RQF LEVEL 5

INDUSTRIAL ELECTRICITY

MODULE CODE: IELFE501

TEACHER'S GUIDE

Module name: FUNDAMENTAL ELECTRONICS

Table of content

LIST OF FIGURES

ACRONYMS

MOSFET: Metal oxide semiconductor field effect transistor

CSA cross-sectional area

DC Direct current

AC Alternating current

Z Impedance

NEC Nation Electric Commission

EEE Electrical and Electronics Engineering

C Capacitance

L Inductance

HZ Hertz

XC Capacitive Reactance

XL Inductive Reactance

EMF Electromotive Force

PD Potential Difference

BJT: bipolar junction transistor

NPN: negative positive negative

PNP: positive negative positive

K: cathode

A: anode

INTRODUCTION

This general module describes the knowledge and attitude required to apply basic electronics. The industrial electrician will be able to identify electronic components/devices, implement different types of electronic circuits and use electronic components in measuring, detection and automation systems. This will allow the electrician to easily pursue further learning at higher level.

IELEF 501: FUNDAMENTAL OF ELECTRONICS

Learning Units:

1. Identify electronic components/devices

2. Implement different types of electronic circuits

3. Use electronic components in measuring, detection and automation systems

Learning Unit 1: Identify electronic components/devices

STRUCTURE OF LEARNING UNIT

Learning outcomes:

1.1. Proper differentiation of electronic devices

1.2. Proper Identification of electronic devices characteristics

1.3. Proper identification of electronic devices applications

Learning outcome 1.1 Proper differentiation of electronic devices

Duration: **4** hrs

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Differentiate all passive components

2. Differentiate materials used in electronics

3. Differentiate all active components

Resources

Equipment	Tools	Materials
-Books	**-Internet**	**Resistor** **- Inductor** **- Capacitor** **- Transistor** **- Diode**

Advance preparation:

- **A trainer should visit a workshop to see if all components are available before starting session**
- **A trainer should have a sample of those components**

Indicative content 1.1.1: Introduction to passive components used in electronics

Passive components are the components which do not require external supply and they not amplify input signal like resistor, capacitor and inductor.

- ✓ **RESISTOR**

A *resistor* is a component that resists the flow of current. It's one of the most basic components used in electronic circuits.

Figure 1: Resistor symbol

- ✓ **INDUCTOR**

Inductor is then a passive component that has the ability to store energy in the form of a magnetic field.

Inductance: It is a property of a coil, which opposes changes in current by means of energy storage in the form of magnetic field. Also inductance can be defined as a measure of energy stored in the coil in the form of magnetic field.

Figure 2 : Inductor symbol

- ✓ **CAPACITOR**

Capacitance is the property of a system of conductor and insulator which allow them to store electric charge when a potential difference exists between the conductors. In other words capacitance is the property of a circuit in which energy can be stored in the form of electric charges

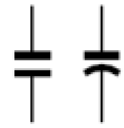


Figure 3: Inductor symbol

Indicative content 1.1.2: Introduction to materials used in Electronics

✓ Conductor

are materials that readily allow current. They have a large number of free electrons and are characterized by one to three valence electrons in their structure. Most metals are good conductors. Silver is the best conductor, and copper is next. Copper is the most widely used conductive material because it is less expensive than silver. Copper wire is commonly used as a conductor in electric circuits.

✓ Semiconductors

Semiconductors are classed below the conductors in their ability to carry current because they have fewer free electrons than do conductors. Semiconductors have four valence electrons in their atomic structures. However, because of their unique characteristics, certain semiconductor materials are the basis for electronic devices such as the diode, transistor, and integrated circuit. Silicon and germanium are common semi conductive materials.

✓ Insulators

Insulators are non-metallic materials that are poor conductors of electric current; they are used to prevent current where it is not wanted. Insulators have no free electrons in their structure. The valence electrons are bound to the nucleus and not considered “free.” Although non-metal elements are generally considered to be insulators, most practical insulators used in electrical and electronic applications are compounds such as glass, porcelain, Teflon, and polyethylene, to name a few.

Indicative content 1.1.3: Introduction to active components used in electronics

An active component is a device that has an analogue electronic filter with the ability to amplify a signal or produce a power gain. There are two types of active components: electron tubes and semiconductors or solid-state devices like diodes, transistors, scr and ICs.

- ✓ **PN Junction diode**

A p-n junction created on silicon with electrodes is a diode. Diodes that use a p-n junction are called general rectifying diodes. General rectifying diodes with improved switching characteristics are called fast recovery diodes (FRD), which are differentiated from general rectifying diodes. A diode that uses metal instead of a p-type semiconductor is called a Schottky barrier diode (SBD).

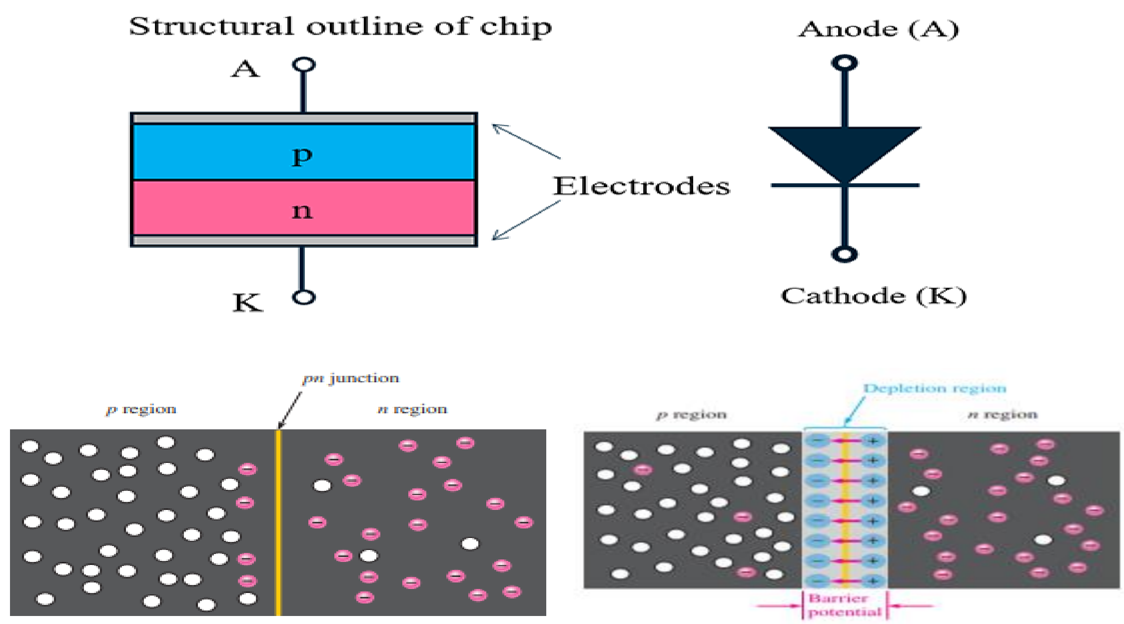


Figure 4: Structure of diode and symbol

Features of diode

Diodes are made of silicon p-n junction with two terminals, anode and cathode. Diode is forward biased when anode is made positive with respect to the cathode. Diode conducts fully when the diode voltage is more than the cut-in voltage (0.7 V for Si).

Diode is reverse biased when cathode is made positive with respect to anode. When reverse biased, a small reverse current known as leakage current flows.

✓ Zener diode

A Zener diode is an electronic active component that maintain a constant DC output voltage. An ideal regulator would output a constant voltage regardless of input fluctuations or variation of load current.

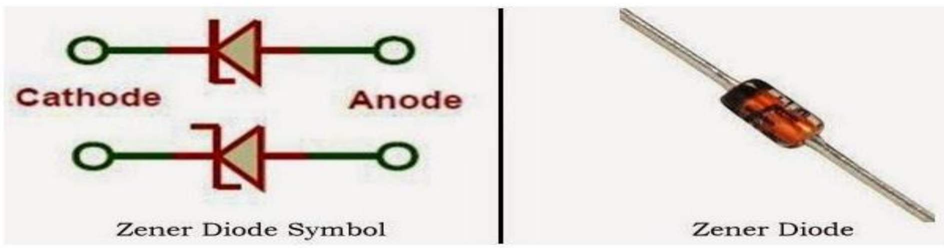


Figure 5: Structure of diode and symbol

✓ LED

A light-emitting diode (LED) is a semiconductor device that emits light when an electric current flows through it. When current passes through an LED, the electrons recombine with holes emitting light in the process. LEDs allow the current to flow in the forward direction and blocks the current in the reverse direction.

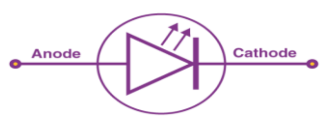


Figure 6: LED symbol

✓ Tunnel

A tunnel diode or Esaki diode is a type of semiconductor that is capable of very fast operation, well into the microwave frequency region, made possible by the use of the quantum mechanical effect called tunneling

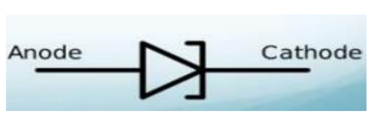


Figure 7: Tunnel symbol

- **Varicap**

In electronics, a varicap diode, Varactor diode, variable capacitance diode, variable reactance diode or tuning diode is a type of diode designed to exploit the voltage-dependent capacitance of a reverse-biased p–n junction.

Figure 8: Varicap symbol

- ## Photodiode

The photodiode is a pn junction device that operates in reverse bias, Note the schematic symbol for the photodiode. The photodiode has a small transparent window that allows light to strike the pn junction

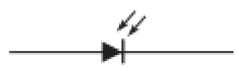


Figure 9: Symbol of photo diode

- ## Schottky Diode

The Schottky diode is a type of metal – semiconductor junction diode, which is also known as hot-carrier diode, low voltage diode or Schottky barrier diode. The Schottky diode is formed by the junction of a semiconductor with a metal. Schottky diode offers fast switching action and has a low forward voltage drop.

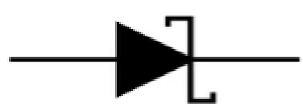


Figure 10: Schottky Diode symbol

Structure and features of transistor

An active component is a device that has an analogue electronic filter with the ability to amplify a signal or produce a power gain. There are two types of active components: electron tubes and semiconductors or solid-state devices

✓ PNP and NPN transistor

A transistor consists of two pn junctions formed by *sandwiching either p-type or n-type semiconductor between a pair of opposite types. Accordingly; there are two types of transistors, namely;

(i) n-p-n transistor

(ii) p-n-p transistor

An n-p-n transistor is composed of two n-type semiconductors separated by a thin section of p type as shown in figure (i). However, a p-n-p transistor is formed by two p-sections separated by a thin section of n-type as shown in figure (ii).

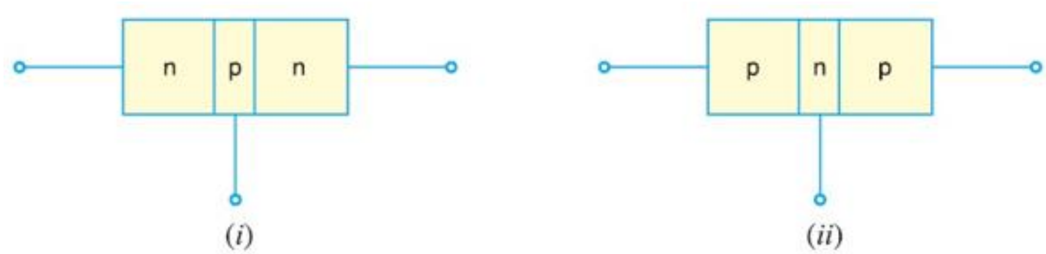


Figure 11: Structure of NPN and PNP

Naming the Transistor Terminals

A transistor (**pnp or npn**) has three sections of doped semiconductors. The section on one side is the emitter and the section on the opposite side is the collector. The middle section is called the base and forms two junctions between the emitter and collector.

(i) **Emitter**. The section on one side that supplies charge carriers (electrons or holes) is called the emitter. The emitter is always forward biased w.r.t. base so that it can supply a large number of *majority carrier. In Figure (i), the emitter (p-type) of pnp transistor is forward biased and supplies hole charges to its junction with the base. Similarly, in Figure (ii), the emitter (n-type) of npn transistor has a forward bias and supplies free electrons to its junction with the base.

(ii) **Collector.** The section on the other side that collects the charges is called the collector. The collector is always reverse biased. Its function is to remove charges from its junction with the base. In Figure (i), the collector (p-type) of pnp transistor has a reverse bias and receives hole charges that flow in the output circuit. Similarly, in Figure (ii), the collector (n-type) of npn transistor has reverse bias and receives electrons.

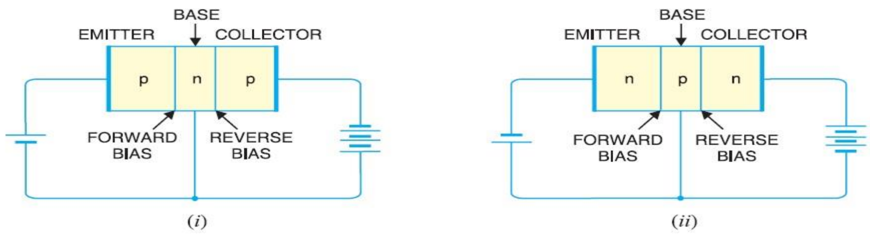


Figure 12: Transistor terminals

(iii) **Base**. The middle section which forms two pn-junctions between the emitter and collector is called the base. The base-emitter junction is forward biased, allowing low resistance for the emitter circuit.

The base-collector junction is reverse biased and provides high resistance in the collector circuit.

✓ **FET (JFET, MOSFET)**

Field-effect transistor (FET)

The field-effect transistor (FET) is a type of transistor which uses an electric field to control the flow of current. FETs are devices with three terminals: source, gate, and drain. FETs are also known as unipolar transistors since they involve single-carrier-type operation.

Types of Field Effect Transistors

A bipolar junction transistor (BJT) is a current controlled device i.e., output characteristics of the device are controlled by base current and not by base voltage. However, in a field effect transistor (FET), the output characteristics are controlled by input voltage (i.e., electric field) and not by input current. This is probably the biggest difference between BJT and FET.

There are two (2) basic types of field effect transistors:

(i) Junction field effect transistor (JFET)

(ii) Metal oxide semiconductor field effect transistor (MOSFET)

To begin with, we shall study about JFET and then improved form of JFET, namely; MOSFET.

Junction Field Effect Transistor (JFET)

A junction field effect transistor is a three terminal semiconductor device in which current conduction is by one type of carrier i.e., electrons or holes. In a JFET, the current conduction is either by electrons or holes and is controlled by means of an electric field between the gate electrode and the conducting channel of the device. The JFET has high input impedance and low noise level.

Constructional details: A JFET consists of a p-type or n-type silicon bar containing two pn junctions at the sides as shown in Figure below. The bar forms the conducting channel for the charge carriers. If the bar is of n-type, it is called n-channel JFET as shown in Figure (i) and if the bar is of P-type, it is called a P-channel JFET as shown in Figure(ii). The two pn junctions forming diodes are connected *internally and a common terminal called gate is taken out. Other terminals are source and drain taken out from the bar as shown. Thus a JFET has essentially three terminals viz., **gate (G), source (S)** and **drain (D).**

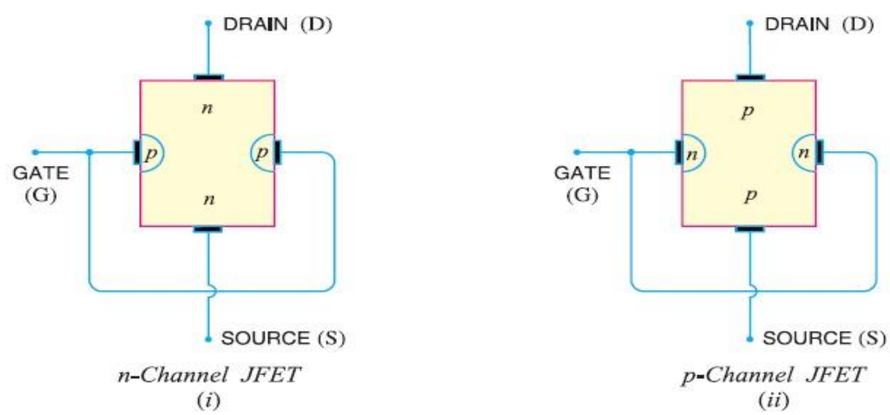


Figure 13: N-channel JFET and P-channel JFET

Principle and Working of JFET

Figure below shows the circuit of n-channel JFET with normal polarities. Note that the gate is reversing biased.

Principle. The two pn junctions at the sides form two depletion layers. The current conduction by charge carriers (i.e. free electrons in this case) is through the channel between the two depletion layers and out of the drain. The width and hence *resistance of this channel can be controlled by changing the input voltage VGS. The greater the reverse voltage VGS, the wider will be the depletion layers and narrower will be the conducting channel. The narrower channel means greater resistance and hence source to drain current decreases. Reverse will happen should VGS decrease. Thus JFET operates on the principle that width and hence resistance of the conducting channel can be varied by changing the reverse voltage VGS. In other words, the magnitude of drain current (ID) can be changed by altering VGS.

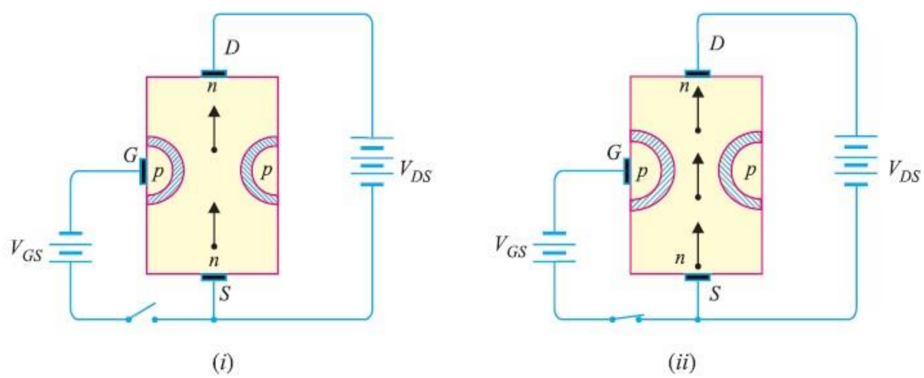


Figure 14: JFET biasing

It is clear from the above discussion that current from source to drain can be controlled by the application of potential (i.e. electric field) on the gate. For this reason, the device is called field effect transistor. It may be noted that a p-channel JFET operates in the same manner as an n -channel JFET except that channel current carriers will be the holes instead of electrons and the polarities of VGS and VDS are reversed.

Note. If the reverse voltage VGS on the gate is continuously increased, a state is reached when the two depletion layers' touch each other and the channel is cut off. Under such conditions, the channel becomes a non-conductor.

Schematic Symbol of JFET

Figure below shows the schematic symbol of JFET. The vertical line in the symbol may be thought

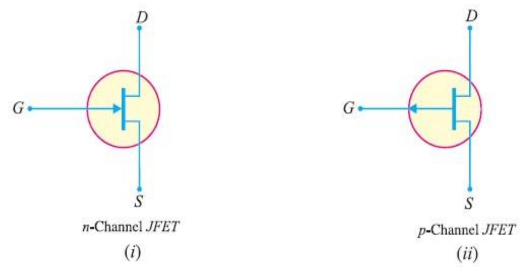


Figure 15: Types of MOSFETs

There are two basic types of MOSFETs viz.

1. Depletion-type MOSFET or D-MOSFET. The D-MOSFET can be operated in both the depletion-mode and the enhancement-mode. For this reason, a D-MOSFET is sometimes called depletion/enhancement MOSFET.
2. Enhancement-type MOSFET or E-MOSFET. The E-MOSFET can be operated only in enhancement mode.

The manner in which a MOSFET is constructed determines whether it is D-MOSFET or EMOSFET.

1. D-MOSFET. shows the constructional details of n-channel D-MOSFET. It is similar to n channel JFET except with the following modifications/remarks:

(i) The n-channel D-MOSFET is a piece of n-type material with a p-type region (called substrate) on the right and an insulated gate on the left as shown in Fig. 31. The free electrons (Q it is n-channel) flowing from source to drain must pass through the narrow channel between the gate and the p-type region (i.e. substrate).

(ii) Note carefully the gate construction of D-MOSFET. A thin layer of metal oxide (usually silicon dioxide, SiO_2) is deposited over a small portion of the channel. A metallic gate is deposited over the oxide layer. As SiO2 is an insulator, therefore, gate is insulated from the channel. Note that the arrangement forms a capacitor. One plate of this capacitor is the gate and the other plate is the channel with SiO2 as the dielectric. Recall that we have a gate diode in a JFET.

(iii) It is a usual practice to connect the substrate to the source (S) internally so that a MOSFET has three terminals viz source (S), gate (G) and drain (D).

(iv) Since the gate is insulated from the channel, we can apply either negative or positive voltage to the gate. Therefore, D-MOSFET can be operated in both depletion-mode and enhancement-mode.

However, JFET can be operated only in depletion-mode.

* With the decrease in channel width, the X-sectional area of the channel decreases and hence its resistance

increases. This means that conductivity of the channel will decrease. Reverse happens if channel width increases.

** With gate reverse biased, the channel is depleted (i.e. emptied) of charge carriers (free electrons for n-channel and holes for p-channel) and hence the name depletion-mode. Note that depletion means decrease. In this mode of operation, conductivity decreases from the zero-bias level.

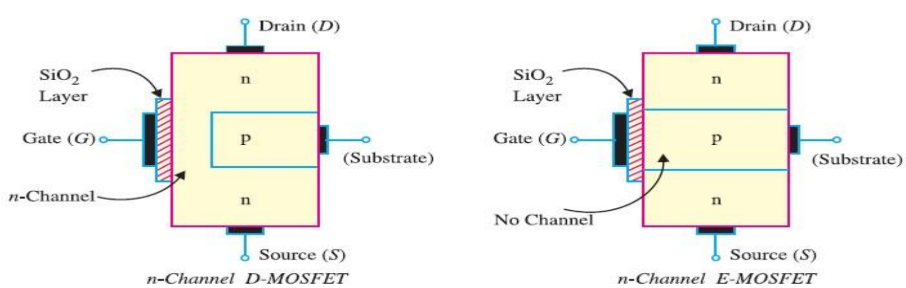


Figure 16: N-channel D-MOSFET and E-MOSFET

2. E-MOSFET. Above shows the constructional details of n-channel E-MOSFET. Its gate construction is similar to that of D-MOSFET. The E-MOSFET has no channel between source and drain unlike the DMOSFET. Note that the substrate extends completely to the SiO2 layer so that no channel exists. The E-MOSFET requires a proper gate voltage to form a channel (called induced channel). It is reminded that E-MOSFET can be operated only in enhancement mode. In short, the construction of E-MOSFET is quite similar to that of the D-MOSFET except for the absence of a channel between the drain and source terminals.

There are two types of D-MOSFETs is

(i) n-channel D-MOSFET and

(ii) p-channel D-MOSFET.

(i) n-channel D-MOSFET. Figure below (i) shows the various parts of n-channel D-MOSFET.

The p-type substrate constricts the channel between the source and drain so that only a small passage

through this narrow channel. The symbol for n-channel D-MOSFET is shown in figure below (ii). The gate appears like a capacitor plate. Just to the right of the gate is a thick vertical line representing the channel. The drain lead comes out of the top of the channel and the source lead connects to the bottom. The arrow is on the substrate and points to the n-material, therefore we have n-channel DMOSFET.

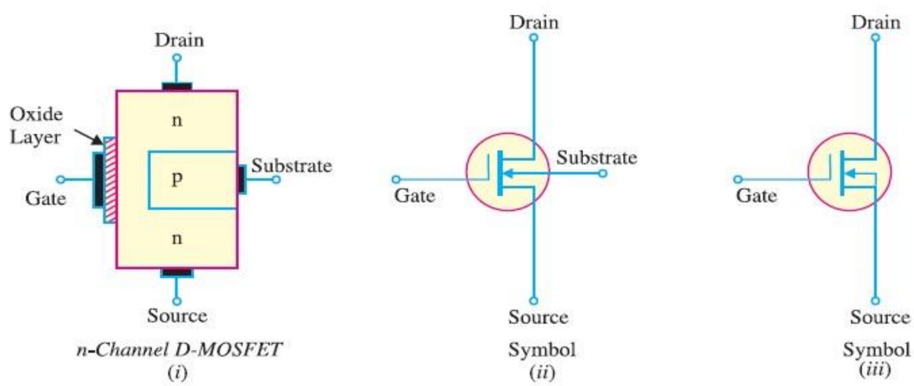


Figure 17: N-channel D-MOSFET

It is a usual practice to connect the substrate to source internally as shown in Figure below (iii). This gives rise to a three-terminal device.

(ii) p-channel D-MOSFET. Figure below (i) shows the various parts of p-channel D-MOSFET.

The n-type substrate constricts the channel between the source and drain so that only a small passage remains at the left side. The conduction takes place by the flow of holes from source to drain through this narrow channel. The symbol for p-channel D-MOSFET is shown in figure below (ii). It is a usual practice to connect the substrate to source internally. This results in a three-terminal device whose schematic symbol is shown in Fig. below

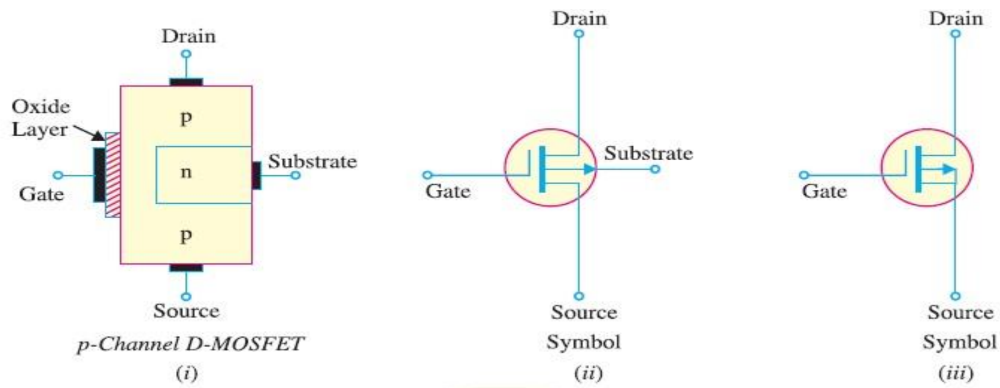


Figure 18: P-channel D-MOSFET symbol

- ✓ **phototransistor**

A Photo Transistor is a sensor that detects ambient light, a bit like an LDR (and works in a similar way). We prefer these sensors as the package is a little more robust than your traditional LDRs. When light enters the chip on top, it creates a flow of current from the long to the short pin. When there's no light there's almost no current going across the pins at all. It manages to detect light in a similar way to your own eyes, so it's great for projects that require human-level light monitoring Phototransistor circuit symbol,

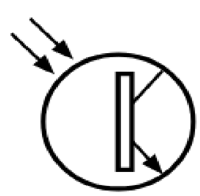


Figure 19: Phototransistor symbol

Standard circuit symbols are essential for each type of electronic component, enabling circuit diagrams to be drawn easily and recognizable by all. The phototransistor symbol consists of the basic bipolar transistor symbol with two arrows pointing towards the junction of the bipolar transistor. This diagrammatically represents the operation of the phototransistor.

Theoretical learning Activity

- ✓ Brainstorming on passive and active components
- ✓ Group discussion on electronic devices
- ✓ Physical demonstration of electronic devices
- ✓ Documentary research

Practical learning Activity

- ✓ Differentiation of resistor
- ✓ Differentiation of inductor
- ✓ Differentiation of capacitor
- ✓ Differentiation of conductors
- ✓ Differentiation of insulators
- ✓ Differentiation of semiconductors
- ✓ Structure and features of diode
- ✓ Description of diode characteristics
- ✓ Structure and features of transistor
- ✓ Description of transistor characteristics

Points to Remember (Take home message)

- ✓ A transistor is a semiconductor device that controls current between two terminals based on the current or voltage at a third terminal
- ✓ A *resistor* is a component that resists the flow of current
- ✓ Inductor is then a passive component that has the ability to store energy in the form of a magnetic field.
- ✓ An active component is a device that has an analogue electronic filter with the ability to amplify a signal or produce a power gain.

Learning outcome 1.1: formative assessment

Q1. Answer with **true** or **false**

1. Active components not need external supply**? False**

2. Resistor is an electronic passive component? **True**

Q2. Choose correct answer

1. A transistor has the following terminals
   a) Emitter, collector and resistor
   b) Emitter, resistor and diode
   c) Collector, emitter and base
   d) Collector, base and cathode

Q3. What are the types of transistor?

- ✓ BJT (bipolar junction transistor)
- ✓ FET (field effect transistor)

References

[1] https://www.elprocus.com/phototransistor-basics-circuit-diagram-advantages-applications/

[2] Kalsi H. S. (2004). Electronic instrumentation Tata McGraw-Hill Education, [Textbook of methods and instrumentation for measurement of electrical quantities

[3] https://byjus.com/jee/inductor/

Learning outcome 1.2: Identify electronic devices characteristics

Duration: **4** hrs

Learning outcome 1.2: objectives:

By the end of the learning outcome, the trainees will be able to:

1. identify all passive components

2. Identify materials used in electronics

3. identify all active components

Resources

Equipment	Tools	Materials
-Books	**-Internet**	**Resistor** **- Inductor** **- Capacitor** **- Transistor** **- Diode**

Advance preparation:

- A trainer should test all circuits before of giving task to learners
- A trainer should be having testing results of all components will be used by trainees

Indicative content 1.2.1: Introduction to passive components used in electronic

Passive components are the components which do not require external supply and they not amplify input signal like resistor, capacitor and inductor.

- ✓ **RESISTOR**

(a) Resistor Colour Codes

What is a color code?

Generally, code refers to a representation of information in another form by using symbols, signals, and letters for the purposes of secrecy. Here, the signals or symbols act as codes. In the similar way, in resistors we use different colours as codes to specify the resistance (information) of the resistor. Here, the different colours coated on the resistor act as codes.

Color	1st digit	2nd digit	3rd digit	Multiplier	Tolerance	TCR (ppm/k)
Black	0	0	0	10^0		
Brown	1	1	1	10^1	1% (F)	100
Red	2	2	2	10^2	2% (G)	50
Orange	3	3	3	10^3		15
Yellow	4	4	4	10^4		25
Green	5	5	5	10^5	0.5% (D)	
Blue	6	6	6	10^6	0.25% (C)	10
Violet	7	7	7	10^7	0.10% (B)	5
Gray	8	8	8	10^8	0.05%	
White	9	9	9	10^9		
Gold				10^{-1}	5% (J)	
Silver				10^{-2}	10% (K)	

Figure 20: Color coding image

4 band color code resistor

A 4 band color code resistor has 3 colour bands on left side and one color band on right side. The 3 color bands on left side are very close to each other and the 4th color band on right side is separated from first 3 bands with some space.

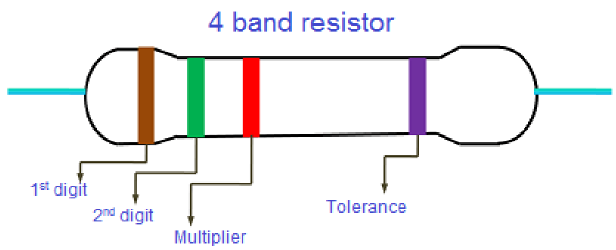


Figure 21: 4 band resistor image

The 3 color bands on the left side are grouped together to indicate the resistors resistance value and the 4th color band on the right side indicates the tolerance of the resistor.

- The 1st color band on the resistor indicates the 1st significant value or 1st digit of the resistors resistance and
- the 2nd color band indicates 2nd significant value or 2nd digit of the resistors resistance.
- The 3rd color band is the decimal multiplier and
- the 4th color band indicates the resistors tolerance.

Tolerance is the variation in the resistance of a resistor from its actual resistance

5 band color code resistor

A 5 band color code resistor has 4 color bands on left side and one color band on right side. The 4 color bands on left side are very close to each other and the 5th color band on right side is separated from the first 4 bands with some space.

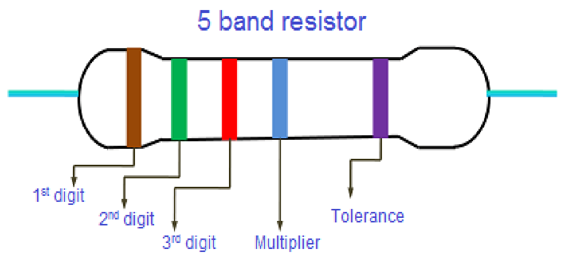


Figure 22: 5 band of resistor image

The 4 color bands on the left side are grouped together to represent the resistance value of a resistor and the 5th color band on the right side indicates the tolerance of the resistor.

- The 1st color band indicates the 1st significant value or 1st digit of the resistors value.
- The 2nd color band indicates the 2nd significant value or 2nd digit of the resistor value.
- The 3rd color band indicates the 3rd significant value or 3rd digit of the resistors value.
- The 4th color band is the decimal multiplier.
- The 5th color band indicates the resistors tolerance.

6 band color code resistor

A 6 band color code resistor consists of 6 color bands. The 4 color bands on the left side are grouped together to represent the resistors resistance value. The 5th color band on the right side represent the tolerance of the resistor and the 6th color band represents the TCR (Temperature Co-efficient of Resistance).

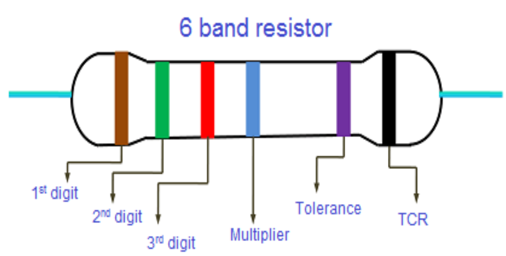


Figure 23: 6 bands resistor image

- The 1^{st} color band indicates the 1^{st} significant value of the resistors value.
- The 2^{nd} color band indicates the 2^{nd} significant value of the resistors value.
- The 3^{rd} color band indicates the 3^{rd} significant value of the resistors value.
- The 4^{th} color band is the decimal multiplier.
- The 5^{th} color band indicates the resistors tolerance.
- The 6^{th} color band indicates the TCR (Temperature Co-efficient of Resistance).

Ohm's law

Ohm's law states that the current *I* flowing in a circuit is directly proportional to the applied voltage *V* and inversely proportional to the resistance *R*, provided the temperature remains constant. Thus,

$$I = \frac{V}{R} \text{ or } V = IR \text{ or } R = \frac{V}{I}$$

Problem 1. The current flowing through a resistor is 0.8A when a p.d. of 20V is applied. Determine the value of the resistance.

From Ohm's law,

$$\text{resistance } R = \frac{V}{I} = \frac{20}{0.8} = \frac{200}{8} = \mathbf{25\ \Omega}$$

(b) Letter and digit code for resistors

Another way of indicating the value of resistors is the letter and digit code shown in Table below

Resistance Value	Marked as:
0.47 Ω	R47
1 Ω	1R0
4.7 Ω	4R7
47 Ω	47R
100 Ω	100R
1 kΩ	1K0
10 kΩ	10 K
10 MΩ	10 M

Tolerance is indicated as follows: $F = \pm 1\%$, $G = \pm 2\%$, $J = \pm 5\%$, $K = \pm 10\%$ and $M = \pm 20\%$

Thus, for example,

$$R33M = 0.33\ \Omega \pm 20\%$$

$$4R7K = 4.7\ \Omega \pm 10\%$$

$$390RJ = 390\ \Omega \pm 5\%$$

Relationship between resistors and conductance

The unit of electric resistance is the ohm (Z) where one ohm is one volt per ampere. It is defined as the resistance between two points in a conductor when a constant electric potential of one volt applied at the two points produces a current flow of one ampere in the conductor. Thus,

resistance, in ohms $\boxed{R = \frac{V}{I}}$

where V is the potential difference across the two points in volts and I is the current flowing between the two points in amperes.

The reciprocal of resistance is called conductance and is measured in Siemens (S). Thus,

conductance, in siemens $\boxed{G = \frac{1}{R}}$

where R is the resistance in ohms.

Eg. Find the conductance of a conductor of resistance

(a) 10 Ω, (b) 5 kΩ and (c) 100 mΩ

(a) Conductance $G = \frac{1}{R} = \frac{1}{10}$ siemen $= \mathbf{0.1}$ **s**

(b) $G = \frac{1}{R} = \frac{1}{5 \times 10^3}\text{ S} = 0.2 \times 10^{-3}\text{ S} = \mathbf{0.2\ mS}$

(c) $G = \frac{1}{R} = \frac{1}{100 \times 10^{-3}}\text{ S} = \frac{10^3}{100}\text{ S} = \mathbf{10\ S}$

Electric power and energy

When a direct current of I amperes is flowing in an electric circuit and the voltage across the circuit is V volts, then

power, in watts $\boxed{P = VI}$

Electrical energy = Power × time

= ***VIt*** **Joules**

Although the unit of energy is the joule, when dealing with large amounts of energy, the unit used is the kilowatt hour (kWh) where

1 kWh = 1000 watt hour

= 1000 × 3600 watt seconds or joules

= 3 600 000 J

E.g. 2. A source e.m.f. of 5 V supplies a current of 3 A for 10 minutes. How much energy is provided in this time?

Energy = power × time and power = voltage × current. Hence

$$\text{Energy} = VIt = 5 \times 3 \times (10 \times 60) = 9000 \text{ Ws or J}$$
$$= \mathbf{9\ kJ}$$

Power

Power The unit of power is the watt (W) where one watt is one joule per second.

Power is defined as the rate of doing work or transferring energy. Thus,

$$\text{power in watts, } \boxed{P = \frac{W}{t}}$$

Where W is the work done or energy transferred in joules and t is the time in seconds. Thus

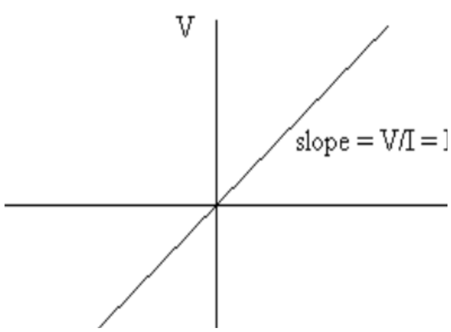
$$\text{energy, in joules, } \boxed{W = Pt}$$

Resistance of a material ∝ resistivity of the material:

$$R = \rho L/A \quad [\Omega]$$

V-I Characteristics of a Resistor

V-I Characteristics of a resistor are the relation between the applied voltages and the current flowing through it.



TYPES OF RESISTOR

The first major categories into which the different types of resistor can be fitted is into whether they are fixed or variable. These different resistor types are used for different applications:

- **Fixed resistors:** Fixed resistors are by far the most widely used type of resistor. They are used in electronics circuits to set the right conditions in a circuit. Their values are determined during the design phase of the circuit, and they should never need to be changed to "adjust" the circuit. There are many different types of resistor which can be used in different circumstances and these different types of resistor are described in further detail below.
- **Variable resistors:** These resistors consist of a fixed resistor element and a slider which taps onto the main resistor element. This gives three connections to the component: two connected to the fixed element, and the third is the slider. In this way the component acts as a variable potential divider if all three connections are used. It is possible to connect to the slider and one end to provide a resistor with variable resistance

Other types of resistor

Whilst the majority of resistors are standard fixed resistors or variable resistors, there is a number of other resistor types that are sued in some more niche or specialized applications.

- **Light dependent resistor / photo resistor**: Light dependent resistors or photo resistors change their resistance with the level of light. They are used in a number of sensor applications and provide a very cost effective solution in many instances. Read more about Light Dependent Resistors.
- **Varistor:** Varistors are available in a number of forms. They vary their resistance with the applied voltage and as a result they find uses for spike and surge protection. Read more about Varistors.
- **Surface mount resistors**: Surface mount technology, SMT is now the major format used for electronic components. They are easier to use in automated manufacturing, and they are able to provide very high levels of performance.

Types of resistor chart

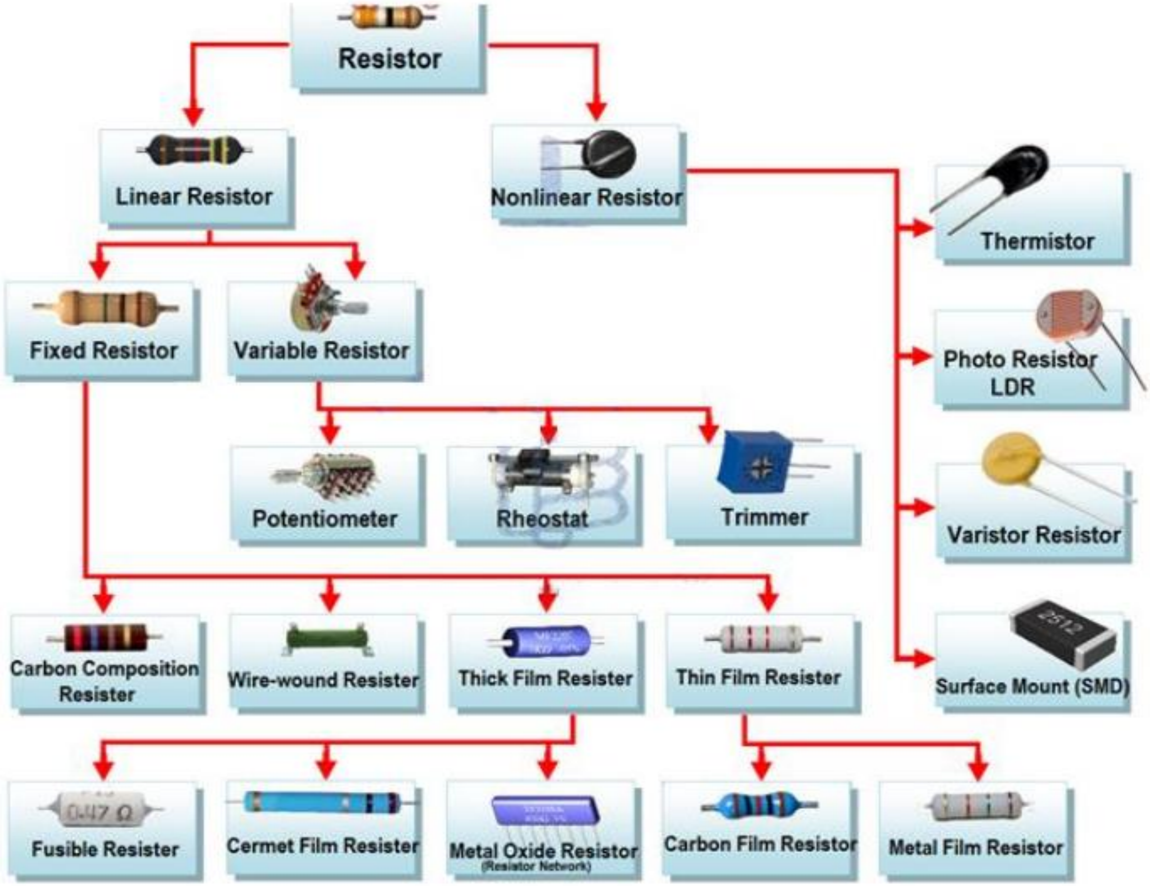


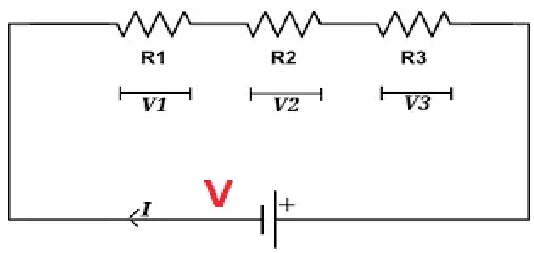
Figure 24: Resistor types chart

Types of connection of resistor

- Series connection
- Parallel connection
- Combination connection

Resistor series connection:

Refer the diagram, here the resistor R1, R2 and R3 are connected in series, Req is the equivalent resistance of the circuit and the V1, V2, and V3 are the **voltage** drop across the resistor, V is the input voltage and the current I is flowing through all the resistor.



$$V = V1 + V2 + V3$$

$$I * Requ = IR1 + IR2 + IR3$$

$$\boxed{Requ = R1 + R2 + R3}$$

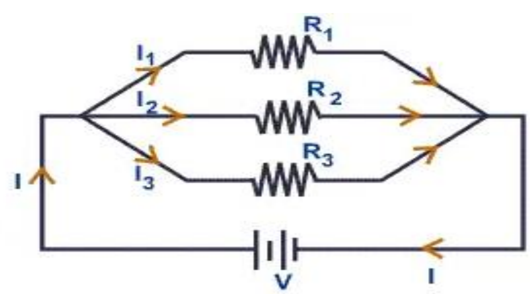
Figure 25: Resistor series connection circuit

Apply Kirchhoff voltage rule

The resistor in parallel Connection

Refer the diagram, here the resistance R1, R2 and R3 are connected in parallel, Req is the equivalent resistance or sum of all resistance of the circuit.

V is the voltage drop across the resistor, V is the input voltage and the current I1, I2 and I3 are flowing through the individual the resistance R1, R2, and R3.



$$\frac{V}{Requ} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$$

$$\boxed{\frac{1}{Requ} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}}$$

Figure 26: Resistor parallel connection circuit

$$I = I1 + I2 + I3$$

Combination connection

A combination circuit contains sections of resistors in series and parallel. The circuit diagram below shows two resistors connected in series to two resistors in parallel.

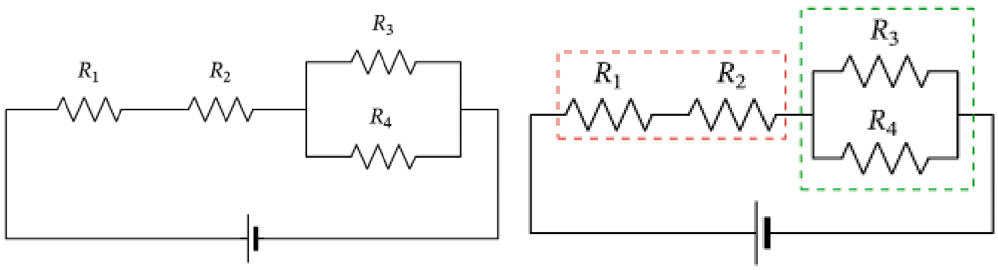


Figure 27: Resistor mixed connection circuit

- ✓ **Inductor**

Inductor is then a passive component that has the ability to store energy in the form of a magnetic field.

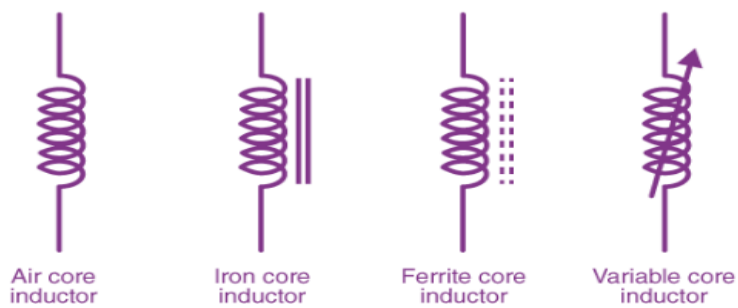


Figure 28: Symbol of inductor

Inductance of Inductor

Inductance is the property of an Inductor The current generated in the inductor due to magnetic field is proportional to the rate of change of magnetic field is called as inductance. Higher the inductance value, more the inductor will resist from the sudden changes in the current.

An inductor is described by its distinctive nature of inductance, which is defined as the ratio of the voltage to the rate of change of current. Inductance is a result of the induced magnetic field on the coil. It is also determined by several factors such as;

- The shape of the coil.
- The number of turns and layers of the wire.
- The space that is given between the turns.
- Permeability of the core material.
- The size of the core.

Different Types of Inductors

Depending on the type of material used inductors can be classified as follows:

1. Iron Core Inductor
2. Air Core Inductor
3. Iron Powder Inductor
4. Ferrite Core Inductor which is divided into,

- Soft Ferrite
- Hard Ferrite

Inductance is given by $\mathbf{L = \mu N^2 A / l}$

Where

L – Inductance of the coil

μ – Permeability of the core

N-Number of turns in the coil

A-Area of the coil

l -Length of the inductor

series connection of inductor

When ‘n’ number of inductors are connected in series the total inductance value is the sum of all the individual inductances.

L total = L1+L2+… +Ln

Figure 29: Inductors in series

Inductors in parallel

When ‘n’ numbers of inductors are connected in parallel the total inductance value is the low and is equated as follows

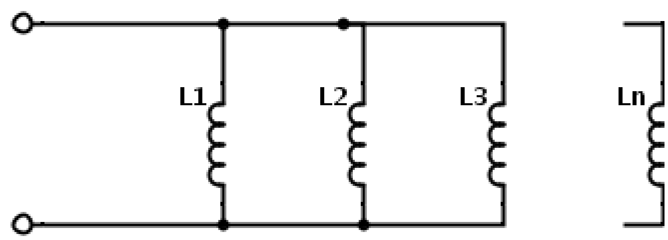


Figure 30: Inductors in parallel

Ltotal = 1/ ((1/L1) + (1/L2) +..+ (1/Ln))

If we observe these two equations these are very similar to the resistors connected in series and parallel.

Inductance Units

The SI unit of inductance is Henry. It is named after the American physicist Joseph Henry. This is denoted by ‘H’.

One Henry is nothing but the rate of change of current in a circuit is one ampere per second, then the resultant emf is one volt. This is equated as

H= (V.s)/A = Wb/A.

Where V = Volts, s = second, Wb = Weber, and A = Ampere.

- ✓ **CAPACITOR**

what's capacitor?

It is known as condenser is two terminal passive components which stores energy in electric field

Capacitance it's a property of capacitor to store energy in form of electric field

Capacitor consists of two conducting plates separated by dielectric

Dielectric is insulating material or very poor conductor that can be polarized by an applied electric field

Capacitor is often named according to the nature of dielectric inside the plates like

-air, mica, paper, ceramic, plastic, tantalum, aluminium

TYPES OF CAPACITOR

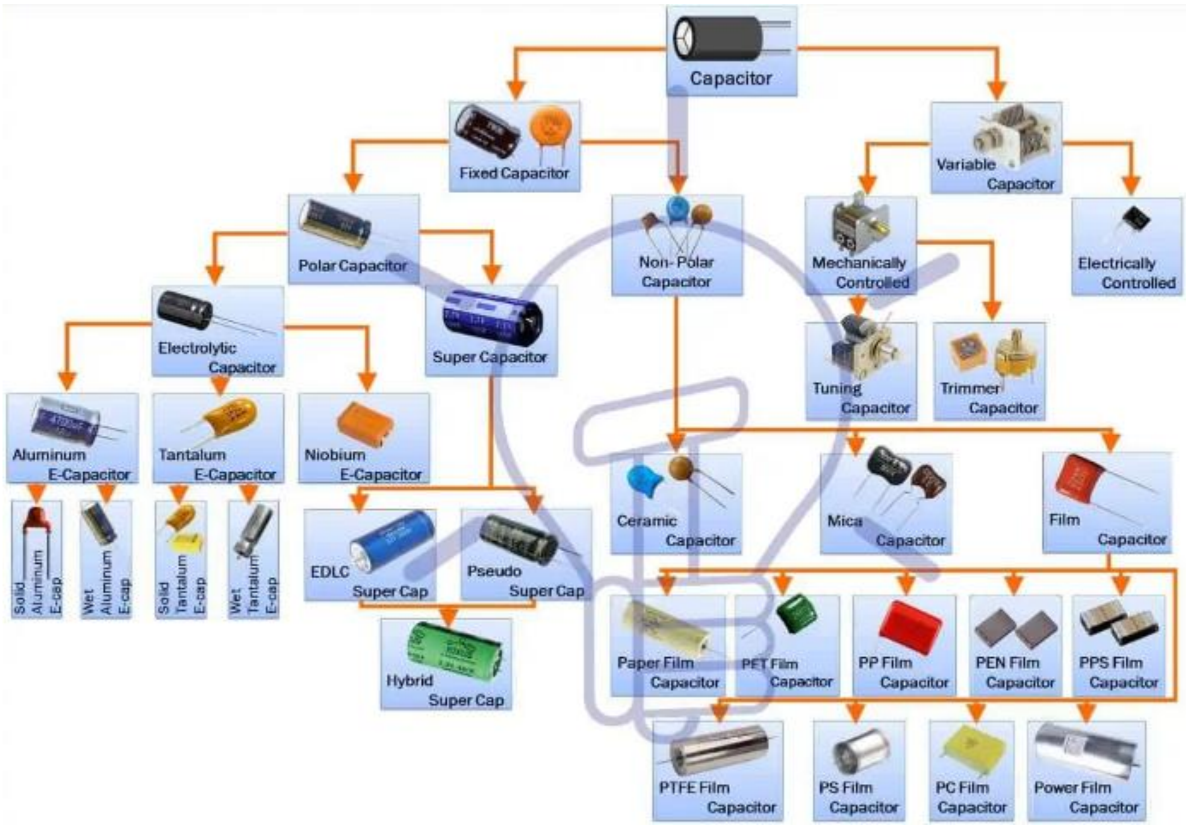


Figure 31: Inductors in parallel

Energy stores in capacitor is calculated as follow

$E=1/2CV^2$ (joule)

The combination is connected to a battery to apply a potential difference (V) and charge the plates (Q). We can define the equivalent capacitance of the combination between two points to be $C = \frac{Q}{V}$

Series Combination of Capacitors

When capacitors are connected in series, the magnitude of charge Q on each capacitor is the same. The potential difference across C_1 and C_2 is different, i.e., V_1 and V_2.

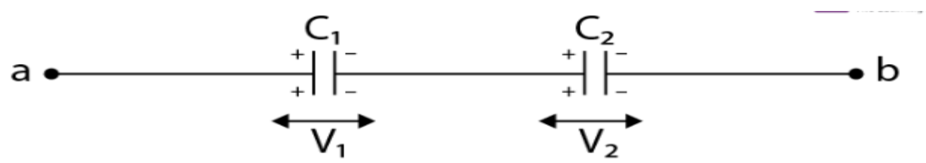


Figure 32: Capacitor in series circuit

The total potential difference across combination is:

$V = V_1 + V_2$

$V = \frac{Q}{C_1} + \frac{Q}{C_2}$

$\frac{V}{Q} = \frac{1}{C_1} + \frac{1}{C_2}$

The ratio Q/V is called the equivalent capacitance C between points a and b.

The equivalent capacitance C is given by:

$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$

The potential difference across C_1 and C_2 is V_1 and V_2 respectively, is given as follows:

$V_1 = \frac{C_2}{C_1+C_2}$; $\qquad V_2 = \frac{C_1}{C_1+C_2}V$

In the case of more than two capacitors, the relation is:

$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \ldots\ldots$

Parallel Combination of Capacitors

When capacitors are connected in parallel, the potential difference V across each is the same and the charge on C_1 and C_2 is different, i.e., Q_1 and Q_2

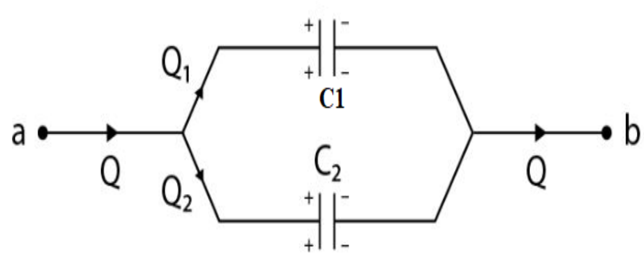


Figure 33: Capacitor parallel connection

The total charge in Q is given as:

$$Q = Q_1 + Q_2$$
$$Q = C_1V + C_2V$$
$$\frac{Q}{V} = C_1 + C_2$$

The equivalent capacitance between a and b is:

$C = C_1 + C_2$

The charges on capacitors are given as:

- $Q1 = \frac{C_1}{C_1+C_2}Q$
- $Q2 = \frac{C_2}{C_1+C_2}Q$

In case of more than two capacitors, $C = C_1 + C_2 + C_3 + C_4 + C_5 + ...$

Indicative content 1.2.2: materials used in Electronics

Comparison of Semiconductors to Conductors and Insulators

In an intrinsic semiconductor, there are relatively few free electrons, so semiconductors are not very useful in their intrinsic states. Pure semi conductive materials are neither insulators nor good conductors because current in a material depends directly on the number of free electrons. A comparison of the energy bands in Figure below for insulators, semiconductors and conductors shows the essential differences among them regarding conduction. The energy gap for an insulator is so wide that hardly any electrons acquire enough energy to jump into the conduction band. The valence band and the conduction band in a conductor (such as copper) overlap so that there are always many conduction electrons, even without the application of external energy. A semiconductor, as Figure below(b) shows, has an energy gap that is much narrower than that in an insulator.

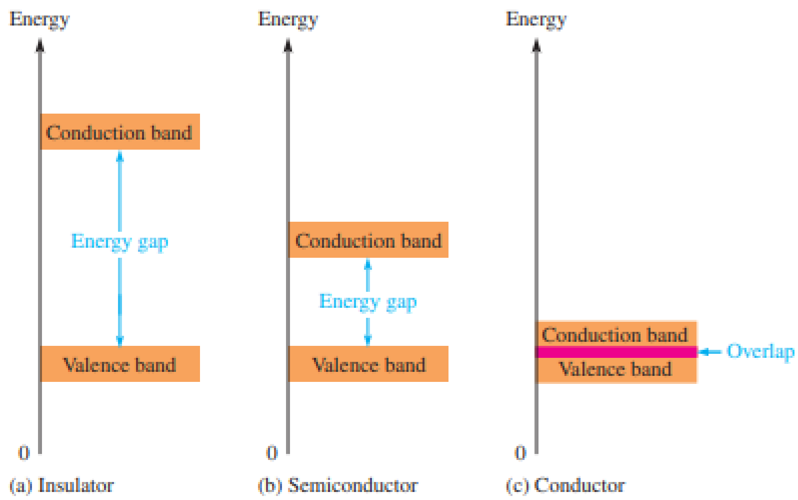


Figure 34: Energy gap of materials

Indicative content 1.2.3: Structure and features of diodes

✓ **PN junction diode**

Biasing Conditions for the P-N Junction Diode

There are two operating regions in the P-N junction diode:

- P-type
- N-type

There are three biasing conditions for the P-N junction diode, and this is based on the voltage applied:

Zero bias: No external voltage is applied to the P-N junction diode.

Forward bias: The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.

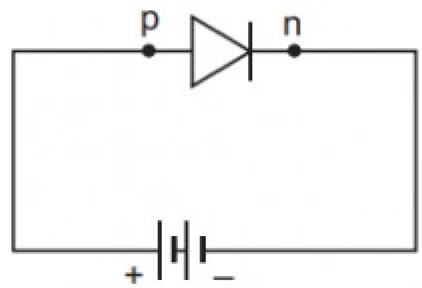


Figure 35: Forward bias diagram

Reverse bias: The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

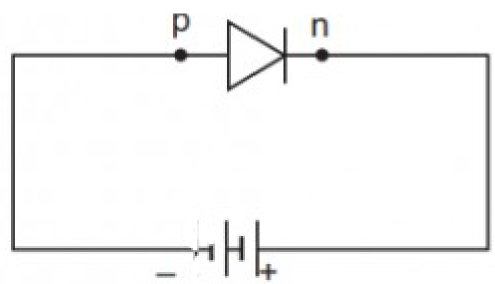


Figure 36: Reverse bias diagram

Some Common Applications of Diodes

Before taking a look at various applications of diodes, let us quickly take a peek at a small list of common applications of diodes.

- Rectifiers
- Clipper Circuits
- Clamping Circuits
- Reverse Current Protection Circuits
- In Logic Gates
- Voltage Multipliers

✓ **ZENER**

There are two types of breakdowns for a Zener Diode:

- Avalanche Breakdown

- Zener Breakdown

Avalanche Breakdown in Zener Diode

Avalanche breakdown occurs in the normal diode and Zener Diode at high reverse voltage. When a high value of reverse voltage is applied to the PN junction, the free electrons gain sufficient energy and accelerate at high velocities. These free electrons moving at high velocity collide with other atoms and knock off more electrons.

Zener Breakdown in Zener Diode

When the applied reverse bias voltage reaches closer to the Zener voltage, the electric field in the depletion region gets strong enough to pull electrons from their valence band. The valence electrons that gain sufficient energy from the strong electric field of the depletion region break free from the parent atom

V-I Characteristics of Zener Diode

The diagram given below shows the V-I characteristics of the Zener diode.

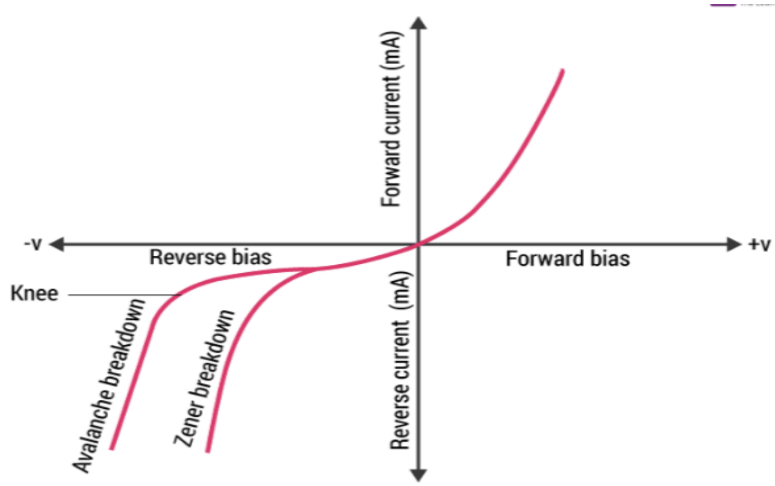
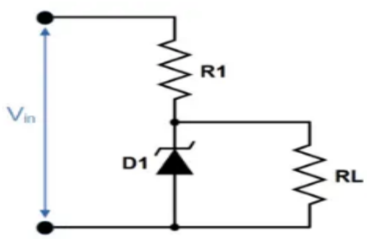


Figure 37: V-I Characteristics of Zener Diode

Zener Diode Specifications

Some commonly used specifications for Zener diodes are as follows:

- **Zener/Breakdown Voltage** – The Zener or the reverse breakdown voltage ranges from 2.4 V to 200 V, sometimes it can go up to 1 kV while the maximum for the surface-mounted device is 47 V.
- **Current Iz (max)** – It is the maximum current at the rated Zener Voltage (Vz – 200µA to 200 A)
- **Current Iz (min)** – It is the minimum value of current required for the diode to break down.
- **Power Rating –** It denotes the maximum power the Zener diode can dissipate. It is given by the product of the voltage of the diode and the current flowing through it.
- **Temperature Stability** – Diodes around 5 V have the best stability
- **Voltage Tolerance** – It is typically ±5%
- **Zener Resistance** (Rz) – It is the resistance to the Zener diode exhibits.



$$R_{min} = \frac{V_{in} - V_Z}{I_{max}} \qquad I_R = I_Z + I_L \qquad I_{max} = \frac{P_{max}}{V_Z}$$

Figure 38: V-I Characteristics of Zener Diode

- ✓ **Led**

Simple LED Circuit

The figure below shows a simple LED circuit.

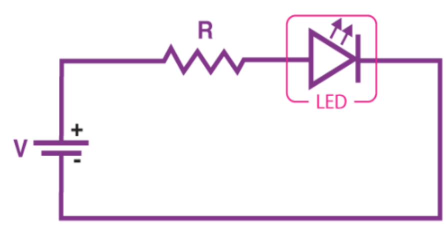


Figure 39: Image of LED

Types of LED

Below is the list of different types of LED that are designed using semiconductors:

- Miniature LEDs
- High-Power LEDs
- Flash LED
- Bi and Tri-Colour
- Red Green Blue LEDs
- Alphanumeric LED
- Lighting LED

Uses of LED

LEDs find applications in various fields, including optical communication, alarm and security systems, remote-controlled operations, robotics, etc. It finds usage in many areas because of its long-lasting capability, low power requirements, swift response time, and fast switching capabilities. Below are a few standards LED uses:

- Used for TV back-lighting
- Used in displays
- Used in Automotive
- LEDs used in the dimming of lights

✓ **Tunnel**

A Tunnel diode is a heavily doped p-n junction diode in which the electric current decreases as the voltage increases.

In tunnel diode, electric current is caused by “Tunnelling”. The tunnel diode is used as a very fast switching device in computers. It is also used in high-frequency oscillators and amplifiers.

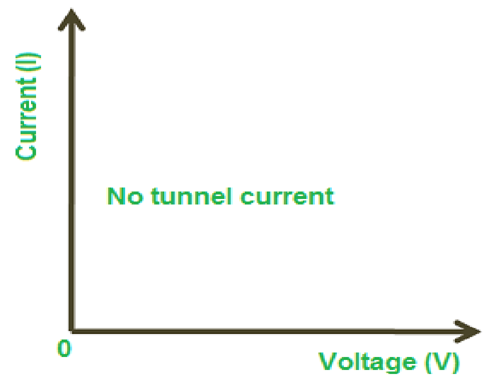


Figure 40: Unbiased tunnel

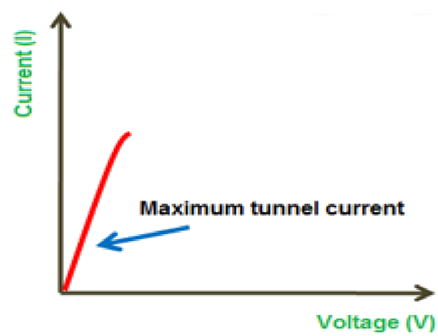


Figure 41: Biased tunnel

Advantages of tunnel diodes

- Long life
- High-speed operation
- Low noise
- Low power consumption

Disadvantages of tunnel diodes

- Tunnel diodes cannot be fabricated in large numbers
- Being a two terminal device, the input and output are not isolated from one another.

Applications of tunnel diodes

- Tunnel diodes are used as logic memory storage devices.
- Tunnel diodes are used in relaxation oscillator circuits.
- Tunnel diode is used as an ultra-high-speed switch.
- Tunnel diodes are used in FM receivers.

✓ **Varicap**

What are the key characteristics of a varicap diode?

Important characteristics are capacitance when designated bias voltage is applied (ex. C_{3V} where V_R=3V), capacitance variation when applied voltage changes (capacitance ratio) and series resistance that affects Q index when used in oscillators or filters.

Advantages of Varactor Diode

1. Low Noise: It generates less noise as compared to the other P-N junction diode. Thus, the power loss due to noise is low in Varactor diodes.
2. Portability: It is portable due to the small size and lightweight.
3. Reliability: It is more reliable than other P-N junction diodes.
4. Economical: It is a low-cost diode thus; it is economical to use in various applications.

Disadvantages of Varactor Diode

These are specially designed to work in the reverse biased mode, it possesses the least significance when operated in forward biasing.

Applications of Varactor Diode

1. **Television receivers:** Varactor diodes are used as tuned capacitors and have replaced mechanically tuned capacitors in various applications. It is used in television in the resonant tank circuit.

2. **Radio receivers**: Radio receivers also use this diode for tuning purposes.
3. **Frequency Multiplier:** It is also used as a frequency multiplier in various electronic circuits.
4. **Phase Locked Loops:** It is used in Phase locked loop for frequency modulation. Varactor diodes help in achieving frequency modulation. Thus, in communication devices varactor diodes are significant.
5. **Voltage controlled oscillators**: Voltage control oscillators are used extensively in transmission and receiving circuits in communication. And varactor diode plays a significant role in construction of voltage controlled oscillator.
6. **Parametric Amplifiers**: It is used in parametric amplifier as a significant component.

- ✓ **Photodiode**

Connecting a Photodiode in an External Circuit

A Photodiode operates in a circuit in reverse bias. Anode is connected to circuit ground and cathode to positive supply voltage of the circuit. When illuminated by light, current flows from cathode to anode.

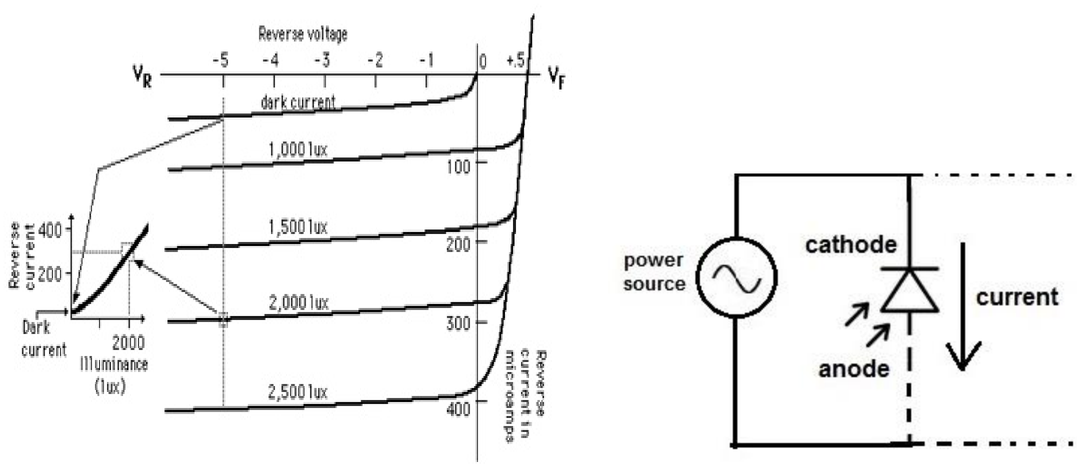


Figure 42: V-I Characteristics of Photodiode

Photodiode operates in reverse bias condition. Reverse voltages are plotted along X axis in volts and reverse current are plotted along Y-axis in microampere. Reverse current does not depend on reverse voltage. When there is no light illumination, reverse current will be almost zero. The minimum amount of current present is called as Dark Current. Once when the light illumination increases, reverse current also increases linearly.

- ✓ **Schottky Diode**

The Schottky diode is a type of metal – semiconductor junction diode, which is also known as hot-carrier diode, low voltage diode or Schottky barrier diode

V-I Characteristics of Schottky Diode

The V-I characteristics of Schottky diodes are very much similar to the PN junction diode. Current is the dependent variable while voltage is the independent variable in the Schottky diode. The forward voltage drop of the Schottky diode is low between 0.2 to 0.3 volts.

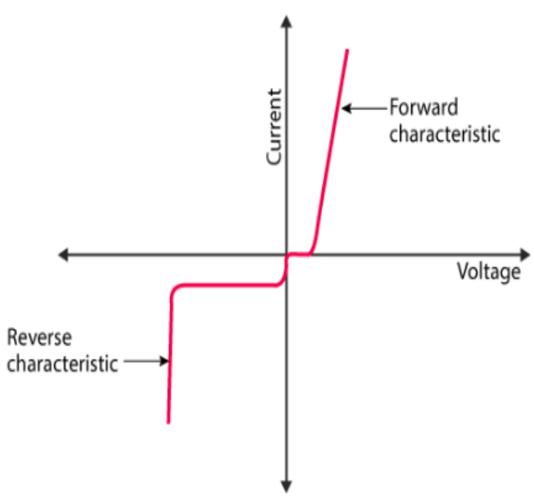


Figure 43: Behaviour of Schottky

Advantages of Schottky diode

Following are the advantages of Schottky diode:

- The capacitance of the diode is low as the depletion region of the diode is negligible.
- The reverse recovery time of the diode is very fast, that is the change from ON to OFF state is fast.
- The current density of the diode is high as the depletion region is negligible.
- The turn-on voltage of the diode is 0.2 to 0.3 volts, which is very low.

Disadvantages of Schottky diode

The only disadvantage of Schottky diodes is that the reverse saturation current of the diode is large.

✓ V-I characteristics

VI characteristics of P-N junction diodes is a curve between the voltage and current through the circuit. Voltage is taken along the x-axis while the current is taken along the y-axis. The above graph is the V-I characteristics curve of the P-N junction diode. With the help of the curve, we can understand that there are three regions in which the diode works, and they are:

- Zero bias
- Forward bias
- Reverse bias

When the P-N junction diode is in zero bias condition, there is no external voltage applied and this means that the potential barrier at the junction does not allow the flow of current.

When the P-N junction diode is in forward bias condition, the p-type is connected to the positive terminal while the n-type is connected to the negative terminal of the external voltage. When the diode is arranged in this manner, there is a reduction in the potential barrier. For silicone diodes, when the voltage is 0.7 V and for germanium diodes, when the voltage is 0.3 V, the potential barriers decrease, and there is a flow of current.

When the diode is in forward bias, the current increases slowly, and the curve obtained is non-linear as the voltage applied to the diode overcomes the potential barrier. Once the diode overcomes the potential barrier, the diode behaves normally, and the curve rises sharply as the external voltage increases, and the curve obtained is linear.

When the P-N junction diode is in negative bias condition, the p-type is connected to the negative terminal while the n-type is connected to the positive terminal of the external voltage. This results in an increase in the potential barrier. Reverse saturation current flows in the beginning as minority carriers are present in the junction.

When the applied voltage is increased, the minority charges will have increased kinetic energy which affects the majority charges. This is the stage when the diode breaks down. This may also destroy the diode.

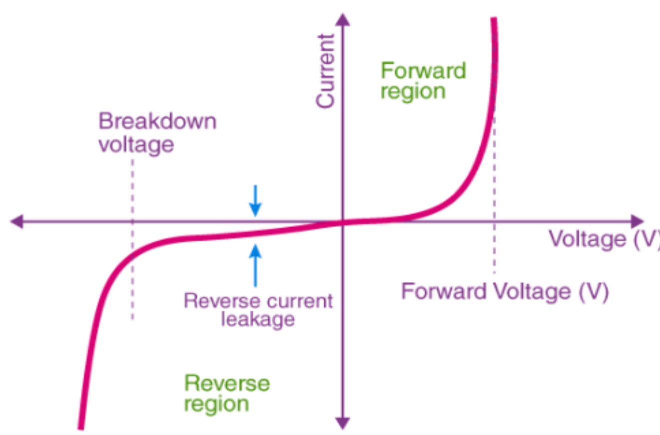


Figure 44: Ordinary diode VI characteristics

Indicative content 1.2.4: Structure and features of transistor

to both input and output terminals. The input is fed between this common terminal and one of the other two terminals. The output is obtained between the common terminal and the remaining terminal.

Accordingly; a transistor can be connected in a circuit in the following three ways:

(i) common base connection (ii) common emitter connection

(iii) common collector connection

Each circuit connection has specific advantages and disadvantages. It may be noted here that regardless of circuit connection, the emitter is always biased in the forward direction, while the collector always has a reverse bias.

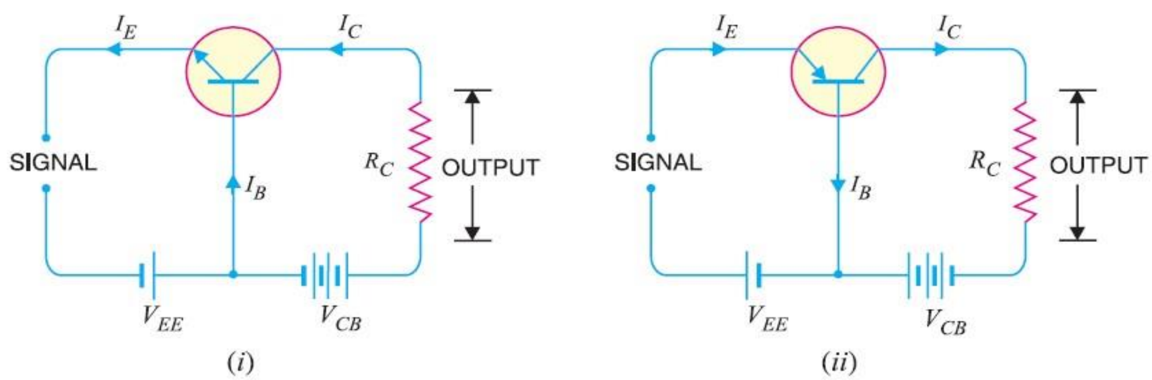


Figure 45: Common Base Connection

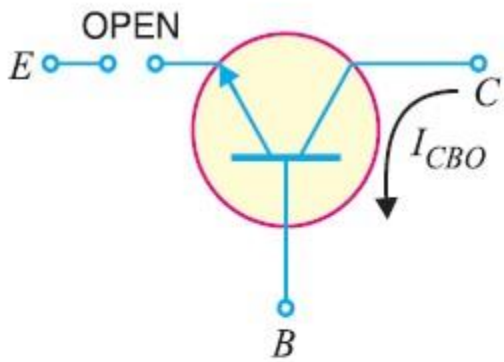
Common Base Connection

In this circuit arrangement, input is applied between emitter and base and output is taken from collector and base. Here, base of the transistor is common to both input and output circuits and hence the name common base connection. In Fig. 8.9 (i), a common base npn transistor circuit is shown whereas Fig. 8.9 (ii) shows the common base pnp transistor circuit.

1. Current amplification factor ( ). It is the ratio of output current to input current. In a common base connection, the input current is the emitter current IE and output current is the collector current IC. The ratio of change in collector current to the

change in emitter current at constant collector base voltage VCB is known as current amplification factor i.e.

$$*\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at constant } V_{CB}$$



This value can be increased (but not more than unity) by decreasing the base current. This is achieved by making the base thin and doping it lightly. Practical values of β in commercial transistors Range from 0.9 to 0.99.

2. **Expression for collector current.**

The whole of emitter current does not reach the collector. It is because a small percentage of it, as a result of electron-hole combinations occurring in base area, gives rise to base current. Moreover, as the collector-base junction is reverse biased, therefore some leakage current flows due to minority carriers. It follows, therefore, that total collector current consists of:

(i) That part of emitter current which reaches the collector terminal i.e. ***αIE.

(ii) The leakage current I leakage. This current is due to the movement of minority carriers across base-collector junction on account of it being reverse biased. This is generally much smaller than

IE.

∴ Total collector current, IC = αIE + Ileakage

It is clear that if IE = 0 (i.e., emitter circuit is open), a small leakage current still flows in the collector circuit. This I leakageis abbreviated as ICBO, meaning collector-base current with emitter open. The ICBO is indicated in Fig. 8.10.

$$\therefore \qquad I_C = \alpha I_E + I_{CBO}$$

$$\text{Now} \qquad I_E = I_C + I_B$$

$$\therefore \qquad I_C = \alpha (I_C + I_B) + I_{CBO}$$

$$\text{or} \qquad I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

$$\text{or} \qquad I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}$$

Relation (i) or (ii) can be used to find IC. It is further clear from these relations that the collector current of a transistor can be controlled by either the emitter or base current. Fig. 8.11 shows the concept of ICBO. In CB configuration, a small collector current flows even when the emitter current is zero. This is the leakage collector current (i.e. the collector current when emitter is open) and is denoted by ICBO. When the emitter voltage VEE is also applied, the various currents are as shown in Fig. 8.11 (ii).

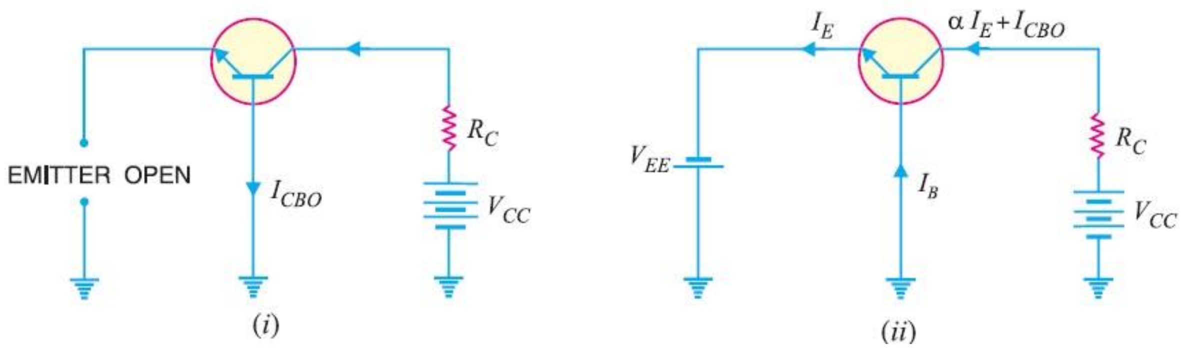
Note. Owing to improved construction techniques, the magnitude of ICBO for general-purpose and low-powered transistors (especially silicon transistors) is usually very small and may be neglected in calculations. However, for high power applications, it will appear in microampere range. Further, ICBO is very much temperature dependent; it increases rapidly with the increase in temperature. Therefore, at higher temperatures, ICBO plays an important role and must be taken care of in calculations.

* If only d.c. values are considered, then $\alpha = I_C/I_E$.

** At first sight, it might seem that since there is no current gain, no voltage or power amplification could be possible with this arrangement. However, it may be recalled that output circuit resistance is much higher than the input circuit resistance. Therefore, it does give rise to voltage and power gain.

*** $$\alpha = \frac{I_C}{I_E} \quad \therefore \quad I_C = \alpha I_E$$

In other words, αI_E part of emitter current reaches the collector terminal.



Example 8.2. *In a common base connection, $I_E = 1mA$, $I_C = 0.95mA$. Calculate the value of I_B.*

Solution. Using the relation, $I_E = I_B + I_C$

or $1 = I_B + 0.95$

$\therefore$ $I_B = 1 - 0.95 =$ **0.05 mA**

Example 8.3. *In a common base connection, current amplification factor is 0.9. If the emitter urrent is 1mA, determine the value of base current.*

Solution. Here, $\alpha = 0.9$, $I_E = 1$ mA

Now $$\alpha = \frac{I_C}{I_E}$$

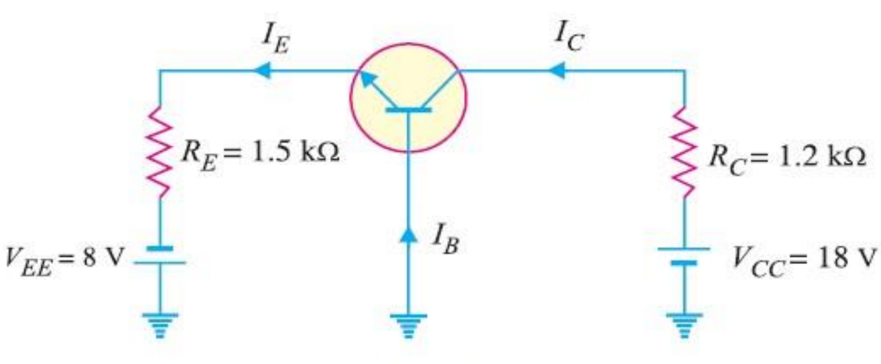
or $I_C = \alpha I_E = 0.9 \times 1 = 0.9$ mA

Also $I_E = I_B + I_C$

$\therefore$ Base current, $I_B = I_E - I_C = 1 - 0.9 =$ **0.1 mA**

Example 8.7. For the common base circuit shown in

Fig. 8.13, determine IC and VCB. Assume the transistor to be of silicon.



Solution. Since the transistor is of silicon, VBE = 0.7V. Applying Kirchhoff's voltage law to the emitter-side loop, we get,

$$V_{EE} = I_E R_E + V_{BE}$$

or $$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

$$= \frac{8V - 0.7V}{1.5\ k\Omega} = 4.87\ mA$$

$$\therefore \quad I_C \simeq I_E = \mathbf{4.87\ mA}$$

Applying Kirchhoff's voltage la to the collector-side loop, we have,

$$V_{CC} = I_C R_C + V_{CB}$$

$$\therefore \quad V_{CB} = V_{CC} - I_C R_C$$

$$= 18\ V - 4.87\ mA \times 1.2\ k\Omega = \mathbf{12.16\ V}$$

Common Emitter Connection

In this circuit arrangement, input is applied between base and emitter and output is taken from the collector and emitter. Here, emitter of the transistor is common to both input and output circuits and hence the name common emitter connection. Fig. 8.16 (i) shows common emitter npn transistor circuit whereas Fig. 8.16 (ii) shows common emitter pnp transistor circuit.

* IE has to be kept constant because any change in IE will produce corresponding change in IC. Here, we are interested to see how VCB influences IC**.**

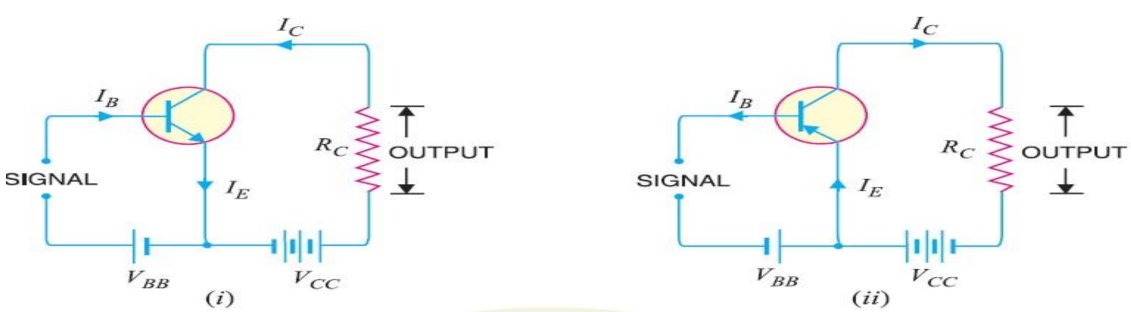


Figure 46: Common Emitter Connection

1. Base current amplification factor (β). In common emitter connection, input current is IB and output current is IC.

The ratio of change in collector current (dIC) to the change in base current (dIB) is known as base current amplification factor i.e.

$$\beta^* = \frac{\Delta I_C}{\Delta I_B}$$

Relation between β and α.

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad ...(i)$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad ...(ii)$$

Now $I_E = I_B + I_C$

or $\Delta I_E = \Delta I_B + \Delta I_C$

or $\Delta I_B = \Delta I_E - \Delta I_C$

Substituting the value of ΔI_B in exp. (*i*), we get,

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} \quad ...(iii)$$

Dividing the numerator and denominator of R.H.S. of exp. (*iii*) by ΔI_E, we get,

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1-\alpha} \quad \left[\because \alpha = \frac{\Delta I_C}{\Delta I_E}\right]$$

$$\therefore \quad \beta = \frac{\alpha}{1-\alpha}$$

Expression for collector current.

In common emitter circuit, IB is the input current and IC is the output current.

$$\text{We know } I_E = I_B + I_C \quad ...(i)$$

and

$$I_C = \alpha I_E + I_{CBO} \quad ...(ii)$$

From exp. (*ii*), we get,

$$I_C = \alpha I_E + I_{CBO} = \alpha (I_B + I_C) + I_{CBO}$$

or

$$I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

or

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \quad ...(iii)$$

From exp. (*iii*), it is apparent that if $I_B = 0$ (*i.e.* base circuit is open), the collector current will be the current to the emitter. This is abbreviated as I_{CEO}, meaning collector-emitter current with base open.

$$\therefore \quad I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

Substituting the value of $\frac{1}{1-\alpha} I_{CBO} = I_{CEO}$ in exp. (*iii*), we get,

$$I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

or

$$I_C = \beta I_B + I_{CEO} \quad \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

Concept of ICEO. In CE configuration, a small collector current flows even when the base current is zero [See Figure below (i)]. This is the collector cut off current (i.e. the collector current that flows when base is open) and is denoted by ICEO. The value of ICEO is much larger than ICBO.

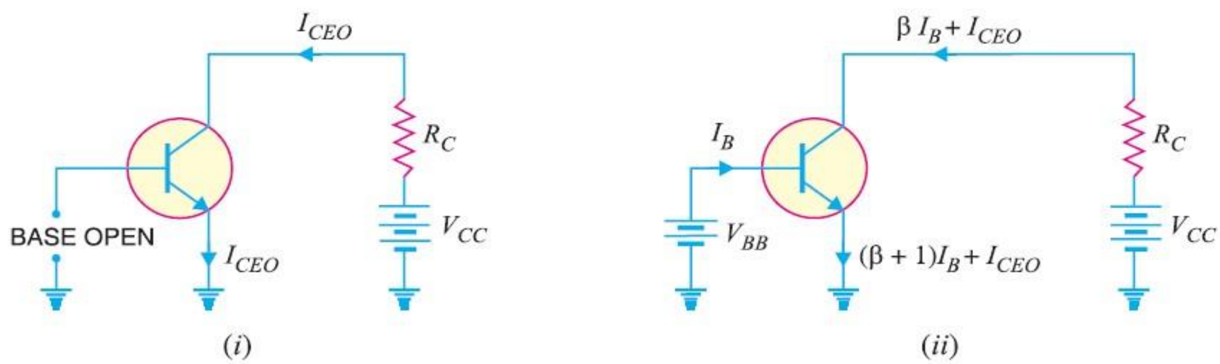


Fig. 8.17

When the base voltage is applied as shown in Fig. 8.17 (*ii*), then the various currents are :

$$\text{Base current} = I_B$$

$$\text{Collector current} = \beta I_B + I_{CEO}$$

$$\text{Emitter current} = \text{Collector current} + \text{Base current}$$

$$= (\beta I_B + I_{CEO}) + I_B = (\beta + 1) I_B + I_{CEO}$$

It may be noted here that :

$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO} = (\beta + 1) I_{CBO} \qquad \left[\because \frac{1}{1-\alpha} = \beta + 1\right]$$

Example 8.8. *Find the value of β if (i) α = 0.9 (ii) α = 0.98 (iii) α = 0.99.*

Solution. (*i*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = \mathbf{9}$$

(*ii*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \mathbf{49}$$

(*iii*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = \mathbf{99}$$

Example 8.9. *Calculate I_E in a transistor for which β = 50 and I_B = 20 μA.*

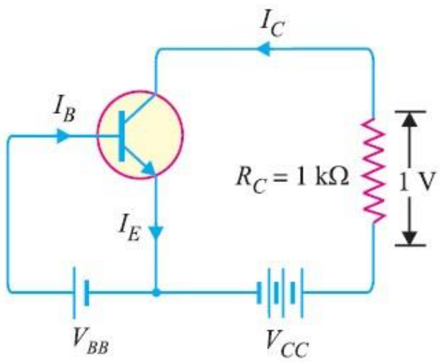
Solution. Here $\beta = 50$, $I_B = 20\mu A = 0.02$ mA

Now
$$\beta = \frac{I_C}{I_B}$$

∴
$$I_C = \beta I_B = 50 \times 0.02 = 1 \text{ mA}$$

Using the relation,
$$I_E = I_B + I_C = 0.02 + 1 = \mathbf{1.02\ mA}$$

Example 8.11. For a transistor, β= 45 and voltage drop across 1kΩ which is connected in the collector circuit is 1 volt. Find the base current for common emitter connection



Solution. Fig. 8.21 shows the required common emitter connection. The voltage drop across R_C (= 1 kΩ) is 1volt.

$$\therefore \quad I_C = \frac{1\,V}{1\,k\Omega} = 1 \text{ mA}$$

$$\text{Now} \quad \beta = \frac{I_C}{I_B}$$

$$\therefore \quad I_B = \frac{I_C}{\beta} = \frac{1}{45} = \mathbf{0.022 \text{ mA}}$$

Common Collector Connection

In this circuit arrangement, input is applied between base and collector while output is taken between the emitter and collector. Here, collector of the transistor is common to both input and output circuits and hence the name common collector connection. Figure below (i) shows common collector npn transistor circuit whereas Figure below(ii) shows common collector pnp circuit.

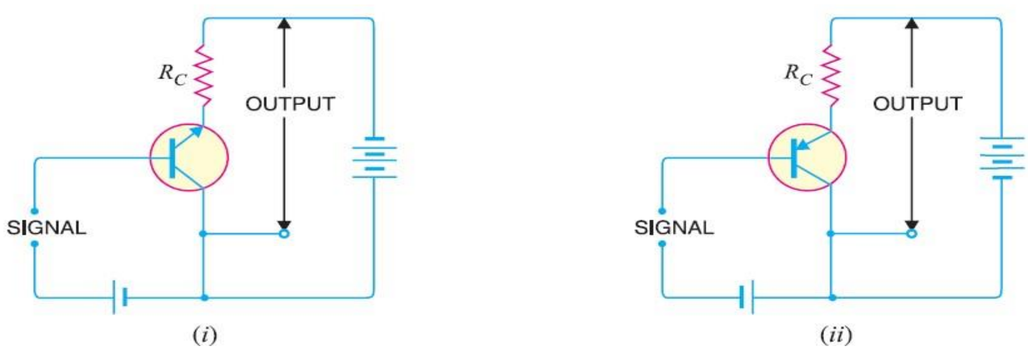


Figure 47: Common collector circuit

(i) Current amplification factor γ. In common collector circuit, input current is the base current I_B and output current is the emitter current I_E. Therefore, current amplification in this circuit arrangement can be defined as under :

The ratio of change in emitter current (ΔI_E) to the change in base current (ΔI_B) is known as **current amplification factor** *in common collector (CC) arrangement i.e.*

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

This circuit provides about the same current gain as the common emitter circuit as $\Delta I_E \simeq \Delta I_C$. However, its voltage gain is always less than 1.

Relation between γ and α

$$\gamma = \frac{\Delta I_E}{\Delta I_B} \quad ...(i)$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad ...(ii)$$

Now $\quad I_E = I_B + I_C$

or $\quad \Delta I_E = \Delta I_B + \Delta I_C$

or $\quad \Delta I_B = \Delta I_E - \Delta I_C$

Substituting the value of ΔI_B in exp. (*i*), we get,

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

Dividing the numerator and denominator of R.H.S. by ΔI_E, we get,

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{1}{1-\alpha} \quad \left(\because \alpha = \frac{\Delta I_C}{\Delta I_E}\right)$$

$\therefore \quad \gamma = \frac{1}{1-\alpha}$

(ii) Expression for collector current

We know $\quad I_C = \alpha I_E + I_{CBO}$ (See Art. 8.8)

Also $\quad I_E = I_B + I_C = I_B + (\alpha I_E + I_{CBO})$

$\therefore \quad I_E(1-\alpha) = I_B + I_{CBO}$

or $\quad I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$

or $\quad I_C \simeq I_E = *(\beta + 1) I_B + (\beta + 1) I_{CBO}$

Comparison of Transistor Connections

The comparison of various characteristics of the three connections is given below in the tabular form.

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

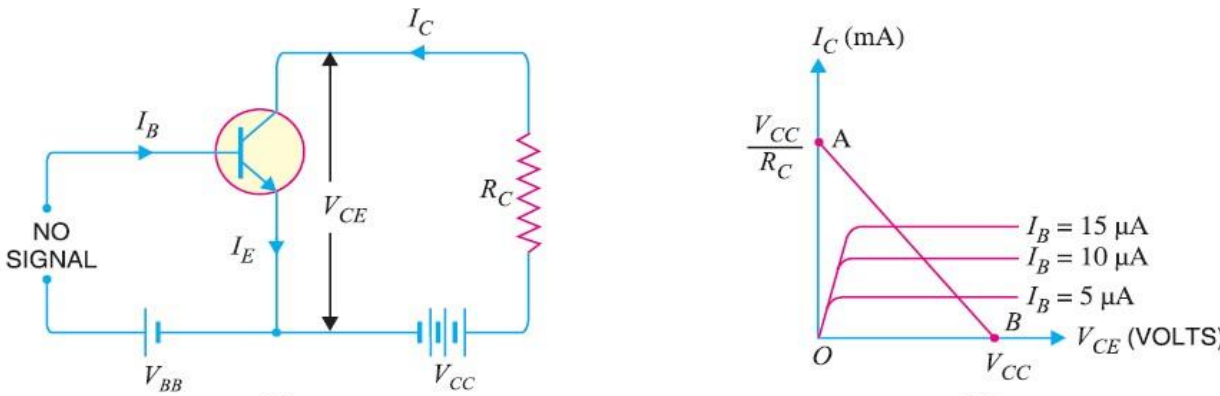
Transistor Load Line Analysis

In the transistor circuit analysis, it is generally required to determine the collector current for various collector-emitter voltages. One of the methods can be used to plot the output characteristics and determine the collector current at any desired collector-emitter voltage. However, a more convenient method, known as load line method can be used to solve such problems. As explained later in this section, this method is quite easy and is frequently used in the analysis of transistor applications.

d.c. load line. Consider a common emitter npn transistor circuit shown in Figure below (i) where no signal is applied. Therefore, d.c. conditions prevail in the circuit. The output characteristics of this circuit are shown in Figure below (ii).

The value of collector-emitter voltage VCE at any time is given

by ; VCE = VCC – IC RC



(*i*) (*ii*)

As V_{CC} and R_C are fixed values, therefore, it is a first degree equation and can be represented by a straight line on the output characteristics. This is known as *d.c. load line* and determines the locus of $V_{CE} - I_C$ points for any given value of R_C. To add load line, we need two end points of the straight line. These two points can be located as under :

(*i*) When the collector current $I_C = 0$, then collector-emitter voltage is maximum and is equal to V_{CC} *i.e.*

$$\text{Max. } V_{CE} = V_{CC} - I_C R_C$$
$$= V_{CC} \qquad (\because I_C = 0)$$

This gives the first point B ($OB = V_{CC}$) on the collector-emitter voltage axis as shown in Fig. 8.35 (*ii*).

(*ii*) When collector-emitter voltage $V_{CE} = 0$, the collector current is maximum and is equal to V_{CC}/R_C *i.e.*

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

or $$0 = V_{CC} - I_C R_C$$

$\therefore$ $$\text{Max. } I_C = V_{CC}/R_C$$

This gives the second point A ($OA = V_{CC}/R_C$) on the collector current axis as shown in Fig. 8.35 (*ii*). By joining these two points, d.c. *load line AB is constructed.

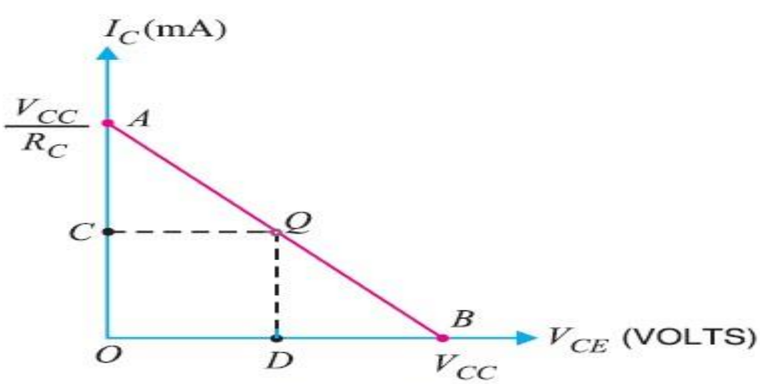


Fig. 8.36

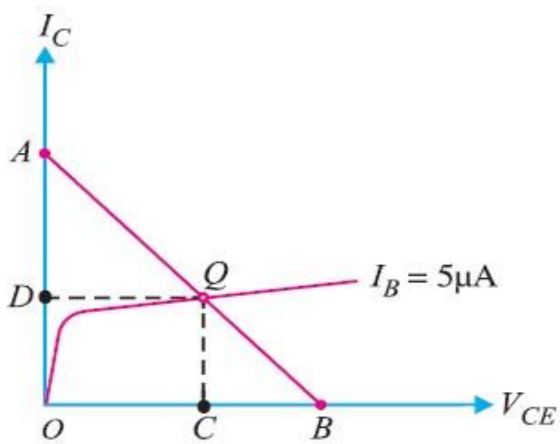
Operating Point

The zero signal values of IC and VCE are known as the operating point. It is called operating point because the variations of IC and VCE take place about this point when signal is applied. It is also called quiescent (silent) point or Q-point because it is the point on IC – VCE characteristic when the transistor is silent i.e. in the absence of the signal.

Suppose in the absence of signal, the base current is 5 μA. Then IC and VCE conditions in the circuit must be represented by some point on IB = 5 μA characteristic. But IC and VCE conditions in the circuit should also be represented by some point on the d.c. load line AB. The point Q where the load line and the characteristic intersect is the only point which satisfies both these conditions. Therefore, the point Q describes the actual state of affairs in the circuit in the zero signal conditions and is called the operating point. Referring to Figure below, for IB = 5 μA, the zero signal values are :

VCE = OC volts

IC = OD mA



It follows, therefore, that the zero signal values of IC and VCE (i.e. operating point) are determined by the point where d.c. load line intersects the proper base current curve.

Example: For the circuit shown in Figure (i), draw the d.c. load line

Solution. The collector-emitter voltage V_{CE} is given by :

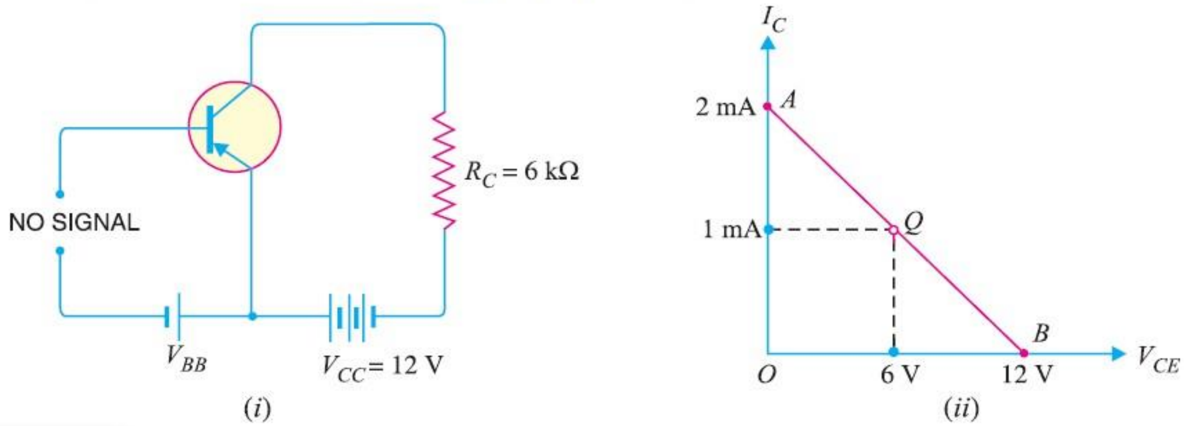
$$V_{CE} = V_{CC} - I_C R_C$$

When $I_C = 0$, $V_{CE} = V_{CC} = 12$ V. This locates the point *B* of the load line. When $V_{CE} = 0$, $I_C = V_{CC}/R_C = 12$ V/6 kΩ = 2 mA. This locates the point *A* of the load line. By joining these two points, load line *AB* is constructed as shown in Fig. 8.39 (*ii*).

Zero signal base current, $I_B = 20\ \mu A = 0.02$ mA

Current amplification factor, $\beta = 50$

$\therefore$ Zero signal collector current, $I_C = \beta I_B = 50 \times 0.02 = 1$ mA



Zero signal collector-emitter voltage is

$$V_{CE} = V_{CC} - I_C R_C = 12 - 1\text{ mA} \times 6\text{ k}\Omega = 6\text{ V}$$

$\therefore$ Operating point is **6 V, 1 mA.**

Solution. The collector-emitter voltage V_{CE} is given by ;

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

When $I_C = 0$, then,

$$V_{CE} = V_{CC} = 12.5\text{ V}$$

This locates the point *B* of the load line on the collector-emitter voltage axis.

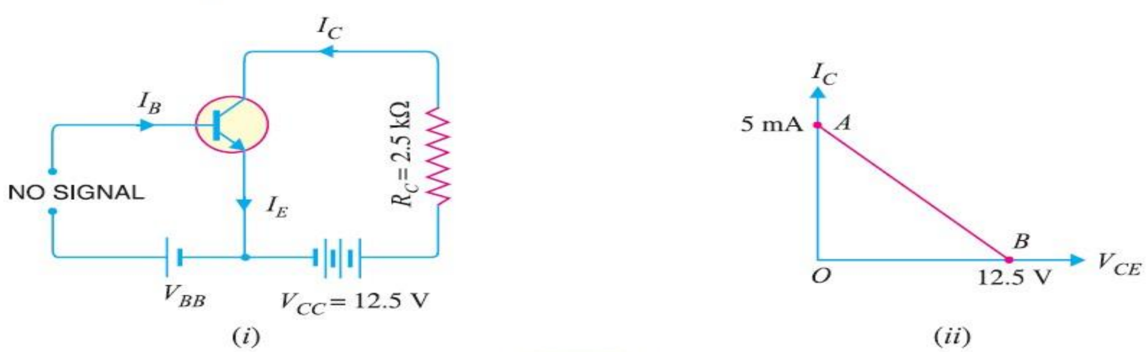


Figure 48: Common collector circuit

Example: In the circuit diagram shown in Fig. 27 (i), if VCC = 12V and RC = 6 k, draw the d.c. load line. What will be the Q point if zero signal base current is 20µA and β= 50?

Example 8.24. *In a transistor circuit, collector load is 4 kΩ whereas quiescent current (zero signal collector current) is 1mA.*

(i) What is the operating point if V_{CC} = 10 V ?

(ii) What will be the operating point if R_C = 5 kΩ ?

Solution. $V_{CC} = 10\text{ V}, I_C = 1\text{ mA}$

(i) When collector load $R_C = 4\text{ k}\Omega$, then,

$$V_{CE} = V_{CC} - I_C R_C = 10 - 1\text{ mA} \times 4\text{ k}\Omega = 10 - 4 = 6\text{ V}$$

∴ Operating point is **6 V, 1 mA**.

(ii) When collector load $R_C = 5\text{ k}\Omega$, then,

$$V_{CE} = V_{CC} - I_C R_C = 10 - 1\text{ mA} \times 5\text{ k}\Omega = 10 - 5 = 5\text{ V}$$

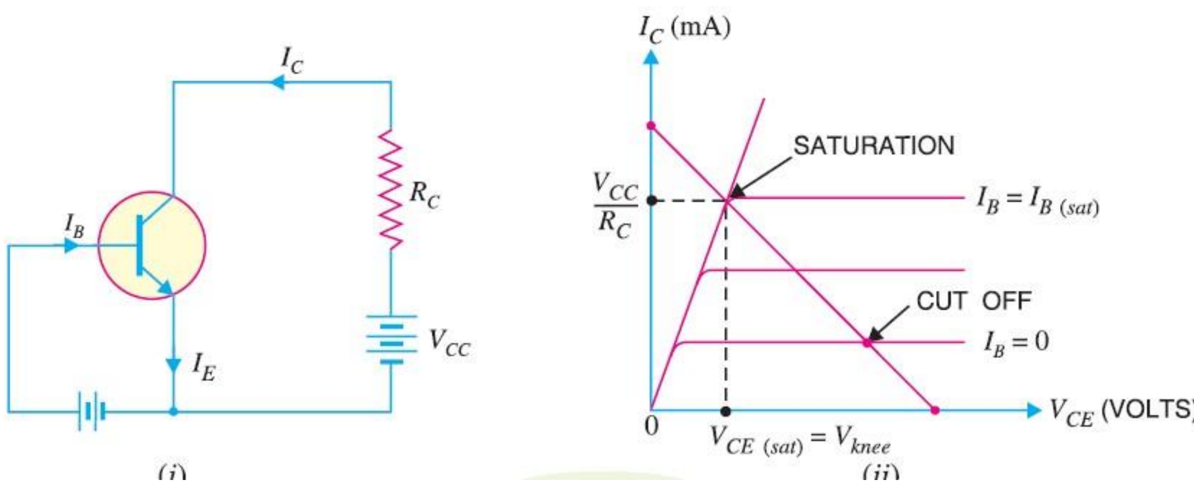
∴ Operating point is **5 V, 1 mA**.

Cut off and Saturation Points

Figure below (i) shows CE transistor circuit while Figure below (ii) shows the output characteristics along with the d.c. load line.

(i) Cut off. The point where the load line intersects the IB = 0 curve is known as cut off. At this point, IB = 0 and only small collector current (i.e. collector leakage current ICEO) exists. At cut off, the base emitter junction no longer remains forward biased and normal transistor action is lost. The collector emitter voltage is nearly equal to VCC i.e.

VCE (cut off) = VCC



(ii) Saturation. The point where the load line intersects the IB = IB(sat) curve is called saturation. At this point, the base current is maximum and so is the collector current. At saturation, collector base junction no longer remains reverse biased and normal transistor action is lost.

$$I_{C(sat)} \simeq \frac{V_{CC}}{R_C}; \quad V_{CE} = V_{CE(sat)} = V_{knee}$$

If base current is greater than IB(sat), then collector current cannot increase because collector-base junction is no longer reverse-biased.

(iii)Active region. The region between cut off and saturation is known as active region. In the active region, collector-base junction remains reverse biased while base-emitter junction remains forward biased. Consequently, the transistor will function normally in this region.

Note. We provide biasing to the transistor to ensure that it operates in the active region. The reader may find the detailed discussion on transistor biasing in the next chapter.

Summary. A transistor has two pn junctions i.e., it is like two diodes. The junction between base and emitter may be called emitter diode. The junction between base and collector may be called collector diode. We have seen above that transistor can act in one of the three states: **cut-off, saturated and active**. The state of a transistor is entirely determined by the states of the emitter diode and collector diode [See Figure below]. The relations between the diode states and the transistor states are:

CUT-OFF: Emitter diode and collector diode are **OFF**.

ACTIVE: Emitter diode is **ON** and collector diode is **OFF.**

SATURATED: Emitter diode and collector diode are **ON.**

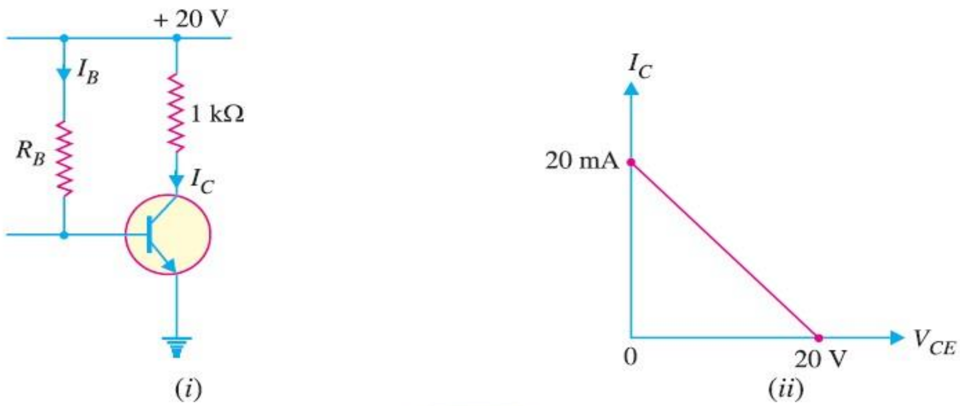
Example: Find IC(sat) and VCE (cut off) for the circuit shown in Figure below (i).

Solution: As we decrease RB, base current and hence collector current increases. The increased collector current causes a greater voltage drop across RC; this decreases the collector-emitter voltage. Eventually at some value of RB, VCE decreases to Knee. At **this**

point, collector-base junction is no longer reverse biased and transistor action is lost. Consequently, further increase in collector current is not possible. The transistor conducts maximum collector current; we say the transistor is saturated.

$$I_{C(sat)} = \frac{V_{CC} - {}^*V_{knee}}{R_C} = \frac{V_{CC}}{R_C} = \frac{20\,V}{1\,k\Omega} = \mathbf{20mA}$$

$$V_{CE(cut\text{-}off)} = V_{CC} = \mathbf{20\ V}$$



Power Rating of Transistor

The maximum power that a transistor can handle without destruction is known as **power rating** *of the transistor.*

When a transistor is in operation, almost all the power is dissipated at the reverse biased *collector-base junction. The power rating (or maximum power dissipation) is given by :

$$P_{D\ (max)} = \text{Collector current} \times \text{Collector-base voltage}$$

$$= I_C \times V_{CB}$$

$$\therefore \quad P_{D\ (max)} = I_C \times V_{CE}$$

$$[\because V_{CE} = V_{CB} + V_{BE}. \text{ Since } V_{BE} \text{ is very small, } V_{CB} \simeq V_{CE}]$$

Indicative content 1.2.5: transistor characteristics

There are the curves which represents relationship between different d.c. currents and voltages of a transistor. The three important characteristics of a transistor are:

1. Input characteristic,

2. Output characteristic,

3. Constant-current transfer characteristic.

Common Base Test Circuit:

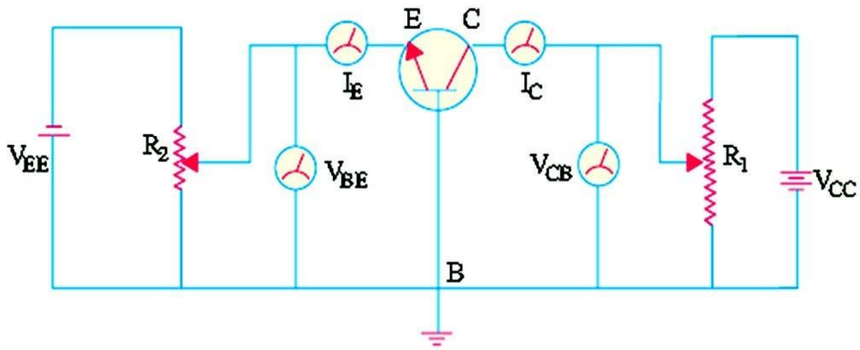


Figure 49: Common Base Test Circuit

Common Base Static Characteristics

(a) Input Characteristic

It shows how I_E varies with V_{BE} when voltage V_{CB} is held constant.

First, voltage V_{CB} is adjusted to a suitable value with the help of R_1 .

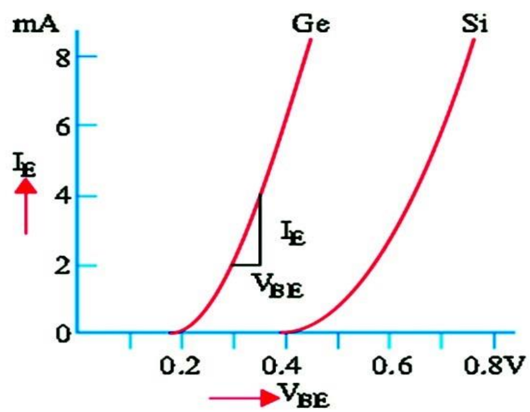
Next, voltage V_{BE} is increased in a number of discrete steps and corresponding values of I_E are noted from the milliammeter.

When plotted, we get the input characteristic shown in Fig. below, one for Ge and the other for Si. Both curves are exactly similar to the forward characteristic of a PN diode.

This characteristic may be used to find the input resistance of the transistor.

$$R_{in} = \Delta V_{BE} / \Delta I_E \quad \text{— } V_{CB} \text{ constant.}$$

This characteristic is hardly affected by changes either in V_{CB} or temperature.



(b) Output Characteristic

It shows the way I_C varies with V_{CB} when I_E is held constant.

First, movable contact, on R_2 is changed to get a suitable value of V_{BE} and hence that of I_E. While keeping I_E constant at this value, V_{CB} is increased from zero in a number of steps and the corresponding collector current I_C that flows is noted. Next, V_{CB} is reduced back to zero, I_E is increased to a value a little higher than before and the whole procedure is repeated. In this way, whole family of curves is obtained.

1. The reciprocal of the near horizontal part of the characteristic gives the output resistance R_{out} of the transistor. R_{out} is very high, a typical value being 500 kΩ.

$$R_{out} = \frac{1}{\Delta I_C / \Delta V_{CB}} = \frac{\Delta V_{CB}}{\Delta I_C}$$

2. It is seen that I_C flows even when $V_{CB} = 0$. For example, it has a value = 1.8 mA corresponding to $V_{CB} = 0$ for $I_E = 2$ mA. It is due to the fact that electrons are being injected into the base under the action of forward-biased E/B junction and are being collected by the collector due to the action of the internal junction voltage at the C/B junction. For reducing I_C to zero, it is essential to neutralize this potential barrier by applying a small forward bias across C/B junction.
3. Another important feature of the characteristic is that a small amount of collector current flows even when emitter current $I_E = 0$. it is collector leakage current I_{CBO}.

4. This characteristic may be used to find α_{ac} of the transistor.

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E} = \frac{DE}{BC}$$

$$= \frac{6.2 - 4.3}{2} = 0.95$$

5. Another point worth noting is that although I_C is practically independent of V_{CB} over the working range of the transistor, yet if V_{CB} is permitted to increase beyond a certain value, I_C eventually increases rapidly due to avalanche breakdown.

Current Transfer Characteristic

It shows how I_C varies with changes in I_E when V_{CB} is held constant. For drawing this characteristic, first V_{CB} is set to a convenient value and then I_E is increased in steps and corresponding values of I_C noted.

$$\boldsymbol{\alpha_{ac} = \Delta I_C / \Delta I_E}$$

Its current gain is less than unity.

(i) Its input and output resistances are so different.

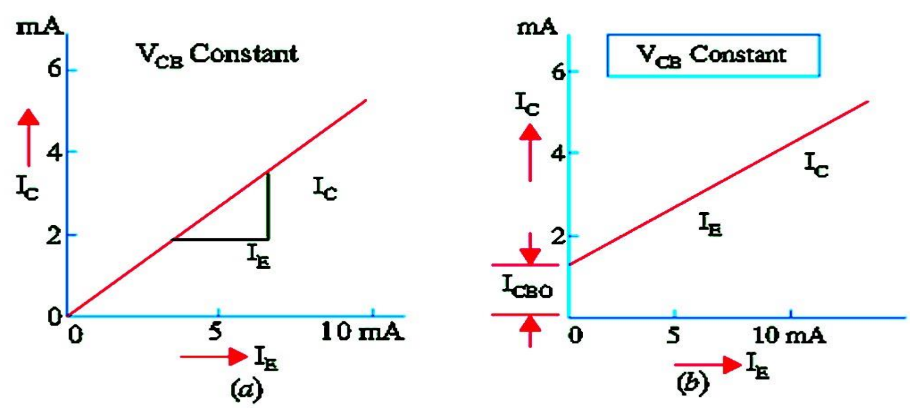


Figure 50: Common Emitter Test Circuit

The static characteristics of an NPN transistor connected in CE configuration may be determined by the use of circuit diagram shown in Fig. below.

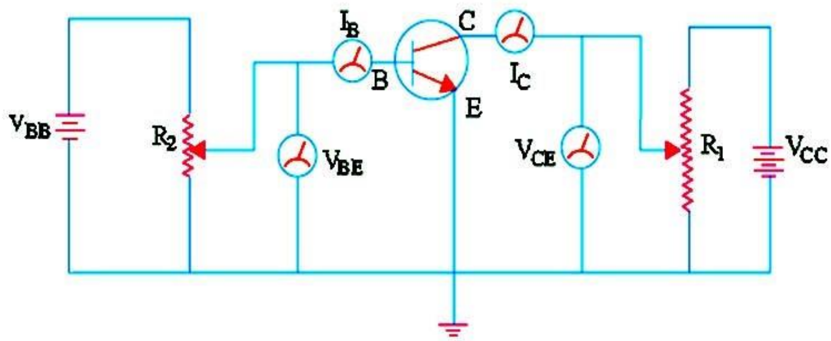


Figure 51: Common Emitter Test Circuit

Common Emitter Static Characteristics

(a) Input Characteristic

It shows how I_B varies with changes in V_{BE} when V_{CE} is held constant at a particular value.

$$R_{in} = \frac{\Delta V_{BE}}{\Delta I_B}$$

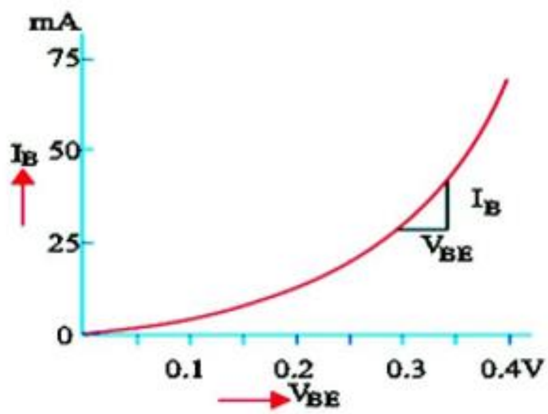


Figure 52: Common emitter input graph

(b) Output or Collector Characteristic

It indicates the way in which I_C varies with changes in V_{CE} when I_B is held constant.

It is seen that as V_{CE} increases from zero, I_C rapidly increases to a near saturation level for a fixed value of I_B. a small amount of collector current flows even when $I_B = 0$. It is called I_{CEO}. Since main collector current is zero, the transistor is said to be cut-off. If V_{CE} is allowed to increase too far, C/B junction completely breaks down and due to this avalanche breakdown, I_C increases rapidly and may cause damage to the transistor.

When V_{CE} has very low value (ideally zero), the transistor is said to be saturated and it operates in the saturation region of the characteristic. Here, change in I_B does not produce a corresponding change in I_C. We can find β_{ac} at a specific value of I_B and V_{CE}.

$\beta_{ac} = \Delta I_C / \Delta I_B$

from two points A and B in the fig. below. **ΔI_B = (60 – 40) = 20 µA**, and we can be finding **ΔI_C.**

R_{out} (= $\Delta V_{CE} / \Delta I_C$) varies from 10 kΩ to 50 kΩ.

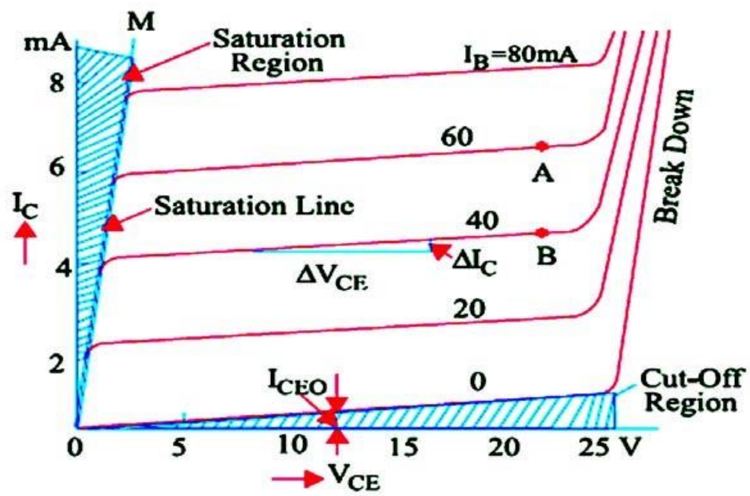


Figure 53: Common emitter output graph

(c) Current Transfer Characteristic

It indicates how I_C varies with changes in I_B when V_{CE} is held constant at a given value. In fig. below (a). The slope gives

$$\beta_{ac} = \Delta I_C / \Delta I_B$$

A small collector current flows even when I_B = 0. It is the common-emitter leakage current I_{CEO} = (1 + β) I_{CO}. I_{CO} it is also due to the flow of minority carriers across the reverse-biased C/B junction.

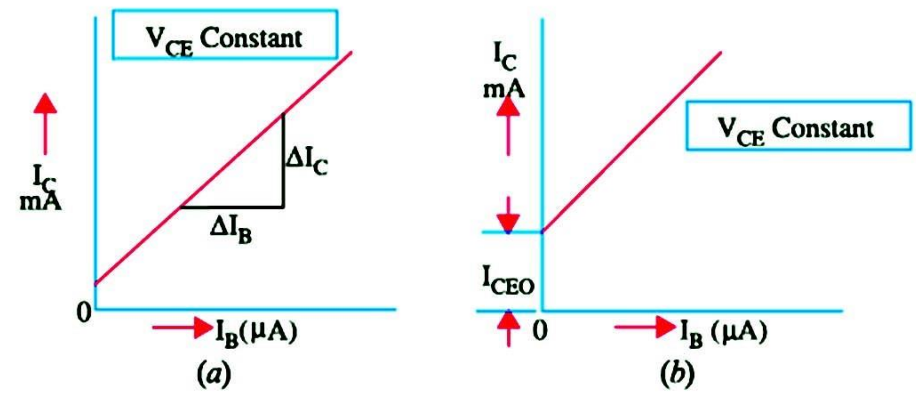


Figure 54: Current Transfer Characteristic circuit

Common Collector Static Characteristics

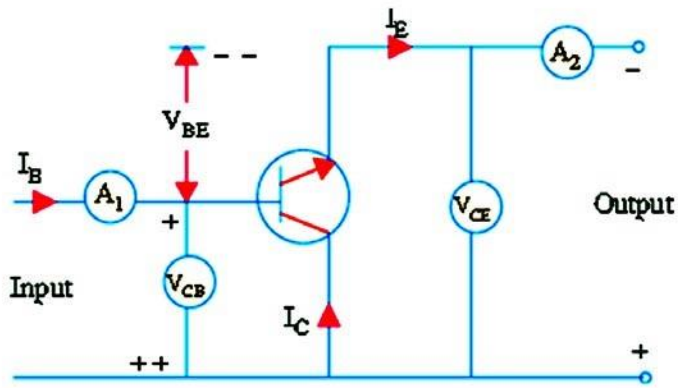


Figure 55: Common Collector Static Characteristics circuit

In this case, collector terminal is common carrier to both the input (CB) and output (CE) carrier's circuits. The output characteristic is I_E versus V_{CE} for several fixed values of I_B. Since $I_C \approx I_E$, as shown in Fig. below (a). The CC input characteristic is a plot of V_{CB} versus I_B for different values of V_{CE} and is shown in fig. below (b).

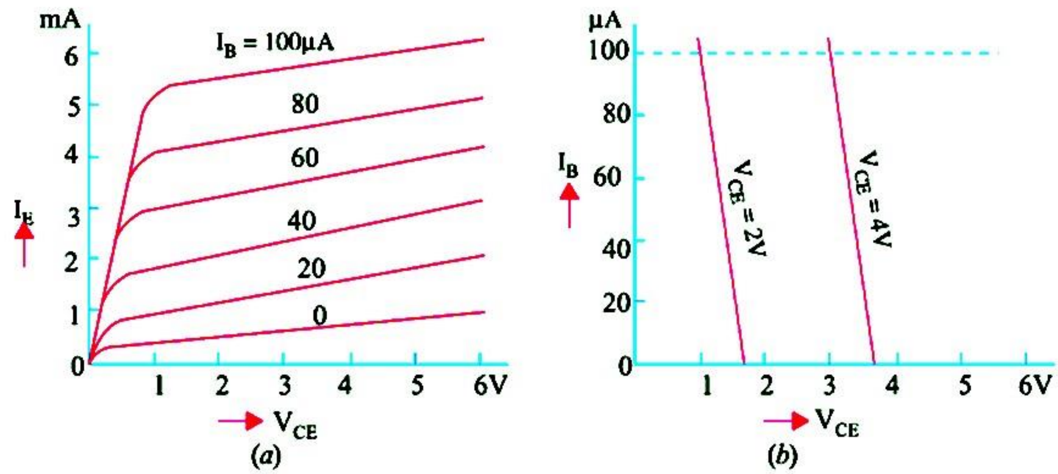


Figure 56: Common Collector Static Characteristics graph

For I_B = 100 µA and V_{CE} = 2 V.

$V_{CB} = V_{CE} - V_{BE} = 2 - 0.7 = 1.3$ V — for Si material

Moreover, as V_{CB} is increased, V_{BE} is reduced there by reducing I_B. Now, consider the values V_{CE} = 4 V and I_B = 100 µA

$V_{CB} = 4 - 0.7 = 3.3$ V

Again, as V_{CB} increases, I_B is decreased.

Common Base Formulas

Consider the circuit MEBM. In fig. below, Applying Kirchhoff's voltage law and starting from point B (or ground) upwards, we get

(a) $-V_{BE} - I_E R_E + V_{EE}^{*} = 0$ or $I_E = \frac{V_{EE} - V_{BE}}{R_E}$

where V_{BE} = 0.3 V (for *Ge*) and 0.7 V (for *Si*)

$_{EE}$ » V_{BE}, we can simplify the above to $I_E \cong V_{EE}/R_E$ = 10V/20 K

Since, generally, V

= 0.5 mA

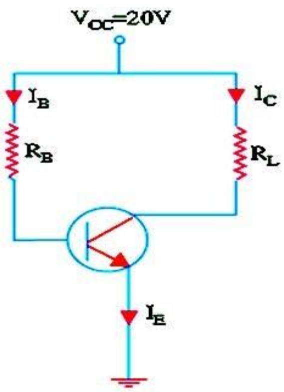
Taking V_{BE} into account and assuming silicon transistor

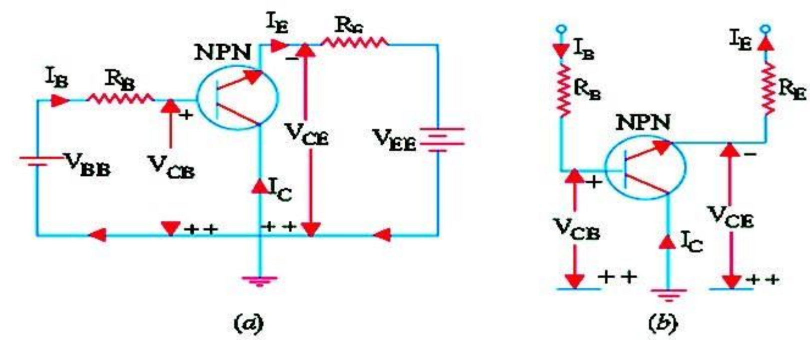
I_E = (10 – 0.7) V/20 K = 0.465 mA

(b) $I_C = \alpha I_E \cong I_E = 0.5$ mA neglecting leakage current.

(c) From circuit *NCBN*, we get

$V_{CB} = V_{CC} - I_C \cong V_{CC} - I_E R_L = 25 - 0.5 \times 10 = 20$ V $(\therefore I_C \cong I_E)$





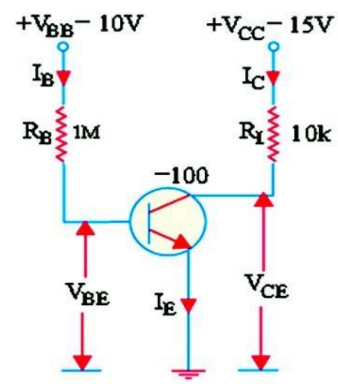
Common Emitter Formula

Consider the CE circuit of Fig. below. Taking the emitter-base circuit, we have

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \cong \frac{V_{BB}}{R_B}$$

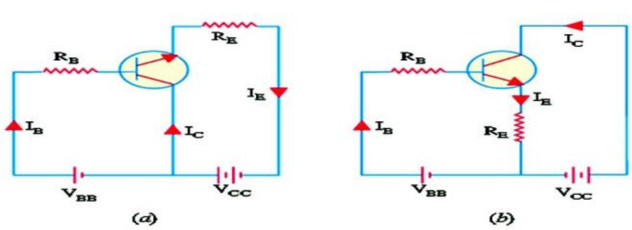
$$I_C = \beta I_B \quad \text{— neglecting leakage current } I_{CEO}$$

$$V_{CE} = V_{CC} - I_C R_L$$



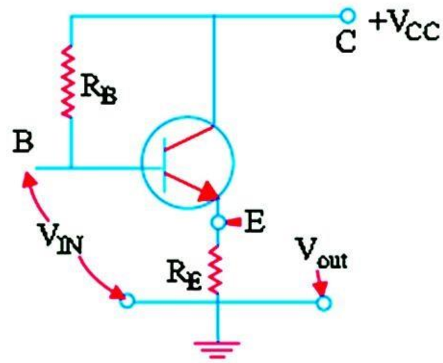
Common Collector Formulas

The CC circuit with its proper d.c. biasing voltage sources is shown in Fig. below (a). The two circuits given represent the same thing.



Another way of drawing the same circuit is shown in Fig. below (a) where only one battery has been used. It should be noted that load resistor is not in the collector lead but in the emitter lead as shown.

The fig. below makes the circuit connection quite clear. Input is between base and collector terminals whereas output is between emitter and collector terminals. It is seen that



$$I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B / \beta};$$

$$V_{CC} = V_{CE} + I_E R_E;$$

$$I_E = \frac{V_{CC} - V_{BE}}{R_E + \beta R_E} \; ; I_C = \beta I_B$$

Indicative content 1.2.6: FET (JFET, MOSFET)

JFET or Junction Field Effect Transistor is one of the simplest types of field-effect transistor. Contrary to the Bipolar Junction Transistor, JFETs are voltage-controlled devices. In JFET, the current flow is due to the majority of charge carriers. However, in BJTs, the current flow is due to both minority and majority charge carriers. Since only the majority of charge carriers are responsible for the current flow, JFETs are unidirectional.

JFET Construction

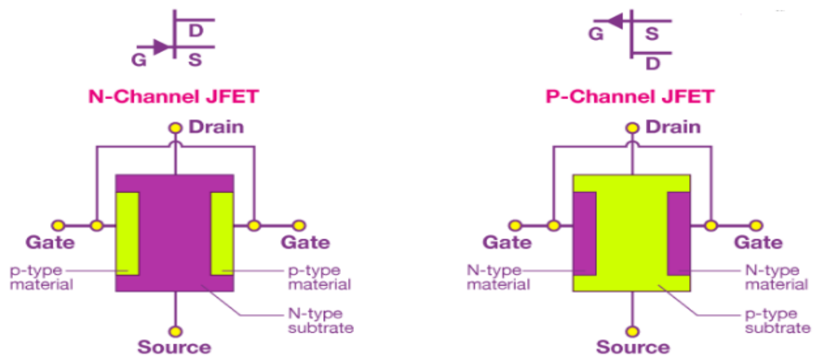


Figure 57: N and P channel of JFET internal construction

In an N-channel JFET, the material is of P-type, and the substrate is N-type, while in a P channel JFET the material is of N-type, and the substrate used is p-type. JFET is made of a long channel of semiconductor material. Ohmic contacts are provided at each end of the semiconductor channels to form source and drain connections. A P-type JFET contains many positive charges, and if the JFET contains a large number of electrons, it is called an N-type JFET.

JFET Characteristics

The curves plotted in between the current value at the drain and the voltage applied in between drain and the source by considering the voltage at the gate and the source as the parameter decides the characteristics of output that are also referred to as the **drain characteristics**.

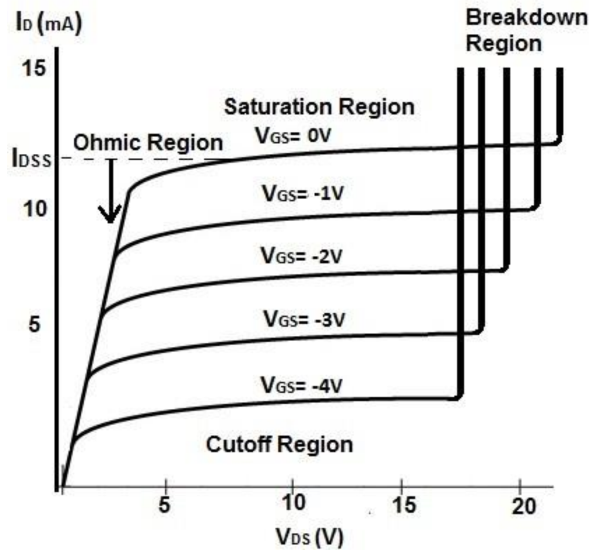


Figure 58: N-Channel JFET Characteristics

Drain Characteristics of Junction Field Effect Transistor(JFET)

The drain characteristics of the JFET are

1. When the positive voltage is applied to the drain to source terminal of JFET and when the gate to source voltage is zero, the Drain current starts flowing and the device is said to be in **ohmic region**.
2. As the drain voltage is increased the channel of conductance tends to become narrower and narrower and current at the drain terminal gets smaller.
3. At a particular drain to source voltage called the **pinch-off voltage** the drain current reaches the saturation level.
4. Now if a negative voltage is applied to the gate terminal then, in that case, the channel present at the gate is reverse biased and the saturation current starts decreasing further. At a particular gate voltage, the device stops conduction this is called the **cut-off-voltage**.
5. But if the drain to source voltage is increased further then the device reaches the breakdown region in which the drain current increases indefinitely.

Junction Field Effect Transistor Applications

Some applications of JFET are listed below:

- JFET is used as a switch
- JFET is used as a chopper
- JFET is used as a buffer
- JFETs are used in oscillatory circuits
- JFETs are used in cascade amplifiers

JFET Advantages

Some advantages of JFET are listed below:

- JFET has a high impedance
- JFETs are low power consumption devices
- JFET can be fabricated in a smaller size, and as a result, they occupy less space in circuits due to their smaller size.

JFET Disadvantages

Some disadvantages of JFETs are as follows:

- It has a low gain-bandwidth product
- The performance of JFET is affected as frequency increases due to feedback by internal capacitance.

Construction of MOSFET:

The metallic gate terminal in the MOSFET is insulated from the semiconductor layer by a SiO_2 layer or dielectric layer. The MOSFET consists of three terminals, they are source(S), Gate (G), Drain (D) and the body which is called as substrate. The substrate is connected to the source internally.

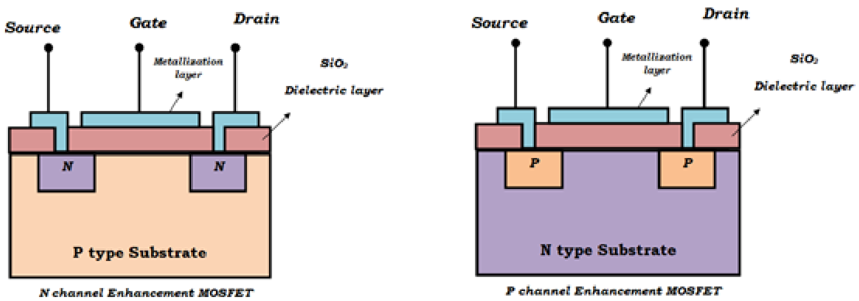


Figure 59: Construction of N channel and P Channel Enhancement MOSFET

In N Channel Enhancement MOSFET the source and drain are of N type semiconductor which is heavily doped and the Substrate is of P type semiconductor. Majority charge carriers are electrons. The source and drain terminals are physically separated in Enhancement mode.

In P Channel Enhancement MOSFET the source and drain are of P type semiconductor which is heavily doped and the Substrate is of N type semiconductor. Majority charge carriers are holes.

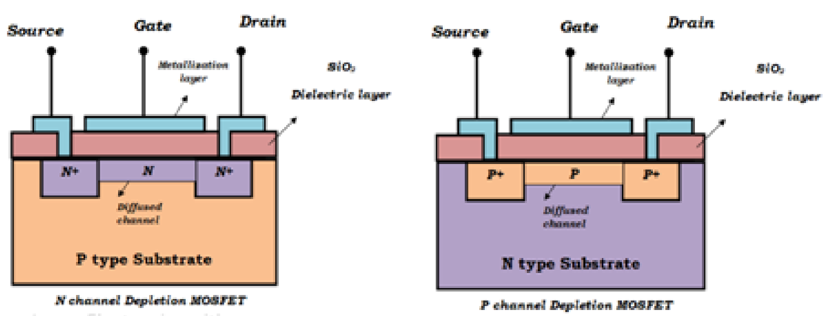


Figure 60: Construction of N channel and P Channel Depletion MOSFET

V-I Characteristics of MOSFET

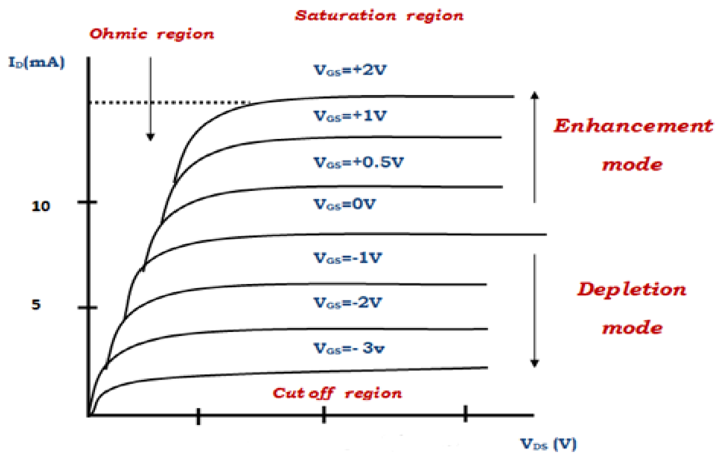


Figure 61: V-I Characteristics of MOSFET

Cut off region:

No current flows through it and the MOSFET is off.

Ohmic region:

Drain current increases when the drain source voltage increases. Used as amplifier in this region.

Saturation region:

Drain current is constant for drain source voltage. Used as switch in this region. This occurs when the drain source voltage reaches pinch off voltage.

Depletion mode:

The MOSFET is ON by default. When negative voltage is applied to the gate terminal it operates in the depletion mode and when positive voltage is applied, it operates in the enhancement mode.

Enhancement mode:

When positive voltage is applied to the gate terminal, it starts conducting and the current starts to flow.

Advantages of MOSFET

- Ability to scale down in size
- It has low power consumption to allow more components per chip surface area
- They have high drain resistance due to lower resistance of a channel
- Physical size is less than 4 mm^2 when it is a package form
- It is widely used than JFET
- The enhancement type MOSFET find wide application in digital circuitry
- They support high speed operation compare to JFETs
- They have high input impedance compare to JFET
- It is easier to fabricate MOSFET than JFET
- They can easy to manufacture

Disadvantages of MOSFET:

- Has a short life
- Required repeated calibration for accurate dose measurement
- They have very susceptible to overload voltage, hence due to installation special handling is to be required

Indicative content 1.2.7: phototransistor

A **phototransistor** is nothing but an ordinary bi-polar transistor in which the base region is exposed to illumination. It is available in both the P-N-P and N-P-N types having different configurations like common emitter, common collector, and common base but generally, common emitter configuration is used. It can also work while the base is made open. Compared to the conventional transistor it has more base and collector areas.

The figure below represents the constructional structure of an NPN Phototransistor

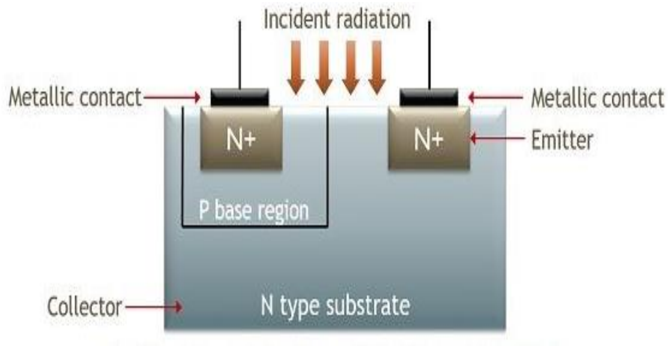


Figure 62: Structure of phototransistor

Working of Phototransistor

The operation of a phototransistor depends on the intensity of radiation falling at its base region. Its working is almost similar to a normal transistor, however; the variation lies in the input current that drives the circuit. And in the case of a phototransistor, the incident light generates driving current. The figure below represents the biasing arrangement of a phototransistor

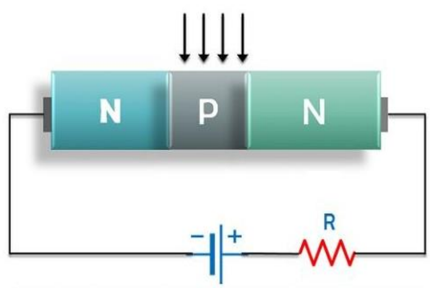


Figure 63: Structure of phototransistor

Characteristics Curve of Phototransistor

The figure below represents the characteristics curve of phototransistor

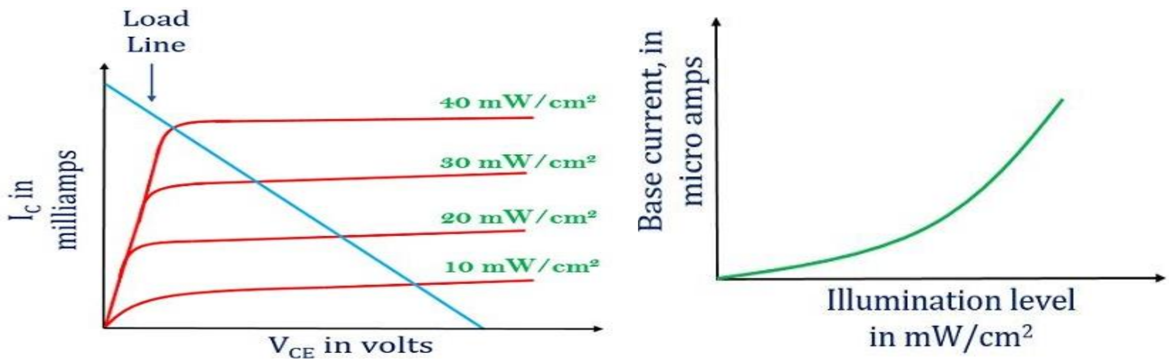


Figure 64: Characteristics of phototransistor curve

Advantages of Phototransistor

1. These are a highly sensitive optoelectronic device.
2. It is less complex and inexpensive.
3. Phototransistors provides a large output current with high gain.

Disadvantages of Phototransistor

1. It provides a low-frequency response.
2. In the case when a small amount of illumination is provided, the circuit is not able to detect it effectively.
3. Electric surges are more severe in phototransistors rather than a photodiode.
4. Phototransistors gets affected by the variation in electromagnetic energy.

Theoretical learning Activity

- ✓ Brainstorming on electronics devices characteristic
- ✓ Group discussion on electronic devices characteristic
- ✓ Practical exercise on electronic devices V-I characteristic
- ✓ Documentary research

Practical learning Activity

- ✓ Identification of resistor
- ✓ Identification of inductor
- ✓ Identification of capacitor
- ✓ Identification of conductors
- ✓ Identification of insulators
- ✓ Identification of semiconductors
- ✓ Structure and features of diode
- ✓ Description of diode characteristics
- ✓ Structure and features of transistor
- ✓ Description of transistor characteristics

Points to Remember (Take home message)

- ✓ The phenomenon in which an emf is induced in a coil due to the change of current through the coil itself is known as self-induction
- ✓ The operation of a phototransistor depends on the intensity of radiation falling at its base region
- ✓ The two operating regions in the P-N junction diode are P type and N types.
- ✓ The area in the region of the junction becomes depleted of holes and electrons due to electron-hole recombination

Learning outcome 1.2: formative assessment

Q1. Zener diode in forward bias, it behaves like **(a)** ………………..and I reverse bias behaves like **(b)**…………………….

Answer

a) **ordinary diode**
b) **regulator**

Q2. Answer YES /NO

Light emitting diode emits light once is connected in reverse bias **NO**

Q3. Reply by **true /false**

Capacitor is an electronic component that stores energy in form of magnetic field **NO**

References

[1] https://www.watelectronics.com/junction-field-effect-transistor-working-characteristics-applications/

[2] https://www.elprocus.com/phototransistor-basics-circuit-diagram-advantages-applications/

[3] https://tutorialslink.com/library/Getting-Started-with-Basic-Electronics/V-I-Characteristics-of-JFET/23/422

Learning outcome 1.3 Identify electronic devices applications

Duration: **6** hrs

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify application of diode
2. Identify application of transistor
3. Explain Zener Diode as Voltage Regulator

Resources

Equipment	Tools	Materials
-Books	**-Internet**	**Resistor** **- Inductor** **- Capacitor** **- Transistor** **- Diode**

Advance preparation:

- A trainer should revise all connection types of diode
- A trainer should have many examples of where transistor used as an application

Indicative content 1.3.1: Use of diodes

Rectifier circuits

Rectifier circuits play a vital role in the DC power supplies for converting the AC signal into a DC signal. The process of converting an AC (sinusoidal) signal into a DC signal is called Rectification.

The following two rectifier circuits can be used:

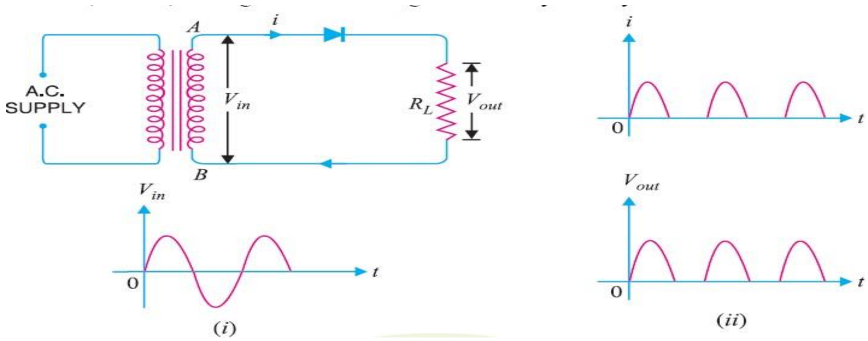
(i) Half-wave rectifier

(ii) Full-wave rectifier

Half-Wave Rectifier

In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input

a.c. supply. The negative half-cycles of a.c. supply are suppressed i.e. during negative half-cycles, no current is conducted and hence no voltage appears across the load.



Operation. The a.c. voltage across the secondary winding AB changes polarities after every half-cycle.

During the positive half-cycle of input a.c. voltage, end A becomes positive w.r.t. end B.

<u>Disadvantages</u>:

The main disadvantages of a half-wave rectifier are :

(i) The pulsating current in the load contains alternating component whose basic frequency is equal to the supply frequency. Therefore, an elaborate filtering is required to produce steady direct current.

(ii) The a.c. supply delivers power only half the time. Therefore, the output is low.

Full-Wave Rectifier

In full-wave rectification, current flows through the load in the same direction for both half-cycles of input a.c. voltage.

(i) Centre-tap full-wave rectifier

(ii) Full-wave bridge rectifier

Centre-Tap Full-Wave Rectifier

During the positive half-cycle of secondary voltage, the end A of the secondary winding becomes positive and end B negative. This makes the diode D1 forward biased and diode D2 reverse biased. Therefore, diode D1 conducts while diode D2 does not. The conventional current flow is through diode D1, load resistor RL and the upper half of secondary winding as shown by the dotted arrows. During the negative half-cycle, end A of the secondary winding becomes negative and end B positive. Therefore, diode D2 conducts while diode D1 does not. The conventional current flow is through diode D2, load RL and lower half winding as shown by solid arrows.

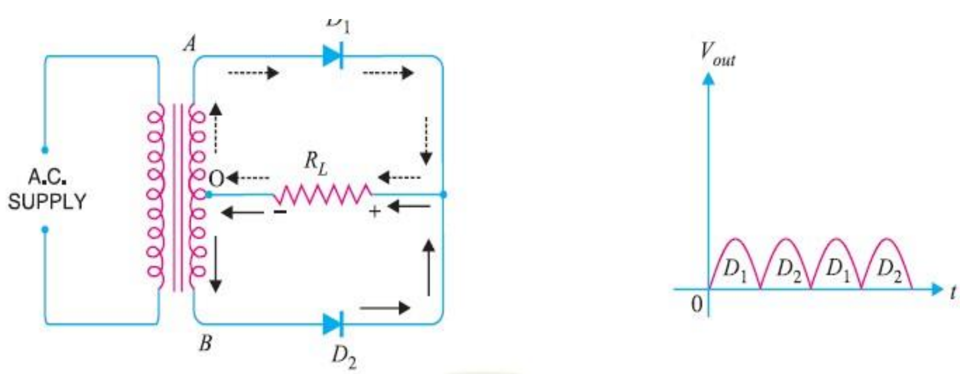


Figure 65: Centre tape full wave rectifier circuit

Disadvantages

(i) It is difficult to locate the centre tap on the secondary winding.

(ii) The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.

(iii) The diodes used must have high peak inverse voltage.

Full-Wave Bridge Rectifier

It contains four diodes D1, D2, D3 and D4 connected to form bridge as shown in Figure below the a.c. supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between other two ends of the bridge, the load resistance RL is connected.

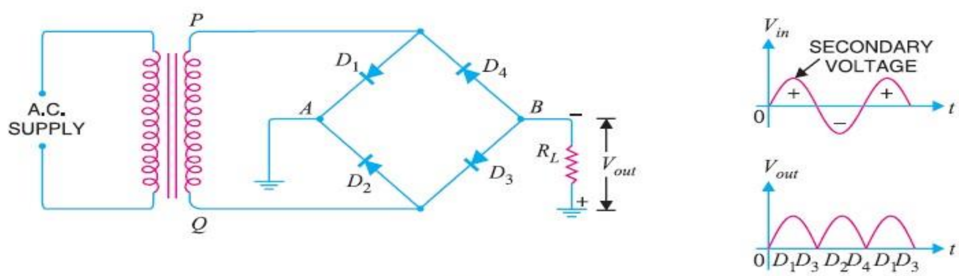


Figure 66: Bridge rectifier circuit

Operation

During the positive half-cycle of secondary voltage, the end P of the secondary winding becomes positive and end Q negative. This makes diodes D1 and D3 forward biased while diodes D2 and D4 are reverse biased.

Stabilization and regulation

Stabilization is the process of making something physically more secure or stable.

Zener Diode as Voltage Stabiliser

A zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range and **Zener Diodes** can be used to produce a stabilised voltage output with low ripple under varying load current conditions. By passing a small current through the diode from a voltage source, via a suitable current limiting resistor (R_S), the zener diode will conduct sufficient current to maintain a voltage drop of Vout.

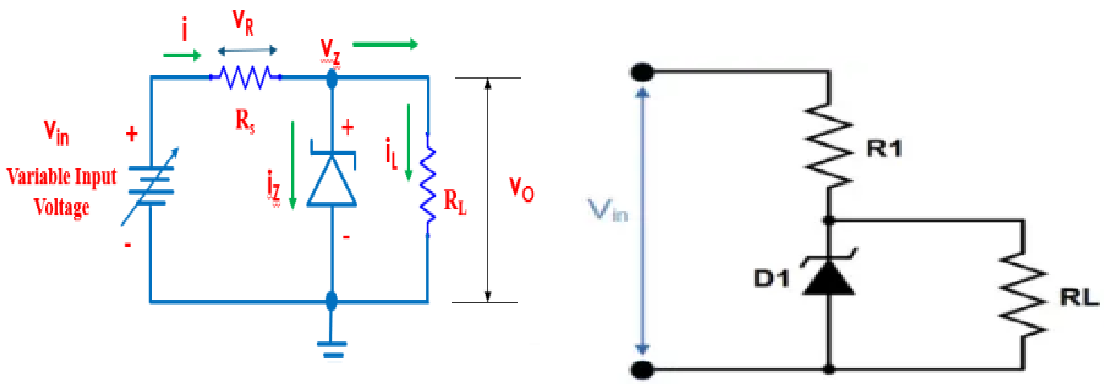


Figure 67: Zener diode circuit

Zener diode calculation

Power Rating=$VZImax$

Current of the circuit

$$\boldsymbol{Imax} = \frac{\boldsymbol{Vz}}{\boldsymbol{Pmax}}$$

Minimum Resistance Value

$$R_{min} = \frac{V_{in} - V_Z}{I_{max}} \qquad I_R = I_Z + I_L$$

Zener diode I-V characteristics curve

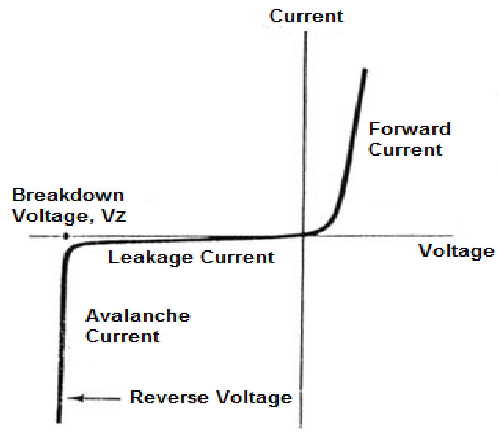


Figure 68: Zener diode I-V characteristics curve

You can see in the above curve the how steady and constant the voltage across the zener diode is after it reaches the breakdown voltage, despite large changes in current.

This makes the zener diode very useful in circuits where steady voltages need to be supplied.

Limiting, protection circuit

The diode protection circuit shown in Figure below is designed to protect the input of a circuit from voltages higher than the Vdd voltage rail (in this example the rail is considered 3.3V), and lower than ground. Circuits like this are commonly used in digital systems that are sensitive to over voltages, where they need the input voltage of a circuit to be kept within a specific range.

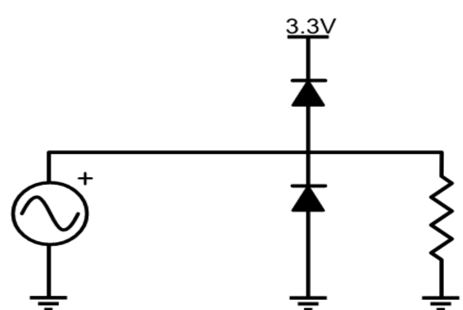


Figure 69: Diode circuit protection

Indicative content 1.3.2: Use of transistor

BJT AS Switch

Figure below illustrates the basic operation of a transistor as a switching device.

In part (a), the transistor is in the cut off region because the base-emitter junction is not forward-biased.

In part (b), the transistor is in the saturation region because the base emitter junction and the base-collector junction are forward-biased, and the base current is made large enough to cause the collector current to reach its saturated value.

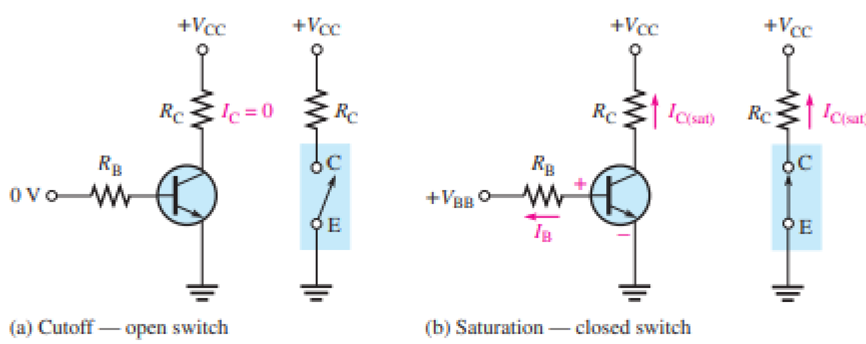


Figure 70: Bjt as a switch circuit

Conditions in Cut-off as mentioned before, a transistor is in cut off when the base emitter junction is not forward-biased. Neglecting leakage current, all of the currents are approximately zero, and VCE is approximately equal to VCC

$$V_{CE(cutoff)} \cong V_{CC}$$

Conditions in Saturation When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. Since VCE(sat) is very small compared to VCC, it can usually be neglected, so the collector current is

$$I_{C(sat)} \cong \frac{V_{CC}}{R_C}$$

The minimum value of base current needed to produce saturation is

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

BJT as an amplifier

The circuit in Figure below produces an output signal with the same waveform as the input signal but with a greater amplitude. This increase is called amplification. The collector voltage is the output signal, as indicated. The input signal voltage causes the base current to vary at the same frequency above and below its dc value. The ratio of the ac collector current (Ic) to the ac base current (Ib) is designated ac (the ac beta) or hfe

$$\beta_{ac} = \frac{I_c}{I_b}$$

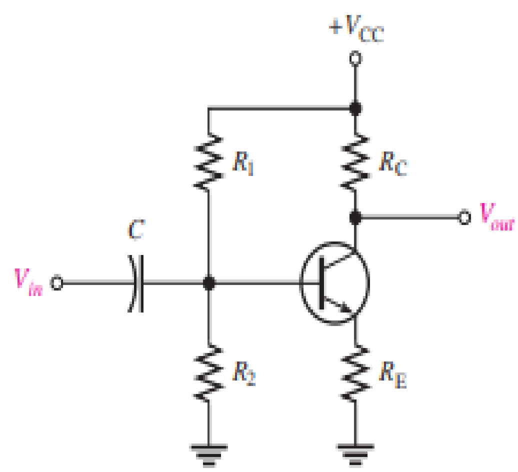
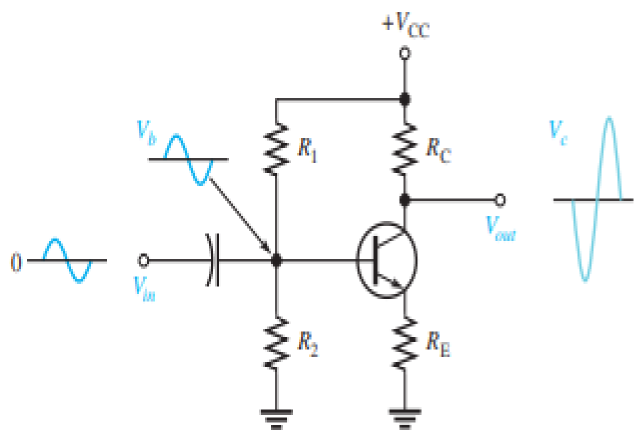


Figure 71: Bjt as amplifier circuit

An amplifier with voltage-divider bias with capacitive coupled input signal. Vin and Vout are with respect to ground.

The value of ac differs only slightly from that of DC for a given transistor and data sheets do not always show this parameter. Remember that lowercase subscripts distinguish ac currents and voltages from dc currents and voltages. Signal Voltage Gain of an Amplifier Now let's take the amplifier in Figure above and examine its voltage gain with a signal input. The output voltage is the collector voltage. The variation in collector current produces a variation in the voltage across RC and a resulting variation in the collector voltage, as shown in Figure below.



As the collector current increases, the **IcRC** drop increases. The increase produces a decrease in collector voltage because Vc =VCC- IcRC. Likewise, as the collector current decreases, the IcRC drop decreases and produces an increase in collector voltage. Therefore, there is a 180° phase difference between the collector current and the collector voltage.

Theoretical learning Activity

- ✓ Brainstorming on application of rectifiers circuit
- ✓ Group discussion on electronics devices
- ✓ Practical exercise on electronic circuit
- ✓ Documentary research

Practical learning Activity

- ✓ Identification of application of diode
- ✓ Identification of application of transistor

Points to Remember (Take home message)

- ❖ **Two types of rectifier circuits**

(i) Half-wave rectifier

(ii) Full-wave rectifier

- ❖ **Two circuits are commonly used for full-wave rectification**

(iii) Centre-tap full-wave rectifier

(iv) Full-wave bridge rectifier

Learning outcome 1.3: formative assessment

Q1**. Fill the following sentence the missing wards**

During the cut off zone, the transistor is **(a)**………….. and during the saturation period, it is **(b)**………...

Answer

- **(a) OFF**
- **(b) ON**

Q2. BJT how many junction does it contain?

Answer: two junction

Q3. when Zener diode is connected in reverse bias, it behaves like **(a)**………...

And when it is connected in forward bias, it behaves like **(b)**………………

Answer: (a)voltage regulator (b)PN junction

References

[1]http://www.learningaboutelectronics.com/Articles/What-is-the-zener-voltage-VZ-of-a-zener-diode

[2] https://byjusexamprep.com/rectifier-circuit-i

[3] Electronic devices and circuits by Theodore F. Bogard

Learning Unit: 2: Implement different types of electronic circuits

STRUCTURE OF LEARNING UNIT

Learning outcomes:

2.1 Identify electronic circuit

2.2 Identify integrated circuits

2.3 Implement electronic circuits

Learning outcome 2.1 Identify electronic circuit

Duration: 7 hours

Learning outcome 1 objectives :

By the end of the learning outcome, the trainees will be able to:

- ✓ Identify electronic circuit
- ✓ Identify integrated circuits
- ✓ Implement electronic circuits

Resources

Equipment	Tools	Materials
-Books -disordering pump Digital Multimeter Oscilloscope	- Internet -screw driver -plier -soldering iron	- Manual - Hand-out note -electronic components - cleaning materials -cleaning solution

Advance preparation:

. trainer should read all kind of inverters

. trainer should test one sample of inverter before starting to teach this content

.trainer should make disassemble of one example inverter before teaching

Indicative content 2 .1.1: Rectifier

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

AC to DC Converter Circuit

A **step-down transformer** is used to convert the high voltage AC to the low voltage AC. The transformer is PCB mounted and it is a 1-ampere 13-volt transformer. However, during the load, the transformer voltage drops approximately 12.5-12.7 volt.

Elements of rectifier

Transformer, pn Junction diode, filtering component and load for using out put voltage

DC TO AC

What is DC to AC Converter?

DC to AC converters is mainly designed for changing a DC power supply to an AC power supply. Here, DC power supply is comparatively stable as well as positive voltage source whereas AC oscillates approximately a 0V base stage, typically in a sinusoidal or square or mode.

How to Make a DC to AC Converter?

The DC to AC Converter Circuit using Transistors is shown below. The basic function of an inverter circuit is to generate oscillations with the specified DC & apply these to the transformer's primary winding by increasing the current. This main voltage is then step up to a high voltage based on the number of twists within main and minor coils.

DC to AC Converter Circuit using Transistors

The inverter executed in this circuit can be a square wave, & it works with devices like which do not need pure AC sine wave.

The required components to build DC to AC circuit mainly includes 12v Battery, 2N2222 Transistors, two MOSFET IRF 630, 2.2uf capacitors-2, two Resistors-12k, two 680 ohm resistors, and center tapped transformer (step up).

Circuit Working

AC TO AC

Phase controlled Cycloconverters

By using this type of Cycloconverters, we can change the magnitude of the output voltage in addition to the frequency of the output. Both can be varied by varying the firing angle of the converter.

AC to AC converters with a DC link is classified into two types:

- ✓ Current Source Inverter Converter
- ✓ Voltage Source Inverter Converter

In this type of inverter, one or two series inductors are used between one or both limbs of the connection between the rectifier and inverter. The rectifier used here is a phase-controlled switching device like Thyristors Bridge.

AC- AC circuit Thyristors circuit

Current Source Inverter Converter

Voltage Source Inverter Converter

In this type of converter, the DC link consists of a shunt capacitor and the rectifier consists of a diode bridge. The diode bridges are preferred for the low load as the AC line distortion and low power factor caused by the Diode Bridge are lesser than the Thyristors Bridge.

Indicative content 2.1.2: Voltage regulator

How does a voltage regulator work?

A voltage regulator is a circuit that creates and maintains a fixed output voltage, irrespective of changes to the input voltage or load conditions.

Voltage regulators (VRs) keep the voltages from a power supply within a range that is compatible with the other electrical components. While voltage regulators are most commonly used for DC/DC power conversion, some can perform AC/AC or AC/DC power conversion as well

The oscillator inverting signals are improved with the two Power MOSFETs such as T1 & T4, and these signals will give to the step-up transformer by its center tap associated with 12V DC.

What are the Basic Parameters for a Voltage Regulator IC?

Some of the basic parameters to consider when using a voltage regulator are the input voltage, output voltage, and output current. These parameters are used to determine which VR topology is compatible with a user's IC.

Indicative content 2.1.3: Filter

What Is a Filter?

A filter is a circuit capable of passing (or amplifying) certain frequencies while attenuating other frequencies. Thus, a filter can extract important frequencies from signals that also contain undesirable or irrelevant frequencies.

Indicative contentn2.1.4: Inverter

An inverter converts the DC voltage to an AC voltage. In most cases, the input DC voltage is usually lower while the output AC is equal to the grid supply voltage of either 120 volts, or 240 Volts depending on the country.

The inverter may be built as standalone equipment for applications such as solar power, or to work as a backup power supply from batteries which are charged separately.

Indicative content 2.1.5: Integrated circuit

An integrated circuit or monolithic integrated circuit (also referred to as an IC, a chip, or a microchip) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material, usually silicon

Below is the classification of different types of ICs basis on their chip size.

- SSI: Small scale integration. 3 – 30 gates per chip.
- MSI: Medium scale integration. 30 – 300 gates per chip.
- LSI: Large scale integration. 300 – 3,000 gates per chip.
- VLSI: Very large scale integration. More than 3,000 gates per chip.

i) Small Scale Integration (SSI) where the number of transistors incorporated in a single IC chip is up to 100.

ii) Medium Scale Integration (MSI) where the number of transistors incorporated in a single IC chip is from 100 to 1000.

iii) Large Scale Integration (LSI) where the number of transistors incorporated in a single IC chip is from 1000 to 20,000.

iv) Very Large Scale Integration (VLSI) where the number of transistors incorporated in a single IC chip is from 20,000 to 10,000,000.

v) Ultra Large Scale Integration (ULSI) where the number of transistors incorporated in a single IC chip is from 10,000,000 to 1,000,000,000.

Depending upon the active devices used in ICs, it can be further classified as bipolar ICs and unipolar ICs. In bipolar ICs the main components are bipolar junction transistors, whereas in unipolar ICs the main components are field effect transistors or MOSFETs.

Types of ICs (Integrated Circuits)

Based on the method or techniques used in manufacturing them, *types of ICs* can be divided into three classes:

1. Thin and thick film ICs
2. Monolithic ICs
3. Hybrid or multichip ICs

Thin and Thick ICs:

In thin or thick film ICs, passive components such as resistors, capacitors are integrated but the diodes and transistors are connected as separate components to form a single and a complete circuit. Thin and thick ICs that are produced commercially are merely the combination of integrated and discrete (separate) components.

Monolithic ICs

In monolithic ICs, the discrete components, the active and the passive and also the interconnections between then are formed on a silicon chip. The word monolithic is actually derived from two Greek words “mono” meaning one or single and Lithos meaning stone. Thus monolithic circuit is a circuit that is built into a single crystal.

Hybrid or Multi chip ICs

As the name implies, “Multi”, more than one individual chips are interconnected. The active components that are contained in this kind of ICs are diffused transistors or diodes. The passive components are the diffused resistors or capacitors on a single chip.

Advantages of Integrate Circuit or IC

1. It is quite small in size practically around 20,000 electronic components can be incorporated in a single square inch of IC chip.
2. Many complex circuits are fabricated in a single chip and hence this simplifies the designing of a complex electronic circuit. Also it improves the performance.
3. Reliability of ICs is high
4. These are available at low cost due to bulk production.
5. ICs consume very tiny power.
6. Very easily replaceable from the mother circuit.

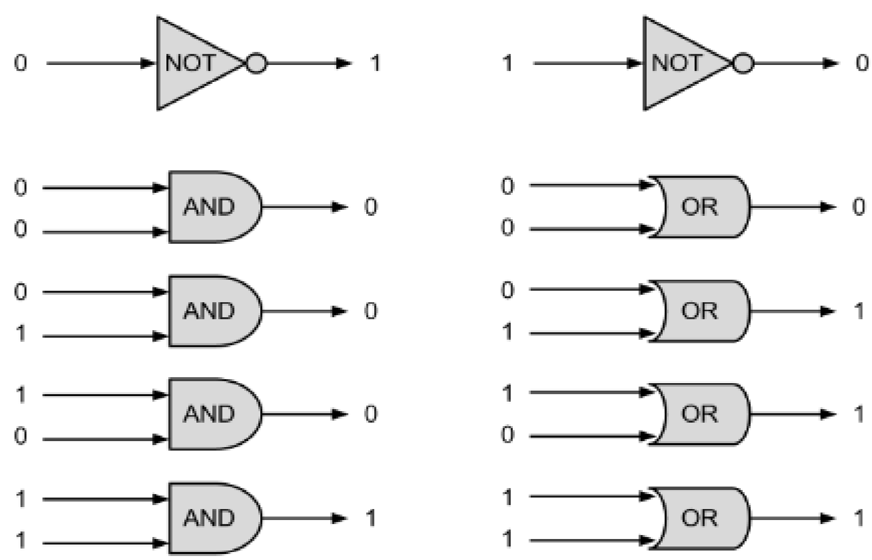
Disadvantages / Limitation for different types

- Inductors and Transformers cannot be incorporated in ICs.
- Limited power rating
- It operates at low voltage
- High grade of PNP is not possible
- It produces noise during operation
- Its components such as resistors and capacitors are voltage dependent
- It is delicate/fragile i.e it cannot withstand rough handling etc.

Basic Logic Function

A digital circuit represents and manipulates information encoded as electric signals that can assume one of two voltages: logic high (Vdd) or logic low (GND). Here we will dig further into the workings of digital circuits now that you have a better foundation for understanding.

The three primary logic relationships, *AND*, *OR*, and *NOT* (or inversion) can be used to express any logical relationship between any number of variables. These simple logic functions form the basis for all digital electronic devices—from a simple microwave oven controller to a desktop PC.



Introduction of K-Map (Karnaugh Map)

In many digital circuits and practical problems we need to find expression with minimum variables. We can minimize Boolean expressions of 3, 4 variables very easily using K-map without using any Boolean algebra theorems. K-map can take two forms Sum of Product (SOP) and Product of Sum (POS) according to the need of problem. K-map is table like representation but it gives more information than TRUTH TABLE. We fill grid of K-map with 0's and 1's then solve it by making groups.

Steps to solve expression using K-map-

1. Select K-map according to the number of variables.
2. Identify minterms or maxterms as given in problem.
3. For SOP put 1's in blocks of K-map respective to the minterms (0's elsewhere).
4. For POS put 0's in blocks of K-map respective to the maxterms(1's elsewhere).
5. Make rectangular groups containing total terms in power of two like 2,4,8 ..(except 1) and try to cover as many elements as you can in one group.
6. From the groups made in step 5 find the product terms and sum them up for SOP form.

SOP FORM :

1. K-map of 3 variables –

Z= ∑A,B,C(1,3,6,7)

From red group we get product term—

A'C

From green group we get product term—

AB

Summing these product terms we get- Final expression (A'C+AB)

2. K-map for 4 variables –

F(P,Q,R,S)=∑(0,2,5,7,8,10,13,15)

From red group we get product term—

QS

From green group we get product term—

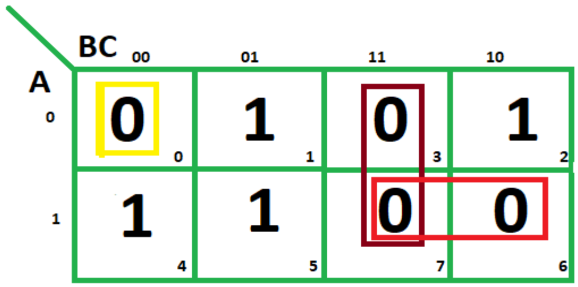
Q'S'

Summing these product terms we get- Final expression (QS+Q'S')

POS FORM :

1. K-map of 3 variables –

F(A,B,C)=π(0,3,6,7)



From red group we find terms

A B

Taking complement of these two

A' B'

Now sum up them

(A' + B')

From brown group we find terms

B C

Taking complement of these two terms

B' C'

Now sum up them

(B'+C')

From yellow group we find terms

A' B' C'

Taking complement of these two

A B C

Now sum up them

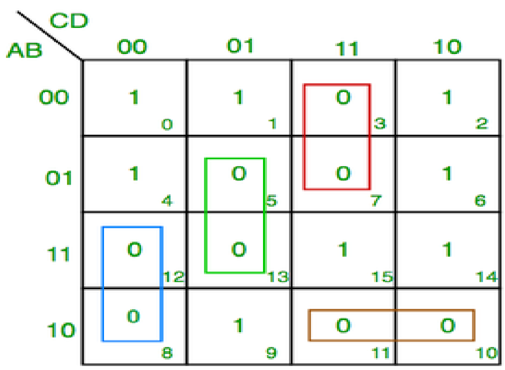
(A + B + C)

We will take product of these three terms : Final expression –

(A' + B’) (B’ + C’) (A + B + C)

2. K-map of 4 variables –

F(A,B,C,D)=π(3,5,7,8,10,11,12,13)



From green group we find terms

C’ D B

Taking their complement and summing them

(C+D’+B’)

From red group we find terms

C D A’

Taking their complement and summing them

(C’+D’+A)

From blue group we find terms

A C’ D’

Taking their complement and summing them

(A'+C+D)

From brown group we find terms

A B' C

Taking their complement and summing them

(A'+B+C')

Finally we express these as product –

(C+D'+B').(C'+D'+A).(A'+C+D).(A'+B+C')

Minimization Of Boolean Expressions-

There are following two methods of minimizing or reducing the boolean expressions-

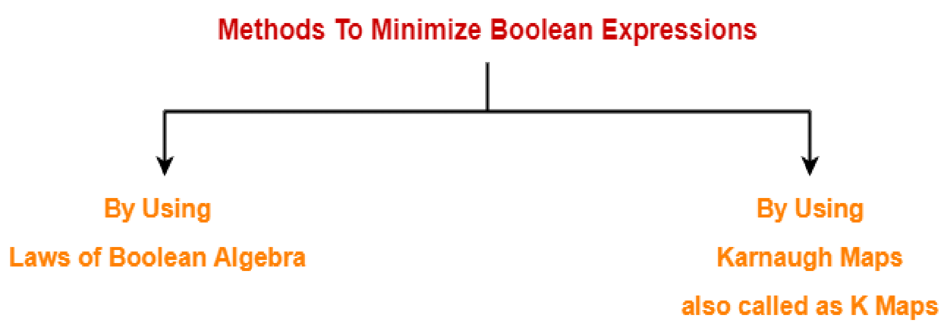


Figure 72: Boolean expression graph

1. **By using laws of Boolean Algebra**
2. **By using Karnaugh Maps also called as K Maps**

In this article, we will discuss about Karnaugh Maps or K Maps.

Karnaugh Map-

The Karnaugh Map also called as K Map is a graphical representation

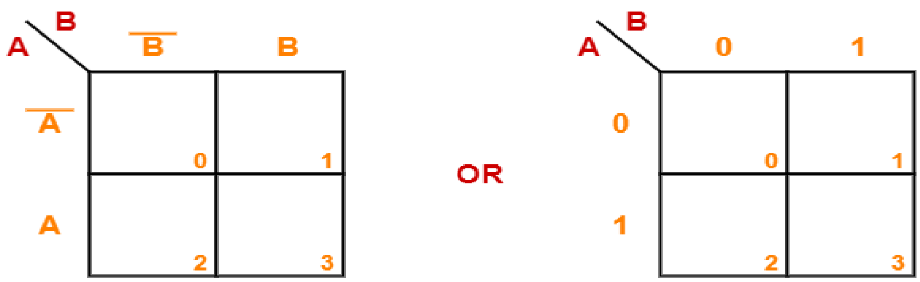
that provides a systematic method for simplifying the boolean expressions.

For a boolean expression consisting of n-variables, number of cells required in K Map = 2^n cells.

Two Variable K Map-

- **Two variable K Map is drawn for a boolean expression consisting of two variables.**
- **The number of cells present in two variable K Map = 2^2 = 4 cells.**
- **So, for a boolean function consisting of two variables, we draw a 2 x 2 K Map.**

Two variable K Map may be represented as-



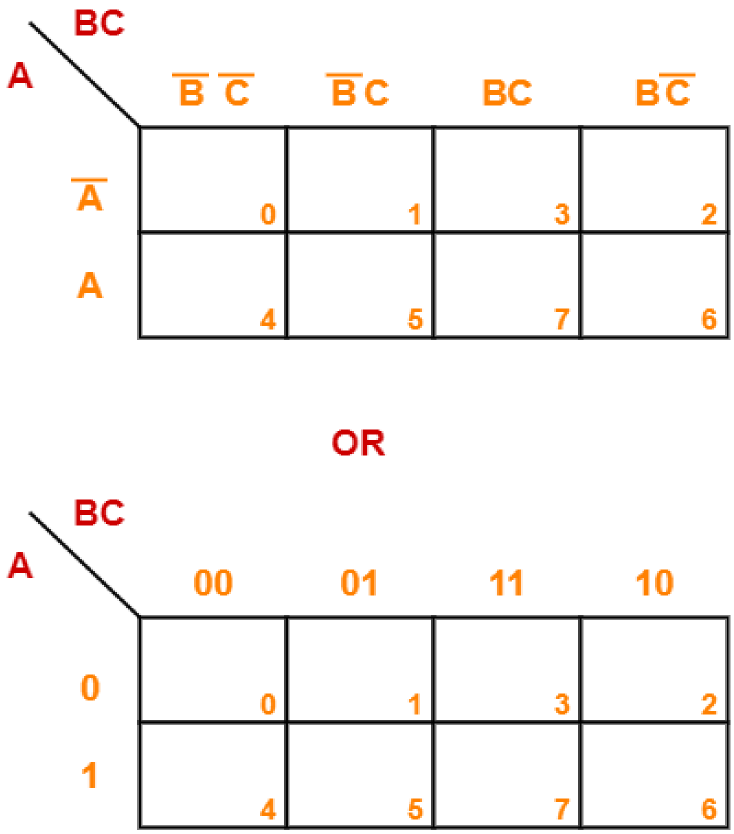
Two Variable K Map

Here, A and B are the two variables of the given boolean function.

Three Variable K Map-

- **Three variable K Map is drawn for a boolean expression consisting of three variables.**
- **The number of cells present in three variable K Map = 2^3 = 8 cells.**
- **So, for a boolean function consisting of three variables, we draw a 2 x 4 K Map.**

Three variable K Map may be represented as-



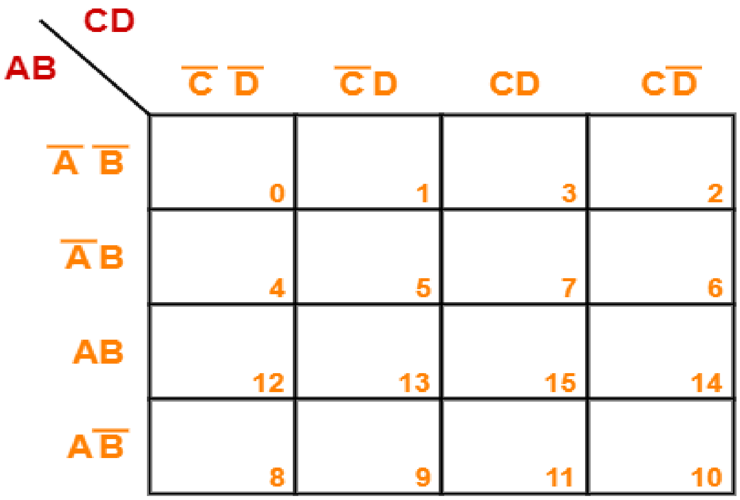
Three Variable K Map

Here, A, B and C are the three variables of the given boolean function.

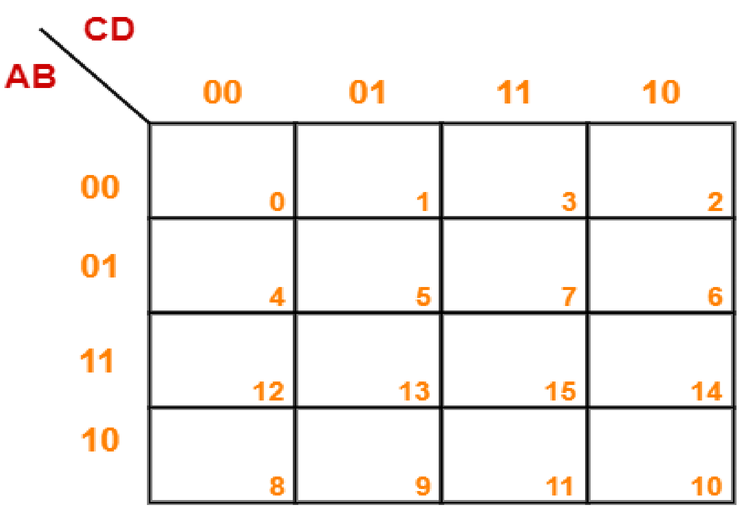
Four Variable K Map-

- **Four variable K Map is drawn for a boolean expression consisting of four variables.**
- **The number of cells present in four variable K Map = 2^4 = 16 cells.**
- **So, for a boolean function consisting of four variables, we draw a 4 x 4 K Map.**

Four variable K Map may be represented as-



OR



Four Variable K Map

Here, A, B, C and D are the four variables of the given boolean function

Inductive content 2.1.6: Operational Amplifier

What is an Operational Amplifier (Op-amp)?

An operational amplifier is an integrated circuit that can amplify weak electric signals. An operational amplifier has two input pins and one output pin. Its basic role is to amplify and output the voltage difference between the two input pins.

Derivation-integration

In simple Op-Amp applications, the output is proportional to the input amplitude. But when op-amp is configured as an integrator, the duration of the input signal is also considered. Therefore, an op-amp based integrator can perform mathematical integration with respect to time

Applications of Op-amp Integrator

- ✓ Integrator is an important part of the instrumentation and is used in Ramp generation.
- ✓ In function generator, the integrator circuit is used to produce the triangular wave.
- ✓ Integrator is used in wave shaping circuit such as a different kind of charge amplifier.
- ✓ It is used in analog computers, where integration is needed to be done using the analog circuit.
- ✓ Integrator circuit is also widely used in analog to the digital converter.
- ✓ Different sensors also use an integrator to reproduce useful outputs.

Theoretical learning Activity

- ✓ identification of elements of rectifier
- ✓ Working principle of rectifier
- ✓ Identification of elements of voltage regulator
- ✓ Working principle of voltage regulator
- ✓ Identification of binary numbers, coding and decoding
- ✓ Identification of simple logic functions
- ✓ Identification of operational amplifier

Practical learning Activity

- ✓ identification of elements of rectifier
- ✓ Working principle of rectifier
- ✓ Identification of elements of voltage regulator
- ✓ Working principle of voltage regulator

Points to Remember (Take home message)

- ❖ An operational amplifier is an integrated circuit that can amplify weak electric signals.
- ❖ An operational amplifier has two input pins and one output pin
- ❖ rectifier is an electronic device that converts an alternating current into a direct current by using one or more P-N junction diodes
- ❖ AC to AC converters with a DC link generally consists of a rectifier, DC link, and inverter as in this process the AC is converted into DC by using the rectifier

Learning outcome 2.1: formative assessment

Q1. What are the functions of integrated circuits?

Answer: A tiny chip known as an integrated circuit serves as a microprocessor, oscillator, amplifier, or computer memory.

Q2. Describe each element of the IC.

Answer: Resistors, diodes, transistors, capacitors, and conducting pathways are all parts of an IC. They are also connected by conducting pathways.

Q3. What exactly is a monolithic integrated circuit?

Answer: An integrated circuit (IC) made from a single piece of silicon is known as a monolithic integrated circuit (MIC).

References

[1] https://circuitdigest.com/tutorial/op-amp-integrator-circuit-working-construction-applications

[2] http://www.learningaboutelectronics.com/Articles/How-to-connect-a-voltage-regulator-in-a-circuit

[3] https://how2electronics.com/12v-dc-to-220v-ac-inverter-circuit/

Learning outcome 2.2: Identify integrated circuits

Duration: **7** hrs

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. identify regulator IC
2. identify filter IC
3.identify op-amp IC
4. identify integrated IC

Resources

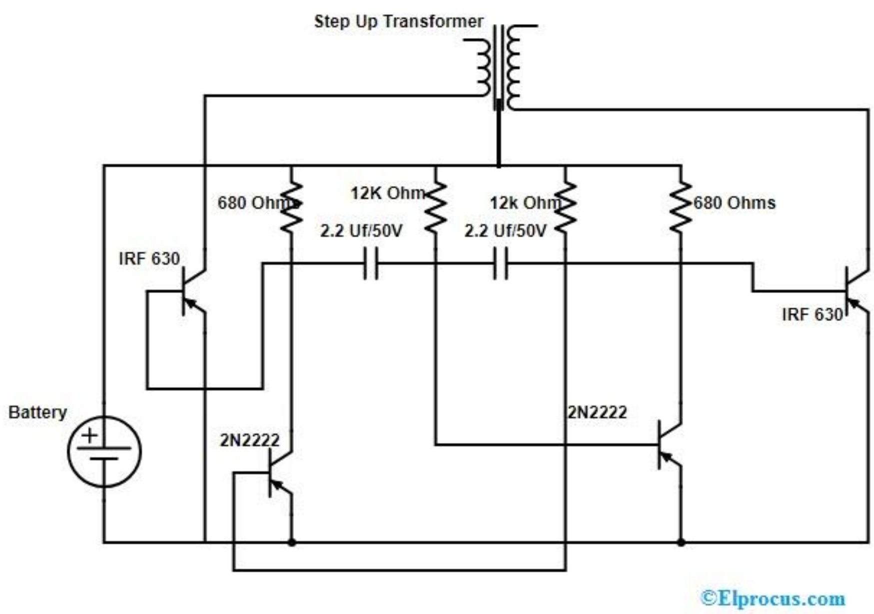
Equipment	Tools	Materials
-Books	-Internet	Op-amp ICs Filter Rectifier Inverter

Advance preparation:

- A trainer should visit a workshop to see if all ICs are available before starting session
- A trainer should have a sample of those components mounting

Indicative content 2.2.1: DC TO AC

The circuit diagram of 12V DC-to-220V AC converter can be built with using simple transistors, and this circuit can be employed for powering lamps up to 35Watts although they can be designed for driving more influential loads by utilizing more MOSFETs**.**



DC to AC Converter Circuit using Transistors

The inverter executed in this circuit can be a square wave, & it works with devices like which do not need pure AC sine wave.

The required components to build DC to AC circuit mainly includes 12v Battery, 2N2222 Transistors, two MOSFET IRF 630, 2.2uf capacitors-2, two
Resistors-12k, two 680 ohm resistors, and center tapped transformer (step up).
Circuit Working

The DC to AC circuit can be separated into three portions namely amplifier, transistor, **an oscillator**. As the AC supply frequency is 50Hz then a 50Hz oscillator is used. This can be attained by designing an astable multivibrator which generates a 50Hz square wave signal. The oscillator can be formed using the resistors like R1, R2, R3, R4, capacitors like C1,& C2, and transistors like T2 & T3.

Every transistor generates square waves (inverting), and the frequency will be decided by the resistor and capacitor values. The frequency formula for the generated square wave with the astable multivibrator is F = 1/(1.38 * R2 * C1)

Indicative content 2.2.2: AC TO AC

Phase controlled Cycloconverters

By using this type of Cycloconverters, we can change the magnitude of the output voltage in addition to the frequency of the output. Both can be varied by varying the firing angle of the converter.

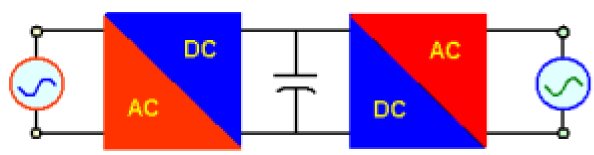


Figure 73: Phase controlled Cycloconverters

AC to AC converters with a DC link is classified into two types:

1.Current Source Inverter Converter

In this type of inverter, one or two series inductors are used between one or both limbs of the connection between the rectifier and inverter. The rectifier used here is a phase-controlled switching device like Thyristor Bridge.

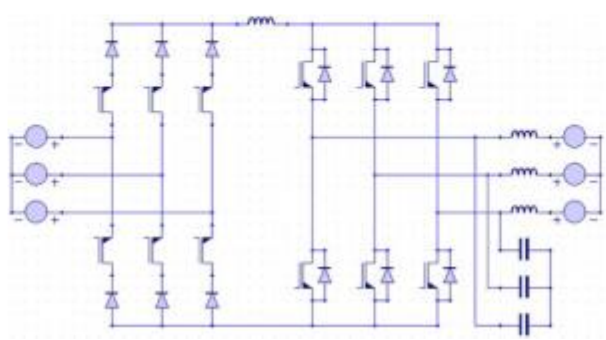


Figure 74: Current Source Inverter Converter

2.Voltage Source Inverter Converter

In this type of converter, the DC link consists of a shunt capacitor and the rectifier consists of a diode bridge. The diode bridges are preferred for the low load as the AC line distortion and low power factor caused by the Diode Bridge are lesser than the Thyristor Bridge.

Voltage regulator

How does a voltage regulator work?

Linear regulators, such as the MP2018, only require an input and output capacitor to operate . Their simplicity and reliability make them intuitive and simple devices for engineers, and are often highly cost-effective.

Depending on the voltage regulator in use, we can get a regulated positive or negative voltage, at whichever voltage we want. The LM78XX voltage regulators are a popular kind for regulating and outputting positive voltage, while the LM79XX are a popular series of regulators for negative voltage. In this article, we use a positive voltage regulator, which outputs 5V, the LM7805 regulator.

A voltage regulator is a 3-terminal device.

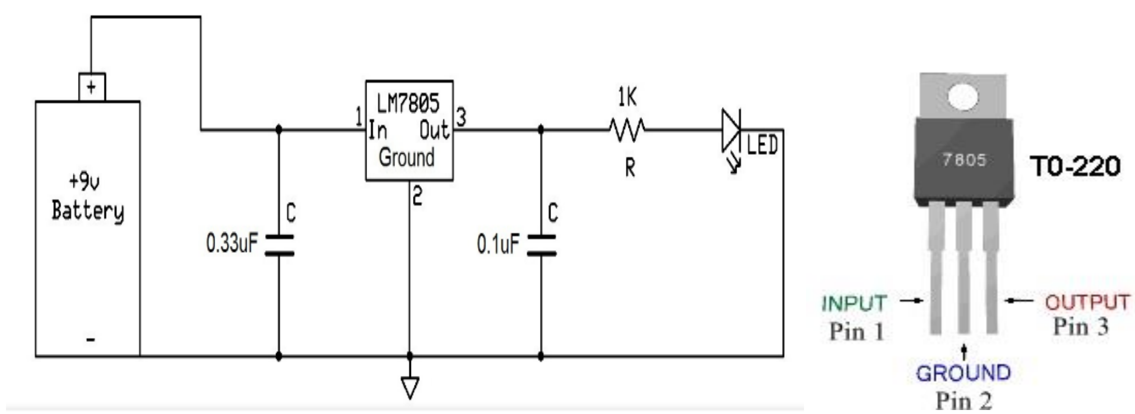


Figure 75: Regulator circuit

Indicative content 2.2.3: Filter

Working principle of filter

The electronic filter is a signal processing filter and these are available in electrical circuit form. The main function of a filter is to allow the DC component of the load of the filter & blocks the AC component of the output of the rectifier. Therefore, the filter circuit output will be a stable DC voltage. The designing of a filter circuit can be done using basic electronic components like resistors, capacitors & inductors

Element of filter

Filter elements may be of the 5-micron, woven mesh, Micronics, porous metal, or magnetic type

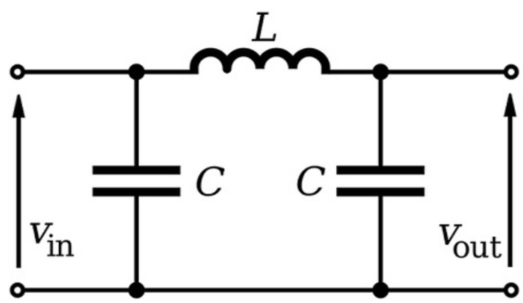


Figure 76: Filter circuit

Indicative content 2.2.4: Inverter

Working of the Circuit

The IC CD4047 is configured in a stable multivibrator mode with the help of variable resistor RV1 and capacitor C1. By varying the value of RV1 we can get a different range of output pulse at Q and Q' pins of CD4047. Consequently, there is a variation in the output voltage at the transformer.

The n-channel power MOSFETs IRFZ44 Drain pins are connected with the transformer secondary pins and common pin in the secondary winding is connected with battery positive. Both MOSFET source pins are connected to the negative terminal of the battery. When the alternate square pulse from Q & Q' drives the MOSFET, it switches ON. Then the secondary winding is forced to induce an alternate magnetic field. This magnetic field induced produces high alternate voltage around 220V.

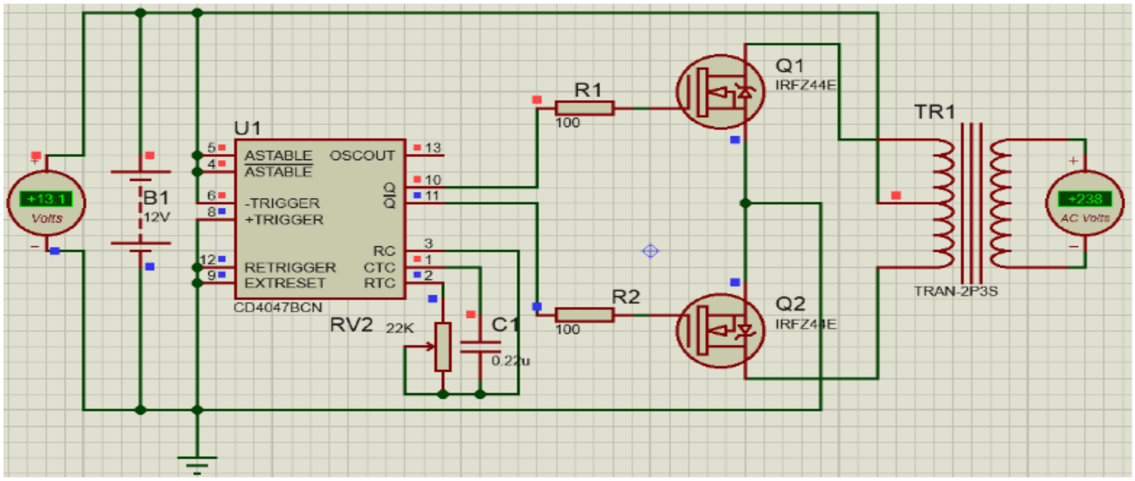


Figure 77: Inverter circuit

Indicative content 2.2.5: Integrated circuit

Integrated Circuit Features

ICs are built with semiconducting components such as silicon. Because of the small size and delicate nature of IC, a series of tiny gold and aluminium wires are joined together and molded into a flat block of plastic or ceramic. Metal pins on the block's exterior link to cables inside. The solid block stops the chip from overheating and keeps it cool.

Size of an IC

The size of the integrated chip varies between 1 square mm to more than 200 mm.

Integration of an IC

Because they combine various devices on one chip, integrated chips get their name. A microcontroller is an integrated circuit (IC) that combines a microprocessor, memory, and interface into a single unit.

Commonly Used ICs

Logic Gate ICs

The combinational circuit generates logical outputs based on a variety of input signals. It may only have two to three inputs but one output.

Timer ICs

A Timer IC is produced with accurate timing cycles with a 100 % or 50 % duty cycle.

Operational Amplifiers

An Op- Amp or an Operational Amplifier is a high gain voltage amplifier with a differential input and a single-ended output.

Voltage Regulators

A voltage regulator IC provides a constant DC output irrespective of the changes in DC input.

Indicative content 2.2.6: Operational Amplifier

An operational amplifier is an integrated circuit that can amplify weak electric signals. An operational amplifier has two input pins and one output pin. Its basic role is to amplify and output the voltage difference between the two input pins.

When an operational amplifier is combined with an amplification circuit, it can amplify weak signals to strong signals. It behaves like a megaphone where the input signal is a person's voice and the megaphone is the operational amplifier circuit. For example, such a circuit can be used to amplify minute sensor signals.

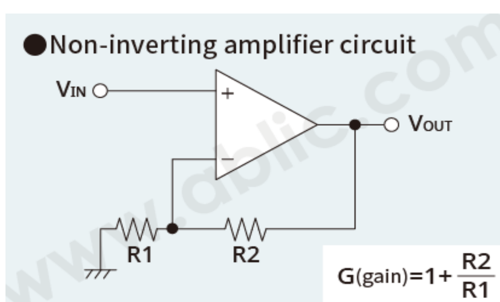
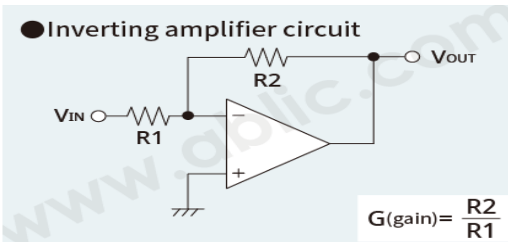


Figure 78: Non-inverting amplifier circuit

As explained in (1), this also is a circuit for amplifying and outputting input signals.

- **$V_{OUT}=(1+R2/R1)\times V_{IN}$**

Inverting amplifier circuit



An inverting amplifier circuit is indicated by a minus sign. If the V_{IN} voltage increases, the V_{OUT} voltage decreases.

- **$V_{OUT}=-R2/R1\times V_{IN}$**

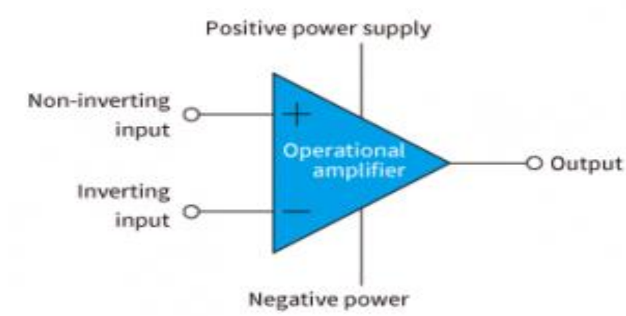


Figure 79: Op-amp circuit

Derivation-integration

In simple Op-Amp applications, the output is proportional to the input amplitude. But when op-amp is configured as an integrator, the duration of the input signal is also considered. Therefore, an op-amp based integrator can perform mathematical integration with respect to time. The integrator produces an output voltage across the op-amp, which is directly proportional to the integral of the input voltage; therefore, the output is dependent on the input voltage over a period of time.

Construction and Working of Op-amp Integrator Circuit

Op-amp is very widely used component in Electronics and is used to build many useful amplifier circuits. The construction of **simple Integrator circuit using op-amp** requires two passive components and one active component. The two passive components are resistor and capacitor. The Resistor and the Capacitor form a first-order low pass filter across the active component Op-Amp. Integrator circuit is exactly opposite of Op-amp differentiator circuit.

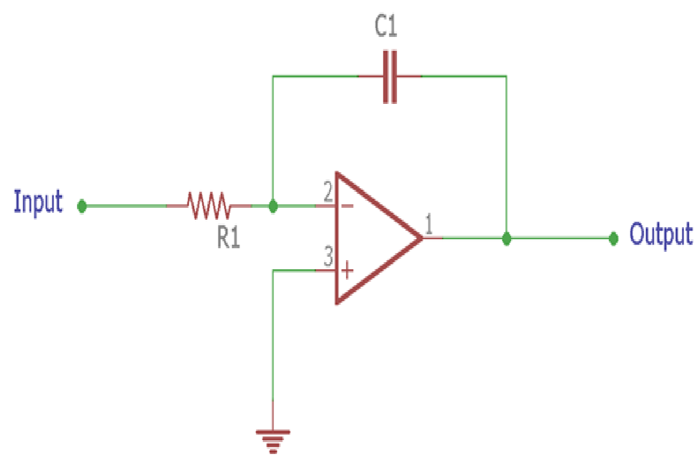


Figure 80: Integrator circuit

Theoretical learning Activity

- ✓ identification of elements of rectifier
- ✓ Working principle of rectifier
- ✓ Identification of elements of voltage regulator
- ✓ Working principle of voltage regulator
- ✓ Identification of binary numbers, coding and decoding
- ✓ Identification of simple logic functions
- ✓ Identification of operational amplifier

Practical learning Activity

- ✓ identification of elements of rectifier
- ✓ Working principle of rectifier
- ✓ Identification of elements of voltage regulator
- ✓ Working principle of voltage regulator

Points to Remember (Take home message)

- ❖ An operational amplifier is an integrated circuit that can amplify weak electric signals.
- ❖ An operational amplifier has two input pins and one output pin
- ❖ rectifier is an electronic device that converts an alternating current into a direct current by using one or more P-N junction diodes
- ❖ AC to AC converters with a DC link generally consists of a rectifier, DC link, and inverter as in this process the AC is converted into DC by using the rectifier

Learning outcome 2.2: formative assessment

Q1. Why are the integrated circuits significant?

Answer: The development of integrated circuits led to the development of numerous household products, CD players, computers, and televisions.

Q2: how many voltage IC7805 maintain constant**?**

Answer: 5V

Q3. How many terminals of IC7812 contains?

Answer: 3 terminals

References

[1]https://www.ablic.com/en/semicon/products/analog/opamp/intro/#:~:text=An%20operational%20amplifier%20is%20an,between%20the%20two%20input%20pins.

[2] http://www.learningaboutelectronics.com/Articles/How-to-connect-a-voltage-regulator-in-a-circuit

[3] https://how2electronics.com/12v-dc-to-220v-ac-inverter-circuit/

Learning outcome 2.3: Implement electronic circuits

Duration: **6 Hours**

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. implement rectifier circuit

2.implement operational amplifier circuit

3.implement voltage regulator circuit

Resources

Equipment	Tools	Materials
- Internet	- Books - Manual - Hand-out note	-ICs Active components Passive components

Advance preparation:

. trainer should be able to draw electronic circuit in simulation software

. trainer should run electronic circuit before giving work to learners

Indicative content 2.3.1: Rectifier

Working of the AC to DC Converter Circuit

A **step-down transformer** is used to convert the high voltage AC to the low voltage AC. The transformer is PCB mounted and it is a 1-ampere 13-volt transformer. However, during the load, the transformer voltage drops approximately 12.5-12.7 volt.

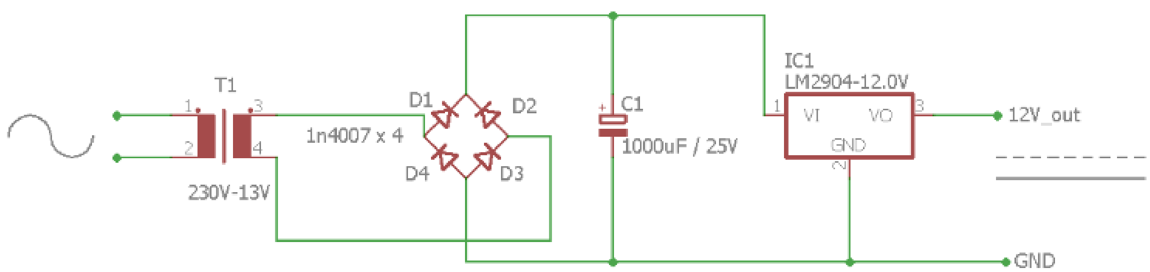
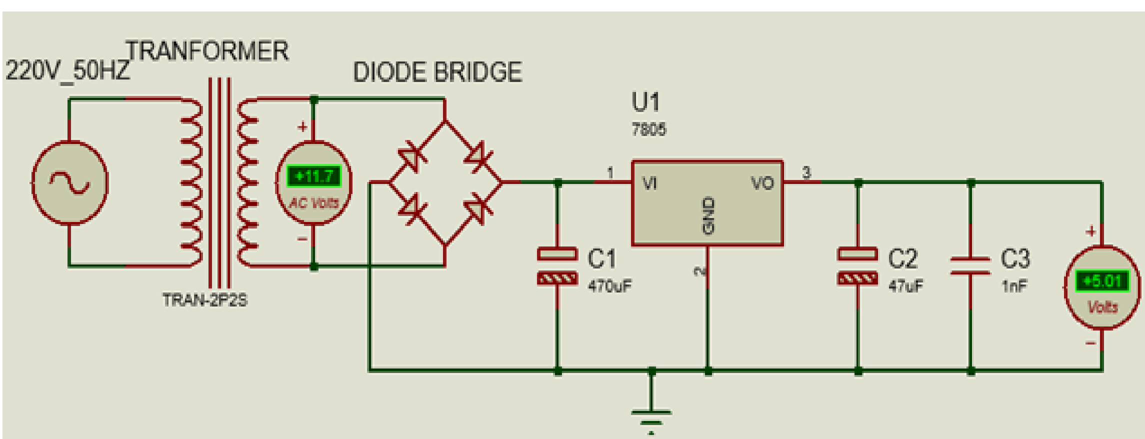


Figure 81: rectifier circuit

Implementation of rectifier circuit



Indicative content2.3.2 : Implementation of Inverter circuit

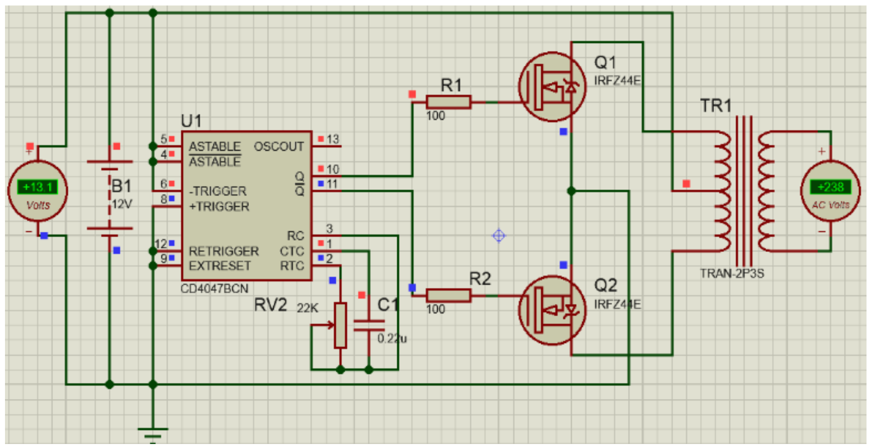


Figure 82: Inverter circuit

Indicative content 2.3.3 Implementation of filters circuit

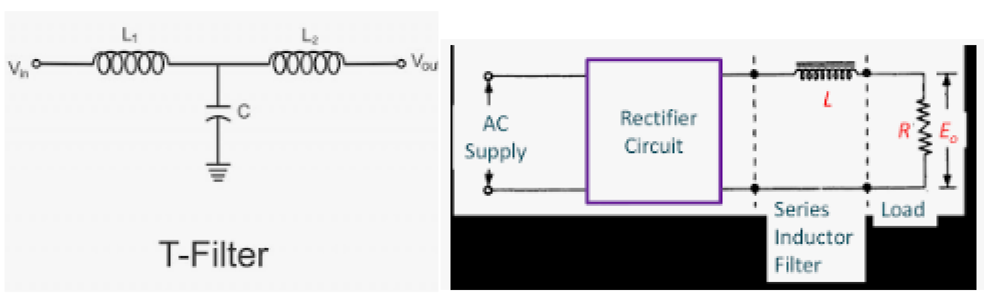


Figure 83: filters circuit

Indicative content 2.3.4 Implementation of voltage regulator circuit

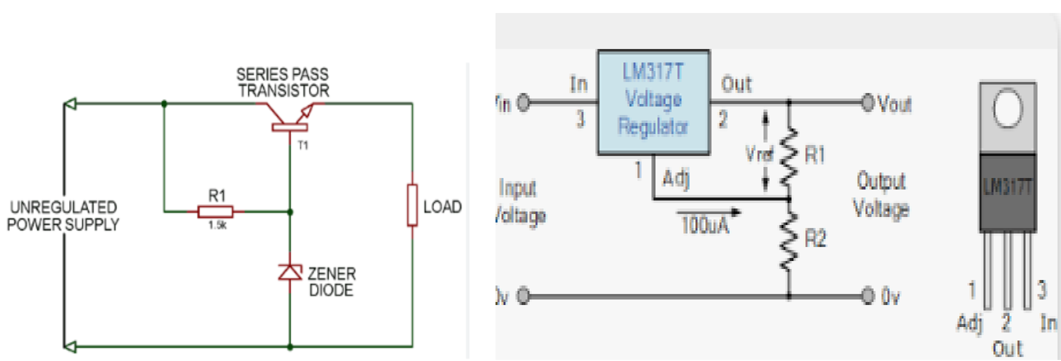
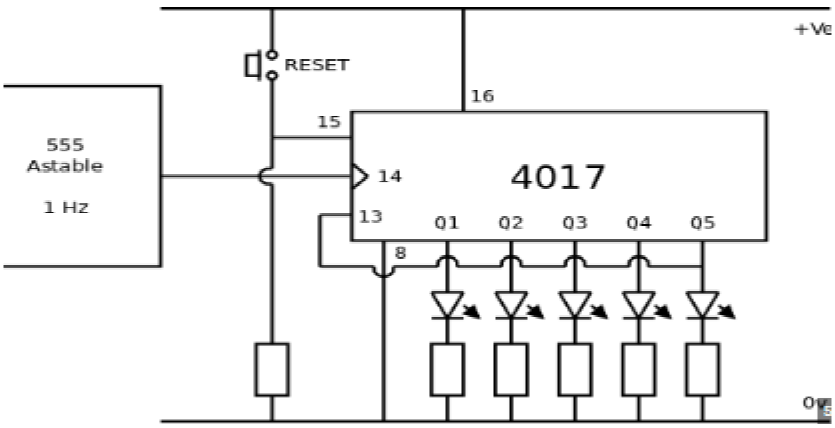


Figure 84: regulator circuit

Indicative content 2.3.5 : Use of Integrated circuits implementation



Theoretical learning Activity

- ✓ Identification of components used in rectifier circuit
- ✓ Identification of components used in inverter circuit
- ✓ Identification of components used in filter circuit
- ✓ Identification of components used in voltage regulator circuit
- ✓ Use of tools, equipment and materials
- ✓ Connection of rectifier circuit
- ✓ Connection of inverter circuit
- ✓ Connection of filter circuit
- ✓ Connection of voltage regulator circuit

Practical learning Activity

- ✓ Implementation of rectifier circuit
- ✓ Implementation of inverter circuit
- ✓ Implementation of filters circuit
- ✓ Implementation of voltage regulator circuit
- ✓ Use of Integrated circuits in implementation

Points to Remember

- ✓ How to design and implement all rectifier circuits
- ✓ How to design and implement all inverter circuits
- ✓ How to design and implement all filters circuits

References

[1]https://www.ablic.com/en/semicon/products/analog/opamp/intro/#:~:text=An%20operational%20amplifier%20is%20an,between%20the%20two%20input%20pins.

[2] http://www.learningaboutelectronics.com/Articles/How-to-connect-a-voltage-regulator-in-a-circuit

[3] https://how2electronics.com/12v-dc-to-220v-ac-inverter-circuit/

Learning Unit 3: Use electronic components in measuring, detection and automation systems

STRUCTURE OF LEARNING UNIT

Learning outcomes:

3.1 Identify sensors
3.2 Describe the operation of sensors
3.3 Use sensors

Learning outcome 3.1: Identify sensors

Duration: **4Hours**

Learning outcome 1 objectives:

By the end of the learning outcome, the trainees will be able to:

1. Describe the function of sensors

2.Identify different types of sensors

3.Identify different selection criteria

Resources

Equipment	Tools	Materials
books	-internet - Manual - Hand-out note	Sensors

Advance preparation:

A trainer should have enough information about the working principal of sensors

Mounting sensors, even the correction of their troubleshooting

Indicative content 3.1.1: General functional of sensor

1) A sensor is a device that detects and responds to some type of input from the physical environment. The input can be light, heat, motion, moisture, pressure or any number of other environmental phenomena.

2) A sensor is a device or module that detects and measures physical or chemical phenomena and converts them into electrical or digital signals that can be interpreted by a computer or other electronic device.

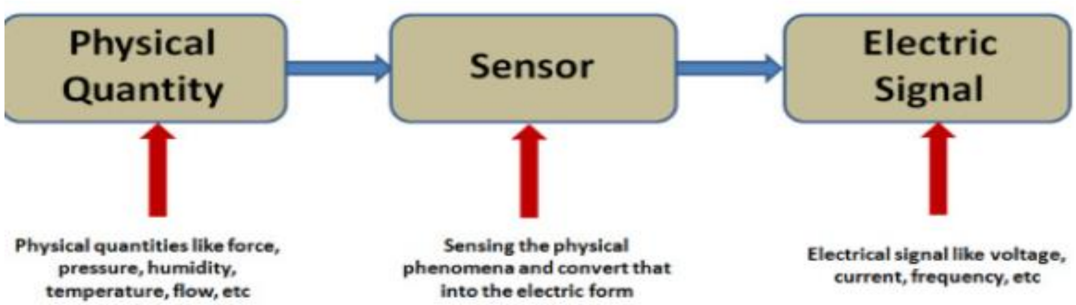


Figure 85: References

The main function of a sensor is to provide information about its surroundings or environment. This information can be used to monitor, control, or automate various processes or systems. Some common functions of sensors include:

1. Sensing physical or environmental variables such as temperature, pressure, humidity, light, sound, motion, and acceleration.
2. Converting physical or environmental variables into measurable electrical signals that can be processed and analyzed.
3. Transmitting the electrical signals to a control unit or processor that can interpret the data and make decisions based on it.

4. Triggering alarms or alerts when certain conditions or thresholds are met, such as detecting smoke or carbon monoxide.
5. Providing feedback to adjust or optimize a system, such as maintaining a constant temperature in a room or controlling the speed of a motor.

Overall, sensors play a crucial role in many modern technologies, from smart home devices to autonomous vehicles, by enabling them to gather data about their surroundings and respond to changing conditions in real-time.

- ✓ **Measures of presence or proximity**

Proximity sensors are non-contacting devices that measure the relative distance between the probe tip and the conductive surface that it is observing.

- ✓ **Capacitive sensor**

A capacitive sensor is an electronic device that can detect solid or liquid targets without physical contact. To detect these targets, capacitive sensors emit an electrical field from the sensing end of the sensor. Any target that can disrupt this electrical field can be detected by a capacitive sensor.

- ✓ **Inductive sensor**

An inductive sensor is a device that uses the principle of electromagnetic induction to detect or measure objects. An inductor develops a magnetic field when a current flows through it; alternatively, a current will flow through a circuit containing an inductor when the magnetic field through it changes.

- ✓ **Magnetic sensor**

A magnetic sensor is a sensor that detects the magnitude of magnetism and geomagnetism generated by a magnet or current.

- ✓ **Photoelectric detectors**

Photoelectric Sensors detect objects, changes in surface conditions, and other items through a variety of optical properties. A Photoelectric Sensor consists primarily of an Emitter for emitting light and a Receiver for receiving light.

- ✓ **Resistive sensors**

Resistive sensors are sensors which detect changes in their resistance. These changes are monitored and used to perform certain tasks. Resistance is a quantity which measures how device or material reduces flow of current through it.

Indicative content 3.1.2: Selection criteria and operation related constraints

- ✓ **Linearity**

The fact of involving a series of events or thoughts in which one follows another one directly: Linearity is rare in true autobiographies. We don't live in a straight line. The conventional linearity of the narrative is constantly subverted.

- ✓ **Accuracy**

Refers to how close a measurement is to the true or accepted value. Precision refers to how close measurements of the same item are to each other

- ✓ **Type of material to detect**

Materials testing breaks down into five major categories: mechanical testing; testing for thermal properties; testing for electrical properties; testing for resistance to corrosion, radiation, and biological deterioration; and non-destructive testing.

- ✓ **Nominal range**

The nominal range is the maximum distance at which a light can be seen in clear weather as defined by the International Visibility Code (meteorological visibility of 10 nautical miles). The geographic range The maximum distance at which the curvature of the earth and terrestrial refraction permit an aid to navigation (light or unlighted object) of height (h) to be seen from a particular height of eye (HE) without regard to the luminous intensity of the light.

- ✓ **Sensor signal**

The processed sensor signals then go to a multiplexer (MUX) that selects the sensor to be digitized and passes the signal along to an analogue-to-digital converter (ADC) that samples the analogue signal from the sensor and converts it to a stream of binary values, usually 8 to 16 bits long.

- ✓ **Lifetime**

Lifetime is the period of time during which someone lives or something exists.

The lifetime is up to 15 years, depending on the sensor type, configuration, environment, and use.

Theoretical learning Activity

- ✓ Brainstorming on sensor
- ✓ Group discussion on sensor
- ✓ Physical demonstration of sensors
- ✓ Identification of application of sensors in security

Practical learning Activity

- ✓ Identification of types of sensors
- ✓ Identification of type of material to detect
- ✓ Identification of functional operation of sensors

Points to Remember (Take home message)

- ✓ A sensor is a device that detects and responds to some type of input from the physical environment.
- ✓ The main function of a sensor is to provide information about its surroundings or environment.
- ✓ The nominal range is the maximum distance at which a light can be seen in clear weather as defined by the International Visibility Code
- ✓ Lifetime is the period of time during which someone lives or something exist

Learning outcome .3.1.1: Formative assessment

Q1)Define the following terms

a) Sensors

b) Nominal range

c) Lifetime

Q2 What are the common functions of sensors ?

Q3. What are the type of sensors

Learning outcome 3.2: Describe the operation of sensors

Duration: **7Hours**

Learning outcome objectives:

By the end of the learning outcome, the trainees will be able to:

1. Describe working principle of sensors

2.Identify linear displacement potentiometer

3.Identify rotary potentiometer

Resources

Equipment	Tools	Materials
boks	-internet - Manual - Hand-out note	Sensors

Advance preparation:

A trainer should have enough information about the working principal of all sensors

Indicative content 3.2.1:Working principle of sensors

A sensor is a detection device that can sense the measured data and convert it into electrical signals or other required forms of information output according to particular rules, in order to meet the requirements of data transmission, processing, storage, and display, as well as recording and control.

Sensors are frequently categorized based on their functioning principle, input data, and application scope. They may be loosely split into three types based on their diverse functioning principles: physical type, chemical type, and biological type.

Sensors enable objects to have senses such as touch, taste, and smell, and they gradually become alive as a result of their evolution. Thermal elements, photosensitive elements, gas-sensitive elements, force-sensitive elements, magnetic-sensitive elements, humidity-sensitive elements, sound-sensitive elements, radiation-sensitive elements, color-sensitive elements, and taste-sensitive elements are the ten categories according to their basic sensing functions.

Sensors are frequently categorized based on their functioning principle, input data, and application scope. They may be loosely split into three types based on their diverse functioning principles: physical type, chemical type, and biological type.

Ⅰ. Physical sensors

Sensors built with the physical qualities of specific transforming components and the special physical properties of certain functional materials are known as physical sensor

Ⅱ. Chemical Sensors

Chemical sensors convert the composition and concentration of inorganic and organic chemical compounds into electrical signals using the electrochemical reaction concept.

Ⅲ. Biological Sensors

Biosensors are another type of sensor that has grown in popularity in recent years. It's a sensor that detects and measures biochemical compounds using biologically active chemicals. Functional conversion recognition capacity refers to a biologically active agent's selective affinity for a certain chemical.

Indicative content 3.2.2:Detection mechanism of sensors

Fault detection mechanisms either remove any SDC from a system or convert them to DUE. Error recovery mechanisms can reduce or eliminate both the SDC and DUE rates of a system. Broadly, error recovery mechanisms can be classified into forward and backward error recovery mechanisms.

In a forward error recovery, a system can continue executing from its current state after a fault is detected. The forward error recovery schemes usually maintain a redundant, up-to-date error-free state from which the system can continue execution. In contrast, a backward error recovery scheme usually rolls back to a previous error-free state of a system. Such states are referred to as checkpoints and can be generated incrementally or periodically by a system.

- ✓ **Linear displacement potentiometer**

A potentiometer sensor measures the distance or displacement of an object in a linear or rotary motion and converts it into an electrical signal.

A linear potentiometer is a type of position sensor. They are used to measure displacement along a single axis, either up and down or left and right. Linear potentiometers are often rod actuated and connected to an internal slider or wiper carrier.

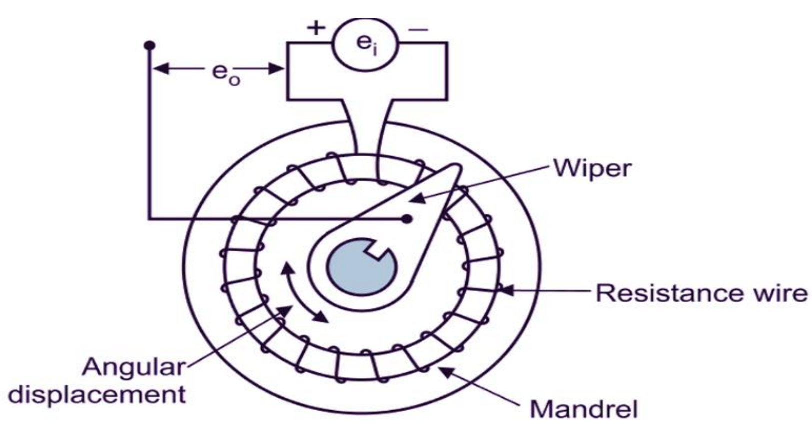
Linear potentiometers are used for length measurement in many laboratories and as well in industrial applications. The sensors are easy to install and offer precise measurement values even under difficult conditions.

- ✓ **Rotary potentiometer**

The rotary type potentiometers are used mainly for obtaining adjustable supply voltage to a part of electronic circuits and electrical circuits. The volume controller of a radio transistor is a popular example of a rotary potentiometer where the rotary knob of the potentiometer controls the supply to the amplifier.

How Does a Rotary Potentiometer Work?

Potentiometers work by varying the position of a sliding contact across a uniform resistance. In a potentiometer, the entire input voltage is applied across the whole length of the resistor, and the output voltage is the voltage drop between the fixed and sliding contact. A rotary potentiometer has two terminals of the input source fixed to the end of the resistor. To adjust the output voltage the sliding contact gets moved along the resistor on the output side.
This kind of potentiometer includes two terminal contacts where a consistent resistance can be located in a semi-circular model. And also, it includes a terminal in the middle that is allied to the resistance using a sliding contact that is connected through a rotating knob. The sliding contact can be turned by turning the knob over the half-circular resistance. The voltage of this can be obtained among the two contacts of resistance & sliding. These potentiometers are used wherever level voltage control is necessary.



The Characteristics of Potentiometers

All the Potentiometers have some characteristics. These characteristics also apply to the rotary ones which are listed in the following:

- They are extremely accurate as they work on the evaluating technique rather than the technique of deflection to determine the unidentified voltages.
- they determine the balance point otherwise null which does not need power for the dimension.
- The potentiometer working is free from the resistance of the source as there is no flow of current throughout the potentiometer as it is balanced.
- The main characteristics of these potentiometers are resolution, taper, marking codes & hop on/hop off resistance.

Theoretical learning Activity

- ✓ Brainstorming on principle of sensors
- ✓ Group discussion on operation conditions of sensors

Practical learning Activity

- ✓ **Description of sensors working principle**
- ✓ **Description of sensors detection mechanism**

Points to Remember (Take home message)

- ✓ Sensors enable objects to have senses such as touch, taste, and smell, and they gradually become alive as a result of their evolution.
- ✓ Fault detection mechanisms either remove any SDC from a system or convert them to DUE.

Learning outcome 3.2: Formative assessment

Q1) Fill in the blanks with appropriate word (**Linear, measurement values, functioning, Rotary**)

a. Sensors are frequently categorized based on their ……………………….. principle, input data, and application scope.

b. ……………………potentiometers are used for length measurement in many laboratories and as well in industrial applications.

c. ………………………… potentiometer has two terminals of the input source fixed to the end of the resistor.

d. The sensors are easy to install and offer precise…………………………… even under difficult conditions.

Q2) As an industrial electrician, describe the working principle of sensors.

Q3) How Does a Rotary Potentiometer Work?

Reference:

1.https://www.sciencedirect.com/topics/computer-science/detection-mechanism

2. https://www.google.com/search?q=linear+displacement+potentiometer

3. https://www.linquip.com/blog/what-is-rotary-potentiometer/

4. **electricalworkbook.com**

Learning outcome 3.3: Use sensors

Duration: **10 Hours**

Learning outcome objectives:

By the end of the learning outcome, the trainees will be able to:

1. Identify the application of sensors in industrial robots

2.Identify the application of sensors in servomechanism

3.Identify the application of sensors in NC machine tools

4.Identify the application of sensors in security.

Resources

Equipment	Tools	Materials
books	-internet - Manual - Hand-out note	Sensors

Advance preparation:

A trainer should have enough information about the use of sensors especially in industries

Indicative content 3.3.1: Application of sensors

Sensors are independent devices integrated into regular items or machines for smart use.

No	Application	Description
1	Managing day to day activities	There are many specialized applications of sensors devices in day-to- day activities. These are used to manage key processes in the chemical, oil, gas, and nuclear energy sectors. Here, sensors are required to control geographically vast power transmission and distribution systems in the electric energy business as well.
2	Safety	Devices can also be networked in conjunction with the internet and can be used for enhanced safety and convenience through intelligent home solution. These solutions involve networks of data collection, cloud, and machine-to- machine communication.
3	Cleaning	Sensors guarantee that the flat is cleaned at every aspect and vacuum cleaners can avoid physical barriers. In the future, water sensors can also prevent damage to the house caused by washing machines or dishwashers. Smart sensor systems are everywhere in our daily lives. They offer safety, save lives and enhance living quality. More and more

		automated and networked living sectors will raise the necessity of novel sensor technology.
4	Emergency	Driver assistance systems like autonomous emergency braking systems or parking devices facilitate daily life and boost road safety via cameras, infrared and ultrasonic sensors, and radar sensors. This offered automatic parking aids using ultrasonic front and rear sensors to support the guides during parking. These help to identify parking spaces available and relay information. Free parking places can be accessed immediately by drivers. Innovative, self – sufficient energy parking sensors facilitate daily living to locate a place in urban areas.
5	Food quality control	Sensors in the food sector used for quality control operations are utilized for measuring carbohydrates, alcohol, and acids. These devices are also being employed to monitor fermentation. The use of pathogens in fresh meat, poultry, or fish is very vital to identify. For air and water quality control, sensors are successfully utilized. It can be used to collect traces of pesticides from organophosphates and to monitor wastewater toxicity levels. A kettle utilizes temperature sensors to guarantee the temperature reaches the proper degree while preparing a cup of coffee. A coffee maker utilizes pressure switches to check the volume of liquid delivered.

6	Boilers and washing machines	Some household appliance applications using sensors are the boiler, washing machines and dishwashers for heating systems, and other white products. Many vehicles, including automobiles, trains, buses, etc., employ sensors to monitor petroleum temperature and pressure, jets and steering systems, and so many more.
7	Measure distance	Sensors are commonly employed in all forms of portable and handheld devices They are utilized in fitness applications to measure the distance of each step and the incremental steps that a person has taken. These are also used to detect the user's motion, such as rotating and tilting, providing them with an incredible gaming experience. Motion sensors also have wide range of home and personal safety applications. However, without a motion sensor, it is difficult to establish a safety system. They are particularly successful because during peak night hours, they offer clear views.
8	Doorbells	Sensors play a significant role in wireless doorbells. It may dispose of typical entrance cells employing motion sensors, as movement sensors can inform guests when they reach the door. Motion sensors detect motion using optical, vibration, radiofrequency, sound, and warmth, essentially using electronic chips. The centre of our new safety

		systems is movement sensors. They are utilised for the detection and understanding of location, speed, and acceleration.
9	Automating lighting operations	The primary operation of light sensors is tuning light on the day. In addition to facilitating human-centric lighting, daylight harvesting, and lighting planning for energy savings, efficiency, and the environment, it automates lighting operations in smart buildings. Thermal sensors are required to automate room temperature in smart buildings and businesses. The temperature is continuously inside, regardless of how the temperature swings externally. These sensors also conserve energy by regulating the temperature with the climatic environment.
10	Assure home security	Sensors are designed to assure security for the house since they provide fast warnings and trigger fire burst alarms. They boost the possibility of escaping accident situations dramatically. In addition, more sensors such as time sensors, position sensors, sound sensors, material sensors, and many more are used for this purpose. It assists manufacturers to improve their operations and staff well-being.
11	Monitor temperature changes	In different kinds and sizes, sensors are available. Temperature sensors monitor a source's heat energy content to detect and convert temperature changes

		into data. Machinery used in production generally demands temperatures for the surroundings and device at specific values. Similarly, the soil temperature is an essential component in crop growth within agriculture. Some are purpose-built with numerous integrated individual sensors so that multiple data sources may be monitored and measured.
12	Identify persons/person entering a room	Sensors are meant to identify persons while entering or leaving a room. The sensors transmit a signal to the light system when motion is detected to initiate procedures that reduce the energy supply. It automatically switches lights and other in-house equipment on/off based on the occupancy of the allocated space. In commercial applications which deal with wider regions and people, they can substantially save energy. It is also commonly used in hospitals for monitoring compliance with hand hygiene.
13	Measure water vapour	The measurement of water vapour in the air or other gases is carried out using sensors. In both the industrial and residential fields, humidity sensors are typically found in heating, air-conditioning systems. These are used in many different sectors, including hospitals and weather stations, for weather reporting and prediction. A pressure sensor detects

		gas and fluid changes. The sensor detects various changes and transmits them to linked systems when the pressure changes. Leak tests that can be a result of degradation are everyday situations of usage. Pressure sensors are also essential to produce water systems since variations or pressure dips can be easily detected.
14	Collects radiation	The sensors collect radiation that the item or surrounding regions produce or reflect. The most prevalent radiation source recorded by passive sensors is sunlight reflection. For example, photography, infrared, and radiometers are examples of passive sensors. Passive sensors are employed more because the satellite imagery is of exceptional quality. The passive sensor is preferable in technological monitoring globally, such as multiple spectral and hyperspectral technologies.
15	Avoid injuries	Sensors enable people to be monitored around them to avoid injuries from falling, overwork, heavy machinery, etc. In combination with innovative cognitive capacities and external sources such as environment and weather, sensors have good potential for better management, good health, and security to transform our way of life and work today truly. Wearable technology uses the IoT to gather, integrate, and analyse sensory data. A sensor is

		utilised to detect, measure, and report a single variable in the actual world in these systems.
16	Transit data about the person status	Sensors capture and transmit data about a person's physical status in real-time, which can minimise emergency response time and save lives. This might be important for older patients. These can quickly analyse the elderly persons living alone and provides the timely treatment. These are used to detect and monitor the level of oxygen concentration. Oxygen sensors are used in this system to control and monitor the predicted oxygen delivery to the patient. Electrochemical oxygen sensing elements are typically used to measure the oxygen level in ambient air.
17	Detect level of liquid and other quantities	Sensors are used to detect items such as liquids, powders, and granular solids. Many sectors, including oil, water and drinks processing, and food production, employ high-level sensors. Trash management systems are typical because level sensors can monitor waste levels in waste containers or dumpsters. These sensors measure the presence of fuel or hazardous gases and detect changes in air quality. Mining, oil and gas, chemical research, and manufacturing are the industries adopting sensors.

18	Monitoring environmental factors	Intelligent sensors monitor several environmental factors, including humidity, air temperature, and soil quality. These utilise weather and predictions in real-time to develop an ideal watering schedule for the yard. It plays a vital role in digitalising health services that enhance clinics' operations and the results of the patients. Sensors help to monitor the condition of smart warehousing, guarantee a rapid check-in and check-out and simplify day-to-day operations. Companies are increasingly the applications of sensors in industrial mining.
19	Identify movements	Sensors are commonly employed to identify movements in retail contexts. A shop can send discounts or offers to their mobile phone using the vicinity of a possible consumer. In parking garages, larger venues like airports, malls, and stadiums may check availability via proximity sensors. A moisture detection sensor can offer ahead for home's risk due to frozen pipes or even a damaged water line. The sensors can notify of leaks in the house to resolve the problem rapidly.
20	Home items	Sensors are installed around heaters, washing machines, refrigerators, sinks, pumps, and any leaking water danger. These can notify regarding unwanted water and quickly inspect the situation at home. When visitors come and leave the house, this

		technology may even turn the lights on and off, door and windows. Door and window sensors are the first protection lines for home breakdowns; even when an invader breaks a window, some sensors detect. Sensors can notify the movement of our home and the opening or closing of doors or windows. Motion sensors become an additional eye pair, warning about undesired activities like sneaking out adolescents.
21	Saving electricity	Sensors are employed to save electricity by linking them to lighting or the thermostat to regulate the energy use in a building depending on the occupancy. Motion sensors may also be connected to the video, which allows notification that the sensor has been triggered and activates the video recording to collect incursion footage. A multi-sensor integrates many sensors into one unit. Sensors may help to construct a safe and intelligent house. This technological adoption rapidly catches up and even becomes an insurance incentive. It has certainly helped us build smarter and safer homes.
22	Gas detection and surveillance	Gas detection and surveillance are always strongly related to the safety of people in difficult circumstances when the presence of toxic gases is identified. Sensors can easily monitor and measure the amount of gas frequently to be greater than

		usual and ensure the safety of persons operating in and near dangerous gases. Indoor air quality is another significant business that employs gas sensor technology to monitor.

Use of Sensors in Robotics

The applications of robot sensors include the following.

- Robotic sensors are mainly used to estimate the condition & environment of the robot.
- These sensors ensure the smooth working of a robot.
- Robot sensors assist robots to respond to the received commands.
- These sensors provide the effortless achievement of different tasks. Understanding the surroundings can assist a robot to decide the object's proximity, temperature, chemical reaction, sound, and perform accordingly.
- Sensors in robotics are required to attain reliable solutions with efficient quality, fast response, accuracy & cost-effectiveness.

✓ **Industrial robots**

Robot automation is rapidly progressing technology. In just a few decades, industrial robots have become universal devices in factories worldwide.

An industrial robot is a mechanical device that automatically performs work. It can accept human commands, execute pre-arranged programs, or act according to instructions defined by artificial intelligence (AI) technology. In addition, it can overcome the impact of the harsh environment on production, reduce the use of labor, ensure the safety of workers, and at the same time help the factory save production costs and improve production efficiency, thereby ensuring product quality.

Industrial robots are multi-degree-of-freedom machine devices that can automatically perform work and realize various functions according to their own power and control capabilities. They are composed of three major parts: machinery, sensing, and control. These three major parts are divided into six subsystems. They are:

- **Drive system**: place a transmission device for each joint, that is, each degree of freedom of movement, to make the robot move.
- **Mechanical structure system**: It consists of three parts: body, arm, and end manipulator. Each large piece has several degrees of freedom, forming a multi-degree-of-freedom mechanical system. The arm is generally composed of an upper arm, a lower arm, and a wrist. The end manipulator is an important part that is directly mounted on the wrist. It can be a two-finger or multi-finger claw, a paint spray gun, a welding gun, etc.
- **Sensing system**: Obtain meaningful information in the internal and external environmental status, improve the maneuverability, adaptability, and intelligence level of the robot.
- **Robot-environment interaction system**: A system that enables the robot to interact and coordinate with devices in the external environment.
- **Human-machine interaction system**: a device for humans to communicate with and participate in robot control.
- **Control system**: according to the robot's operation instruction program and the signal returned from the sensor, it controls the robot's actuator to complete the prescribed actions and functions.

✓ **servomechanism**

A servomechanism is a physical device that responds to an input control-signal by forcing an output actuator to perform a desired function. Servomechanisms are often the connection between computers, electronics, and mechanical actions. The name literally means “serving machine.” Servomechanisms use electronic, hydraulic, or mechanical devices to control the power of an object. Servomechanisms enable a control operator to perform dangerous tasks at a distance and they are often employed to control large objects using fingertip control. Servomechanisms have the ability to sense errors within a mechanism. Due to this ability, they receive negative feedback when something is wrong, giving them the opportunity to correct the performance of a machine.

Servomechanisms are classified into two groups: open-loop and closed-loop.

1.Open Loop Servo mechanisms

Open-loop is the simplest version of a servomechanism as they don't feed back the results of their output to their input. The servos don't register when input instructions have been completed or not, and they don't automatically course correct if an error occurs. An example of an open-loop servomechanism is a simple motor used to rotate a television-antenna. There's no automation to verify that the desired action has been accomplished, yet the action will still take place. The operation is purely time-based, meaning a technician can manually input presets that the mechanism can act upon in order to complete a task, but the machine itself will not adjust or override the presets if the clothes are cleaned faster than usual. Regardless of the cleanliness or dirtiness of the clothes, the machine will complete the cycle as it was asked to.

2.Closed Loop Servomechanisms

Closed loop servomechanisms are a bit different. They're an incredibly intelligent mechanism that are able to course correct, send feedback to the input and change the output to the desired value. The output results are sampled continuously and the information is continuously compared with the input instructions. Any interruption is recorded as an error that must be corrected. Closed loop servo systems automatically cancel or correct these disagreements. An example of a closed loop servomechanism would be a thermostat. Thermostats are intelligent designs that sense the temperature of a specific space and adjust accordingly to maintain the desired heat level. While, as with a washing machine, you can manually input settings, a thermostat will automatically adjust itself when it senses something is off.

What's the Purpose of Servomechanisms?

Servo control systems are very efficient and easy to design. On top of that, they reduce errors and improve the functionality of different mechanisms. As seen in the examples above, they're used in everyday household objects, but they're also instrumental when it comes to automation and robotics, particularly in manufacturing and on the factory floor. With servomechanisms, accurate control of motion can be achieved and errors can be caught without the need for extreme human supervision. They cancel out human error and allow for jobs to be handled with better attention to detail and speed. Accuracy can still be maintained even with variations concerning the mechanical load of certain machines, changes in the environment, power supply fluctuations, and even with the aging of machines.

Another massive advantage to servomechanisms is that outputs can be controlled from remotely located inputs, without the use of mechanical linkage. This means an operator doesn't have to be near the mechanism in order to control it. The downside to servos is that they're more complex and they can have high costs. While they span across multiple industries, their maintenance can be difficult and fine tuning is required. Robotics technicians skilled in servomechanisms are highly sought after due to their complexities.

Where Are Servomechanisms Used?

We mentioned where servomechanisms appear today, specifically within the home and in factories, but where else are they used? Servomechanisms were first used in gunlaying, fire-control and marine-navigation equipment. Today, applications of servomechanisms include their use in automatic machine tools, satellite-tracking antennas, celestial-tracking systems on telescopes, automatic navigation systems, and aircraft-gun control systems. Within manufacturing, servomechanisms can be found in assembly lines as they're able to perform repetitive tasks that require precise movements. These servo robots can sense errors and course-correct depending on the task at hand, resulting in more streamlined labour.

- ✓ **Numerical Control (NC) machine tools**

Numerical Control (NC) refers to the method of controlling the manufacturing operation by means of directly inserted coded numerical instructions into the machine tool. It is important to realize that NC is not a machining method, rather, it is a concept of machine control. Although the most popular applications of NC are in machining, NC can be applied to many other operations, including welding, sheet metalworking, riveting, etc.

The major advantages of NC over conventional methods of machine control are as follows:

- Higher precision
- Machining of complex three-dimensional shapes
- Better quality
- Higher productivity
- Multi-operational machining
- Low operator qualification

Types of NC systems

Machine controls are divided into three groups,

- Traditional numerical control (NC);
- Computer numerical control (CNC);
- Distributed numerical control (DNC).

The original numerical control machines were referred to as NC machine tool. They have“hardwired” control, whereby control is accomplished through the use of punched paper (or plastic) tapes or cards. Tapes tend to wear, and become dirty, thus causing misreadings. Many other problems arise from the use of NC tapes, for example the need to manual reload the NC tapes for each new part and the lack of program editing abilities, which increases the lead time. The end of NC tapes was the result of two competing developments, CNC and DNC.

- ✓ **Sensors for Security Applications**

Electronic sensor systems extend their application to fields such as national defence, home, personal safety, office and industry.

As technology progresses, threats and vulnerabilities to human lives including national security also increases. CCTV surveillance systems and other intelligent electronic sensors are being installed in many establishments, industrial setups and high-risk security areas to monitor and guard against these threats. Covering all security issues and sensors is out of the scope of this article. We have trimmed the article down to a few security applications such as national, home, personal, industrial and cybersecurity. Simple to complex sensor hardware and software are involved in guarding against the threats to human lives, properties, financial services and personal privacy.

National security

There is a wide range of national security systems to guard against rogue states and terrorism, and monitor weather reports and natural calamities such as cyclones, earthquakes and tsunamis. A radar sensor is one of the most important electronics security systems. A radar transmits an electronic signal that bounces off objects and returns to the receiver for analysis. A radar sensor monitors areas such as national and international borders, military bases, airports, seaports, refineries and other critical industries.

Satellite is another vital electronic system used in national security. Unlike radar, it is placed in an orbit above the Earth and uses cameras to take pictures of the Earth.

Home security

Motion sensors and CCTVs are the two most common home security systems. Motion sensors are usually installed outside the house. These let you know if someone is walking around your house or premise.

There are different types of motion sensors available in the market, including passive infrared (PIR), ultrasonic and tomographic.

Personal security

Whether you are alone, at home, travelling, at your workplace or in a group, there can be many security issues. Vulnerabilities and possibilities could come from smart TVs, computers, the Internet, smartphones and so on. The main goal of personal security alarms is to make a loud sound and attract attention in an emergency, and alert those nearby that the user is in danger. These gadgets are small, wireless, portable and easy to conceal.

Industrial security

Apart from CCTV systems, there are other security systems meant for industrial setups and related establishments. Due to the variety and complexity of commercial setups and industries, it is important to go beyond basic physical security, from simple to very complex systems.

Industrial security systems may include fire alarms, chemical sensors, access control systems, video surveillance units and intrusion detection systems, for a complete solution for protecting workers and their assets.

Theoretical learning Activity

- ✓ Brainstorming on sensors application
- ✓ Group discussion on sensors application

Practical learning Activity

- ✓ Identification of application of sensors in industrial robot
- ✓ Identification of application of sensors in NC machine tools
- ✓ Identification of application of sensors in security

Points to Remember (Take home message)

- ➢ Machine controls are divided into three groups,
- Traditional numerical control (NC);
- Computer numerical control (CNC);
- Distributed numerical control (DNC).

Learning outcome 3:3 Formative assessment

Q1) Multiple choice

i) A sensor is a ………..

- ○ Subsystem
- ○ Machine
- ○ **Module**
- ○ All the above

ii)The function of a sensor is to ……….

a. **Detect events within specified environment**
b. Separate physical parameters
c. Track and transfer data to computer processor
d. Both a and c

iii)Sensor provides output signal depending on ………….

a. **In put**
b. Physical quantity
c. Both a and b
d. None of the above

Q2) Sensors are independent devices integrated into regular items or machines for smart use. Identify the application of sensors in security.

Q3) What's the Purpose of Servomechanisms?

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