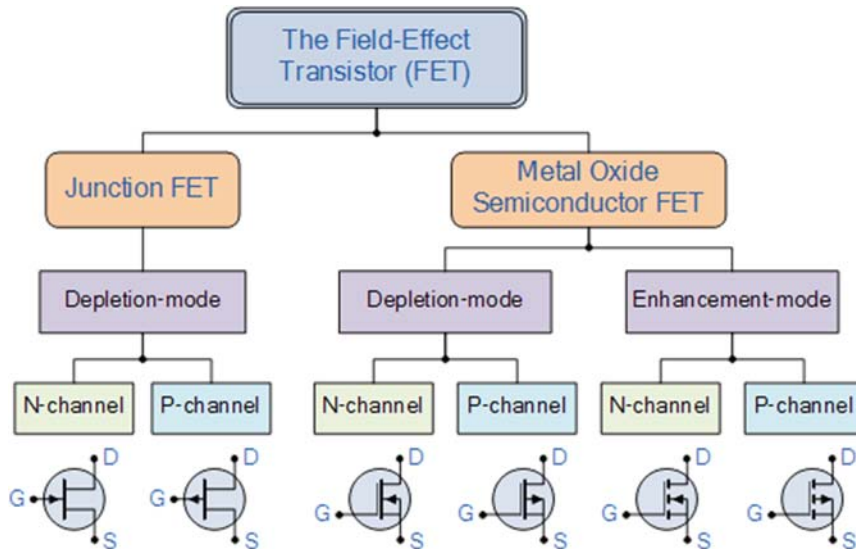
influence of a reverse-bias voltage, eventually occupying the entire width of the channel if the voltage is great enough. This action may be likened to reducing the flow of a liquid through a flexible hose by squeezing it: with enough force, the hose will be constricted enough to completely block the flow.



Note how this operational behavior is exactly opposite of the bipolar junction transistor. Bipolar transistors are normally-off devices: no current through the base, no current through the collector or the emitter. JFETs, on the other hand, are normally-on devices: no voltage applied to the gate allows maximum current through the source and drain. Also take note that the amount of current allowed through a JFET is determined by a voltage signal rather than a current signal as with bipolar transistors. In fact, with the gate-source PN junction reverse-biased, there should be nearly zero current through the gate connection. For this reason, we classify the JFET as a voltage-controlled device, and the bipolar transistor as a current-controlled device.

If the gate-source PN junction is forward-biased with a small voltage, the JFET channel will “open” a little more to allow greater currents through. However, the PN junction of a JFET is not built to handle any substantial current itself, and thus it is not recommended to forward-bias the junction under any circumstances.

This is a very condensed overview of JFET operation. In the next section, we’ll explore the use of the JFET as a switching device.



Classification of FET

Characteristics, applications and working principle of FET are described on the respective types of FET.

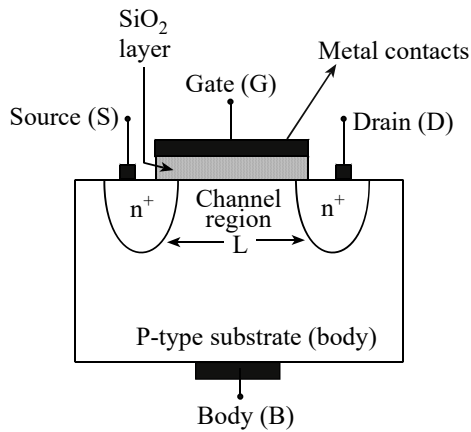
7.2 Types and working principles, characteristics and applications of Field effect transistors.

Structure and Physical Operation of Enhancement type MOSFET

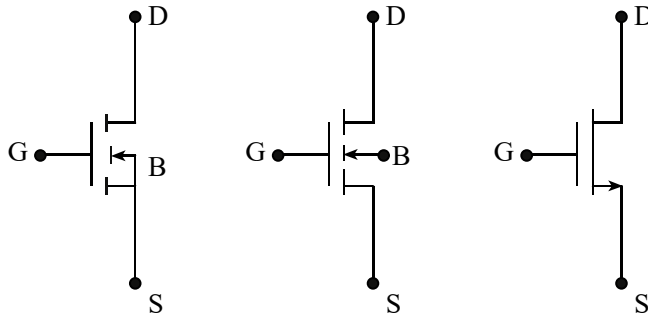
Structure:

The basic structure of enhancement type N-MOSFET is shown in fig 7.1(a). A slab of P-type substrate is formed in which two heavily doped N-type regions (N-Source & N-Drain) are created. A thin ($\approx 0.1 \mu\text{m}$) layer of metal oxide (SiO_2), which is excellent electrical insulator, is formed covering the area between the source and drain regions. Metal contacts are made to those regions to bring out four terminals: Gate (G), Source (S), Drain (D), & Substrate or Body (B).

Another name for the MOSFET is insulated gate-FET or IGFET. In some cases substrate is internally connected to source terminal. MOSFET's are very popular in designing micro-power circuits and high impedance amplifiers because MOSFET's have very high input resistance and consume very low power.



Construction of E-MOSFET



Circuit Symbols of N - EMOSFET

Physical Operation:

With no bias voltage applied to the gate, two back to back diodes exist in series between drain and source prevents current conduction from drain to source.

When V_{DS} is applied and small:

Initially drain to source channel is at cutoff state i.e. no conducting channel. When positive gate to source voltage (V_{GS}) is applied, channel starts to build as shown in fig 7.1(c).

Here, when V_{GS} applied, positive voltage on gate causes free holes (positive charges) to be repelled from substrate region under the gate channel region. These holes are pushed downwards into the substrate, leaving behind populated bound negative charges. Also, positive gate voltage attracts electrons from source and drain

regions into channel regions. These sufficient accumulated electrons create N region connecting source and drain. The induced N region thus forms a channel for current flow from drain to source. This channel is created inverting the substrate surface from P type to N type, hence is called inversion layer.

The value of V_{GS} at which sufficient number of mobile electrons accumulates in the channel region to form a conducting channel is called threshold voltage (V_t). V_t is positive for N-channel MOSFET.

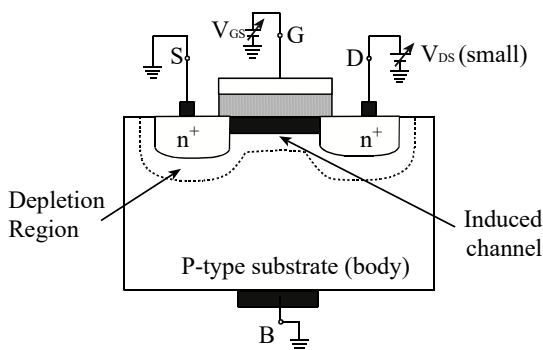
I.e. When $V_{GS} > V_t$; channel is induced.

Thus at $V_{GD} = V_t$, channel is at threshold of pinch-off state i.e. at the point between ohmic region and pinch-off region.

When $V_{GD} > V_t$ i.e. $(V_{GS} - V_{DS}) > V_t$

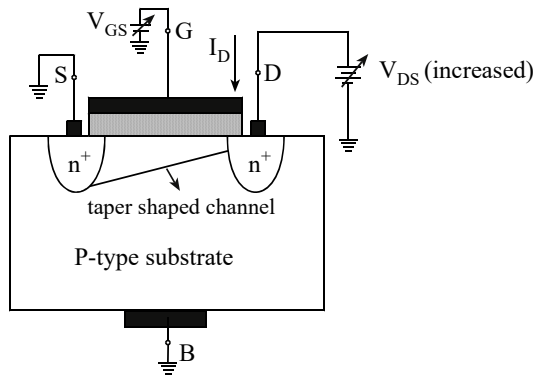
$V_{DS} < V_{GS} - V_t$

The channel is continuous and the conductance of the induced channel is proportional to excessive gate voltage ($V_{GS} - V_t$) for small drain to source voltage (V_{DS}). The E-MOSFET operates in ohmic region (i.e. device operates as a linear resistor).



When V_{DS} is Small

When V_{DS} is Increased:



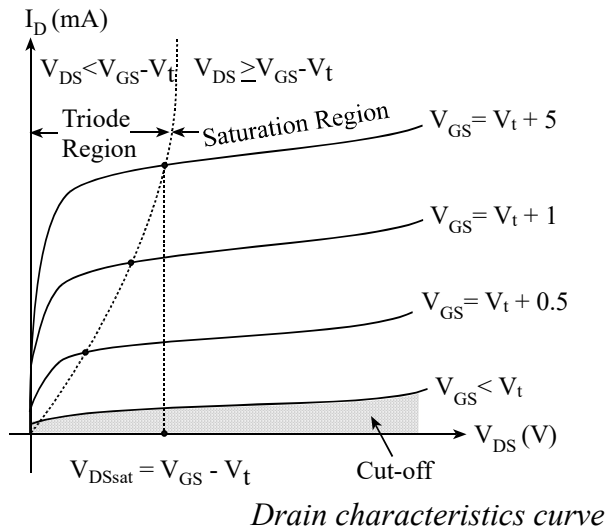
When V_{DS} is increased

When V_{DS} is increased sufficiently so that $V_{GS} > V_t$. For this V_{DS} appears as a voltage drop across the length of the channel (L) travelling along the channel from source to drain. This results varying voltage between gate and the point along channel which is V_{GS} at the source end and

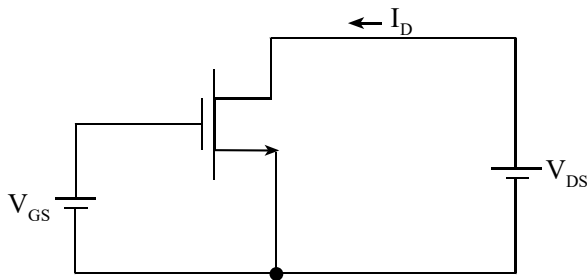
$V_{GS} - V_{DS}$ at the drain end.

This creates non-uniform tapered shape channel, because channel depth depends on this voltage. As V_{DS} increases, the channel becomes more taper and its resistance increases correspondingly. Thus the $I_D - V_{DS}$ curves bends eventually. When V_{DS} is increased to the value that reduces the voltage between gate and channel at the drain end to V_t (i.e. $V_{GS} - V_{DS} = V_t$), the channel depth at drain end decreases to almost zero and the channel is said to be pinched-off.

Increasing V_{DS} beyond this value has little effect on channel shape and the current through channel remains constant. The drain current saturates at this value and the MOSFET is said to have entered the saturation region of operation. The region of $i_D - V_{DS}$ characteristics obtained for $V_{DS} < V_{DSsat}$ is called the triode region. It is shown in fig 7.1(e).



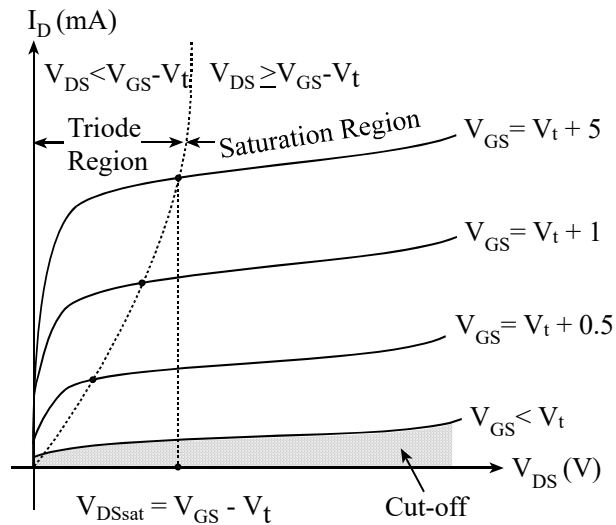
Current Voltage Characteristics of E-MOSFET



Conceptual Circuit to Study Characteristics of MOSFET

The conceptual circuit to study characteristics curve of MOSFET is shown in fig 7.2 (a). The following characteristics curve indicates that there are three distinct regions of operation:

- Cut-off region,
- Triode region and
- Saturation region.



Drain Characteristics Curve of EMOSFET

The E-MOSFET is in cutoff when $V_{GS} < V_t$ and to operate it in the triode region, channel must be induced and for this we have

$V_{GS} > V_t$, channel is induced.

When $V_{GD} > V_t$, channel is continuous for small V_{DS}

i.e. $(V_{GS} - V_{DS}) > V_t$

$V_{DS} < (V_{GS} - V_t)$ i.e. MOSFET operates in Ohmic region.

The general expression for E-MOSFET is given by following approximate equation

$$I_D = K [2 (V_{GS} - V_t) \cdot V_{DS} - V_{DS}^2]$$

Where,

$K = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} = K'_n$ device parameter

μ_n = electron mobility in induced channel

C_{ox} = oxide capacitance per unit area

L = Length of channel

W = width of channel

In Ohmic region or triode region of operation, V_{DS} is very small so V_{DS}^2 can be neglected.

Now equation becomes

$$I_D = K [2(V_{GS} - V_t) V_{DS} - 0]$$

$$= R_{DS} =$$

The value of R_{DS} is controlled by V_{GS} . So, it is called voltage controlled resistance. When V_{DS} is increased sufficiently so that $V_{GD} \leq V_t$, the channel is pinched off.

$$V_{GD} \leq V_t$$

$$V_{GS} - V_{DS} \leq V_t$$

$V_{DS} \geq (V_{GS} - V_t)$; pinched off.

The boundary between the triode region and the saturation region is characterized by

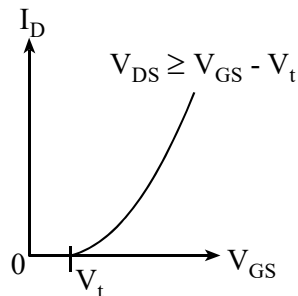
$$V_{DS} = (V_{GS} - V_t); \text{ boundary}$$

Beyond this value of V_{DS} , I_D does not increase.

Put $V_{DS} = V_{GS} - V_t$ in equation we get

$$I_{Dsat} = K(V_{GS} - V_t)^2.$$

In saturation the MOSFET provides a drain current whose value is independent of the drain voltage V_{DS} and is determined by the gate voltage V_{GS} according to the square law relationship.



Transfer Characteristics of EMOSFET

The Depletion Type MOSFET

For depletion type N channel MOSFET an N channel is diffused on P type substrate (body). Then two heavily doped N type wells are formed at both sides of the channel. One of these two wells functions as Source (S) and the second well functions as Drain (D). A thin layer of silicon-oxide (SiO_2) is developed on the top of the N-channel. Then a metal contact is formed and a gate (G) terminal is taken out. The structure is shown in fig7.3 (a).

Its structure is similar to that of E-MOSFET and the main difference is depletion MOSFET has a physically implanted channel. Thus if a voltage V_{DS} is applied

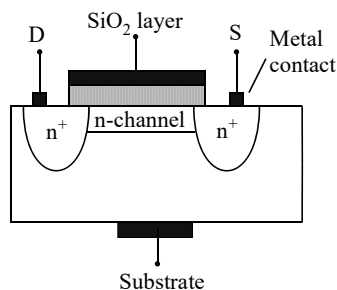
between drain and source, a current i_D flow for $V_{GS} = 0$. In other words, there is no need to induce channel unlike the E-MOSFET.

The channel depth and hence its conductivity can be controlled by V_{GS} as in E-MOSFET. Applying a positive V_{GS} enhances the channel by attracting more electrons into it. However, we can also apply a negative V_{GS} , which causes electrons to be repelled from the channel and thus channel becomes thinner. The negative V_{GS} is said to deplete the channel and this mode of operation (negative V_{GS}) is called depletion mode. As magnitude of V_{GS} increases in negative direction a value is reached at which channel is completely depleted of charge carriers and i_D is reduced to zero. This negative value of V_{GS} is the threshold voltage of the N channel D-MOSFET.

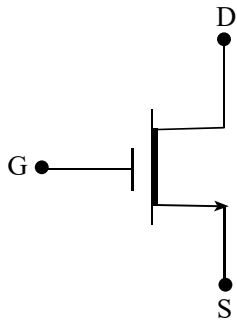
Thus an N channel D-MOSFET can be operated in enhancement mode by applying positive V_{GS} and in depletion mode by applying negative V_{GS} .

The current-voltage characteristics of D-MOSFET are described by the equations similar for the enhancement type except that for an N channel depletion type, V_t is negative. For D-MOSFET the value of drain current obtained in saturation with $V_{GS} = 0$ is denoted by I_{DSS} and given by

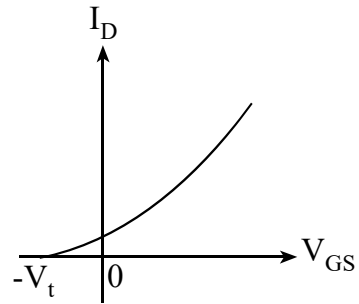
$$I_{DSS} = KV^2t.$$



Construction of N-DMOSFET

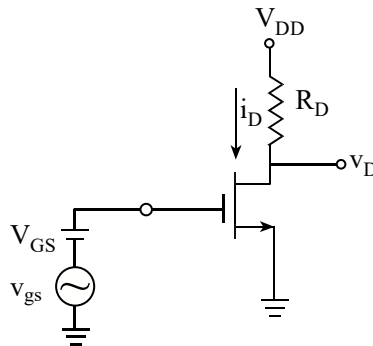


Symbol of N- DMOSFET



Transfer characteristics for D-type MOSFET

Application of MOSFET/FET: MOSFET as an Amplifier



$$V_i = v_{GS} = V_{GS} + v_{gs}$$

MOSFET as an Amplifier

To operate MOSFET as an amplifier, it should be in saturation region. MOSFET acts as a voltage controlled current source: changes in the V_{GS} give rise to change in drain current i_D . Basic structure of the common source amplifier is shown in fig7.5 (a).

As shown above, V_{GS} is the dc bias voltage for E-MOSFET and v_{gs} is the input signal to be amplified superimposed on V_{GS} . The output is taken from the drain end.

Initially $v_{gs} = 0$, thus only dc analysis

$$I_D = K(V_{GS} - V_t)^2$$

Also the dc voltage at the drain i.e. output voltage

$$V_D = V_{DD} - I_D R_D$$

To ensure that MOSFET is in saturation region,

$$V_D > V_{GS} - V_t$$

Now when v_{gs} is applied

$$v_{GS} = V_{GS} + v_{gs}$$

The total instantaneous drain current

$$\begin{aligned} i_D &= K (v_{GS} - V_t)^2 \\ &= K (V_{GS} + v_{gs} - V_t)^2 \\ &= K (V_{GS} - V_t)^2 + 2Kv_{gs}(V_{GS} - V_t) + Kv_{gs}^2 \end{aligned}$$

Here, first term in RHS is dc bias current I_D , second term represents a current component proportional to v_{gs} and the third component is proportional to square of v_{gs} . This third term represents non-linear distortion and is undesirable.

So for non-linear distortion to be low

$$Kv_{gs}^2 \ll 2Kv_{gs}(V_{GS} - V_t)$$

$$v_{gs} \ll 2(V_{GS} - V_t)$$

If this condition is satisfied Kv_{gs}^2 term can be neglected and hence

$$i_D = I_D + i_d = K (V_{GS} - V_t)^2 + 2Kv_{gs}(V_{GS} - V_t)$$

Comparing ac to ac and dc to dc we have,

$$I_D = K (V_{GS} - V_t)^2$$

$$i_d = 2Kv_{gs}(V_{GS} - V_t)$$

$$g_m = 2K (V_{GS} - V_t)$$

Where g_m = trans-conductance of the MOSFET.

$$i_d = g_m v_{gs}$$

Now, the total instantaneous drain voltage is

$$v_D = V_{DD} - i_D R_D$$

$$\begin{aligned} V_D + v_d &= V_{DD} - (I_D + i_d) R_D \\ &= (V_D - I_D R_D) - i_d R_D \end{aligned}$$

Thus the signal component of drain voltage is

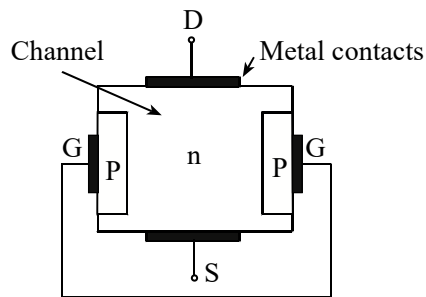
$$v_d = -i_d R_D = -g_m v_{gs} R_D$$

$$\text{Voltage Gain } (A_v) = v_d / v_{gs} = \text{output} / \text{input} = -g_m R_D.$$

This relation shows that output signal is 180° out of phase with respect to input signal and is amplified.

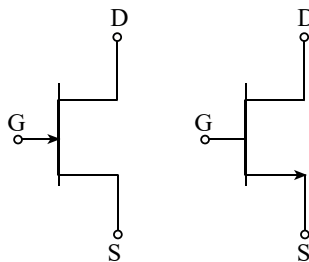
Junction field effect transistor (JFET):

JFET is a unipolar semiconductor device (transistor) because the current flow in the device is due to only one type of charges (either electrons or holes). The place where the charges flow is called channel. JFETs are used in designing special amplifiers with very high input impedance. They are also used in designing very high frequency (giga hertz) amplifiers. The basic structural diagram of n channel JFET is shown below:



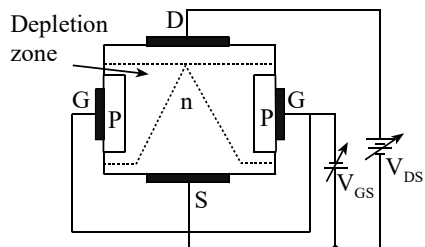
Construction of N- JFET

As it is clear from the diagram that JFET consists of n type of slab. Opposite type of semi- conductor is doped on the both sides of the slab. These doped semiconductor layers function as "Gates" of the device. The two gates are internally connected to each other. Metal contacts are formed at the both ends of the channel and on the top of gates as shown. One end of the channel with metal contact functions as "Source" (S) and other functions as "Drain" (D).

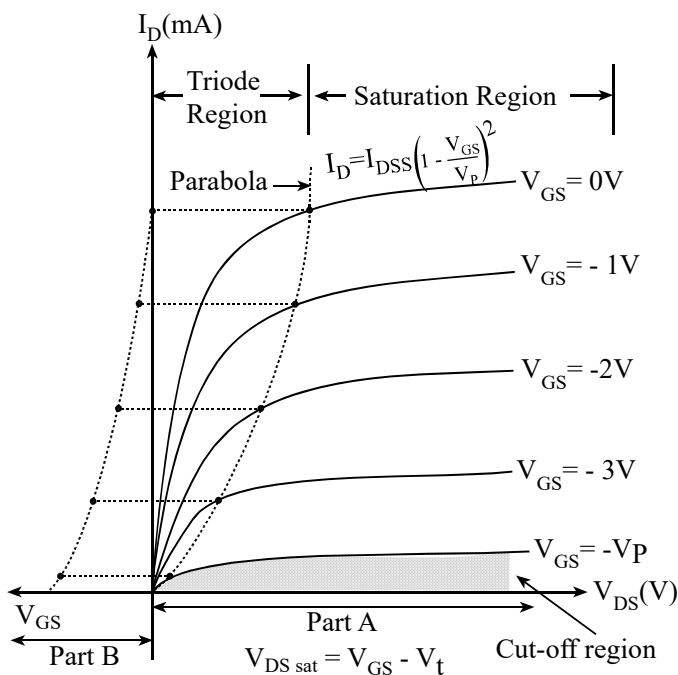


Circuits Symbols of N-JFET

Working principle of n-type JFET:



Operation of JFET



Drain characteristics curve (Part A)

Transfer characteristics curve (Part B)

When $V_{GS} = 0$ i.e. when voltage between the source and gate is zero there will be small uniform depletion layer between the channel and the gates. Now when V_{DS} is increased i.e. due to increasing voltage between drain and source the voltage between gate and channel at the drain side V_{DG} will be equal to V_{DS} . Due to this reason the depletion layer will have tapered shape as shown in figure. This means the width of channel will be narrower as it moves from source side to the drain side. For higher value of V_{DS} the channel will be more tapered and the channel gets narrower and

narrower. Thus the channel resistance will go on increasing with increasing V_{DS} . Now if V_{DS} is kept on increasing a point will come when the channel will be pinched off at the drain side. This happens when $V_{GD} = -V_P$. Since this is the case for $V_{GS} = 0$ the pinch off occurs when $V_{DS} = V_{GD} = -V_P$. At this point drain current, remains practically constant and any further increase in V_{DS} will not affect I_D . This value of drain-source current is called "saturation current".

$$I_{DS} = I_D = I_{DSS}; \text{ for } V_{GS} = 0 \text{ and } V_{DS} = -V_P.$$

Where,

I_{DSS} = Drain to source with a shorted gate.

Now, let us increase V_{GS} from 0 to $-V$ volt. As V_{DS} increase depletion region will be more taper shaped and the channel will get more and more narrower at the drain side. When V_{DS} is kept on increasing pinch off condition of channel at drain side will be reached earlier than in the previous case. At this condition following voltage condition will reach.

$$V_{GD} = -V_P$$

or, $V_{DS} - V_{GS} = -V_P$

or, $V_{DS} = -V_P + V_{GS}$

or, $V_{DS} = V_{GS} - V_P$, at pinch off point.

The general expression of JFET can be approximated by

$$I_D = I_{DSS} [2(1 - V_{GS}/V_P)(-V_{DS}/V_P) - 0] \dots\dots\dots (1)$$

Analysis of JFET in ohmic or triode region:

In this region of operation we have $V_{DS} < V_{GS} - V_P$

i.e. < 1 so that $\ll 1$

Then equation (1) becomes

$$I_D = I_{DSS} [2(1 - V_{GS}/V_P)(-V_{DS}/V_P) - 0]$$

or, =

or, =

or, $R_{DS} = \dots\dots\dots(2)$

Where,

R_{DS} = drain to source resistance in ohmic region.

Analysis of JFET in pinch off region:

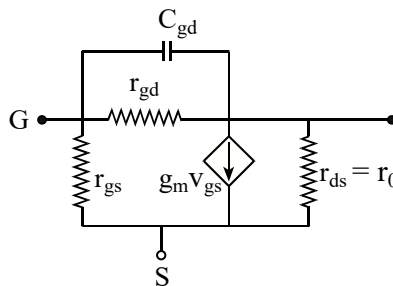
For pinch off region $V_{DS} \geq V_{GS} - V_P$ and therefore substituting $V_{DS} = V_{GS} - V_P$ in equation(1) we get,

$$I_D = I_{DSS}$$

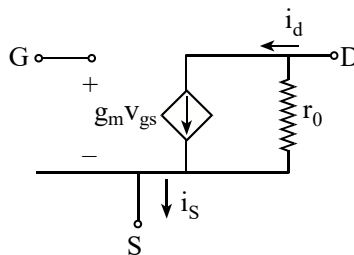
or, $I_D = I_{DSS}$

or, $I_D = I_{DSS} = I_{DSat} \dots\dots\dots (3)$

- The curve represented by this equation (3) is parabola so is also called square law principle of JFET.
- The pinch-off region is the region where JFET works as an amplifier so this region is also called "Active Region."
- AC equivalent model for JFET and MOSFET



Equivalent π -model for FET



Simple π -model for FET

$I_D = I_{DSS}$ for JFET

$I_D = K (V_{GS} - V_t)^2$ for MOSFET

When they are operating in active mode or pinch off mode.

To find Transconductance (g_m) of JFET.

We have,

$$I_D = I_{DSS} \dots\dots (i)$$

Differentiating eqn (i) w.r.t. V_{GS} we get,

$$= 2ID_{SS}$$

$$= g_m$$

Alternative Method:

$$i_D = ID_{SS}$$

$$\text{But } i_D = ID + id \text{ \& } v_{GS} = V_{GS} + v_{gs}$$

$$\square ID + id = ID_{SS}$$

$$\text{or, } ID + id = ID_{SS}$$

$$\text{or, } ID + id = ID_{SS}$$

[\square v_{gs} is small $v_{gs}/V_P < 1$. Hence $(v_{gs}/V_P)^2$ can be neglected]

$$\text{or, } ID + id = ID_{SS}$$

Comparing a.c. to ac and d.c to dc we get,

$$ID = ID_{SS}$$

$$\text{or, } id = ID_{SS}$$

7.3 Difference between Depletion MOSFET and Enhancement MOSFET

Depletion MOSFET

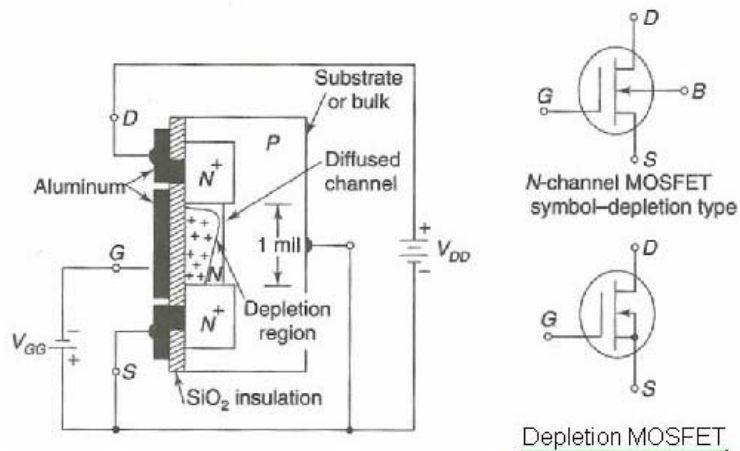


Figure-1 depicts construction of depletion type MOSFET. It also mentions circuit symbol of N-channel MOSFET of depletion type. Due to its construction it offers very high input resistance (about 10^{10} to 10^{15}). Significant current flows for given V_{DS} at V_{GS} of 0 volt.

When gate(i.e. one plate of capacitor) is made positive, the channel((i.e. the other plate of capacitor) will have positive charge induced in it. This will result into depletion of majority carriers(i.e. electrons) and hence reduction in conductivity. Hence the curve similar to JFET is obtained as shown in the figure-2.

As shown in the symbol here gate is insulated from the channel. For P-channel type MOSFET symbol, arrow will be reversed.

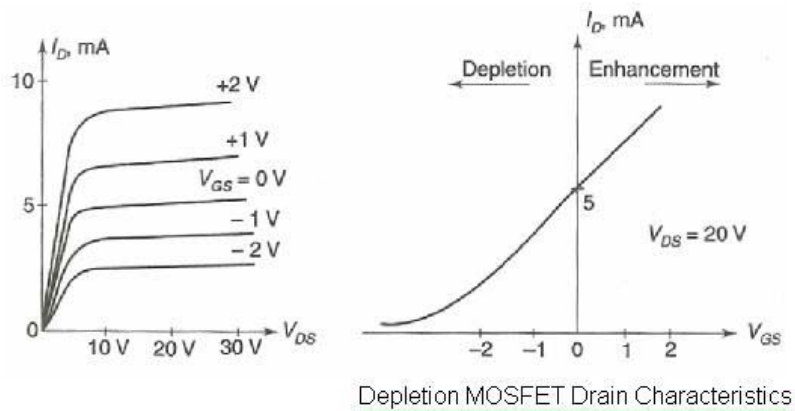


Figure-2 depicts drain characteristics and transfer curve of depletion type of MOSFET(N-channel).

Enhancement MOSFET

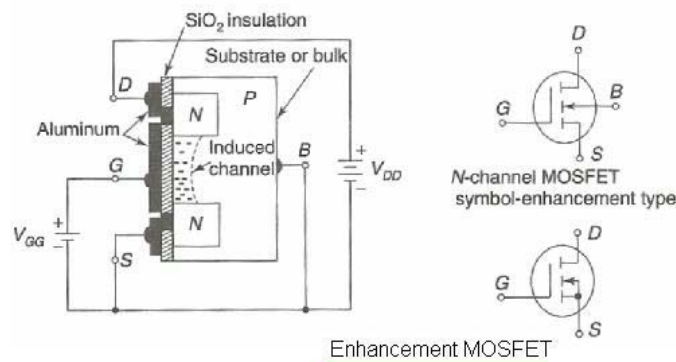
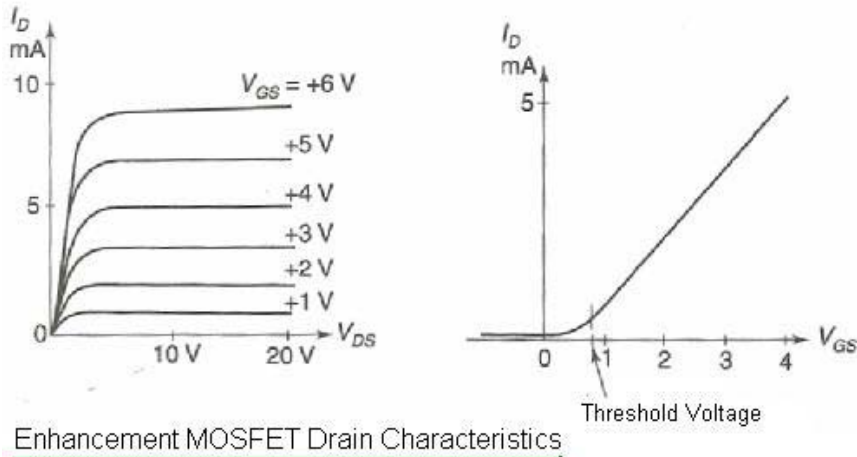


Figure-3 depicts construction of enhancement type MOSFET. It also mentions circuit symbol of N-channel MOSFET of enhancement type. Here continuous channel does not exist from source to drain. Hence no current flows at zero gate voltage. Symbol depicts broken channel between 'S' to 'D' terminals.

When positive voltage is applied to the gate, it will induce a channel by flowing minority carriers (i.e. electrons) from P-type bulk into the concentrated layer.



Enhancement MOSFET Drain Characteristics

Figure-4 depicts drain characteristics and transfer curve of enhancement type of MOSFET(N-channel). As shown in the figure-4 minimum threshold voltage is needed for the flow of drain current to start.

This type of FET is ideal for switching application. This is due to the fact that no gate voltage is needed to keep the device in 'off' state. Moreover the device can be powered ON with the application of same polarity as drain terminal.

Following are the important comparison features between Depletion and Enhancement MOSFET types:

- Enhancement MOSFET does not conduct at 0 volt, as there is no channel in this type to conduct. Depletion MOSFET conducts at 0 volt. Moreover when positive cut-off gate voltage is applied to depletion MOSFET, hence it is less preferred.
- The depletion MOSFET does not have any kind of leakage currents such as gate oxide and sub threshold type.
- Depletion MOSFET logic operations are opposite to enhancement type of MOSFETs.
- Diffusion current(i.e. sub-threshold leakage current) exists in enhancement MOSFET while depletion MOSFET do not have any diffusion current.

Instruction for teacher

1. Give the practical examples found at their home and surrounding.
 2. Use the Charts as far as possible to explain the content.
 3. Assign the homework at the end of every class from the chapter so far covered during that class.
 4. Conduct group discussions after finishing one lesson.
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REFERENCES

A K Rauniyar, PC Roy, Electronic Devices and Circuits.

Sedra, Smith. Microelectronic Circuits: Theory and Applications. 5th ed. New York, Oxford University Press, 2010.

R.L. Boylestad, Louis Naschelsky. Electronic Device and Circuit Theory. 9th ed. New Jersey: Pearson Education, 2006.

Malvino. Electronic Principles. 6th ed. New York: The Mc Graw-Hill Companies, 2006.

Theodore F. Bogart. Electronic Devices and Circuits. 4th ed. New York: Bell & Howell Company, 2000.

Jacob Millman, Christos C. Halkias. Electronic Devices and Circuits. 5th ed. New York: The Mc Graw-Hill Companies, 2008.

J.B. Gupta. A Course in Electrical Technology. 12th ed. New Delhi: S.K. Kataria & Sons, 2010.

<http://www.allaboutcircuits.com/textbook/semiconductors/chpt-5/junction-field-effect-transistors-jfet/>