

CHAPTER 1: BASIC ELECTRONIC SKILLS

Unit of learning code: IT/CU/ICT/CC/1/5

Related Unit of Competency in Occupational Standard: Apply Basic Electronic

1.1 Introduction to the unit of learning

This unit specifies the competencies required to demonstrate basic skills of electronics. It involves identification of electric circuits, electronic components, understand semi-conductor theory, identify, and classify memories, apply number systems and identify emerging trends in electronics.

1.2 Summary of Learning Outcomes

1. Identify electric circuits.
2. Identify Electronic components
3. Understand Semi-conductor theory.
4. Identify and classify memory.
5. Apply Number Systems
6. Emerging trends in Electronics

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1.2.1 Learning Outcome 1: Identify electrical circuits.

1.2.1.1 Introduction to the learning outcome

This learning outcome covers definition of electrical circuit, Basic electrical quantities and their units including EMF in volts, Current in Amperes, Power in watts, Energy in joules, and Resistance in ohms. The outcome also covers types of electrical circuits, Simple AC circuits and simple DC circuits.

1.2.1.2 Performance Standard

- 1.2.1.2.1. Electrical circuit are identified.
- 1.2.1.2.2. Electrical quantities and their units are identified.
- 1.2.1.2.3. Types of electrical circuits are identified.

1.2.1.3 Information Sheet

a) Electric circuit

In order for electrons to flow they need a closed circuit. An Electric Circuit is a closed path for transmitting an electric current through the medium of electrical and magnetic fields. The flow of electrons across the loop constitutes the electric current. Electrons enter the circuit through the 'Source' which can be a battery or a generator. The source provides energy to the electrons, by setting up an electrical field which provides the electromotive force. The electrons leave the circuit through the load, to the earth ground, thus completing a closed path. The load or output can be any

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simple home appliance like television, lamp, refrigerator, or can be a complex load such as that on a hydroelectric power generating station.

A simple electric circuit consists of a source (such as a battery), wires as conducting medium and a load (such as a light bulb). The battery provides required energy for flow of electrons, to the light bulb.

b) Standard Electrical quantities and their units of measure

The table shows electrical quantities which are used in electronics and the unit (and unit symbol) which is used to measure each quantity. The relationship between quantities can be written using words or symbols (letters), but symbols are normally used because they are much shorter; for example, V is used for voltage, I for current and R for resistance.

Table 3: Standard Electrical quantities and their units of measure

Electrical Parameter	Measuring Unit	Symbol	Description
Voltage	Volt	V or E	Unit of Electrical Potential $V = I \times R$
Current	Ampere	I or i	Unit of Electrical Current $I = V \div R$
Resistance	Ohm	R or Ω	Unit of DC Resistance $R = V \div I$
Conductance	Siemen	G or \mathcal{U}	Reciprocal of Resistance $G = 1 \div R$
Capacitance	Farad	C	Unit of Capacitance $C = Q \div V$
Charge	Coulomb	Q	Unit of Electrical Charge $Q = C \times V$

c) Basic Electrical Circuits

As mentioned above in the introduction, a circuit is an interconnection of elements. These elements are classified into active or passive elements, based on their capability to generate energy.

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d) Active Circuit Elements

Active Elements are those which can generate energy. Examples include batteries, generators, operational amplifiers, and diodes. Note that in an electrical circuit, the source elements are the most significant active elements.

An energy source, whether a voltage or current source, is of 2 types – Independent and Dependent sources. Example of an Independent source is the battery which provides a constant voltage to the circuit, irrespective of the current flowing through the terminals.

Example of a dependent source is a transistor, which provides current to the circuit, depending upon the voltage applied to it. Another example is an Operational Amplifier, which provides voltage, depending upon the differential input voltage applied to its terminals.

e) Passive circuit Elements

Passive Elements can be defined as elements which can control the flow of electrons through them. They either increase or decrease the voltage. Here are some examples of passive elements.

- Resistor**: A resistor opposes the flow of current through it. For a linear circuit, Ohm's law is applicable, which states that voltage across the resistor is directly proportional to the current flowing through it, the proportional constant being the resistance.

- Inductor**: An inductor stores energy in form of the electromagnetic field. The voltage across an inductor is proportional to the rate of change of current flowing through it.

- Capacitor**: A capacitor stores energy in form of the electrostatic field. The voltage across a capacitor is proportional to the charge.

f) Types of Electrical Circuits

DC Circuits

In DC Circuits, the excitation applied is a constant source. Based on the type of connection of active and passive components with the source, a circuit can be classified into Series and Parallel circuits.

Series Circuits

When several passive elements are connected in series with an energy source, such a circuit is known as a series circuit. For a series circuit, same amount of current flows through each element and voltage is divided. In series circuit, as the elements are connected in a line, if there is a faulty element among them, the complete circuit acts as an open circuit.

- For a resistor connected in DC circuits, the voltage across its terminals is directly proportional to the current passing through it, thus maintaining a linear relationship between the voltage and current. For resistors connected in series, the total resistance is equal to the sum of all resistance values.
- For capacitors connected in series, the total capacitance is equal to the sum of reciprocals of all capacitance values.
- For inductors connected in series, total inductance is equal to the sum of all inductance values.

Parallel Circuits

In a parallel circuit, one terminal of all the elements is connected to the one terminal of the source and the other terminal of all elements is connected to the other terminal of the source.

In parallel circuits, the voltage remains the same in the parallel elements while the current changes. If there is any faulty element among parallel elements there is no effect on the circuit.

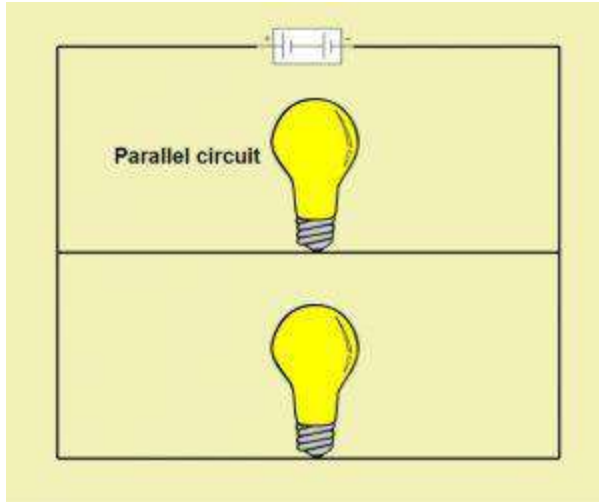


Figure 1: Parallel circuit

- For resistors connected in parallel, the total resistance is equal to the sum of reciprocals of all resistance values.
- For capacitors connected in series, the total capacitance is equal to the sum of all capacitance values.
- For inductors connected in series, total inductance is equal to the sum of all reciprocals of inductance values.

AC circuits

Ac circuits are those circuits, whose excitation element is an AC source. Unlike DC source which is constant AC source has variable current and voltage at regular intervals of time. Generally, for high power applications, AC circuits are used.

Simple AC Circuit using resistance

For alternating current passing through the resistor, the ratio of current and voltage depends upon the phase and frequency of the supply. The applied voltage will change constantly with time and Ohm's law can be used to calculate current passing through the resistor at any instant of time.

In other words, if at time t seconds, the value of voltage is v volts, current will be:

$$i = v/R$$

where the value of R is always constant.

Above equation shows that polarity of current depends upon that of the voltage. Also, both current and voltage reach their maximum and zero points at the same time. Thus, for a resistor, voltage is in phase with the applied current.

Consider the below circuit diagram

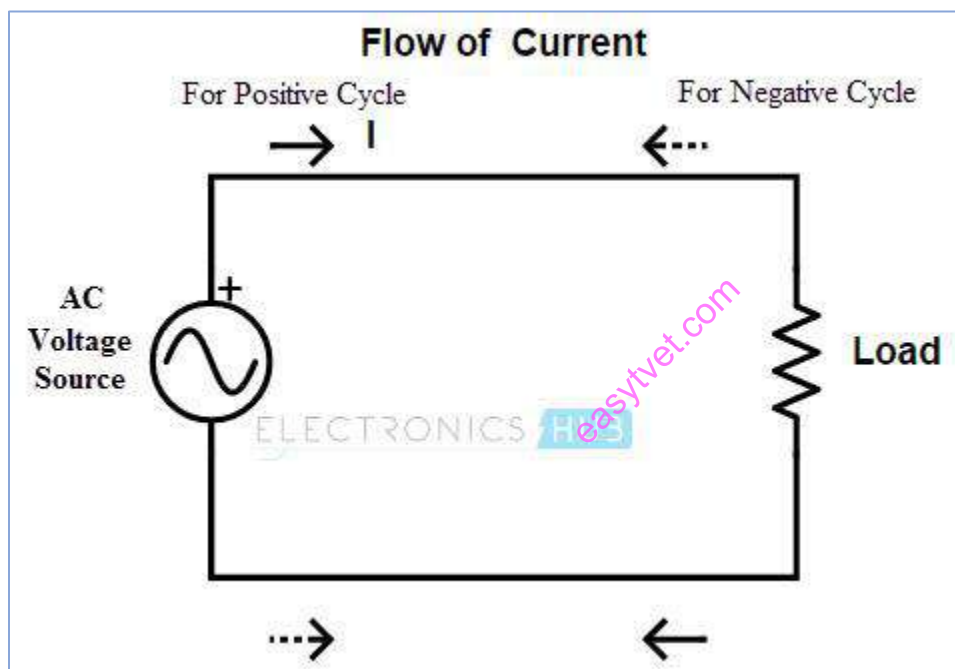


Figure 2: Flow of current (adapted from electronics hub)

When the switch is closed, current passes through the resistor and is given by the below equation

$$i = I_m \cos(\omega t + \Phi)$$

$$\text{Voltage, } V = IR = R I_m \cos(\omega t + \Phi)$$

For a resistor, both voltage and current values will rise and fall at the same time. Hence, the phase difference between voltage and current is zero.

AC Circuit using pure inductance

A coil of thin wire wrapped on a cylindrical core is known as an Inductor. The core can be an air core (hollow laminated) or an iron core. As alternating current flows through the inductor, the magnetic field also changes. This change in magnetic field results in an induced voltage across the inductor. As per Lenz law, the induced voltage is such that it opposes the flow of current through it.

During the first half cycle of the source voltage, the inductor stores energy in form of magnetic field and in the next half, it releases energy. The induced EMF is given as below

$$e = L \frac{di}{dt}$$

Here, L is the self-inductance.

Now, Input AC voltage applied is given as $v(t) = V_m \sin \omega t$

Current through the inductor is: $I(t) = I_m \sin \omega t$

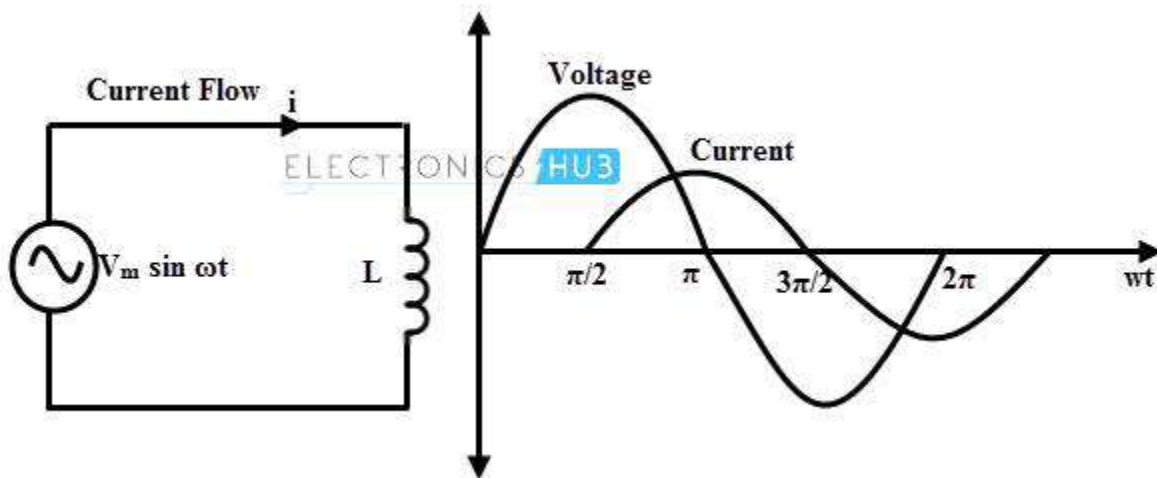


Figure 3: Current flow graph (adapted from electronics hub)

So, the voltage across the inductor would be

$$e = L \frac{di}{dt} = \omega L I_m \cos[\omega t] = \omega L I_m \sin[\omega t + 90^\circ]$$

Thus, for an inductor, voltage leads the current by 90 degrees.

Now, resistance by an inductor is termed as Reactance and given by

Thus, impedance or resistance is proportional to rate of change of current for an inductor.

AC Circuit with a capacitor

For a constant DC supply, the capacitor plates charge up to the applied voltage, stores this charge temporarily and then starts discharging. Once a capacitor is fully charged, it blocks the flow of current as the plates get saturated.

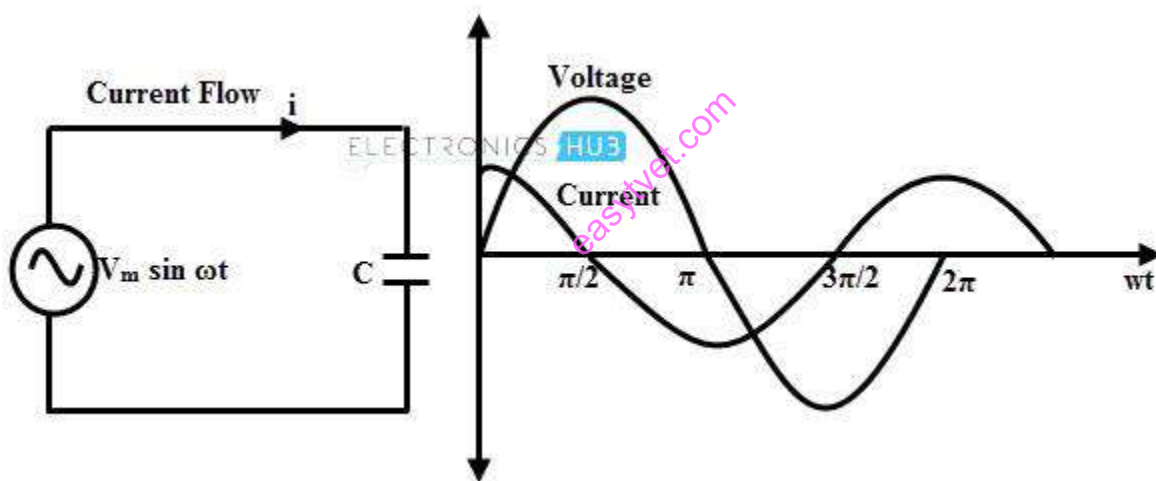


Figure 4: AC Circuit with Capacitor (adapted from electronics hub)

When AC supply voltage is applied to a capacitor, the rate of charging and discharging depends upon the supply frequency. Voltage across the capacitor lags the current flowing through it by 90 degrees.

Current through the capacitor is given as

$$e = L \frac{di}{dt}$$

The capacitive reactance is given as:

$$e = Ld/idt$$

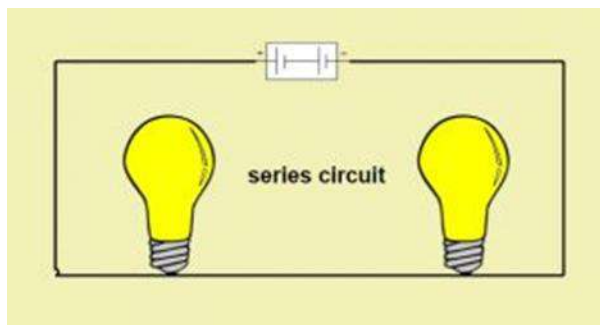
Thus, impedance or reactance to AC supply is inversely proportional to the frequency of supply.

1.2.1.4 Learning Activities

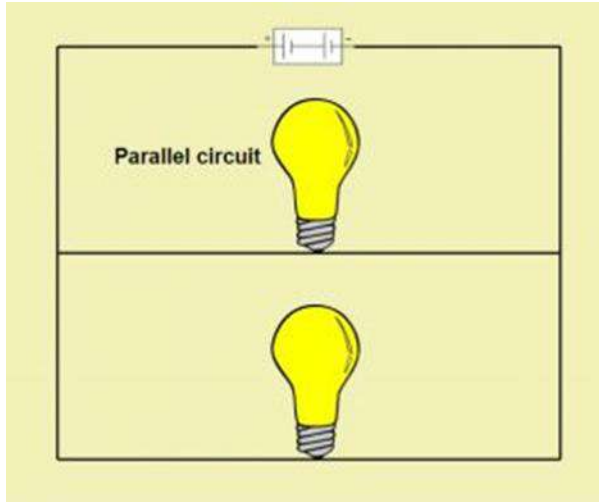
- The trainee is required to visit any active electrical or electronic workshop, either within the institution or outside. The trainee is required to identify at least six of the available electric components.
- In the visit above, the trainee is required to classify the identified components in writing as either active or passive, based on their use.

1.1.2.5 Self-Assessment

1. What is the difference between active and passive elements?
2. Examine the figure below and illustrate how the total voltage, resistance and inductance is determined.



3. Examine the figure below and illustrate how total voltage, resistance and inductance is determined.



4. As per Lenz law, analyze how an inductor works
5. Illustrate by use of a diagram how a capacitor works in both AC and DC circuits
6. With an aid of a formula, elaborate a simple AC Circuit using resistance

1.2.1.6 Tools, Equipment, Supplies and Materials

Tools

1. Screw Drivers
2. Pliers
3. Wire cutters
4. Wire Strippers
5. Clamps
6. Vises

Equipment

- Voltmeter
- Ohmmeter
- Ammeter
- Multimeter
- Power supplies
- LCR meter

Materials and supplies

- Circuits
- Semiconductor materials
- Conductors e.g. copper, gold, silver
- Insulators e.g. rubber, glass, mica

1.2.1.7 References

2. Wempen, F. (2014). Computing fundamentals: Introduction to computers. John Wiley & Sons.
3. Hamacher, C., Vranesic, Z., & Zaky, S. (2002). Computer organization. McGraw-Hill.

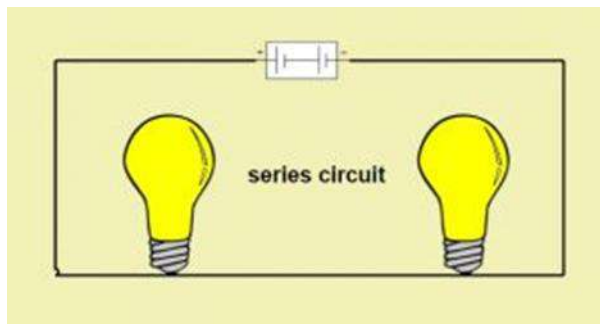
1.2.1.7 Answers to self-assessment

What is the difference between active and passive elements?

Active Elements are those which can generate energy. Examples include batteries, generators, operational amplifiers and diodes.

Passive Elements can be defined as elements which can control the flow of electrons through them. They either increase or decrease the voltage. Here are some examples of passive elements.

Examine the figure below and illustrate how the total voltage, resistance and inductance is determined.

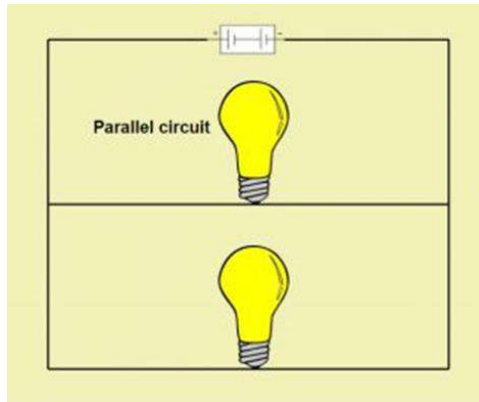


•For a resistor connected in DC circuits, the voltage across its terminals is directly proportional to the current passing through it, thus maintaining a linear relationship between the voltage and current. For resistors connected in series, the total resistance is equal to the sum of all resistance values.

•For capacitors connected in series, the total capacitance is equal to the sum of reciprocals of all capacitance values.

•For inductors connected in series, total inductance is equal to the sum of all inductance values.

Examine the figure below and illustrate how the total voltage, resistance and inductance is determined.



• For resistors connected in parallel, the total resistance is equal to the sum of reciprocals of all resistance values.

• For capacitors connected in series, the total capacitance is equal to the sum of all capacitance values.

• For inductors connected in series, total inductance is equal to the sum of all reciprocals of inductance values.

As per Lenz law, analyze how an inductor works

A coil of thin wire wrapped on a cylindrical core is known as an Inductor. The core can be an air core (hollow laminated) or an iron core. As alternating current flows through the inductor, the magnetic field also changes. This change in magnetic field results in an induced voltage across the inductor. As per Lenz law, the induced voltage is such that it opposes the flow of current through it.

Illustrate by use of a diagram how a capacitor works in both AC and DC circuits

For a constant DC supply, the capacitor plates charge up to the applied voltage, stores this charge temporarily and then starts discharging. Once a capacitor is fully charged, it blocks the flow of current as the plates get saturated.

When AC supply voltage is applied to a capacitor, the rate of charging and discharging depends upon the supply frequency. Voltage across the capacitor lags the current flowing through it by 90 degrees.

With an aid of a formula, elaborate a simple AC Circuit using resistance

For alternating current passing through the resistor, the ratio of current and voltage depends upon the phase and frequency of the supply. The applied voltage will change constantly with time and Ohm's law can be used to calculate current passing through the resistor at any instant of time.

In other words, if at time t seconds, the value of voltage is v volts, current will be:

$i = v/R$, where the value of R is always constant.

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1.2.2 Learning Outcome 2: Identify Electronic components

1.2.2.1 Introduction to the learning outcome

This learning outcome covers identification of electronic components including Resistor, Capacitor, Diode and Inductor. It further elaborates some characteristic of electronic components, application of electronic components and identification of integrated circuit characteristics.

1.2.2.2 Performance Standard

1. Identification of electrical components is done.
2. Characteristic of electronic components are identified.
3. Application of electronic components are Identified.
4. Characteristics of integrated circuit are identified.

1.2.2.3 Information Sheet

a) Identification of electronic components

There are numerous basic electronic components that are used for building electronic circuits. Without these components, circuit designs are never complete or didn't function well. These components include resistors, diodes, capacitors, integrated circuits, and so on. Some of these components consist of two or more terminals that are soldered to circuit boards. Some may be packaged types like integrated circuits in which different semiconductor devices are integrated. Here is a brief overview of each of these basic electronic components and you can get in-depth information by clicking links attached to each component.

b) Definition of Basic Electronics Components

Electronic components are basic discrete devices in any electronic system to use in electronics otherwise different associated fields. These components are basic elements that are used to design electrical and electronic circuits. These components have a minimum of two terminals which are used to connect to the circuit. The classification of electronic components can be done based on applications like active, passive, and electromechanical.

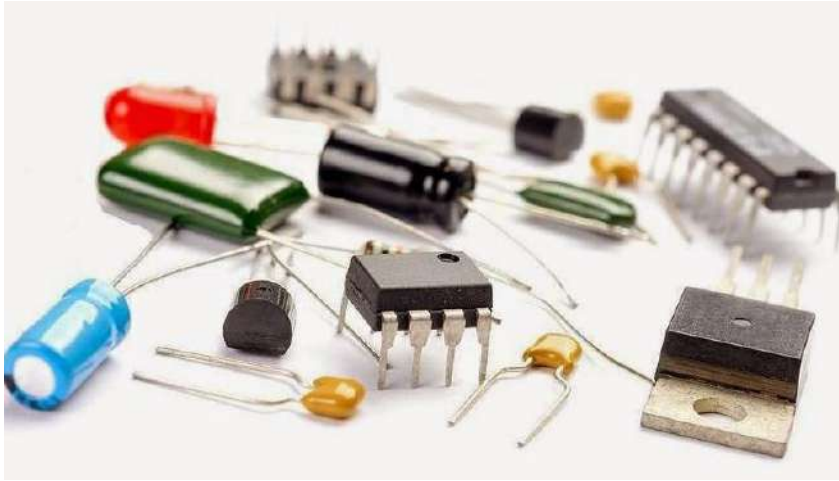


Figure 5: Major Electronic Components

In designing an electronic circuit following are taken into consideration:

- Basic electronic components: capacitors, resistors, diodes, transistors, etc.
- Power sources: Signal generators and DC power supplies.
- Measurement and analysis instruments: Cathode Ray Oscilloscope (CRO), multimeters, etc.

c) Active Components

These components are used to amplify electrical signals to generate electric power. The functioning of these components can be done like an AC circuit within electronic devices to protect from voltage and enhanced power. An active component executes its functions because it is power-driven through an electricity source. All these components require some energy source that is normally removed from a DC circuit. Any quality type of active component will include an oscillator, IC (integrated circuit) & transistor.

d) Passive Components

These types of components cannot use mesh energy into the electronic circuit because they don't rely on a power source, excluding what is accessible from the AC circuit they are allied to. As a result, they cannot amplify, although they can increase a current otherwise voltage or current. These components mainly include two-terminals like resistors, inductors, transformers & capacitors.

e) Electromechanical Components

These components use an electrical signal to make some mechanical changes like rotating a motor. Generally, these components use electrical current to form a magnetic field so that physical movement can be caused. Different types of switches and relays are applicable in these kinds of components. The devices which have the process of electrical as well as mechanical are electromechanical devices. An electromechanical component is operated manually to generate electrical output through the mechanical movement.

Passive Electronic Components

These components can store or maintains energy either in the form of current or voltage. Some of these components are discussed below.

1. Resistors

A resistor is a two-terminal passive electronic component, used to oppose or limit the current. Resistor works based on the principle of Ohm's law which states that "voltage applied across the terminals of a resistor is directly proportional to the current flowing through it"

$$V=IR$$

The units of the resistance are ohms

Where R is the constant called resistance

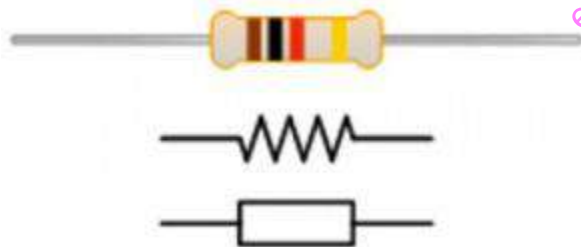


Figure 6: Resistor Components

Resistors are further classified based on the following specifications such as the power rating, type of material used, and resistance value. These resistor types are used for different applications.

a) Fixed Resistors

This type of resistor is used to set the right conditions in an electronic circuit. The values of resistance in fixed resistors are determined during the design phase of the circuit, based on this there is no need to adjust the circuit.

b) Variable Resistors

A device that is used to change the resistance according to our requirements in an electronic circuit is known as a variable resistor. These resistors comprise a fixed resistor element and a slider that taps on to the resistor element. Variable resistors are commonly used as a three-terminal device for calibration of the device.

2. Capacitors

A capacitor made from two conductive plates with an insulator between them and it stores electrical energy in the form of an electric field. A capacitor blocks the DC signals and allows the AC signals and also used with a resistor in a timing circuit.

The stored charge is $Q=CV$

Where C is the capacitance of a capacitor and V is the applied voltage.

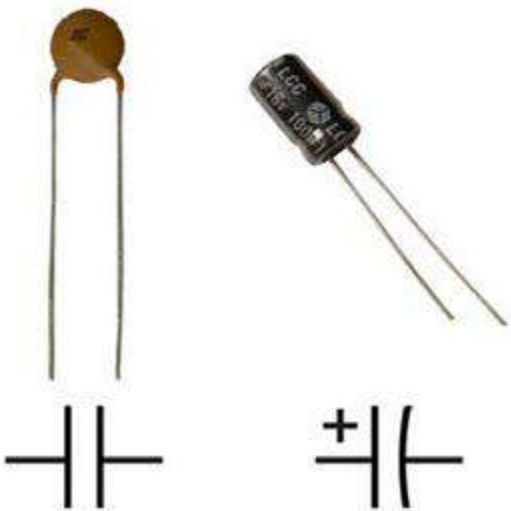


Figure 7: Capacitor Components

These capacitors are of different types like film, ceramic, electrolytic, and variable capacitors. For finding its value number and color-coding methods are used and it also possible to find the capacitance value with LCR meters.

3. Inductors

An inductor is also referred to as an AC resistor which stores electrical energy in the form of magnetic energy. It resists the changes in the current and the standard unit of inductance is Henry. The capability of producing magnetic lines is referred to as inductance.

The inductance of the inductor is given as $L = (\mu \cdot K \cdot N^2 \cdot S) / l$.

Where,

‘L’ is inductance,

‘ μ ’ is Magnetic permeability,

‘K’ is a magnetic coefficient,

‘S’ is the cross-section area of the coil,

‘N’ is the number of turns of the coils,

And ‘l’ is the length of the coil in the axial direction.

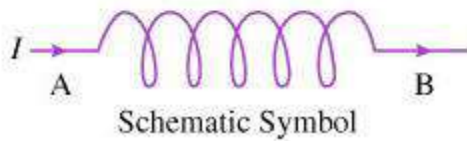
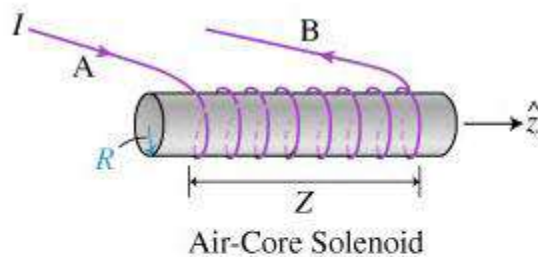


Figure 8: Inductor Components

Other passive electronic components include different types of sensors, motors, antennas etc. To reducing the complexity of this article few of the passive components are discussed above.

Active Electronic Components

These components rely on a source of energy and are able to control the electron flow through them. Some of these components are semiconductors like diodes, transistors, integrated circuits, various displays like LCD, LED, CRTs, and power sources like batteries, PV cells, and other AC and DC supply sources.

4. Diodes

A diode is a device that allows current to flow in one direction and usually made with the semiconductor material. It has two terminals, anode and cathode terminals. These are mostly used in converting circuits like AC to DC circuits. These are of different types like PN diodes, Zener diodes, LEDs, photodiodes, etc.

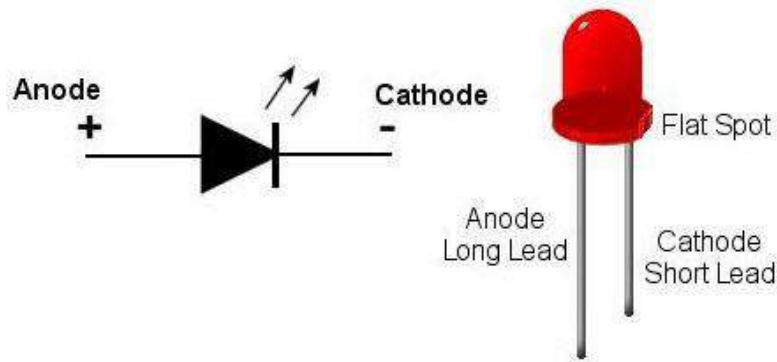


Figure 9: Diodes

5. Transistors

A transistor is a three-terminal semiconductor device. Mostly it is used as a switching device and also as an amplifier. This switching device can be voltage or current controlled. By controlling the voltage applied to the one terminal controls the current flow through the other two terminals. Transistors are of two types, namely bipolar junction transistor (BJT) and field-effect transistors (FET). And further, these can be PNP and NPN transistors.

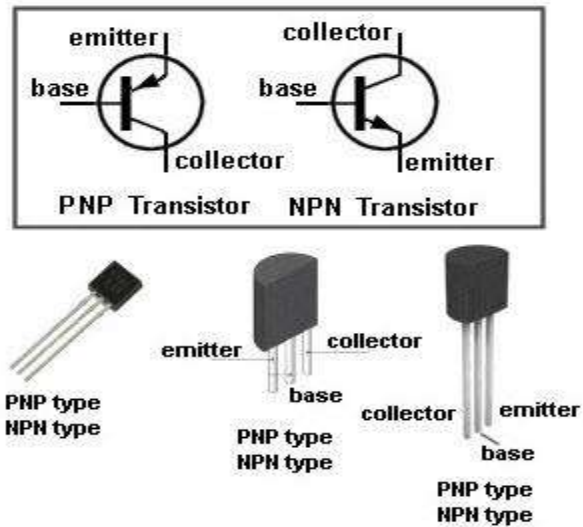


Figure 10: Transistors

Characteristics of Active and Passive Electronic Components

Now that we have understood about the Active and Passive devices and its types, let us do a comparison between the characteristics of active and passive components based on certain parameters as defined below

- 1) **Source of energy** – Active components require an extra source of energy. In the case of passive components, no extra source of energy is required for their operation. A resistor works on its own without the need for a specific voltage.
- 2) **Energy:** Active components produce energy in the form of voltage or current but passive components are those devices that store energy, like a capacitor, stores its energy in form of electric field and an inductor stores its energy in form of a magnetic field.
- 3) **Linearity:** Passive components are linear and active components are non-linear. Meaning in a passive component like a resistor, the voltage drop across will be linear to its resistance value according to Ohms Law. While in a transistor or other active components the output will have an amplification factor that will not be linear.

4) **Power gain:** Active components are capable of providing power gain whereas in the case of passive components the ability to amplify power is not present.

5) **Controlling the current:** Active component as the name implies can easily control the flow of the current. The same task cannot be done by a passive component.

6) **External source:** Active components as seen earlier require an extra source to control and maintain its operations but in the case of passive components, there is no requirement of an external source.

Applications of various electronic components

1. Capacitors

Though capacitors look like batteries, they can perform different types of functions in a circuit such as blocking direct current while allowing alternating current to pass or smooth the output from a power supply. They are also used in electric power transmission systems to stabilize voltage and power flow. One of the most significant functions of a capacitor in the AC systems is power factor correction, without which you can't provide sufficient amount of starting torque to single phase motors.

Filters Capacitor Applications

If you are using a microcontroller in a circuit to run a specific program, you don't want its voltage to drop as that will reset the controller. That's why designers use a capacitor. It can supply the microcontroller with the necessary power for a split second to avoid a restart. In other words, it filters out the noise on the power line and stabilizes the power supply.

Hold-Up Capacitor Applications

Unlike a battery, a capacitor releases its charge rapidly. That's why it is used to provide power to a circuit for a short while. Your camera batteries charge the capacitor attached to the flash gun. When you take a flash photograph, the capacitor releases its charge in a split second to generate a flash of light.

Timer Capacitor Applications

In a resonant or time-dependent circuit, capacitors are used along with a resistor or inductor as a timing element. The time required to charge and discharge a capacitor determines the operation of the circuit.

2. Resistors

Resistors have plenty of applications, but the three most common ones are managing current flow, dividing voltage, and resistor-capacitor networks.

Limiting the Flow of Current

If you don't add resistors to a circuit, the current will flow at dangerously high levels. It can overheat other components and possibly damage them. For example, if you connect an [LED](#) directly to a battery, it would still work. However, after some time the LED will heat up like a fireball. It will eventually burn as LEDs are less tolerant to heat.

But, if you introduce a resistor in the circuit, it will reduce the flow of current to an optimal level. Thus, you can keep the LED on longer without overheating it.

Dividing Voltage

Resistors are also used to reduce the voltage to the desired level. Sometimes, a particular part of a circuit such as a microcontroller may need a lower voltage than the circuit itself. This is where a resistor comes in.

Let's say your circuit runs off of a 12V battery. However, the microcontroller needs only a 6V supply. So, to divide the voltage in half, all you have to do is place two resistors of equal resistance value in series. The wire in between the two resistors will have halved the voltage of your circuit where the microcontroller can be attached. Using appropriate resistors, you can lower the voltage within the circuit to any level.

Resistor-Capacitor Networks

Resistors are also used in combination with capacitors to build ICs that contain resistor-capacitor arrays in a single chip. They are also known as RC filters or RC networks. They are often used to suppress electromagnetic Interference (EMI) or Radio Frequency Interference (RFI) in various instruments, including input/output ports of computers and laptops, Local Area Networks (LANs), and Wide Area Networks (WANs), among others. They are also used in machine tools, switchgears, motor controllers, automated equipment, industrial appliances, elevators, and escalators.

3. Diodes

Though diodes are one of the simplest components in an electronic circuit, they have unique applications across industries.

AC to DC Conversion

The most common and important application of a diode is the rectification of AC power to DC power. Usually, a half-wave (single diode) or a full-wave (four diodes) rectifier is used to convert AC power into DC power, particularly in household power supply. When you pass AC power supply through a diode, only half the AC waveform passes through it. As this voltage pulse is used to charge the capacitor, it produces steady and continuous DC currents without any ripples. Different combinations of diodes and capacitors are also used to build various types of voltage multipliers to multiply a small AC voltage into high DC outputs.

Bypass Diodes

Bypass diodes are often used to protect solar panels. When the current from the rest of the cells passes through a damaged or dusty solar cell, it causes overheating. As a result, the overall output power decreases, creating hot spots. The diodes are connected parallel to the solar cells to protect them against this overheating problem. This simple arrangement limits the voltage across the bad solar cell while allowing the current to pass through undamaged cells to the external circuit.

Voltage Spike Protection

When the power supply is suddenly interrupted, it produces a high voltage in most inductive loads. This unexpected voltage spike can damage the loads. However, you can protect expensive equipment by connecting a diode across the inductive loads. Depending on the type of security, these diodes are known by many names including snubber diode, flyback diode, suppression diode, and freewheeling diode, among others.

Signal Demodulation

They are also used in the process of signal modulation because diodes can remove the negative element of an AC signal efficiently. The diode rectifies the carrier wave, turning it into DC. The audio signal is retrieved from the carrier wave, a process called audio-frequency modulation. You can hear the audio after some filtering and amplification. Hence, diodes are commonly found in radios to extract the signal from the carrier wave.

Reverse Current Protection

Reversing polarities of a DC supply or incorrectly connecting the battery can cause a substantial current to flow through a circuit. Such a reverse connection can damage the connected load. That's why a protective diode is connected in series with the positive side of the battery terminal. The diode becomes forward-biased in the case of correct polarity and the current flows through the circuit. However, in the event of a wrong connection, it becomes reverse-biased, blocking the current. Thus, it can protect your equipment from potential damage.

4. Transistors

Transistors function as both, switches and amplifiers in most electronic circuits. Designers often use a transistor as a switch because unlike a simple switch, it can turn a small current into a much larger one. Though you can use a simple switch in an ordinary circuit, an advanced circuit may need varying amounts of currents at different stages.

Transistors in Hearing Aids

One of the most well-known applications of transistors is the hearing aid. Usually, a small microphone in the hearing aid picks up the sound waves, converting them into fluctuating electrical pulses or currents. When these currents pass through a transistor, they are amplified. The amplified pulses then pass through a speaker, converting them into sound waves once again. Thus, you can hear a substantially louder version of the surrounding noise.

Transistors in Computers and Calculators

We all know that computers store and process information using the binary language of “zero” and “one.” However, most people don’t know that transistors play a critical role in making something called logic gates, which are the backbones of computer programs. Transistors are often hooked up with logic gates to build a unique piece of an arrangement called a flip-flop. In this system, the transistor remains ‘on’ even if you remove the base current. It now flips on or off whenever new current passes through it. Thus, a transistor can store a zero when it’s off or a one when it’s on, which is the working principle of computers.

Darlington Transistors

A Darlington transistor is made of two PNP or NPN polar junction transistors placed together. It is named after its inventor Sidney Darlington. The sole purpose of a Darlington transistor is to deliver a high current gain from a low base current. You can find these transistors in instruments that require a high current gain at a low frequency such as power regulators, display drivers, motor controllers, light and touch sensors, alarm systems, and audio amplifiers.

IGBT and MOSFET Transistors

The Insulated-Gate Bipolar Transistor (IGBT) transistors are often used as amplifiers and switches in various instruments including electric cars, trains, refrigerators, air-conditioners, and even stereo systems. On the other hand, Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFET) are commonly used in integrated circuits to control a device’s power levels or for storing data.

Integrated Circuits

An Integrated circuit is a special component that is fabricated with thousands of transistors, resistors, diodes, and other electronic components on a tiny silicon chip. These are the building blocks of current electronic devices like cell phones, computers, etc. These can be analog or digital integrated circuits. Mostly used ICs in electronic circuits are Op-amps, timers, comparators, switches ICs, and so on. These can be classified as linear and nonlinear ICs depending on its application.

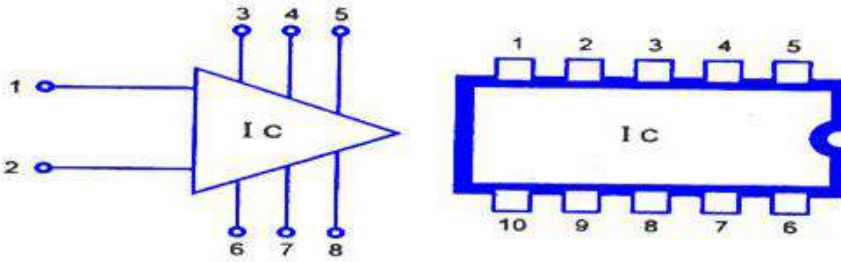


Figure 11: Integrated Circuits

Further reading

<https://www.elprocus.com/different-types-of-integrated-circuits/>

1.2.2.4 Learning Activities

- The trainee is required to visit any active electronic workshop. The trainee is supposed to identify the following electronic components: Resistors, Diodes, Capacitors, and Transistors.
- During the above visit, the trainee is required to give a detailed description on the various applications and uses of each of these components.
- The trainee is required to identify at least one integrated circuit in the arrangement.

1.2.2.5 Self-Assessment

1. Distinguish between fixed and variable resistors
2. What happens if you don't add resistors to a circuit?
3. One of the most well-known applications of transistors is the hearing aid. How does this work?

4. When the power supply is suddenly interrupted, it produces a high voltage in most inductive loads. What can you use to protect expensive equipment in such cases?
5. In designing an electronic circuit, what components are taken into consideration?

1.2.2.6 Tools, Equipment, Supplies and Materials

Tools

1. Screw Drivers
2. Pliers
3. Wire cutters
4. Wire Strippers
5. Clamps
6. Vises

Equipment

- Voltmeter
- Ohmmeter
- Ammeter
- Multimeter
- Power supplies
- LCR meter

easyvet.com

Materials and supplies

- Circuits
- Semiconductor materials

1.2.2.7 References

1. <https://www.encyclopedia.com/computing/dictionaries-thesauruses-pictures-and-press-releases/excess-3-code>
2. Crowe, J., & Hayes-Gill, B. (1998). Introduction to digital electronics. Elsevier.

1.2.2.8 Model answers to self-assessment

1. Distinguish between fixed and variable resistors

Fixed Resistors

This type of resistor is used to set the right conditions in an electronic circuit. The values of resistance in fixed resistors are determined during the design phase of the circuit, based on this there is no need to adjust the circuit.

Variable Resistors

A device that is used to change the resistance according to our requirements in an electronic circuit is known as a variable resistor. These resistors comprise a fixed resistor element and a slider that taps on to the resistor element. Variable resistors are commonly used as a three-terminal device for calibration of the device.

2. What happens if you don't add resistors to a circuit?

If you don't add resistors to a circuit, the current will flow at dangerously high levels. It can overheat other components and possibly damage them.

3. One of the most well-known applications of transistors is the hearing aid. How does this work?

Usually, a small microphone in the hearing aid picks up the sound waves, converting them into fluctuating electrical pulses or currents. When these currents pass through a transistor, they are amplified. The amplified pulses then pass through a speaker, converting them into sound waves once again. Thus, you can hear a substantially louder version of the surrounding noise.

4. When the power supply is suddenly interrupted, it produces a high voltage in most inductive loads. What can you use to protect expensive equipment in such cases?

This unexpected voltage spike can damage the loads. You can protect expensive equipment by connecting a diode across the inductive loads.

5. In designing an electronic circuit, what components are taken into consideration?

- *Basic electronic components: capacitors, resistors, diodes, transistors, etc.*
- *Power sources: Signal generators and DC power supplies.*

Measurement and analysis instruments: Cathode Ray Oscilloscope (CRO), multimeters, etc.

1.2.3 Learning Outcome 3: Understand Semi-conductor theory

1.2.3.1 Introduction to the learning outcome

This learning outcome covers definition of semiconductor and related terms, Description of the structure of matter, explanation of electrons in conductors and semiconductors, types of semiconductors materials, explanation of P-type and N-types materials, description of P-N junction diodes operations and operations of transistors.

1.2.3.2 Performance Standard

- 1.2.3.3.1 Explanation of semiconductor theory is done.
- 1.2.3.3.2 Structure of matter is described.
- 1.2.3.3.3 Electrons in conductors and semiconductors are explained.
- 1.2.3.3.4 Types of semiconductor materials are identified.
- 1.2.3.3.5 P-type and N-type materials are explained.
- 1.2.3.3.6 Description of P-N junction diodes operations is done.
- 1.2.3.3.7 Types and operations of transistors are identified.

1.2.3.3 Information Sheet

1. Semiconductor

A semiconductor is a physical substance that is designed to manage and control the flow of current in electronic devices and equipment. It neither allows a freely flowing electric current nor repels it completely. A semiconductor is in between a conductor and insulator and commonly used in the development of electronic chips, computing components and devices.

2. Semiconductor Materials: Silicon and Germanium

Semiconductor's materials such as silicon (Si), germanium (Ge) and gallium arsenide (GaAs), have electrical properties somewhere in the middle, between those of a “conductor” and an “insulator”. They are not good conductors nor good insulators (hence their name “semi”-conductors). They have very few “free electrons” because their atoms are closely grouped

together in a crystalline pattern called a “crystal lattice” but electrons are still able to flow, but only under special conditions.

The ability of semiconductors to conduct electricity can be greatly improved by replacing or adding certain donor or acceptor atoms to this crystalline structure thereby, producing more free electrons than holes or vice versa. That is by adding a small percentage of another element to the base material, either silicon or germanium.

On their own Silicon and Germanium are classed as intrinsic semiconductors, that is they are chemically pure, containing nothing but semi-conductive material. But by controlling the amount of impurities added to this intrinsic semiconductor material it is possible to control its conductivity. Various impurities called donors or acceptors can be added to this intrinsic material to produce free electrons or holes respectively.

b) Atoms and Atomic Structure of Semiconductors:

To understand how semiconductors work it is necessary to study briefly the **structure of matter**. All atoms are made of **electrons, protons and neutrons**. Most solid materials are classed, from the standpoint of electrical conductivity, as conductors, semiconductors or insulators.

Electrons

To be conductor, the substance must contain some **mobile electrons**—one that can move freely between the atoms. These free electrons come only from the valence (outer) orbit of the atom. Physical force associated with the valence electrons bind adjacent atoms together. The inner electrons below the valence level, do not normally enter into the conduction process.

Conductivity depends on the number of electrons in the valence orbit.

The degree of conductivity is determined as follows:

1. Atoms with fewer than four valence electrons are good conductors.
2. Atoms with more than four valence electron are poor conductors.

3. Atoms with four valence electrons are semiconductors.

c) **P-Type and N-Type Semiconductors**

P-n junction diodes are made up of two adjacent pieces of p-type and n-type semiconducting materials. P-type and n-type materials are simply semiconductors, such as silicon (Si) or germanium (Ge), with atomic impurities; the type of impurity present determines the type of the semiconductor. The process of purposefully adding impurities to materials is called doping; semiconductors with impurities are referred to as "doped semiconductors".

P-type

In a pure (intrinsic) Si or Ge semiconductor, each nucleus uses its four valence electrons to form four covalent bonds with its neighbors (see figure below). Each ionic core, consisting of the nucleus and non-valent electrons, has a net charge of +4, and is surrounded by 4 valence electrons. Since there are no excess electrons or holes in this case, the number of electrons and holes present at any given time will always be equal.

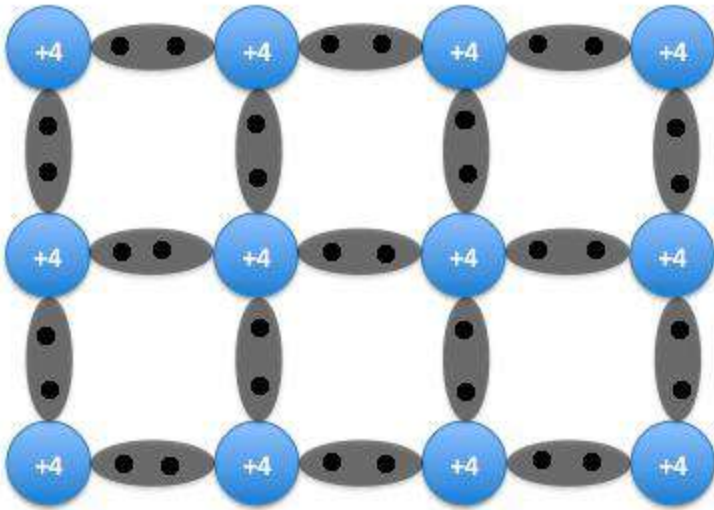


Figure 12: An intrinsic semiconductor. Note each +4 ion is surrounded by four electrons.

Now, if one of the atoms in the semiconductor lattice is replaced by an element with three valence electrons, such as a Group 3 element like Boron (B) or Gallium (Ga), the electron-hole balance will be changed. This impurity will only be able to contribute three valence electrons to the lattice, therefore leaving one excess hole (see figure below). Since holes will "accept" free electrons, a Group 3 impurity is also called an acceptor.

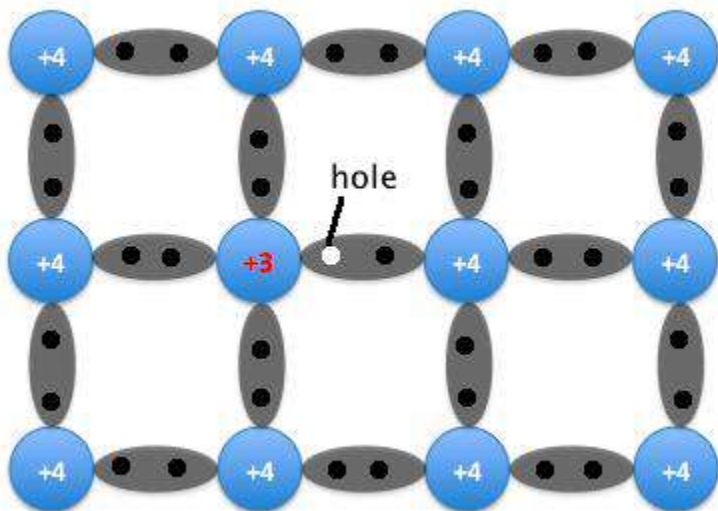


Figure 13: A semiconductor doped with an acceptor. An excess hole is now present.

Because an acceptor donates excess holes, which are considered to be positively charged, a semiconductor that has been doped with an acceptor is called a p-type semiconductor; "p" stands for positive. Notice that the material as a whole remains electrically neutral. In a p-type semiconductor, current is largely carried by the holes, which outnumber the free electrons. In this case, the holes are the majority carriers, while the electrons are the minority carriers.

N-type

In addition to replacing one of the lattice atoms with a Group 3 atom, we can also replace it by an atom with five valence electrons, such as the Group 5 atoms arsenic (As) or phosphorus (P). In this case, the impurity adds five valence electrons to the lattice where it can only hold four. This means that there is now one excess electron in the lattice (see figure below). Because it donates an electron, a Group 5 impurity is called a donor. Note that the material remains electrically neutral.

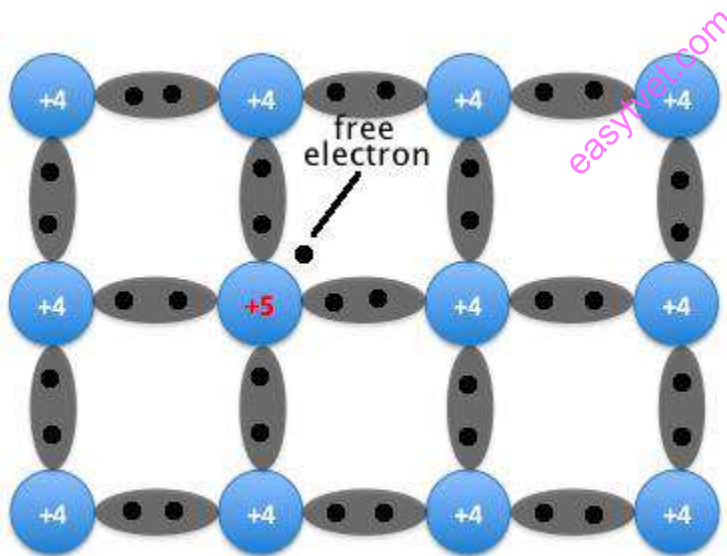


Figure 14: A semiconductor doped with a donor. A free electron is now present.

Donor impurities donate negatively charged electrons to the lattice, so a semiconductor that has been doped with a donor is called an n-type semiconductor; "n" stands for negative. Free electrons outnumber holes in an n-type material, so the electrons are the majority carriers and holes are the minority carriers.

d) P-N junction semiconductor diode

What is p-n junction semiconductor diode?

A p-n junction diode is two-terminal or two-electrode semiconductor device, which allows the electric current in only one direction while blocks the electric current in opposite or reverse direction. If the diode is forward biased, it allows the electric current flow. On the other hand, if the diode is reverse biased, it blocks the electric current flow. P-N junction semiconductor diode is also called as p-n junction semiconductor device.

In n-type semiconductors, free electrons are the majority charge carriers whereas in p-type semiconductors, holes are the majority charge carriers. When the n-type semiconductor is joined with the p-type semiconductor, a p-n junction is formed. The p-n junction, which is formed when the p-type and n-type semiconductors are joined, is called as p-n junction diode.

The p-n junction diode is made from the semiconductor materials such as silicon, germanium, and gallium arsenide. For designing the diodes, silicon is more preferred over germanium. The p-n junction diodes made from silicon semiconductors works at higher temperature when compared with the p-n junction diodes made from germanium semiconductors.

The basic symbol of p-n junction diode under forward bias and reverse bias is shown in the below figure

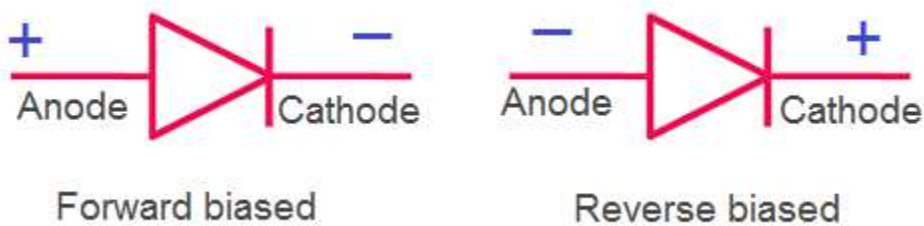


Figure 15: *Forward and Reverse Bias*

In the above figure, arrowhead of a diode indicates the conventional direction of electric current when the diode is forward biased (from positive terminal to the negative terminal). The holes which moves from positive terminal (anode) to the negative terminal (cathode) is the conventional direction of current.

The free electrons moving from negative terminal (cathode) to the positive terminal (anode) actually carry the electric current. However, due to the convention we have to assume that the current direction is from positive terminal to the negative terminal.

Biasing of p-n junction semiconductor diode

The process of applying the external voltage to a p-n junction semiconductor diode is called biasing. External voltage to the p-n junction diode is applied in any of the two methods: forward biasing or reverse biasing.

If the p-n junction diode is forward biased, it allows the electric current flow. Under forward biased condition, the p-type semiconductor is connected to the positive terminal of battery whereas; the n-type semiconductor is connected to the negative terminal of battery.

If the p-n junction diode is reverse biased, it blocks the electric current flow. Under reverse biased condition, the p-type semiconductor is connected to the negative terminal of battery whereas; the n-type semiconductor is connected to the positive terminal of battery.

Terminals of pn junction diode

Generally, terminal refers to a point or place at which any object begins or ends. For example, bus terminal or terminus is a place at which all the buses begins or ends. Similarly, in a p-n junction diode, terminal refers a point at which charge carriers begins or ends.

P-n junction diode consists of two terminals: positive and negative. At positive terminal, all the free electrons will ends and all the holes will begins whereas at negative terminal all the free electrons will begins and all the holes will ends.

- **Terminals of diode under forward bias**

In forward biased p-n junction diode (p-type connected to positive terminal and n-type connected to negative terminal), anode terminal is a positive terminal whereas cathode terminal is negative terminal.

Anode terminal is a positively charged electrode or conductor, which supplies holes to the p-n junction. In other words, anode or anode terminal or positive terminal is the source of positive charge carriers (holes), the positive charge carriers (holes) begins their journey at anode terminal and travel through the diode and ends at cathode terminal.

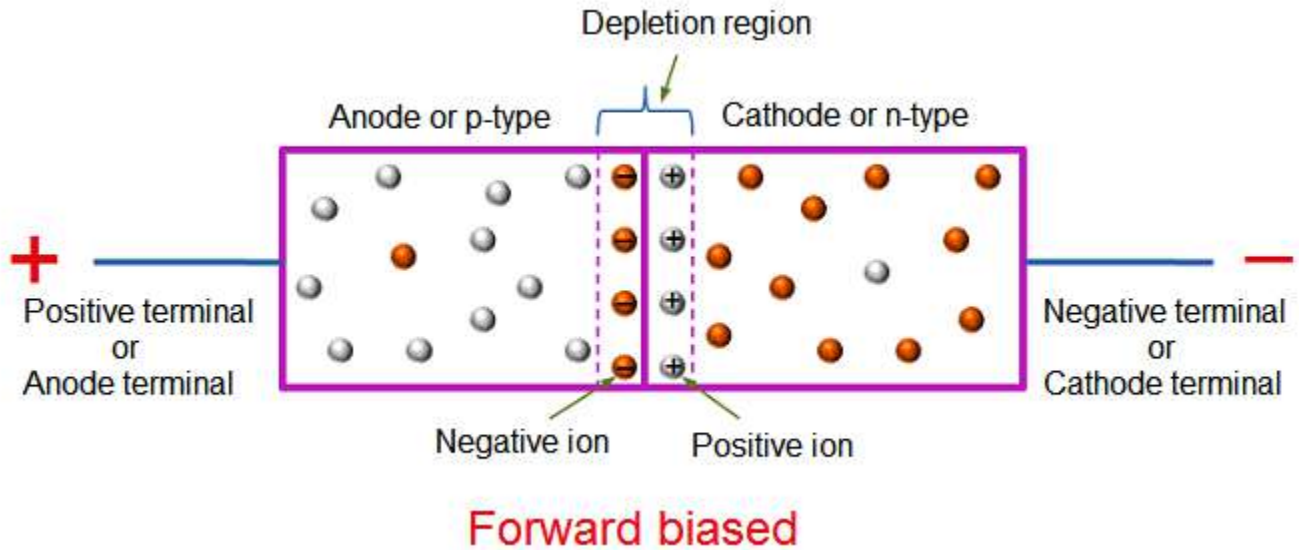


Figure 16: Forward Biased

Cathode is the negatively charged electrode or conductor, which supplies free electrons to the p-n junction. In other words, cathode terminal or negative terminal is the source of free electrons, the negative charge carriers (free electrons) begins their journey at cathode terminal and travel through the diode and ends at anode terminal.

The free electrons are attracted towards the anode terminal or positive terminal whereas the holes are attracted towards the cathode terminal or negative terminal.

- **Terminals of diode under reverse bias**

If the diode is reverse biased (p-type connected to negative terminal and n-type connected to positive terminal), the anode terminal becomes a negative terminal whereas the cathode terminal becomes a positive terminal.

Anode terminal or negative terminal supplies free electrons to the p-n junction. In other words, anode terminal is the source of free electrons, the free electrons begins their journey at negative or anode terminal and fills the large number of holes in the p-type semiconductor. The holes in the p-type semiconductor get attracted towards the negative terminal. The free electrons from the negative terminal cannot move towards the positive terminal because the wide depletion region at the p-n junction resists or opposes the flow of free electrons.

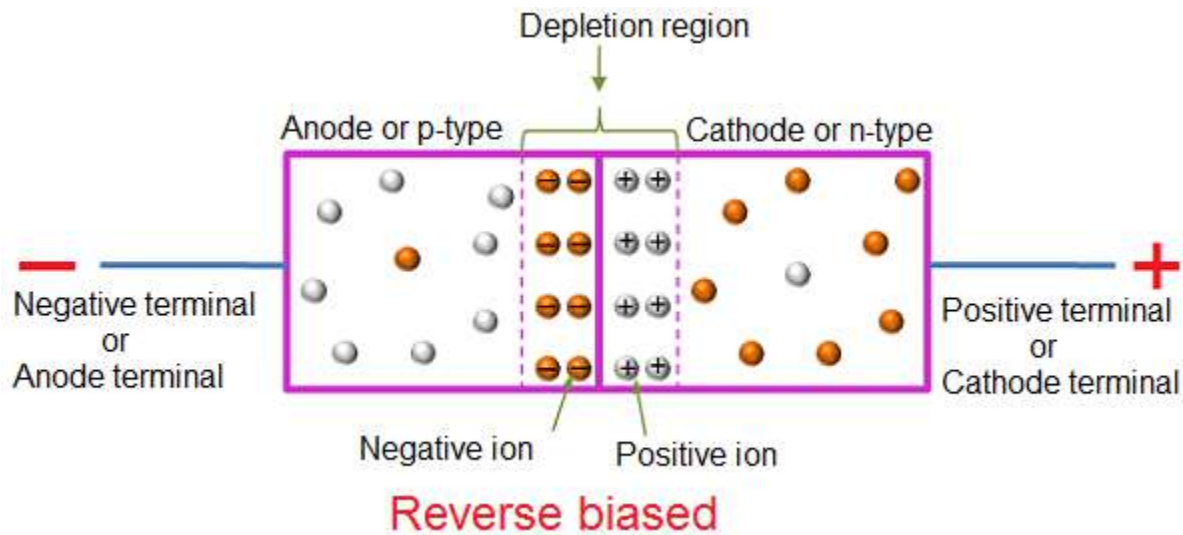


Figure 17: *Reverse Biased*

Cathode terminal or positive terminal supplies holes to the p-n junction. In other words, cathode terminal is the source of holes, the holes begins their journey at positive or cathode terminal and occupies the electrons position in the n-type semiconductor. The free electrons in the n-type semiconductor gets attracted towards the positive terminal. The holes from the positive terminal cannot move towards the negative terminal because the wide depletion region at the p-n junction opposes the flow of holes.

Silicon and germanium semiconductor diodes

- For designing the diodes, silicon is more preferred over germanium.
- The p-n junction diodes made from silicon semiconductors works at high temperature than the germanium semiconductor diodes.
- Forward bias voltage for silicon semiconductor diode is approximately 0.7 volts whereas for germanium semiconductor diode is approximately 0.3 volts.
- Silicon semiconductor diodes do not allow the electric current flow, if the voltage applied on the silicon diode is less than 0.7 volts.
- Silicon semiconductor diodes start allowing the current flow, if the voltage applied on the diode reaches 0.7 volts.

- Germanium semiconductor diodes do not allow the electric current flow, if the voltage applied on the germanium diode is less than 0.3 volts.
- Germanium semiconductor diodes start allowing the current flow, if the voltage applied on the germanium diode reaches 0.3 volts.
- The cost of silicon semiconductors is low when compared with the germanium semiconductors.

Advantages of p-n junction diode

P-n junction diode is the simplest form of all the semiconductor devices. However, diodes play a major role in many electronic devices.

- A p-n junction diode can be used to convert the alternating current (AC) to the direct current (DC). These diodes are used in power supply devices.
- If the diode is forward biased, it allows the current flow. On the other hand, if it is reverse biased, it blocks the current flow. In other words, the p-n junction diode becomes on when it is forward biased whereas the p-n junction diode becomes off when it is reverse biased (I.e. it acts as switch). Thus, the p-n junction diode is used as electronic switch in digital logic circuits.

e) Types of Transistors

Transistor is the proper arrangement of different semiconductor materials. General semiconductor materials used for transistor are silicon, germanium, and gallium-arsenide. Basically the transistors are classified depending on their structure. Each type of transistors has their own characteristics, advantages and disadvantages.

Some transistors are designed primarily for switching purpose, other side some are designed for amplification purpose and some transistors are designed for both amplification and switching purposes. Depending on the structure the transistors are classified into Bipolar Junction Transistors (BJT) and Field Effect Transistors.(FET)

Junction Transistors

Junction transistor is generally called as **Bipolar Junction Transistor (BJT)**. The BJT transistors have three terminals named emitter (E), Base (B), Collector (C). The name itself indicates that it has two junctions between p-type and n-type semiconductors. The BJT transistors are classified into NPN and PNP transistors depending on the construction.

Unlike FET transistors, the BJT transistors are current-controlled devices. If small amount of current flows through the base of a BJT transistor then it causes to flow large current from emitter to collector. The BJT transistors have low input impedance and it causes to flow large current through the transistor.

The BJT transistors are only the transistors which are turned ON by the input current which is given to the base. Bipolar junction transistors can operate in three regions, they are

- **Cut-off Region:** Here the transistor is in 'OFF' state i.e the current flowing through the transistor is zero.
- **Active Region:** Here the transistor acts as an amplifier.
- **Saturation Region:** Here the transistor is in fully 'ON' state and also works as a closed switch.

NPN Transistor

NPN is one of the two types of Bipolar Junction Transistors (BJT). The NPN transistor consists of two n-type semiconductor materials and they are separated by a thin layer of p-type semiconductor. Here the majority charge carriers are electrons and holes are the minority charge carriers. The flowing of electrons from emitter to collector forms the current flow in the transistor through the base terminal.

A small amount of current at base terminal causes to flow large amount current from emitter to collector. Nowadays the generally used bipolar transistor is NPN transistor, because the mobility of electrons is greater than mobility of holes. The standard equation for the currents flowing in the transistor is

$$I_E = I_B + I_C$$

The symbols and structure for NPN transistors are given below.

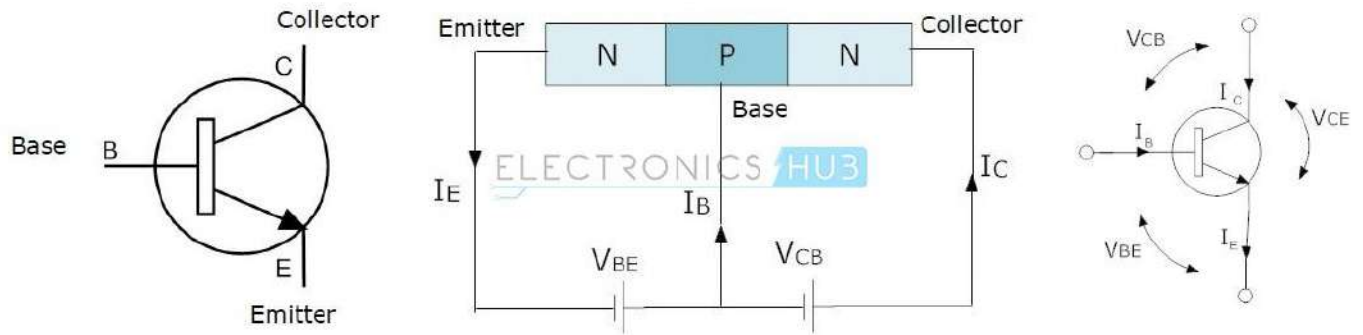


Figure 18: Symbols of NPN Transistor

PNP Transistor

The PNP is another type of Bipolar Junction Transistors (BJT). The PNP transistors contain two p-type semiconductor materials and are separated by a thin layer of n-type semiconductor. The majority charge carriers in the PNP transistors are holes and electrons are minority charge carriers. The arrow in the emitter terminal of transistor indicates the flow of conventional current. In PNP transistor the current flows from Emitter to Collector.

The PNP transistor is ON when the base terminal is pulled to LOW with respect to emitter. The symbol and structure for PNP transistor is shown below.

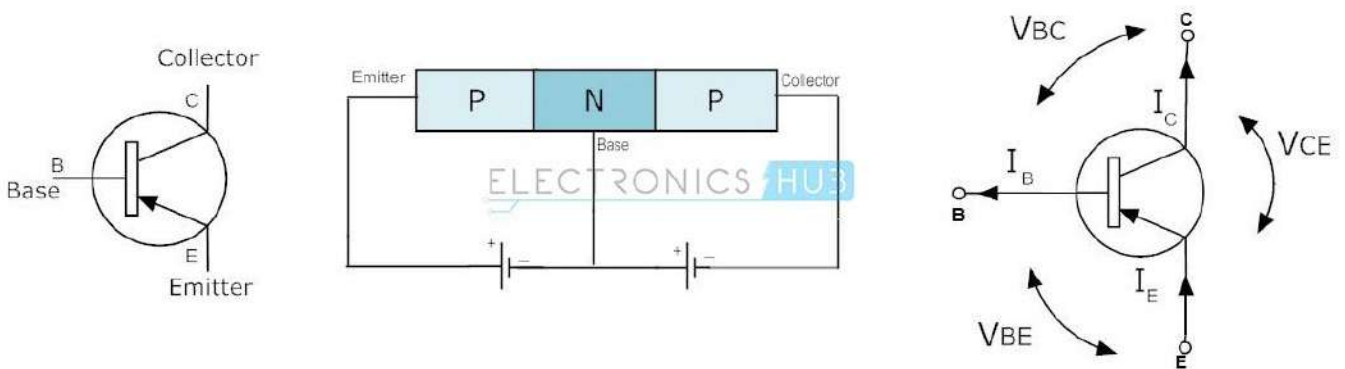
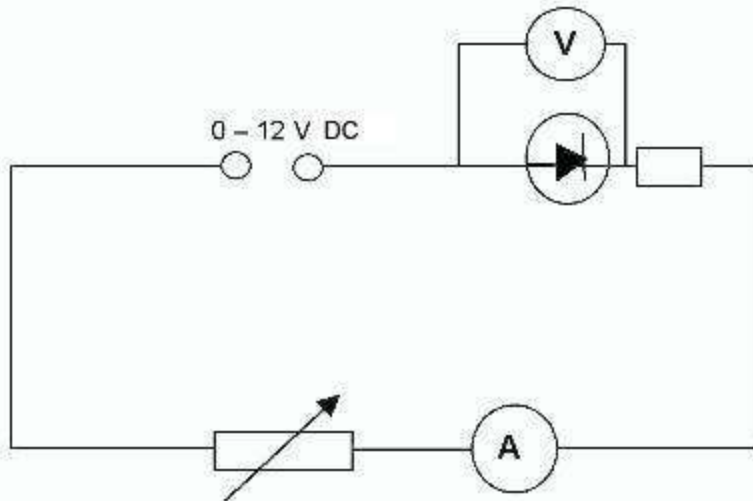


Figure 19: Symbols of PNP transistor (Adapted from electronics hub)

1.2.3.4 Learning Activities

The trainee is required to apply the below procedure in order to carry out the activities

1. Set up the circuit as shown below.



2. Use the variable power supply and the variable resistor to vary the potential difference across the diode from 0 V to +0.8 V in intervals of about 0.1 V. Record pairs of potential difference and current values.
3. Repeat in the range 0 V to -4.0 V in intervals of 0.5V, by reversing the connections on the diode.
4. Analysis. Plot a graph of current/A (y-axis) against potential difference/V (x-axis). Remember to include the readings for 'negative' voltages.
5. The resistance of the diode at a particular voltage = potential difference/current reading.
6. Use the graph to calculate the resistance of the diode at a number of different potential differences.
7. Describe how the resistance changes with potential difference. Is the resistance of the diode the same for 'positive' voltages and 'negative' voltages?
8. The conductance of the diode at a particular potential difference = current/potential difference.
9. Use the graph to calculate the conductance of the diode at a number of potential differences.

Special Instructions

Using a potential divider will enable trainees to get a full range of readings.

1.2.3.5 Self-Assessment

1. How can the ability of semiconductors to conduct electricity be greatly improved?
2. How does a substance become a conductor?
3. How is a P-Type semiconductor formed?

4. How is N-Type semiconductor formed?
5. What is biasing in a p-n junction semiconductor diode?

1.2.3.6 Tools, Equipment, Supplies and Materials

Tools

1. Screw Drivers
2. Pliers
3. Wire cutters
4. Wire Strippers
5. Clamps
6. Vises

Equipment

- Voltmeter
- Ohmmeter
- Ammeter
- Multimeter
- Power supplies
- LCR meter

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Materials and supplies

- Circuits
- Semiconductor materials
- Conductors e.g. copper, gold, silver
- Insulators e.g. rubber, glass, mica

1.2.3.7 References

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Sample Answers to self-assessment

1. How can the ability of semiconductors to conduct electricity be greatly improved?

By replacing or adding certain donor or acceptor atoms to this crystalline structure thereby, producing more free electrons than holes or vice versa. That is by adding a small percentage of another element to the base material, either silicon or germanium.

2. How does a substance become a conductor?

*To be conductor, the substance must contain some **mobile electrons**—one that can move freely between the atoms. These free electrons come only from the valence (outer) orbit of the atom.*

3. How is a P-Type semiconductor formed?

In a pure (intrinsic) Si or Ge semiconductor, each nucleus uses its four valence electrons to form four covalent bonds with its neighbors. Each ionic core, consisting of the nucleus and non-valent electrons, has a net charge of +4, and is surrounded by 4 valence electrons. Since there are no excess electrons or holes In this case, the number of electrons and holes present at any given time will always be equal.

4. How is N-Type semiconductor formed?

In this case, the impurity adds five valence electrons to the lattice where it can only hold four. This means that there is now one excess electron in the lattice (see figure below). Because it donates an electron, a Group 5 impurity is called a donor. Note that the material remains electrically neutral.

5. What is biasing in a p-n junction semiconductor diode?

The process of applying the external voltage to a p-n junction semiconductor diode is called biasing. External voltage to the p-n junction diode is applied in any of the two methods: forward biasing or reverse biasing.

1.2.3.4 Learning Outcome 4: Identify and classify memory.

1.2.4.1 Introduction to the learning outcome

This learning outcome covers definition of memory, classification of memories in terms of RAM, ROM and DAM. Further, the learning outcome covers types of memories, semiconductor memories and magnetic memories.

1.2.4.2 Performance Standard

1. Types of memories are identified
2. Memory hierarchy is identified
3. Levels of memory storage are identified
4. Classification of memories is done

1.2.4.3 Information Sheet

a) Definition of computer memory?

Computer memory is any physical device, used to store data, information or instruction temporarily or permanently. It is the collection of storage units that stores binary information in the form of bits. The memory block is split into a small number of components, called cells. Each cell has a unique address to store the data in memory, ranging from zero to memory size minus one. For example, if the size of computer memory is 64k words, the memory units have $64 * 1024 = 65536$ locations or cells. The address of the memory's cells varies from 0 to 65535.

b) Why do we need a computer memory?

In the computer system, we need computer memory to store various types of data like text, images, video, audio, documents, etc. We can retrieve it when the data is required. For example, when we write and execute any computer program, it is initially stored in primary memory. If the processor does not need particular items for a longer time, the program or data is automatically saved into the permanent or secondary memory. Then the data is called from secondary memory to main memory and performs the execution of codes.

c) Features of Memory

Following are the different features of the memory system that includes:

1. **Location:** It represents the internal or external location of the memory in a computer. The internal memory is inbuilt in computer memory. It is also known as primary memory. The example of primary memory are registers, cache and main memory. Whereas, external memory is the separate storage device from the computer, such as disk, tape, USB pen drive.
2. **Capacity:** It is the most important feature of computer memory. Storage capacity can vary in external and internal memory. External devices' storage capacity is measured in terms of bytes, whereas the internal memory is measured with bytes or words. The storage word length can vary in bits, such as 8, 16 or 32 bits.
3. **Access Methods:** Memory can be accessed through four modes of memory.
 - **DMA:** As the name specifies, Direct Memory Address (DMA) is a method that allows input/output (I/O) devices to access or retrieve data directly or from the main memory.
 - **Sequential Access Method:** The sequential access method is used in a data storage device to read stored data sequentially from the computer memory. Whereas, the data received from random access memory (RAM) can be in any order.
 - **Random Access Method:** It is a method used to randomly access data from memory. This method is the opposite of SAM. For example, to go from A to Z in random access, we can directly jump to any specified location. In the Sequential method, we have to follow all intervening from A to Z to reach at the particular memory location.
 - **Associative Access Method:** It is a special type of memory that optimizes search performance through defined data to directly access the stored information based on a memory address.
4. **Unit of transfer:** As the name suggests, a unit of transfer measures the transfer rate of bits that can be read or write in or out of the memory devices. The transfer rate of data can be different in external and internal memory.
 - **Internal memory:** The transfer rate of bits is mostly equal to the word size.
 - **External memory:** The transfer rate of bit or unit is not equal to the word length. It is always greater than a word or may be referred to as **blocks**.
5. **Performance:** The performance of memory is majorly divided into three parts.

- **Access Time:** In random access memory, it represents the total time taken by memory devices to perform a read or write operation that an address is sent to memory.
 - **Memory Cycle Time:** Total time required to access memory block and additional required time before starting second access.
 - **Transfer rate:** It describes the transfer rate of data used to transmit memory to or from an external or internal memory device. Bit transfer can be different for different external and internal devices.
6. **Physical types:** It defines the physical type of memory used in a computer such as magnetic, semiconductor, magneto-optical and optical.
 7. **Organization:** It defines the physical structure of the bits used in memory.
 8. **Physical characteristics:** It specifies the physical behavior of the memory like volatile, non-volatile or non-erasable memory. Volatile memory is known as RAM, which requires power to retain stored information, and if any power loss has occurred, stored data will be lost. Non-volatile memory is a permanent storage memory that is used to obtain any stored information, even when the power is off. Non-erasable memory is a type of memory that cannot be erased after the manufactured like ROM because at the time of manufactured ROM are programmed.

d) **Classification of Memory**

The following figure represents the classification of memory:

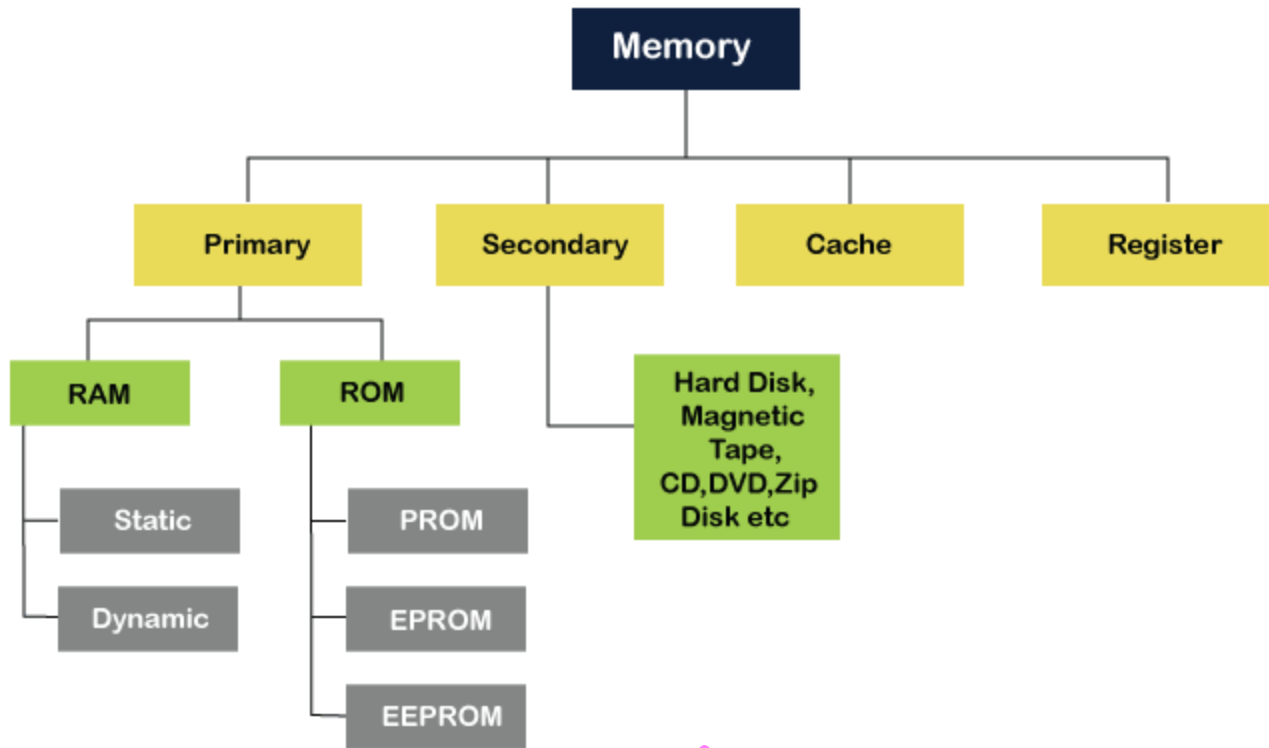


Figure 20: *Classification of memory*

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e) **Primary or Main Memory**

Primary memory is also known as the computer system's main memory that communicates directly within the CPU, Auxiliary memory and the Cache memory. Main memory is used to keep programs or data when the processor is active to use them. When a program or data is activated to execute, the processor first loads instructions or programs from secondary memory into main memory, and then the processor starts execution. Accessing or executing of data from primary memory is faster because it has a cache or register memory that provides faster response, and it is located closer to the CPU. The primary memory is volatile, which means the data in memory can be lost if it is not saved when a power failure occurs. It is costlier than secondary memory, and the main memory capacity is limited as compared to secondary memory.

The primary memory is further divided into two parts:

1. RAM (Random Access Memory)
2. ROM (Read Only Memory)

Random Access Memory (RAM)

Random Access Memory (RAM) is one of the faster types of main memory accessed directly by the CPU. It is the hardware in a computer device to temporarily store data, programs or program results. It is used to read/write data in memory until the machine is working. It is volatile, which means if a power failure occurs or the computer is turned off, the information stored in RAM will be lost. All data stored in computer memory can be read or accessed randomly at any time.

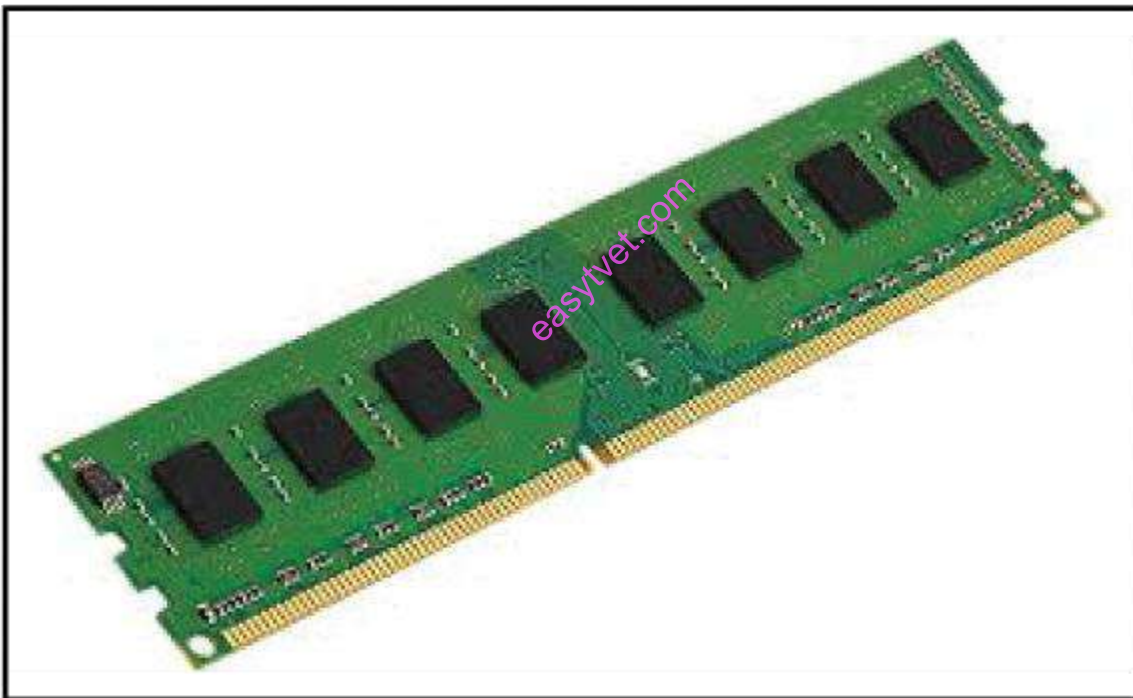


Figure 21: *RAM stick*

There are two types of RAM:

- SRAM
- DRAM

DRAM: DRAM (**Dynamic Random-Access Memory**) is a type of RAM that is used for the dynamic storage of data in RAM. In DRAM, each cell carries one-bit information. The cell is made up of two parts: a **capacitor** and a **transistor**. The size of the capacitor and the transistor is so small, requiring millions of them to store on a single chip. Hence, a DRAM chip can hold more data than an SRAM chip of the same size. However, the capacitor needs to be continuously refreshed to retain information because DRAM is volatile. If the power is switched off, the data store in memory is lost.

Characteristics of DRAM

1. It requires continuously refreshed to retain the data.
2. It is slower than SRAM
3. It holds a large amount of data
4. It is the combination of capacitor and transistor
5. It is less expensive as compared to SRAM
6. Less power consumption

SRAM: SRMA (**Static Random-Access Memory**) is a type of RAM used to store static data in the memory. It means to store data in SRAM remains active as long as the computer system has a power supply. However, data is lost in SRAM when power failures have occurred.

Characteristics of Static Ram

1. It does not require to refresh.
2. It is faster than DRAM
3. It is expensive.
4. High power consumption
5. Longer life
6. Large size
7. Uses as a cache memory

SRAM vs. DRAM

Table 4: Comparison between SRAM and DRAM

SRAM	DRAM
It is a Static Random-Access Memory.	It is a Dynamic Random Access Memory.
The access time of SRAM is slow.	The access time of DRAM is high.
It uses flip-flops to store each bit of information.	It uses a capacitor to store each bit of information.
It does not require periodic refreshing to preserve the information.	It requires periodically refreshing to preserve the information.
It uses in cache memory.	It is used in the main memory.
The cost of SRAM is expensive.	The cost of DRAM is less expensive.
It has a complex structure.	Its structure is simple.
It requires low power consumption.	It requires more power consumption.

Advantages of RAM

- It is a faster type of memory in a computer.
- It requires less power to operate.
- Program loads much faster
- More RAM increases the performance of a system and can multitask.
- Perform read and write operations.
- The processor can read information faster than a hard disc, floppy, USB, etc.

Disadvantages of RAM

- Less RAM reduces the speed and performance of a computer.
- Due to volatile, it requires electricity to preserve the data.
- It is expensive than ROM
- It is unreliable as compared to ROM
- The Size of RAM is limited.

Read-Only Memory (ROM)

ROM is a memory device or storage medium that is used to **permanently** store information inside a chip. It is a read-only memory that can only read stored information, data or programs, but we cannot write or modify anything. A ROM contains some important instructions or program data that are required to start or boot a computer. It is a **non-volatile** memory; it means that the stored information cannot be lost even when the power is turned off or the system is shut down.



Figure 22: ROM

Types of ROM

There are five types of Read Only Memory:

1. MROM (Masked Read Only Memory)

MROM is the oldest type of read-only memory whose program or data is pre-configured by the integrated circuit manufacture at the time of manufacturing. Therefore, a program or instruction stored within the MROM chip cannot be changed by the user.

2. **PROM (Programmable Read Only Memory)**

It is a type of digital read-only memory, in which the user can write any type of information or program only once. It means it is the empty PROM chip in which the user can write the desired content or program only once using the special PROM programmer or PROM burner device; after that, the data or instruction cannot be changed or erased.

3. **EPROM (Erasable and Programmable Read Only Memory):**

It is the type of read only memory in which stored data can be erased and re-programmed only once in the EPROM memory. It is a non-volatile memory chip that holds data when there is no power supply and can also store data for a minimum of 10 to 20 years. In EPROM, if we want to erase any stored data and re-programmed it, first, we need to pass the ultraviolet light for 40 minutes to erase the data; after that, the data is re-created in EPROM.

4. **EEPROM (Electrically Erasable and Programmable Read Only Memory):**

The EEPROM is an electrically erasable and programmable read only memory used to erase stored data using a high voltage electrical charge and re-programmed it. It is also a non-volatile memory whose data cannot be erased or lost; even the power is turned off. In EEPROM, the stored data can be erased and reprogrammed up to 10 thousand times, and the data erase one byte at a time.

5. **Flash**

ROM

Flash memory is a non-volatile storage memory chip that can be written or programmed in small units called Block or Sector. Flash Memory is an EEPROM form of computer memory, and the contents or data cannot be lost when the power source is turned off. It is also used to transfer data between the computer and digital devices.

Advantages of ROM

1. It is a non-volatile memory in which stored information can be lost even power is turned off.
2. It is static, so it does not require refreshing the content every time.
3. Data can be stored permanently.
4. It is easy to test and store large data as compared to RAM.
5. These cannot be changed accidentally
6. It is cheaper than RAM.

7. It is simple and reliable as compared to RAM.
8. It helps to start the computer and loads the OS.

Disadvantages of ROM

1. Store data cannot be updated or modify except to read the existing data.
2. It is a slower memory than RAM to access the stored data.
3. It takes around 40 minutes to destroy the existing data using the high charge of ultraviolet light.

RAM Vs. ROM

Table 5: Comparison between RAM and ROM

RAM	ROM
It is a Random-Access Memory.	It is a Read Only Memory.
Read and write operations can be performed.	Only Read operation can be performed.
Data can be lost in volatile memory when the power supply is turned off.	Data cannot be lost in non-volatile memory when the power supply is turned off.
It is a faster and expensive memory.	It is a slower and less expensive memory.
Storage data requires to be refreshed in RAM.	Storage data does not need to be refreshed in ROM.
The size of the chip is bigger than the ROM chip to store the data.	The size of the chip is smaller than the RAM chip to store the same amount of data.
Types of RAM: DRAM and SRAM	Types of ROM: MROM, PROM, EPROM, EEPROM

Semiconductor memory

Semiconductor memory is a type of semiconductor device tasked with storing data. There are two electronic data storage mediums that we can utilize, magnetic or optical.

Magnetic storage:

- Stores data in magnetic form.
- Affected by magnetic fields.
- Has high storage capacity.
- Doesn't use a laser to read/write data.
- Magnetic storage devices are; Hard disk , Floppy disk, Magnetic tape etc.

Optical storage:

- Stores data optically, uses laser to read/write.
- Not affected by magnetic fields.
- Has less storage than a hard disk.
- Data accessing is high, compared to a floppy disc.
- Optical storage devices are; CD-ROM,CD-R, CD-RW, DVD etc.

There is also volatile memory. This is memory that loses its data once power is cut off, while non-volatile memory retains data even without power.

Semiconductor Memory Types

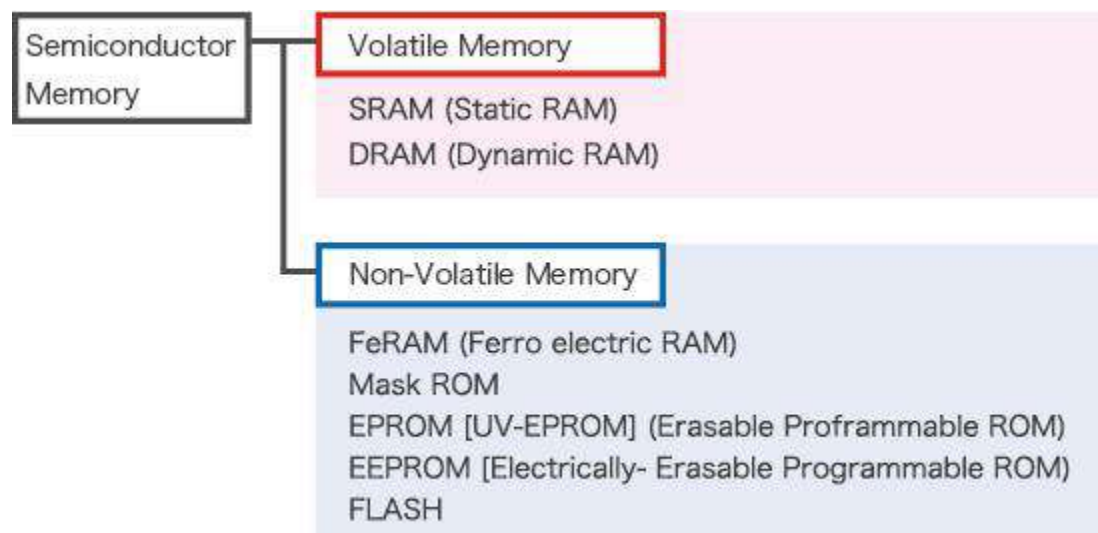


Figure 23: *Semiconductor memory types*

* **RAM** (Random Access Memory): Enables Read/Write of stored contents

* **ROM** (Read Only Memory): Allows only Read operation

f) Magnetic storage

Magnetic storage or **magnetic recording** is the storage of data on a magnetized medium. Magnetic storage uses different patterns of magnetization in a magnetizable material to store data and is a form of non-volatile memory. The information is accessed using one or more read/write heads.

Magnetic storage media, primarily hard disks, are widely used to store computer data as well as audio and video signals. In the field of computing, the term *magnetic storage* is preferred and in the field of audio and video production, the term *magnetic recording* is more commonly used. The distinction is less technical and more a matter of preference. Other examples of magnetic storage media include floppy disks, magnetic recording tape, and magnetic stripes on credit cards.

1.2.4.4 Learning Activities

- The trainee is required to visit a computer lab. Identify a computer that has started to slow down and requires a memory upgrade.
- Determine if your computer runs DDR2, DDR3 or another version by looking up your computer or motherboard specification information.
- Open the case and insert a RAM module into a DIMM slot.
- Record the specifications of the new memory status of the computer.

Special instructions

Computers usually support only a single version of RAM, and incorrect versions will not fit in the slot.

1.2.4.5 Self-Assessment

1. What is computer memory?

2. How do you analyze the performance of memory?
3. The primary memory is volatile, what does this mean?
4. Differentiate between DRAM and SRAM
5. What are some of the disadvantages of ROM?

1.2.4.6 Tools, Equipment, Supplies and Materials

Tools

1. Screw Drivers
2. Pliers
3. Wire cutters
4. Wire Strippers
5. Clamps
6. Vises

Equipment

- Voltmeter
- Ohmmeter
- Ammeter
- Multimeter
- Power supplies
- LCR meter

Materials and supplies

- Circuits
- Semiconductor materials
- Conductors e.g. copper, gold, silver
- Insulators e.g. rubber, glass, mica

1.2.4.7 References

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3. <https://www.studytonight.com/dbms/overview-of-dbms.php>(Retrieved on 30th November 2020)
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1.2.4.8 Model answers to self-assessment

1. What is computer memory?

Computer memory is any physical device, used to store data, information or instruction temporarily or permanently. It is the collection of storage units that stores binary information in the form of bits.

2. How do you analyze the performance of memory?

***Access Time:** In random access memory, it represents the total time taken by memory devices to perform a read or write operation that an address is sent to memory.*

***Memory Cycle Time:** Total time required to access memory block and additional required time before starting second access.*

***Transfer rate:** It describes the transfer rate of data used to transmit memory to or from an external or internal memory device. Bit transfer can be different for different external and internal devices.*

3. The primary memory is volatile, what does this mean?

This means the data in memory can be lost if it is not saved when a power failure occurs. It is costlier than secondary memory, and the main memory capacity is limited as compared to secondary memory.

4. Differentiate between DRAM and SRAM

***DRAM:** DRAM (Dynamic Random-Access Memory) is a type of RAM that is used for the dynamic storage of data in RAM. In DRAM, each cell carries one-bit information. The cell is*

made up of two parts: a **capacitor** and a **transistor**. **SRAM: SRMA (Static Random-Access Memory)** is a type of RAM used to store static data in the memory. It means to store data in SRAM remains active as long as the computer system has a power supply. However, data is lost in SRAM when power failures have occurred.

5. What are some of the disadvantages of ROM?

- *Store data cannot be updated or modify except to read the existing data.*
- *It is a slower memory than RAM to access the stored data.*
- *It takes around 40 minutes to destroy the existing data using the high charge of ultraviolet light.*

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1.2.5 Learning Outcome 5: Apply Number Systems and binary coding

1.2.5.1 Introduction to the learning outcome

This learning outcome covers definition of number system and binary code, types of number systems, base conversion and binary arithmetic including addition, subtraction, multiplication and division. The learning outcome further covers Binary codes, representing decimal numbers in BCD and BCD arithmetic.

1.2.5.2 Performance Standard

1. Types of number systems are identified
2. Base conversion is done
3. Binary arithmetic operations are done
4. Binary codes are identified
5. Representation of decimals in BCD is done
6. BCD arithmetic are performed

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1.2.5.3 Information Sheet

a) Definition of Number System and Binary Code

A number system is defined as a system of writing to express numbers. It is the mathematical notation for representing numbers of a given set by using digits or other symbols in a consistent manner. It provides a unique representation of every number and represents the arithmetic and algebraic structure of the figures. It also allows us to operate arithmetic operations like addition, subtraction and division.

The value of any digit in a number can be determined by:

- The digit
- Its position in the number
- The base of the number system

b) Types of Number System

There are various types of number system in mathematics. The four most common number system types are:

1. Decimal number system (Base- 10)
2. Binary number system (Base- 2)
3. Octal number system (Base-8)
4. Hexadecimal number system (Base- 16)

c) Decimal Number System (Base 10 Number System)

Decimal number system has base 10 because it uses ten digits from 0 to 9. In the decimal number system, the positions successive to the left of the decimal point represent units, tens, hundreds, thousands and so on. This system is expressed in decimal numbers.

Every position shows a particular power of the base (10). For example, the decimal number 1457 consists of the digit 7 in the units position, 5 in the tens place, 4 in the hundreds position, and 1 in the thousands place whose value can be written as

$$(1 \times 10^3) + (4 \times 10^2) + (5 \times 10^1) + (7 \times 10^0)$$

$$(1 \times 1000) + (4 \times 100) + (5 \times 10) + (7 \times 1)$$

$$1000 + 400 + 50 + 7$$

$$1457$$

d) Binary Number System (Base 2 Number System)

The base 2 number system is also known as the Binary number system wherein, only two binary digits exist, i.e., 0 and 1. Specifically, the usual base-2 is a radix of 2. The figures described under this system are known as binary numbers which are the combination of 0 and 1. For example, 110101 is a binary number.

We can convert any system into binary and vice versa.

Example

Write $(14)_{10}$ as a binary number.

Solution:

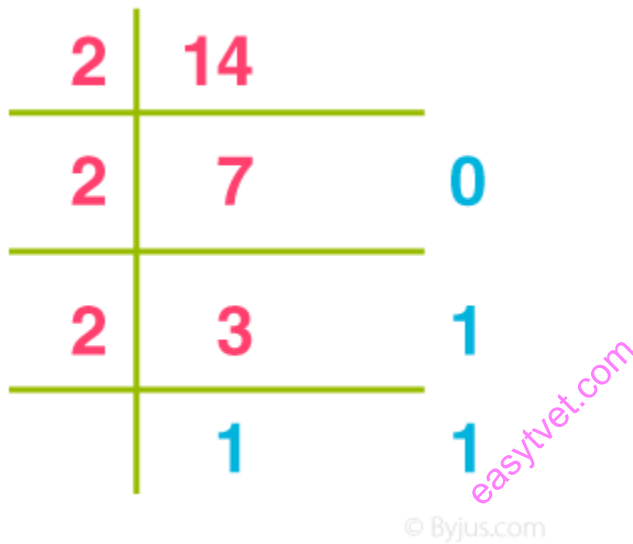


Figure 24: Base 2 Number System Example

$$\therefore (14)_{10} = 1110_2$$

e) Octal Number System (Base 8 Number System)

In the octal number system, the base is 8 and it uses numbers from 0 to 7 to represent numbers. Octal numbers are commonly used in computer applications. Converting an octal number to decimal is the same as decimal conversion and is explained below using an example.

Example: Convert 215_8 into decimal.

Solution:

$$215_8 = 2 \times 8^2 + 1 \times 8^1 + 5 \times 8^0$$

$$= 2 \times 64 + 1 \times 8 + 5 \times 1$$

$$= 128 + 8 + 5$$

$$= 141_{10}$$

f) Hexadecimal Number System (Base 16 Number System)

In the hexadecimal system, numbers are written or represented with base 16. In the hex system, the numbers are first represented just like in decimal system, i.e. from 0 to 9. Then, the numbers are represented using the alphabets from A to F. The below-given table shows the representation of numbers in the hexadecimal number system.

Hexadecimal	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
Decimal	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

g) Number System Conversion (Base Conversion)

As we know, the number system is a form of expressing the numbers. In **number system conversion**, we will study to convert a number of one base, to a number of another base. There are a variety of number systems such as binary numbers, decimal numbers, hexadecimal numbers, octal numbers, which can be exercised.

In this article, you will learn the conversion of one base number to another base number considering all the base numbers such as decimal, binary, octal and hexadecimal with the help of examples. Here, the following number system conversion methods are explained.

- Binary to Decimal Number System
- Decimal to Binary Number System

- Octal to Binary Number System
- Binary to Octal Number System
- Binary to Hexadecimal Number System
- Hexadecimal to Binary Number System

The general representation of number systems are;

Decimal Number – Base 10 – N_{10}

Binary Number – Base 2 – N_2

Octal Number – Base 8 – N_8

Hexadecimal Number – Base 16 – N_{16}

Table 6: Number System Conversion Table

Binary Numbers	Octal Numbers	Decimal Numbers	Hexadecimal Numbers
0000	0	0	0
0001	1	1	1
0010	2	2	2
0011	3	3	3
0100	4	4	4
0101	5	5	5
0110	6	6	6
0111	7	7	7
1000	10	8	8
1001	11	9	9
1010	12	10	A
1011	13	11	B

1100	14	12	C
1101	15	13	D
1110	16	14	E
1111	17	15	F

h) Number System Conversion Methods

Number system conversions deal with the operations to change the base of the numbers. For example, to change a decimal number with base 10 to binary number with base 2. We can also perform the arithmetic operations like addition, subtraction, multiplication on the number system. Here, we will learn the methods to convert the number of one base to the number of another base starting with the decimal number system. The representation of number system base conversion in general form for any base number is;

$$(\text{Number})_b = d_{n-1} d_{n-2} \dots d_1 d_0 . d_{-1} d_{-2} \dots d_{-m}$$

In the above expression, $d_{n-1} d_{n-2} \dots d_1 d_0$ represents the value of integer part and $d_{-1} d_{-2} \dots d_{-m}$ represents the fractional part.

Also, d_{n-1} is the Most significant bit (MSB) and d_{-m} is the Least significant bit (LSB).

Now let us learn, conversion from one base to another.

Decimal to Other Bases

Converting a decimal number to other base numbers is easy. We have to divide the decimal number by the converted value of the new base.

Decimal to Binary Number:

Suppose if we have to convert decimal to binary, then divide the decimal number by 2.

Example 1. Convert $(25)_{10}$ to binary number.

Solution: Let us create a table based on this question.

Operation	Output	Remainder
$25 \div 2$	12	1(MSB)
$12 \div 2$	6	0
$6 \div 2$	3	0
$3 \div 2$	1	1
$1 \div 2$	0	1(LSB)

Therefore, from the above table, we can write,

$$(25)_{10} = (11001)_2$$

Decimal to Octal Number:

To convert decimal to octal number we have to divide the given original number by 8 such that base 10 changes to base 8. Let us understand with the help of an example.

Example 2: Convert 128_{10} to octal number.

Solution: Let us represent the conversion in tabular form.

Operation	Output	Remainder
$128 \div 8$	16	0(MSB)
$16 \div 8$	2	0
$2 \div 8$	0	2(LSB)

Therefore, the equivalent octal number = 200_8

Decimal to Hexadecimal:

Again in decimal to hex conversion, we have to divide the given decimal number by 16.

Example 3: Convert 128_{10} to hex.

Solution: As per the method, we can create a table;

Operation	Output	Remainder
$128 \div 16$	8	0(MSB)
$8 \div 16$	0	8(LSB)

Therefore, the equivalent hexadecimal number is 80_{16}

Here MSB stands for a most significant bit and LSB stands for a least significant bit.

Other Base System to Decimal Conversion

Binary to Decimal:

In this conversion, binary number to a decimal number, we use multiplication method, in such a way that, if a number with base n has to be converted into a number with base 10, then each digit of the given number is multiplied from MSB to LSB with reducing the power of the base. Let us understand this conversion with the help of an example.

Example 1. Convert $(1101)_2$ into a decimal number.

Solution: Given a binary number $(1101)_2$.

Now, multiplying each digit from MSB to LSB with reducing the power of the base number 2.

$$1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$$

$$= 8 + 4 + 0 + 1$$

$$= 13$$

Therefore, $(1101)_2 = (13)_{10}$

Octal to Decimal:

To convert octal to decimal, we multiply the digits of octal number with decreasing power of the base number 8, starting from MSB to LSB and then add them all together.

Example 2: Convert 22_8 to decimal number.

Solution: Given, 22_8

$$2 \times 8^1 + 2 \times 8^0$$

$$= 16 + 2$$

$$= 18$$

Therefore, $22_8 = 18_{10}$

Hexadecimal to Decimal:

Example 3: Convert 121_{16} to decimal number.

$$\text{Solution: } 1 \times 16^2 + 2 \times 16^1 + 1 \times 16^0$$

$$= 16 \times 16 + 2 \times 16 + 1 \times 1$$

$$= 289$$

Therefore, $121_{16} = 289_{10}$

Hexadecimal to Binary Shortcut Method

To convert hexadecimal numbers to binary and vice versa is easy, you just have to memorize the table given below.

Table 7: Hexadecimal to Binary

Hexadecimal Number	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

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You can easily solve the problems based on hexadecimal and binary conversions with the help of this table. Let us take an example.

Example: Convert $(89)_{16}$ into a binary number.

Solution: From the table, we can get the binary value of 8 and 9, hexadecimal base numbers.

$$8 = 1000 \text{ and } 9 = 1001$$

Therefore, $(89)_{16} = (10001001)_2$

Octal to Binary Shortcut Method

To convert octal to binary number, we can simply use the table. Just like having a table for hexadecimal and its equivalent binary, in the same way, we have a table for octal and its equivalent binary number.

Table 8: Octal to Binary

Octal Number	Binary
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

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Example: Convert $(214)_8$ into a binary number.

Solution: From the table, we know,

$$2 \rightarrow 010$$

$$1 \rightarrow 001$$

$$4 \rightarrow 100$$

$$\text{Therefore, } (214)_8 = (010001100)_2$$

i) Binary Arithmetic

Binary arithmetic is used in digital systems mainly because the numbers (decimal and floating-point numbers) are stored in binary format in most computer systems. All arithmetic operations such as addition, subtraction, multiplication, and division are done in binary representation of numbers. It is necessary to understand the binary number representation to figure out binary arithmetic in digital computers.

In most ALU (arithmetic logic unit) hardware, the operated numbers are stored in a fixed number of bits, a typical value between 6 and 16 decimal digits. Therefore, there is a precision limit or precision error performing binary arithmetic on computers. This binary arithmetic is called fixed-precision arithmetic. This contrasts to arbitrary-precision arithmetic, such as Java BigInteger, a technique that calculations are performed on numbers whose precision is only dependent on the amount of memory available in the system. In other words, a number could occupy memory space as large as possible if there is a need for higher precision. We will focus on fixed-precision arithmetic from now on.

Since the precision of numbers stored in the computer is fixed, the size of numbers is fixed and determined when the computer is built. A common integer size found in computer systems is 8, 16, 32, and 64 bits. Once the computer is built, the size of numbers is fixed and may not be changed. Therefore, as a programmer who develops computer programs running on the computer architecture, it makes sense to know what the precision limit is for the underlying architecture. This way some precision errors such as rounding error may be avoided. For example, in integer precision is equal to not . If is expected, the program has to be rewritten in a way to take care of the precision. To remedy this, most programming languages offer type conversions. To get in the previous example, simply rewrite it as . The will tell a compiler to allows float point space for it and assign floating point arithmetic, instead of integer arithmetic.

We will discuss binary arithmetic from the logic design perspective in the following sections. Quite often that there are more than one logic design for a binary operation, a “better one” is always a best choice. The better one means the complexity is manageable and the logic circuit is simple. In hardware domain, simply is good and simply normally leads to better performance.

j) **Finite Precision Arithmetic**

Consider operations are limited to 2-digit non-negative decimal integers. So the numbers are 0, 1, 2, ..., 99, and denoted as S . The result of an operation among the numbers has to be in the set S . Otherwise, the operation is invalid. There a valid operation is defined as follows.

$a \oplus b = c$, where $a, b, c \in S$ and \oplus is an operator.

So a valid operation will map two numbers in the set to another number in the set. The operator can be addition, subtraction, multiplication, division, and the like. Taking addition as an example, $a + b = c$ is a valid operation because the result is still in the set. However, $a + b = c$ is not, because the result is not in the set and only 00 is. In a more precise way, a valid addition over the set is as follows.

$a + b = c$ where $a, b, c \in S$ and $c < 100$.

Since a, b are non-negative, the result of adding a and b is also non-negative. Thus, we only need to limit the result to be less than 100. So it is still in the set S .

Another concern is the carry. In the 2-digit non-negative decimal system, adding the first digit of two numbers may be larger than 9, say $9 + 9 = 18$. In that case we write down 8 as the result for this position, and keep one as the carry for the next position (to the left). Table 1 illustrates a decimal addition example of $34 + 18 = 52$.

Table 9: An Example of Carry for a Decimal Addition

Carry	1		
		3	4
+		1	8
		5	2

Addition

In the binary numeral system, the symbol set is composed of 0 and 1. A positional binary number is a sequence of 0's and 1's. Given an n -bit binary number, the leftmost bit is called most significant bit (MSB) because its weight is 2^{n-1} , and the rightmost bit is called least significant bit (LSB) for the reason that it only weights 2^0 . Once the binary numbers are lined up with their weights, i.e. powers of 2, they may be operated just like the decimal arithmetic. It makes no difference when numbers in another format such as hexadecimal are operated. Consider a 4-bit non-negative numeral system. There are numbers from 0 to 15, i.e., decimal to 15. So, any valid operation among these numbers should result in one of them. Also, the carry mechanism works similar to the decimal addition. For example, Table 2 shows an example of carry for a binary addition. Compared to the decimal carry, the binary carry will “carry” 2 from the first position over the second position. In the addition case, the only possible carry occurs when both operands are 1, i.e., with carry 1.

Table 10: An Example of Carry for a Binary Addition

Carry		1	1		
	0	0	1	1	In the first position:
+	0	1	0	1	
	1	0	0	0	

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In general, the carry mechanism applies to other numeral systems such as octal and hexadecimal. The value of carry in additions is always one. The number we write down for this position is calculated by $\text{sum} - \text{radix}$, where sum is the sum of the two numbers, and radix is the radix or the base. The value of carry could be larger than one in cases such as multiplication. Table 3 shows an example of carry for an octal addition whereas Table 4 gives an example of carry for a hexadecimal addition.

Table 11: An Example of Carry for an Octal Addition

Carry		1		
	1	2	3	In the first position:
+	1	4	9	

Carry		1		
	2	7	4	

Table 12: An Example of Carry for an Hexadecimal Addition

Carry		1		
	A	B	C	In the first position:
+	1	2	5	
	B	E	1	

Hardware Adder

Since numbers stored in computers are in binary format, a hardware adder is built based on binary inputs. Recall that when adding two binary digits in each position, a carry may be generated, which is then added in the position to the left. Based on this observation, a n -bit hardware adder is built upon one-bit adders, each of which is taken care of the one-bit addition for one position. Therefore, we should build the one-bit adder first and combine of them together to perform n -bit addition.

In hardware design, a very first and important step is find out what inputs and output are, and what their relations are? The inputs to the one-bit adder are one bit, say x , from one operand, one bit, say y , from another, and don't forget one carry bit, say z , from the previous position. The outputs are obviously the sum, say s , and the carry bit, say c . With the inputs and outputs ready, the next step is find out their relations. The following truth table (Table 5) shows the relations. The truth table is built based on the binary arithmetic that $0+0=0$, with carry 1, and with carry 1.

Table 13: The Truth Table of One-Bit Adder

input	input	input	output	output
0	0	1	1	0
0	1	0	1	0

0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Subtraction

Subtracting a number from another is equivalent to adding a negative number. In binary arithmetic, we first apply two's complement to the subtrahend, and then add the two's complement of the subtrahend to the minuend. The result will be the difference.

Table 14: An Example of Subtracting 3 from 7 Using Two's Complement Addition

Carry						1	1	1	1
Minuend		0	1	1	1		0	1	1
Subtrahend	-	0	0	1	1	+	1	1	0
Difference							0	1	0

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Using two's complement for subtraction greatly simplifies the computer design as we only need to build a hardware adder for both addition and subtraction. Note that the negative 2 is stored in its two's complement format in memory. So there is no need to build a special hardware circuit for the conversion. Also, the most significant bit (MSB) yields a carry, which can be safely ignored because adding two numbers of different signs will cause any overflow.

Multiplication

Binary multiplication is similar to decimal multiplication, and in fact, the binary one is much easier than the decimal one. Let's revisit the multiplication technique learnt from elementary schools. Table 8 shows the technique to multiply 1234 by 4321. Observe that each time the multiplicand is multiplied by a digit of the multiplier, and the partial product is written down in line with the multiplier digit. The product is obtained by adding up all the partial products. Note that the number of digits for the product should be the sum of the numbers of the multiplicand digits and multiplier digits. In the previous example, the number of the product digits is 7. Should there were a carry at the leftmost digit, the total number of the product digits is 8. The doubled size is normally considered in computer design. In a typical CPU, multiplication is done by a special hardware circuit not in the ALU. There may have several hardware multipliers for fast computation.

Table 15: An Example of Decimal Multiplication

			1	2	3	4	Multiplicand
			4	3	2	1	Multiplier
			1	2	3	4	
			2	4	6	8	
			3	7	0	2	
			4	9	3	6	
			5	3	3	2	Product

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In the binary case, the same multiplication technique applies. Let's take a look at an example, and observe how a hardware multiplier can be implemented. Table 9 illustrates an example of binary multiplication. Observe that the rows with an arrow () are identical to the multiplicand, and the rest are all zeros. Also, the non-zero rows are from the one's digits of the multiplier. When adding up the partial products (all equal to the multiplicand), they only shift left a number of positions according where the multiplier digit is.

Table 16: An Example of Binary Multiplication

			1	0	1	1	Multiplicand
			0	1	0	1	Multiplier
			1	0	1	1	
			0	0	0	0	
		1	0	1	1		
	0	0	0	0			
	0	1	1	0	1	1	Product

With the above observation, a hardware multiplier is designed based on an adder and two shifters. The adder is used to add partial products, whereas the shifters are used to shift the multiplicand left at a time after a corresponding bit in the multiplier is checked, and shift right the multiplier. The figure illustrates the flowchart of the hardware multiplication algorithm. In this algorithm, there are three registers, one for the multiplicand, one for the multiplier, and one for the product. The registers for the multiplicand and multiplier are shift registers. The multiplicand register will shift left whereas the multiplier register will shift right in each iteration. If the size of the multiplier is bits, the size of the multiplier register needs only bits. However, the registers for the product and the multiplicand will have to have bits, simply because the shift left operation for the multiplicand register and the potential space need for the product. These requirements can be improved if we instead shift the product to the right.

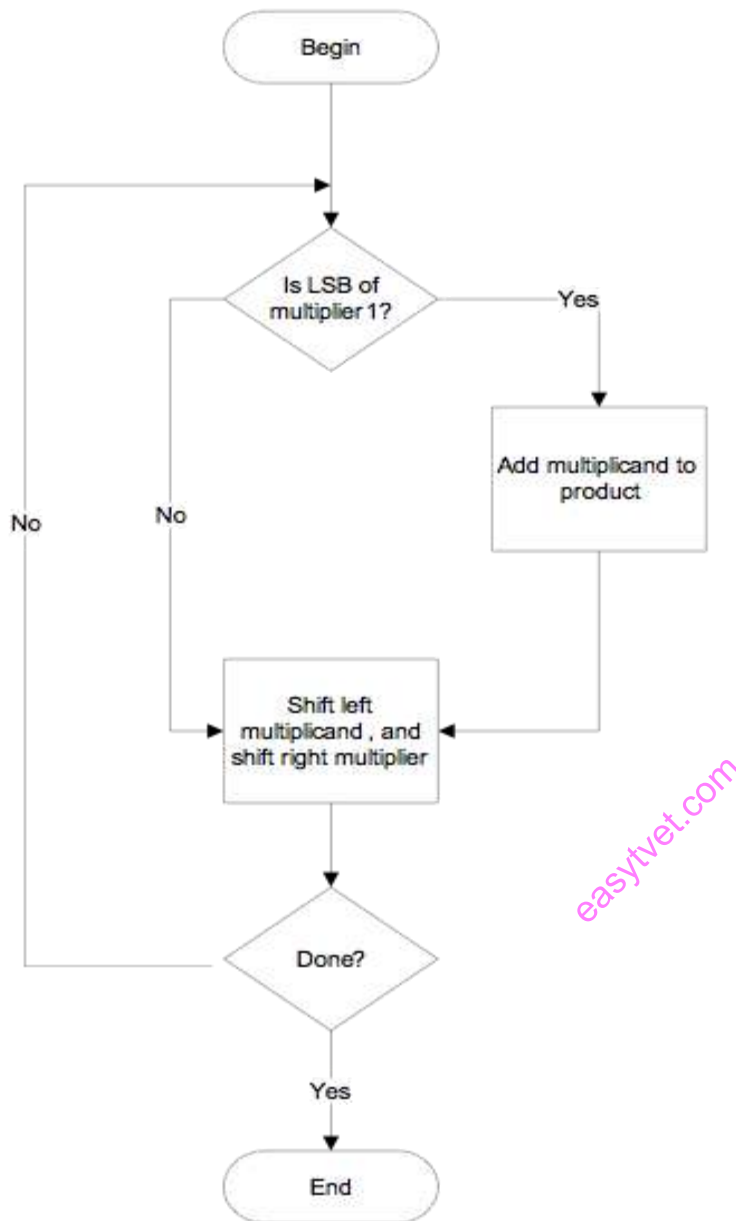
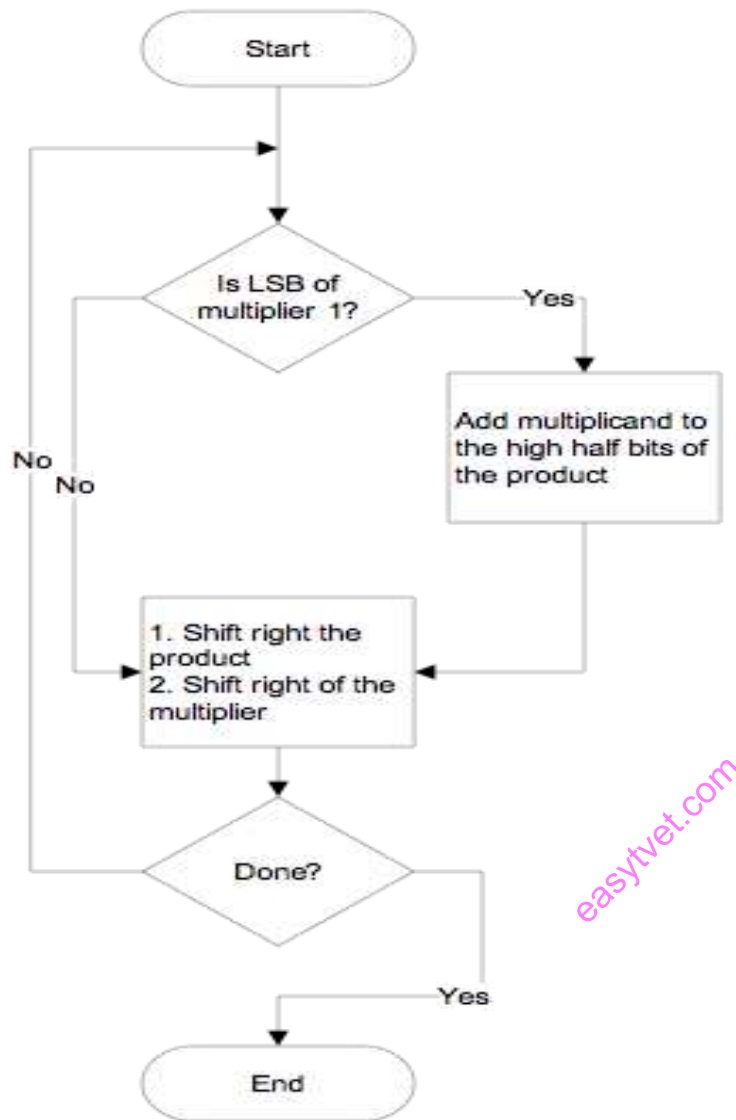


Figure 25: *The Flowchart of a Hardware Binary Multiplication Algorithm*

In the improved version shown in the above figure, instead of shifting multiplicand left, the product register is shifted to the right in each iteration. Thus, the shift register for the multiplicand is saved. However, the adder that adds the multiplicand the partial product will have to store the result to the high half bits. Compared to the previous version, the improved version requires less hardware resource and should perform better based on the rule of thumb that “the less, the better” in hardware design.



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Figure 26: Improved Version of a Hardware MultiplierA

Division

With the experience learnt from the hardware multiplier design in the previous section, binary division works similarly. Let’s start with an example of long division using the technique from the elementary school. Table 10 illustrates the long division for divided by . In decimal, it is 178 divided by 10. The quotient is 17 and the remainder is 8. We call 178 the dividend and 10 the divisor.

Table 17: An Example of Binary Division Based on Traditional Long Division

								1	0	0	0	1						Quotient
Divisor	1	0	1	0)	1	0	1	1	0	0	1	0					Dividend
						1	0	1	0									
							0	0	1	0								
							0	0	0	0								
								0	1	0	0							
								0	0	0	0							
									1	0	0	1						
									0	0	0	0					*	
									1	0	0	1	0					
									1	0	1	0						
									1	0	0	0						Remainder

The binary long division is easier than its decimal version because there are only two choices (0 or 1) when we guess the quotient digits in each iteration. If the first digit of the dividend portion is 0, the quotient digit will be 0. However, if the first digit of the dividend portion is 1, the quotient digit could be either 1 or 0. In the example shown in Table 10, most of the time the quotient digit is 1 when the first digit of the dividend portion is 1. In the row with an asterisk, however, selecting 1 as the quotient digit will be wrong because the divisor is larger than the dividend portion. In that case, the result after subtraction will be negative, i.e., because the dividend is 10 but the dividend portion is 9 in decimal. Therefore, selecting quotient digit equal to the first digit of the dividend portion may fail.

In order to take care of the failure case, we need to validate the result of the subtraction in each iteration. Assume both the dividend and the divisor are positive. The quotient and the remainder are non-negative. The result of each subtraction should be non-negative. If the result is negative, the quotient digit should be 0 and the dividend portion should remain the same. In the previous

example, the row with an asterisk, the subtraction result is. The quotient digit should be 0 and the dividend portion should be restored back to not.

So the binary division algorithm is similar to that of the binary multiplication. The divisor is stored in a shift register, and it is shifted to the right in each iteration. Each time we only got one bit for the quotient, to keep the quotient bits, we can append one bit to the LSB of the quotient register and shift it to the left in each iteration. So a shift register is needed for the quotient. The subtraction can be implemented using an adder by converting the subtrahend to its two's complement. Figure 4 shows the flowchart of the algorithm.

In the binary division algorithm shown in Figure 4, two shift registers are needed. One is for the divisor and the other is for the quotient. Their length is as long as that of the dividend. Including a register for the dividend, there are totally 3 registers. Although the first bit of the dividend portion may not be equal to the quotient bit, the subtraction result serves as a correct decision. If the subtraction result is non-negative, the quotient bit is 1, and the subtraction result is used to update the dividend. On the other hand, if the subtraction result is negative, the dividend remains intact. Note that the operation that adding one to the quotient can be integrated to the shifter for the quotient. A normal shift left operation will put zero the LSB. We could just append one while shifting the quotient register left.

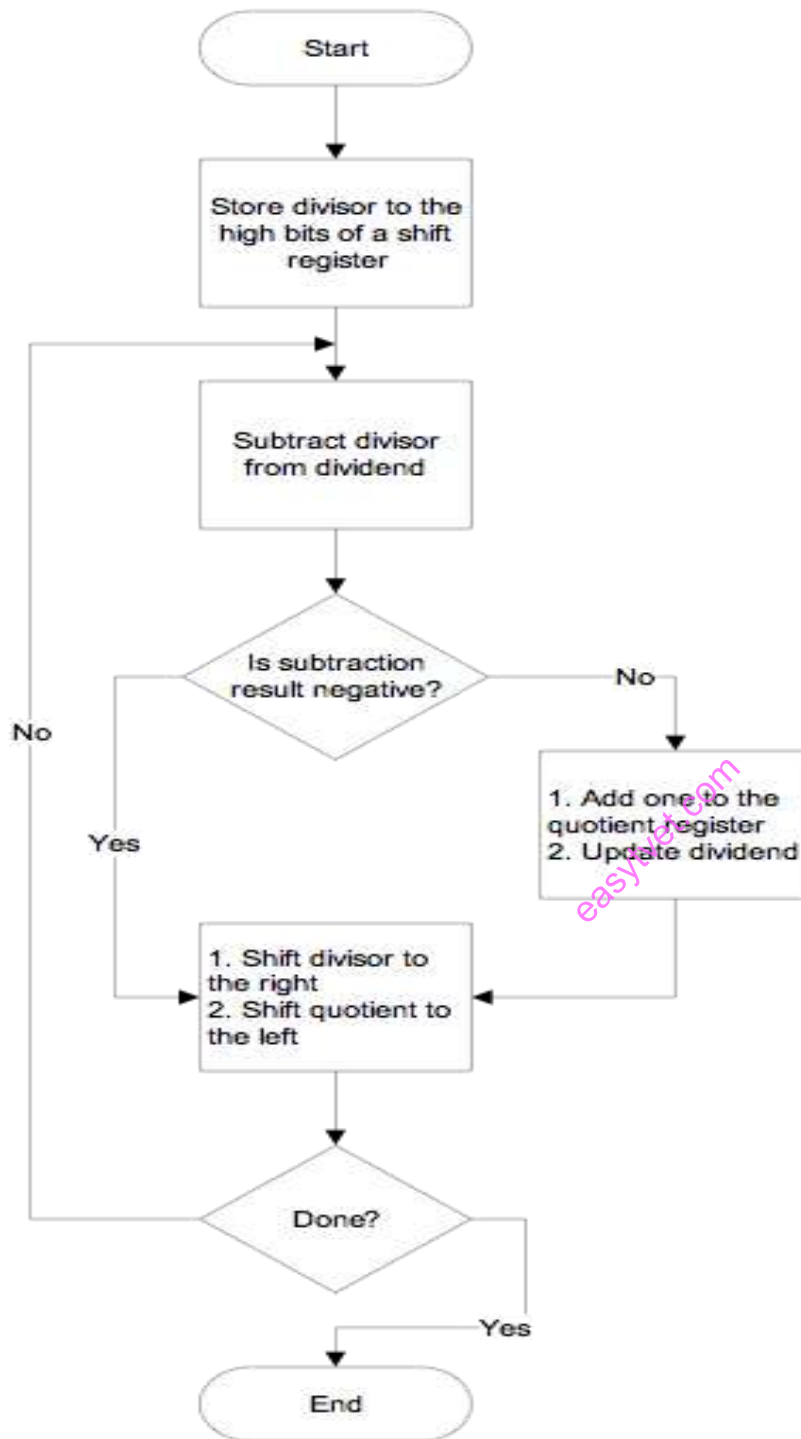


Figure 27: Flowchart of a Binary Division Algorithm

k) Commonly used Binary Codes

Before going into the details of individual binary codes, let us quickly take a look at some of the commonly used Binary Codes. The following is the list:

- 8421 Codes
- 2421 Codes
- 5211 Codes
- Excess-3 Codes
- Gray Codes

In the above list, the first three i.e. 8421, 2421 and 5211 are Weighted codes while the other two are non-weighted binary codes.

Weighted Binary Systems

The values assigned to consecutive places in the decimal system which is a place value system are $10^4, 10^3, 10^2, 10^1, 10^0, 10^{-1}, 10^{-2}, 10^{-3} \dots$ from left to right. It is easily can be understood that the weight of digit of the decimal system is '10'.

For example $(3546.25)_{10} = 3 \times 10^3 + 5 \times 10^2 + 4 \times 10^1 + 6 \times 10^0 + 2 \times 10^{-1} + 5 \times 10^{-2}$

In the same way the values assigned to consecutive places in the binary system which is also a place value system, but called as weighted binary system are $2^4, 2^3, 2^2, 2^1, 2^0, 2^{-1}, 2^{-2}, 2^{-3} \dots$ from left to right. It is easily can be understood that the weight of digit of the binary system is '2'.

For example : $(1110110)_2 = 1 \times 2^6 + 1 \times 2^5 + 1 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$

$= 64 + 32 + 16 + 0 + 4 + 2 + 0 = (118)_{10}$

Binary Weights

Whenever any binary number appears, its decimal equivalent can be found easily as follows.

- When there is 1 in a digit position, weight of that position should be added.
- When there is 0 in a digit position, weight of that position should be disregarded.

For example binary number 1100 has a decimal equivalent of $8 + 4 + 0 + 0 = 12$.

8421 Code or BCD Code

Represent Decimal numbers in Binary code

The decimal numbers 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 can be expressed in Binary numbers as shown below. All these binary numbers again expressed in the last column by expanding into 4 bits. As per the weighted binary digits, the 4 Bit binary numbers can be expressed according to their place value from left to right as 8421 ($2^3 2^2 2^1 2^0 = 8421$).

Table 18: Decimal to Binary code

Decimal Number	Binary Number	4 BIT Expression(8421)
0	0	0000
1	1	0001
2	10	0010
3	11	0011
4	100	0100
5	101	0101
6	110	0110
7	111	0111
8	1000	1000
9	1001	1001

As per the above expression all the decimal numbers written in the 4 Bit binary code in the form of 8421 and this is called as 8421 Code and also as Binary coded decimal BCD.

As this is a straight code, any Decimal number can be expressed easily because the weights of the positions are straight for easy conversion into this 8421 code.

There are other forms of codes which are not so popular but rather confusing. They are 2421 code, 5211 code, reflective code, sequential code, non-weighted code, excess-3 code and Grey code. They are having their own importance for some of the exclusive applications and may be useful for some of the typical applications.

2421 Code

This code also a 4 bit application code where the binary weights carry 2, 4, 2, 1 from left to right.

Table 19: 2421 code

Decimal Number	Binary Number	2421 Code
0	0	0000
1	1	0001
2	10	0010
3	11	0011
4	100	0100
5	101	1011
6	110	1100
7	111	1101
8	1000	1110
9	1001	1111

5211 Code

This code is also a 4 bit application code where the binary weights carry 5, 4, 2, 1 from left to right.

Table 20: 5211 code

Decimal Number	Binary Number	5211 Code
----------------	---------------	-----------

Decimal Number	Binary Number	5211 Code
0	0	0000
1	1	0001
2	10	0011
3	11	0101
4	100	0111
5	101	1000
6	110	1010
7	111	1100
8	1000	1110
9	1001	1111

Reflective Code

It can be observed that in the 2421 and 5211 codes, the code for decimal 9 is the complement of the code for decimal 0, the code for decimal 8 is the complement of the code for decimal 1, the code for decimal 7 is the complement of the code for decimal 2, the code for decimal 6 is the complement of the code for decimal 3, the code for decimal 5 is the complement of the code for decimal 4, these codes are called as reflexive codes. The same can be observed in the following table:

Table 21: Reflective code

Decimal Number	Decimal Number	2421 Code	5211 Code
0	0	0000	0000
1	1	0001	0001
2	10	0010	0011
3	11	0011	0101
4	100	0100	0111

Decimal Number	Decimal Number	2421 Code	5211 Code
5	101	1011	1000
6	110	1100	1010
7	111	1101	1100
8	1000	1110	1110
9	1001	1111	1111

8421 code is not a reflective code.

Sequential Codes

Sequential codes are the codes in which 2 subsequent numbers in binary representation differ by only one digit. The 8421 and Excess-3 codes are examples of sequential codes. 2421 and 5211 codes do not come under sequential codes.

Table 22: Sequential code

Decimal Number	Binary Number	8421 Code	Excess-3
0	0	0000	0011
1	1	0001	0100
2	10	0010	0101
3	11	0011	0110
4	100	100	0111
5	101	0101	1000
6	110	0110	1001
7	111	0111	1010
8	1000	1000	1011
9	1001	1001	1100

Non-Weighted Codes

Some of the codes will not follow the weights of the sequence binary numbers these are called as non-weighted codes. ASCII code and Grey code are some of the examples where they are coded for some special purpose applications and they do not follow the weighted binary number calculations.

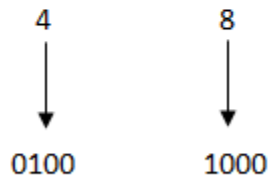
Excess-3 Code

As mentioned above, some of the codes will not follow the binary weights, Excee-3 code is an example of it and it is an important 4 bit code. The excess – 3 code of a decimal number is achieved by adding the number 3 to the 8421 code.

For example to convert 15 to an excess-3 code, first 3 to be added to each digit as shown below.

$$\begin{array}{r} 1 \quad 5 \\ + 3 \quad +3 \\ \hline 4 \quad 8 \end{array}$$

This has to be converted into BCD form as:



So, 0100 1000 is the excess-3 code stands for decimal 15.

Excess -3 Code Examples

1. Find the excess-3 code of $(237.75)_{10}$
2. Find the decimal number of excess-3 number 110010100011.01110101.

Sol:

1) The excess-3 code for $(237)_{10}$ is obtained by adding 3 to all the digits individually, that is 2, 3 an

d 7 will become 5, 6 and 10 respectively. These 5, 6 and 10 decimals have to be converted into binary form and the result is 010101101010.

The excess-3 code for $(.75)_{10}$ is obtained by replacing 7 and 5 with 10 and 8 respectively by adding 3 to each digit. That is, the excess-3 code for $(.75)_{10}$ is 10101000.

Combining the results of the integral and fractional parts, the excess-3 code for $(237.75)_{10}$ is 010101101010.10101000.

2) The excess-3 code is 110010100011.01110101

By separating 4 bits as group the equivalent excess-3 code is given as 1100 1010 0011.0111 0101.

Subtracting 0011 from each four-bit group, we obtain the new number as: 1001 0111 0000.0100 0010.

Therefore, the decimal equivalent is $(970.42)_{10}$.

Gray Code

The gray code is the code where one bit will be differed to the preceding number. For example, decimal numbers 13 and 14 are represented by gray code numbers 1011 and 1001, these numbers differ only in single position that is the second position from the right. In the same way first position on the left changes for 7 and 8 which are 0100 and 1100 and this is also called Unit-distance code. The gray code has very special place in digital electronics.

Table 23: Gray Code

Decimal Number	Binary Code	Gray Code
0	0000	0000
1	0001	0001
2	0010	0011

Decimal Number	Binary Code	Gray Code
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

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1) BCD Arithmetic

BCD Addition

Like other number system in BCD arithmetical operation may be required. BCD is a numerical code which has several rules for addition. The rules are given below in three steps with an example to make the idea of **BCD Addition** clear.

1. At first the given number are to be added using the rule of binary. For example,

Case 1:

$$\begin{array}{r} 1010 \\ + 0101 \\ \hline 1111 \end{array}$$

Case 2:

$$\begin{array}{r} 0001 \\ + 0101 \\ \hline 0110 \end{array}$$

2. In second step we have to judge the result of addition. Here two cases are shown to describe the rules of **BCD Addition**. In case 1 the result of addition of two binary number is greater than 9, which is not valid for BCD number. But the result of addition in case 2 is less than 9, which is valid for BCD numbers.
3. If the four bit result of addition is greater than 9 and if a carry bit is present in the result then it is invalid and we have to add 6 whose binary equivalent is $(0110)_2$ to the result of addition. Then the resultant that we would get will be a valid binary coded number. In case 1 the result was $(1111)_2$, which is greater than 9 so we have to add 6 or $(0110)_2$ to it.

$$(1111)_2 + (0110)_2 = 0001\ 0101 = 15$$

As you can see the result is valid in BCD. But in case 2 the result was already valid BCD, so there is no need to add 6. This is how BCD Addition could be.

Now a question may arrive that why 6 is being added to the addition result in case BCD Addition instead of any other numbers. It is done to skip the six invalid states of binary coded decimal i.e from 10 to 15 and again return to the BCD codes. Now the idea of BCD Addition can be cleared from two more examples.

Example:1

Let, 0101 is added with 0110.

$$\begin{array}{r} 0101 \\ + 0110 \\ \hline 1011 \rightarrow \text{Invalid BCD number} \\ + 0110 \rightarrow \text{Add 6} \\ \hline 0001\ 0001 \rightarrow \text{Valid BCD number} \end{array}$$

Check your self.

$$(0101)_2 \rightarrow (5)_{10} \text{ and } (0110)_2 \rightarrow (6)_{10} \quad (5)_{10} + (6)_{10} = (11)_{10}$$

Example:2

Now let 0001 0011 is added to 0010 0110.

$$\begin{array}{r} 0001\ 0001 \\ + 0010\ 0110 \\ \hline 0011\ 0111 \rightarrow \text{Valid BCD number} \end{array}$$

$$(0001\ 0001)_{BCD} \rightarrow (11)_{10}, (0010\ 0110)_{BCD} \rightarrow (26)_{10} \text{ and } (0011\ 0111)_{BCD} \rightarrow (37)_{10} \quad (11)_{10} + (26)_{10} = (37)_{10}$$

So no need to add 6 as because both $(0011)_2 = (3)_{10}$ and $(0111)_2 = (7)_{10}$ are less than $(9)_{10}$. This is the process of BCD Addition.

BCD Subtraction

There are several methods of **BCD Subtraction**. BCD subtraction can be done by 1's compliment method and 9's compliment method or 10's compliment method. Among all these methods 9's compliment method or 10's compliment method is the most easiest. We will clear our idea on both the methods of **BCD Subtraction**.

Method of BCD Subtraction: 1

In 1st method we will do **BCD Subtraction** by [1's compliment](#) method. There are several steps for this method shown below. They are:-

1. At first 1's compliment of the subtrahend is done.
2. Then the complimented subtrahend is added to the other number from which the subtraction is to be done. This is called adder 1.
3. Now in BCD Subtraction there is a term 'EAC(end-around-carry)'. If there is a carry i.e if $EAC = 1$ the result of the subtraction is +ve and if $EAC = 0$ then the result is -ve. A table shown below gives the rules of EAC.

carry of individual groups	EAC = 1	EAC = 0
1	Transfer real result of adder 1 and add 0000 in adder 2	Transfer 1's compliment result of adder 1 and add 1010 in adder 2
0	Transfer real result of adder 1 and add 1010 in adder 2	Transfer 1's compliment result of adder 1 and add 0000 to adder 2

4. In the final result if any carry bit occurs the it will be ignored.

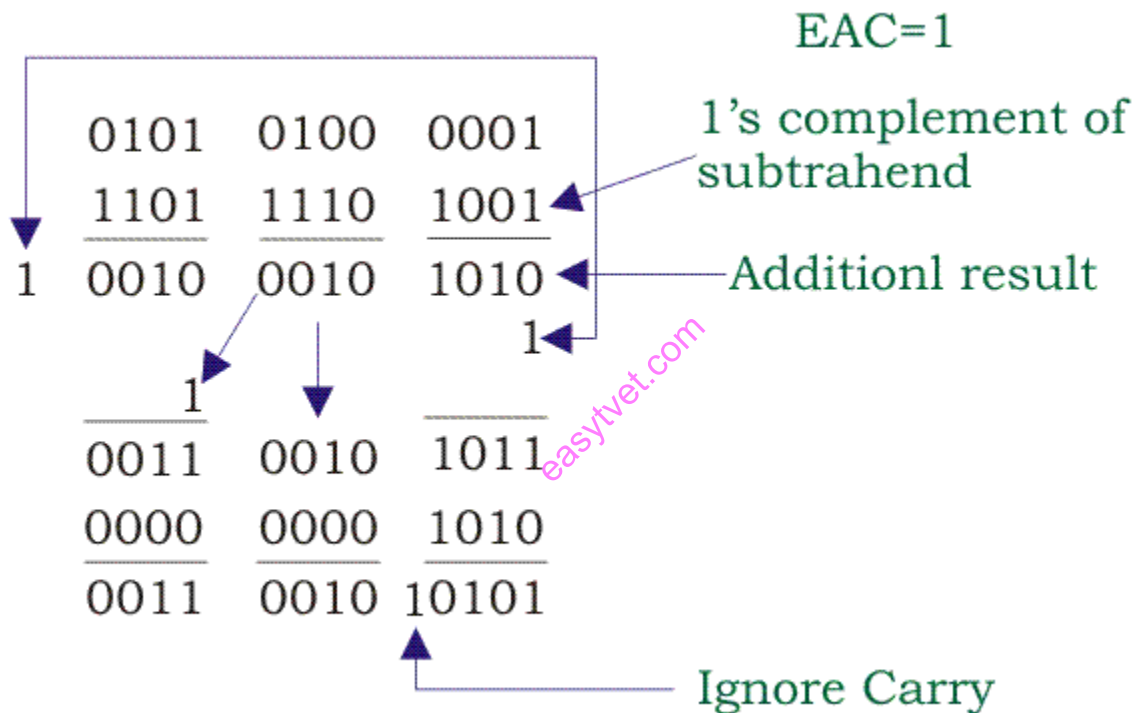
Examples given below would make the idea clear of BCD Subtraction.

Example: 1

In this example 0010 0001 0110 is subtracted from 0101 0100 0001.

- At first 1's compliment of the subtrahend is done, which is 1101 1110 1001 and is added to 0101 0100 0001. This step is called adder 1.
- Now after addition if any carry occurs then it will be added to the next group of numbers towards MSB. Then EAC will be examined. Here, $EAC = 1$. So the result of addition is positive and true result of adder 1 will be transferred to adder 2.
- Now notice from LSB. There are three groups of four bit numbers. 1010 is added 1011 which is the first group of numbers because it do not have any carry. The result of the addition is the final answer.

- Carry 1 will be ignored as it is from the rule.
- Now move to the next group of numbers. 0000 is added to 0010 and gives the result 0010. It is the final result again.
- Now again move to the next group here 0000 is also added to 0011 to give the final result 0011.
- You may have noticed that in this two groups 0000 is added, because result of first adder do not contain any carry. Thus the results of the adder 2 is the final result of BCD Subtraction.



Therefore, $(0101\ 0100\ 0001) - (0010\ 0001\ 0110) = (0011\ 0010\ 0101)$

Now you can check yourself.

$$(0101\ 0100\ 0001) = (541)_{10}$$

$$(0010\ 0001\ 0110) = 216_{10}$$

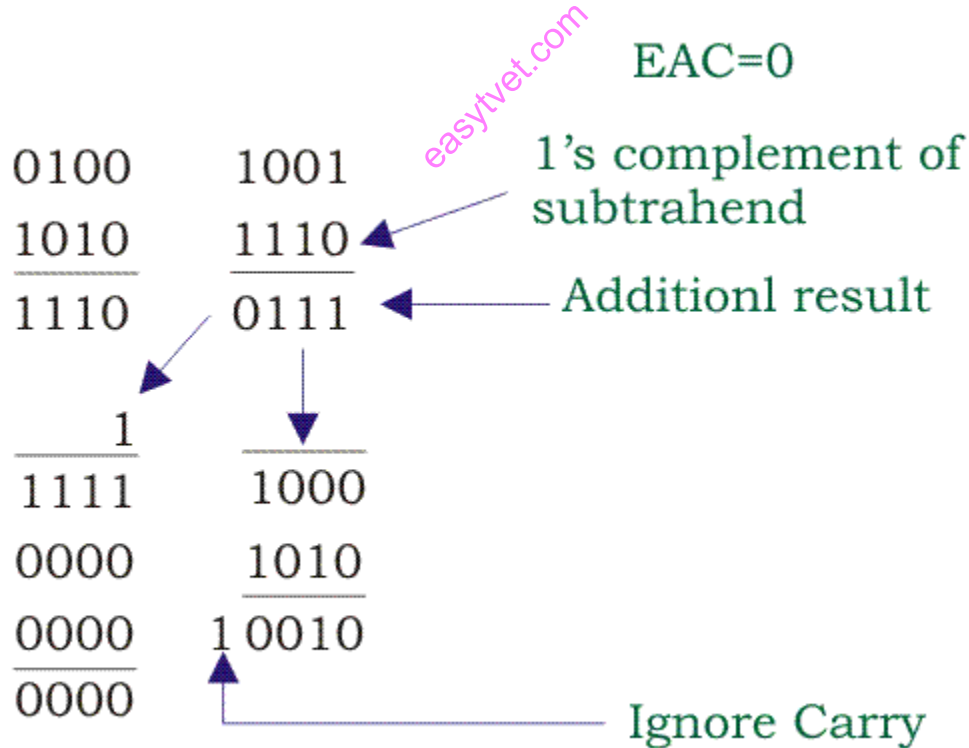
$$(0011\ 0010\ 0101) = 325_{10}$$

We know that $541 - 216 = 325$, Thus we can say that our result of **BCD Subtraction** is correct.

Example:

In this example let 0101 0001 be subtracted from 0100 1001.

- As per rule firstly 1's compliment of the subtrahend is done. Then the addition is done and the result is checked. Here EAC = 0, so the overall result will be -ve.
 - Now see the result of adder 1 from LSB. 1's compliment value of 0111 is transferred to adder 2 and it is added with 1010 since no carry is added with it as per the rule. The answer is the final result.
 - Now move to the next result of adder 1 i.e 1110. Here 1 is added to it which is the carry of the previous result. Then it's value is 1's complimented i.e 0000 and it is added to 0000. Result of adder 2 is the final result. This is the final result of BCD Subtraction.
- $(0100\ 1001)_{BCD} - (0101\ 0001)_{BCD} = (-0000\ 0010)_{BCD}$
- Now you can again check yourself. Decimal equivalent of the given numbers of subtraction is 49 and 51. Therefore $49 - 51 = -2$. So our result is correct.



Method of BCD Subtraction: 2

In 2nd method we will do BCD subtraction in 9's compliment method.

- Here the method is very simple. At first the decimal equivalent of the given Binary Coded Decimal (BCD) codes are found out.
- Then the 9's complement of the subtrahend is done and then that result is added to the number from which the subtraction is to be done.
- If there is any carry bit then the carry bit may be added to the result of the subtraction.

Idea may be cleared from an example given below.
 Let $(0101\ 0001) - (0010\ 0001)$ be the given subtraction.

- As we can see 51 and 21 are the decimal value of the given BCD codes. Then the 9's complement of the subtrahend is done i.e $99 - 21 = 78$.
- This complimented value is added with the 51. i.e $51 + 78 = 129$.
- In this result the MSB i.e 1 is the carry. This carry will be added to 29. Therefore $29 + 1 = 30$, which is the final answer of **BCD Subtraction**.
- The decimal result will be changed into **BCD** codes to get the result in BCD. Therefore from the example we can conclude the final result of BCD Subtraction i.e
 $(0101\ 0001)_{BCD} - (0010\ 0001)_{BCD} = (0011\ 0000)_{BCD}$

$$\begin{array}{r}
 (0101\ 0001) - (0010\ 0001) \\
 \downarrow \qquad \qquad \downarrow \\
 51 \qquad \qquad 21 \text{ [Decimal Equivalent]} \\
 \text{1's complement of 21} = 99 \\
 \qquad \qquad \qquad - 21 \\
 \qquad \qquad \qquad \hline
 \qquad \qquad \qquad 78 \\
 \text{Add 78 with 51} \\
 \begin{array}{r}
 78 \\
 + 51 \\
 \hline
 129 \\
 + 1 \\
 \hline
 130
 \end{array} \\
 \begin{array}{l}
 \leftarrow 1 \\
 \leftarrow 0011\ 0000
 \end{array}
 \end{array}$$

$$\therefore (0101\ 0001) - (0010\ 0001) = 0011\ 0000$$

Binary Coded Decimal Subtraction using 10's complement is same as in case of 9's complement, here the only difference is that instead of 9's complement we have to do 10's complement of the subtrahend.

1.2.5.4 Learning Activities

- The trainee is required to design the flowchart of a Hardware Binary Multiplication Algorithm. In the design, instead of shifting multiplicand left, the product register should be shifted to the right in each iteration. Thus, the shift register for the multiplicand is saved. However, the adder that adds the multiplicand the partial product will have to store the result to the high half bits.
- Further, the trainee is required to design an improved version that requires less hardware resource and should perform better based on the rule of thumb that “the less, the better” in hardware design.

1.2.5.5 Self-Assessment

1. What is Number System and its Types?
2. Why is the Number System Important?
3. What is Base 1 Number System Called?
4. Convert 215_8 into decimal.

1.2.5.6 Tools, Equipment, Supplies and Materials

Tools

1. Screw Drivers
2. Pliers
3. Wire cutters
4. Wire Strippers
5. Clamps
6. Vises

Equipment

- Voltmeter
- Ohmmeter
- Ammeter
- Multimeter
- Power supplies
- LCR meter

Materials and supplies

- Circuits
- Semiconductor materials
- Conductors e.g. copper, gold, silver
- Insulators e.g. rubber, glass, mica

1.2.5.7 References

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1.2.5.8 Model answers to Self-Assessment

1. What is Number System and its Types?

The number system is simply a system to represent or express numbers. There are various types of number systems and the most commonly used ones are decimal number system, binary number system, octal number system, and hexadecimal number system.

2. Why is the Number System Important?

Number system helps to represent numbers in a small symbol set. Computers, in general, use binary numbers 0 and 1 to keep the calculations simple and to keep the amount of necessary circuitry less, which results in the least amount of space, energy consumption and cost.

3. What is Base 1 Number System Called?

Base 1 number system is called the unary numeral system and is the simplest numeral system to represent natural numbers.

4. Convert 215₈ into decimal.

Solution:

$$\begin{aligned}
 215_8 &= 2 \times 8^2 + 1 \times 8^1 + 5 \times 8^0 \\
 &= 2 \times 64 + 1 \times 8 + 5 \times 1 \\
 &= 128 + 8 + 5 \\
 &= 141_{10}
 \end{aligned}$$

1.2.6 Learning Outcome 6: Emerging trends in electronics

1.2.6.1 Introduction to the learning outcome

This learning outcome covers description of emerging trends, explanation of challenges of emerging trends and how to cope with the emerging trends.

1.2.6.2 Performance Standard

1. Description of emerging trends is done
2. Challenges of emerging trends are explained
3. Explanation on coping with the emerging trends is done

1.2.6.3 Information Sheet

Emerging trends in Electronics

Since the time the “electronic revolution” hit the telecommunication industry, the competition in the field has exponentially increased leading to furious investment and innovation, helping to give rise to the digital economy. The digital economy supported the development of many electronic appliances such as smart phones, watches, TVs, refrigerators, security systems, and of course, environmentally friendly electric vehicles.

According to the latest report Electrical and Electronic Manufacturing Market Briefing 2017 from The Business Research Company (TBRC), the global electrical and electronics manufacturing market is expected to reach \$3 trillion by 2020, with Asia Pacific as the largest market by geographic region and China the biggest market by country. India is expected to grow at a heady 16.8% growth rate. Apart from providing market segmentation and growth by region and by country, the report also covers the top five trends in the electronics industry in the coming five-year forecast period.

1. Product Design Outsourcing

Original Equipment Manufacturers (OEMs) are increasingly moving product design and development processes to Electronic Manufacturing Service (EMS) partners. Product design, a

part of the specialized design services market which is expected to reach \$157 billion in 2020 according to TBRC, is being outsourced to reduce overall costs and shift from fixed costs to variable costs.

EMS companies are offering more design services for sub-assemblies and finished products. OEMS are collaborating with EMS partners and moving into new models such as joint design manufacturing (JDM) and outsourced design manufacturing (ODM).

2. Virtual Reality in Electronic Manufacturing

Virtual reality technology is being adopted by electronic manufacturing companies to improve manufacturing efficiency. This technology in the electronic manufacturing industry is often referred to as digital design, simulation, and integration. Virtual reality technology enables companies to inspect design objects at all conceivable scales, thereby eliminating defects in the product in the design stage. Taking into account the growth rate of electronic equipment market globally, which is 5.2% according to TBRC, virtual reality has a big implementation scope in the forecast period.

3. Robotics and Automation

Many electronic equipment companies are using robotics and automation to improve plant efficiency and productivity. Sensors are being used in various machines to access invaluable data for improving efficiencies and reducing potential breakdowns. For instance, according to a report by Boston Consulting Group (BCG) in 2016, 1.2 million industrial robots are expected to be deployed by 2025, while the electronic equipment is expected to reach \$2.1 trillion by 2020 according to TBRC, thus indicating a rise in automation and robotics technology adoption to improve productivity and reduce production costs.

4. IoT Technology Driving Smart Household Appliances

Household appliance manufacturers are integrating their products with the IoT technology to make customers lives comfortable and convenient. Internet of Things technology is the interconnectivity of physical objects and devices that are integrated with sensors and software

that allow them to exchange and collect data. Major technologies enabling smart household appliances include Wi-Fi, Bluetooth Low Energy, micro server and micro-electromechanical systems.

For instance, LG has created homechat, an app that enables the user to monitor their refrigerators, cookers, washing machines, and other devices from anywhere through their smart phones. The homechat technology was introduced by LG initially in South Korea and is moving to other global markets gradually.

According to report by IHS, the global smart connected electronics shipments is estimated to reach over 223 million by 2020, while the overall market of household appliances is expected to hit \$471 billion according to TBRC.

5. Growing Demand for Smart TVs

The demand for smart TVs is being driven by the rising consumer preference for built-in smart functions in personal devices, and increasing internet penetration. A smart TV combines the features of televisions and computers, and comprises a television set with integrated functions for internet use. Smart TV users are also offered direct access to streaming services such as Netflix and Amazon Prime Instant Video.

To capitalize on this trend, television manufacturers across the world are entering the smart TV market. According to the IHS Technology report, 48.5% of televisions shipped globally were smart TVs, and the number is estimated to reach 134 million by 2020, while the audio and video equipment manufacturing market is forecast to reach \$351 billion according to TBRC.

Challenges in Electronics industry

The electronics industry can be broken down into three main categories: semiconductors, Electronics Manufacturing Services (EMS), and Original Equipment Manufacturers (OEM). To simplify things, out of these industry subverticals, we'll focus on the challenges faced by EMS and small to mid-sized contract manufacturers:



Figure 28: *Electronic Manufacturing lab*

1. Shrinking Operating Margins

Global competition and new innovations are driving prices down. Companies must continually become more cost-efficient to remain profitable.

2. Complex Global Supply-Chain

More and more, companies are having to juggle internal and external resources while staying within international standards. Issues such as traceability and compliance are increasing operational burdens. It is not unusual for components and sub-components to embark on a journey that touches three or more continents before reaching the end-consumer.

3. Service and Warranty Management

Leveraging the global supply-chain is putting more focus on supplier quality management. Having a strong quality and traceability system directly affects warranty reserve and post-production service hours.

4. Short Product Lifecycles

With quickly changing consumer tastes and preferences, EMS companies and contract manufacturers need to have effective New Product Introduction (NPI) processes in place.

Closed-loop communication between sales, manufacturing, and engineering is vital to ensure product launches hit time, volume, and quality targets.

5. Uncertain Demand

Aggregately, economic volatility and cyclical demand cause fluctuations in production. On a more granular level, consumer preference can cause spikes in demand for an individual product or company. Efficient lean capabilities must be in place to keep inventory aligned with demand.

6. Sustainability

Emerging regulations and standards are forcing companies to account more and more for Corporate Social Responsibility (CSR) in decisions. E-Waste, a popular topic today, is driving conversations about the disposal of products and their impact on the environment. Companies must now consider of the complete product lifecycle in decisions.

How to cope with the emerging challenges

As manufacturing processes get ever leaner, and customer expectations get more demanding, maintaining an agile and transparent electronics manufacturing supply chain has never been more important.

Being open to the benefits of new digital technologies will be essential for manufacturers who want to safeguard their supply chains, maintain the efficiency of their production processes and guarantee on-time delivery.

Harnessing the real-time analytics potential of Big Data for example, can enable companies to filter, organize and make sense of large amounts of information to support their supply chain strategies.

The threat of cyber-attacks continues to be a growing concern for the electronics manufacturing industry.

And a 2018 report from Supply Chain Insights provided a compelling overview - with cyber-crime being listed as one of the top three events to impact on global supply chains over the past five years.

As the amount of data flowing through the supply chain continues to grow it's ever more important for companies to safeguard their IP assets.

Fortunately though, there are some substantial changes that can be made at grassroots level - starting with the educating of company employees on the risks of security threats such as phishing emails, personal computer theft and password breaches.

As networks become smarter and more complex, the risk of supply chain disruption is an ever-present threat - whether it occurs on a small or large scale, or is due to internal or external factors.

The extent to which manufacturers are able to plan ahead, to predict the "what ifs" - and to react swiftly to changing conditions - will be key in safeguarding productivity, reliability and on-time delivery

1.2.6.4 Learning Activities

Household appliance manufacturers are integrating their products with the IoT technology to make customers lives comfortable and convenient. The trainee is required to give a detailed analysis on how integration with smart sensors, existing data-indicators and controllers is monitoring and possibly influencing environments.

1.2.6.5 Self-Assessment

1. What is a smart TV?
2. What is the difference between OEM and EMS?
3. How is quality affected by Service and Warranty?
4. Why is E-waste an important topic on electronic impact on the environment?
5. The threat of cyber-attacks continues to be a growing concern for the electronics manufacturing industry. Justify how

1.2.6.6 Tools, Equipment, Supplies and Materials

Tools

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1.2.6.7 References

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1.2.6.8 Model answers to self-assessment

1. What is a smart TV?

A smart TV combines the features of televisions and computers and comprises a television set with integrated functions for internet use. Smart TV users are also offered direct access to streaming services such as Netflix and Amazon Prime Instant Video.

2. What is the difference between OEM and EMS?

- *Original Equipment Manufacturers (OEMs)*
- *Electronic Manufacturing Service (EMS)*

3. How is quality affected by Service and Warranty?

Leveraging the global supply-chain is putting more focus on supplier quality management. Having a strong quality and traceability system directly affects warranty reserve and post-production service hours

4. Why is E-waste an important topic on electronic impact on the environment?

E-Waste, a popular topic today, is driving conversations about the disposal of products and their impact on the environment. Companies must now consider of the complete product lifecycle in decisions.

5. The threat of cyber-attacks continues to be a growing concern for the electronics manufacturing industry. Justify how

As the amount of data flowing through the supply chain continues to grow it's ever more important for companies to safeguard their IP assets.

As networks become smarter and more complex, the risk of supply chain disruption is an ever-present threat - whether it occurs on a small or large scale, or is due to internal or external factors.