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**Doctorate: Major in Electrical Engineering**

**Electrical Principles and Applications Questionnaire**

1. What is Ohm's Law?

Ohm's law states that the potential difference or voltage between two points is directly proportional to the electricity or current flowing through the resistance and directly corresponds to the resistance of the circuit, see figure 1.

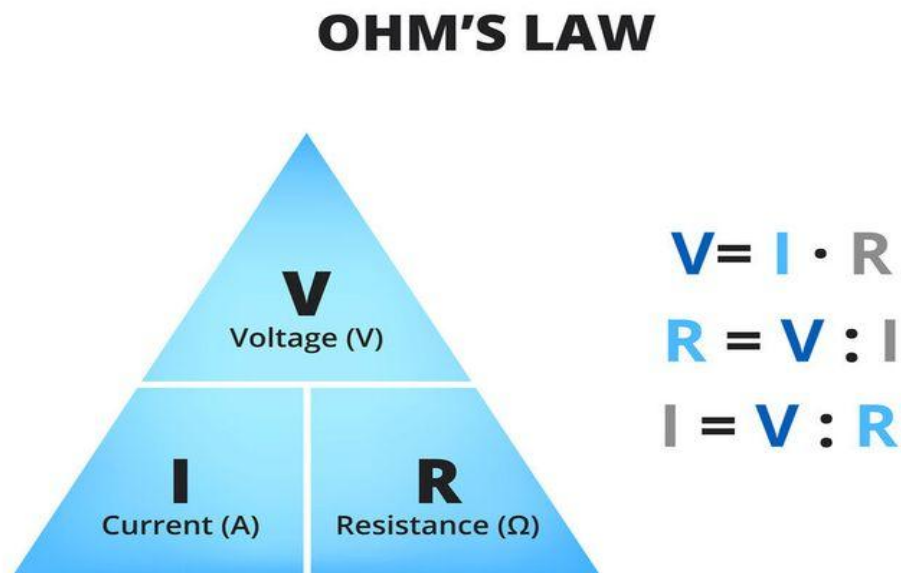
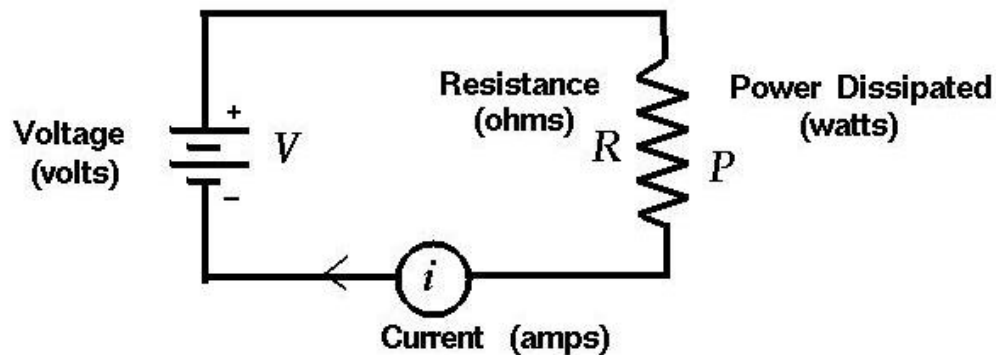


Figure 1: Illustration Diagram of Ohm's Law

And how is it used in electrical circuits?

Ohm's Law is utilized in electrical circuits to compute the correlation between current, resistance and current, enabling determination of the value of one variable if the other two are known; basically, the law helps in understanding the amount of current that will flow through a circuit depending on the circuit resistance and the applied voltage, allowing the circuit designer and analyzer to predict the current flow and the potential voltage drops across circuit see figure 2.



$$V = i R$$

$$P = i V = i^2 R$$

Figure 2: Ohm's Law Illustrated in an Electric Circuit

2. Define the terms voltage, current, and resistance?

Voltage, current and resistance are basic concepts regarding electricity.

Voltage is the electromotive force that drives the potential energy or electrons through a circuit or between points across an electric component or a wire. The measurement of voltage is in Volts (V)

Current is the flow rate of electrons through an electric circuit or the amount of charges that flow in any part of an electric conductor per time interval. The measurement of current is in Amperes (A)

Resistance is the measure of how much a conductor material opposes the flow of electric current in a component or circuit. The measurement of resistance is in Ohms ( $\Omega$ ) and is denoted by letter R

How are they related?

The relationship between voltage, current and resistance is expressed by Ohm's Law ( $V = IR$  in this equation, where V is voltage, I is current and R is resistance).

This law states that the current going through in an electric circuit is directly proportional to the voltage applied and inversely proportional to the resistance of the circuit, provided the temperature remains constant see figure 3.

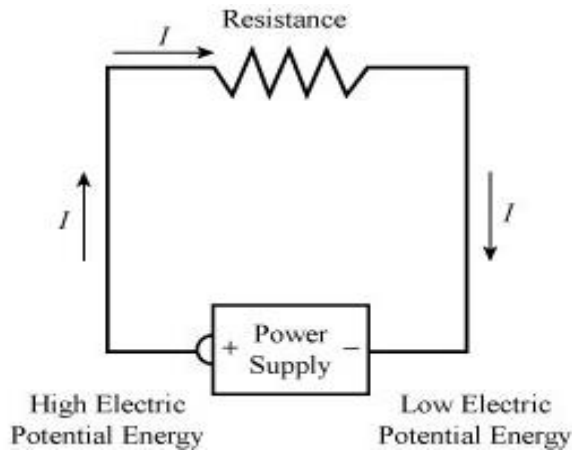


Figure 3: Relationship between Voltage (E), Current (I) and Resistance (R)

3. What are the differences between alternating current (AC) and direct current (DC)?

The significant difference between the alternating current (AC) and the direct current (DC) is the periodically changes or reverses direction of the alternating current (AC) at regular intervals of time, in other word alternating current oscillates, while direct current (DC) flows only in one direction, always flowing from the positive to the negative. Basically alternating current (AC) is a wave type current while direct current (DC) flows steadily see illustration in figure 4.

Alternating current (AC) is essentially used for powering homes, offices and factories, while direct current (DC) is normally used in motor vehicles and high torque industrial motors.

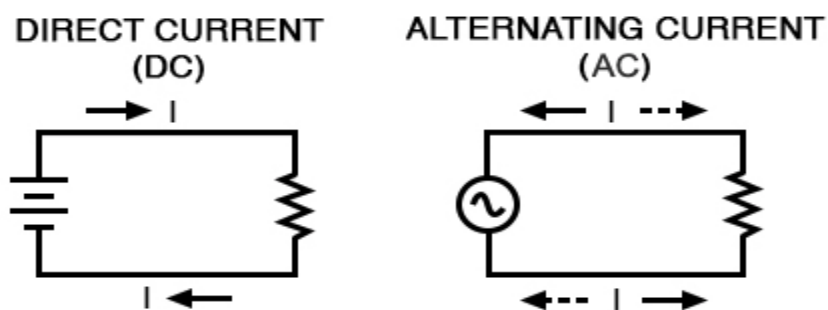


Figure 4: Illustration Diagram showing the difference between Alternating Current (AC) and Direct Current (DC)

#### 4. What is the purpose of a transformer?

A transformer is a device that transfers or transforms electric energy from one alternating current circuit to one or more other circuits via electromagnetic induction, either increasing (stepping up) or reducing (stepping down) the voltage

And how does it work?

A transformer works by using the principle of electromagnetic induction, where changing of magnetic field in a coil of wire induces a voltage in a nearby or opposite coil, allowing it to change the voltage of an alternating current by varying the number of turns on each coil; basically, when AC electricity is applied to the primary coil of a transformer, it creates a fluctuating magnetic field which then induces a voltage in the secondary coil of the same transformer, with the voltage level depending on the ratio of turns between the primary and secondary coils of the transformer, resulting in either a step down or step up transformation of voltage see figure 5.

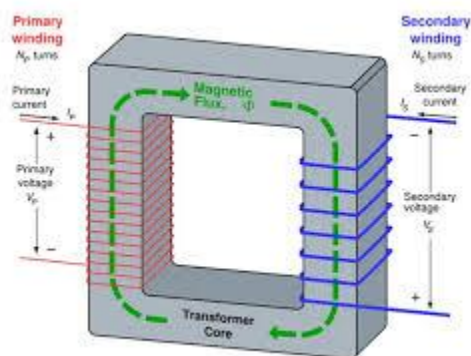


Figure 5: Illustration on how a Transformer works

#### 5. What are the basic components of an electrical circuit?

The basic components of an electrical circuit are the power source, the conductor and the load see figure 6.

Power source to the electrical circuit is from direct current or alternating current wall outlet supplies.

The conductor is the conductive path, such as a wire or printed circuit board, which allows the current to flow through.

The load is the device that needs electrical power to operate, such as a lamp, heating element or a motor.

Other components in an electric circuit are the resistors, capacitors, inductions, switches and transistors.

The resistors in an electrical circuit will regulate or restrict the flow of current and expend voltage within a circuit

The capacitors in an electrical circuit will store electrical energy and generate it to the circuit when required.

The inductors in an electrical circuit will store energy in the form of a magnetic field and release it in the next half cycle

The switches in a circuit will break an electrical circuit by diverting the current from one conductor to another

The transistors in a circuit is used as amplifiers or switches

These components are connected in a continuous loop that allows electricity to flow and power the components as necessary see below figure 6.

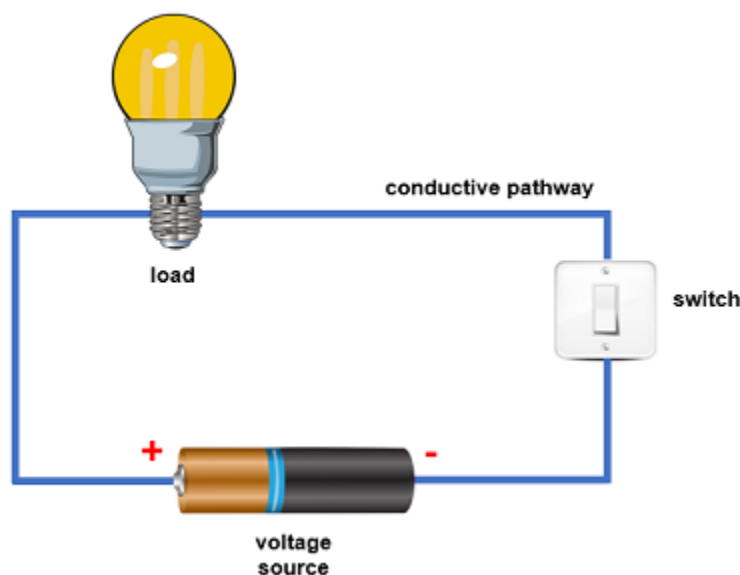


Figure 6: Basic Electrical Circuit Components

6. How do series and parallel circuits differ in terms of current and voltage?

In a series circuit, the current passing through each component is the same, while the voltage is divided across each component; in a parallel circuit, the voltage across each component is the same, while the current flowing splits and is the sum of the currents passing through each branch see below figure 7.

# SERIES vs PARALLEL CIRCUITS

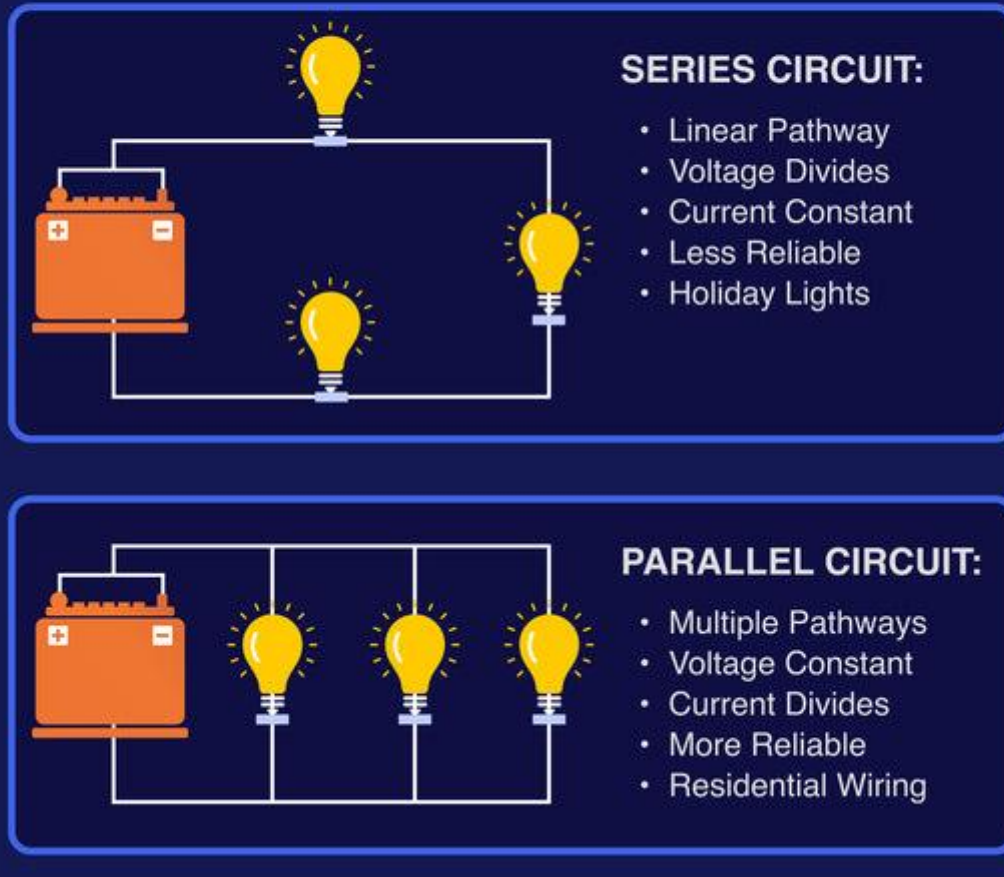


Figure 7: Diagram showing the distinct difference between Series and Parallel circuits

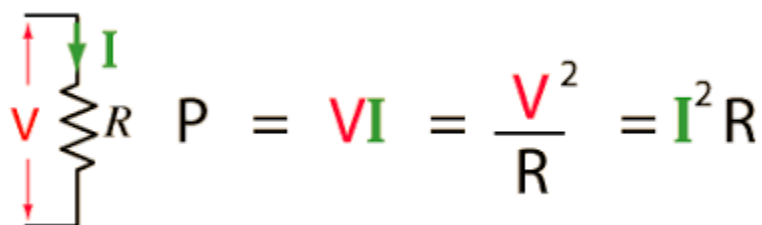
7. What is the power formula in an electrical circuit?

The power formula in an electrical circuit is  $P = V \times I$  where  $P$  represents power (in watts),  $V$  is voltage (in volts), and  $I$  is current (in amperes) see figure 8.

This formula basically states that the power in a circuit is calculated by multiplying the voltage across a component by the current passing through it.

Depending on the statistics given, you can use alternatives like  $P = I^2 \times R$  (where  $R$  is resistance and  $I$  is current) or  $P = V^2 / R$ .





The diagram shows a resistor symbol with a red arrow pointing up labeled 'V' and a green arrow pointing down labeled 'I'. To the right of the resistor is the letter 'R'. Further right is the equation  $P = VI = \frac{V^2}{R} = I^2R$ .

Figure 8: Power Formula in an Electric Circuit

Explain the units involved.

In the power formula for an electrical circuit, the units involved are volts (V) for voltage, amperes (I) for current and watts (W) for power, with the formula being:  $P = V \times I$ .

## 8. What are capacitors and inductors?

A capacitor is an electronic component that reserve electrical energy in an electric field, basically acting like a temporary battery by piling up charge on two conductive plates separated by an insulator (dielectric material) and released when required to the circuit, while an inductor is a component that reserves energy in a magnetic field, the inductor consists of a coil of wire where current flow generates a magnetic field, withstanding changes in current flow within an electric circuit; both capacitors and inductors are considered passive components that are used to filter signals and manage voltage or current fluctuations within electrical circuits see figure 9

The capacitors are good at withstanding sudden changes in the voltage, while inductors withstand sudden changes in the current. .

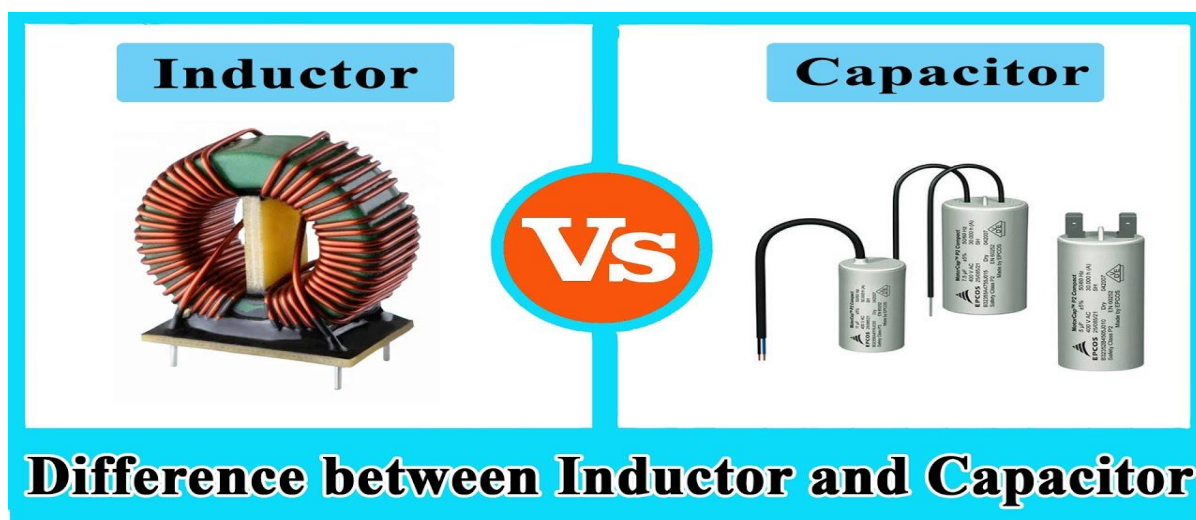


Figure 9: The difference between Inductors and capacitors

And how do they function in AC circuits?

In alternating current (AC) circuits, capacitors are like variable resistors that resist rapid voltage changes by storing and releasing electrical charge when required, while inductors are like variable resistors that resist rapid current changes by creating a magnetic field that opposes the change in current flow, both of which are dependent on the frequency of the alternating current (AC) signal; basically, capacitors lead the current in an alternating current (AC) circuit while inductors lag the current see figure 10.

The resistance to current flow in a capacitor is known as capacitive reactance, which decreases as the frequency of the AC signal increases. In the way an alternating current (AC) voltage changes direction, the capacitor charges and discharges, resulting in the current to lead the voltage and at high frequencies, a capacitor functions like a short circuit, allowing large current to pass.

The restriction to current flow in an inductor is known as inductive reactance, which increases as the frequency of the alternating current (AC) signal increases and when current passes through an inductor, a magnetic field is produced around it, which resists changes in current flow. At minimum frequencies, an inductor functions like a short circuit, allowing large current to pass.

Due to their different behaviors of the capacitors and the inductors, both can produce a phase shift between the voltage and current in an alternating current (AC) circuit. When a capacitor and an inductor are placed in series at resonant frequency, their reactance cancels each other out, producing electrical circuit with low impedance.



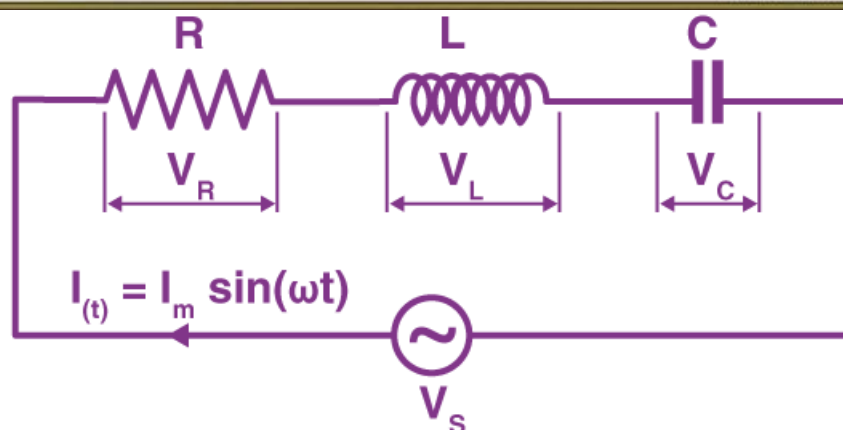


Figure 10: Illustration of Inductors and Capacitors in an Electric Circuit

9. What is the difference between real power, reactive power, and apparent power?

Real power, reactive power and apparent power are related types of electrical power system. Real power or active power is the power that is used to do work or consumed by resistive loads and the measurements are in Watts (W), while reactive power or wattles power is power that is reserved in a coil and then released back to the grid when required and the measurement is in Volt Amperes reactive (VAr). Whereas Apparent power is the cumulative power that is readily available in a system and the grid must be able to contain the sum of real power and reactive power and the measurement is in Volt Amperes (VA).

The relationship between real power, reactive power and apparent power can be represented by using a power triangle as shown below see figure 11.

## The Power Triangle

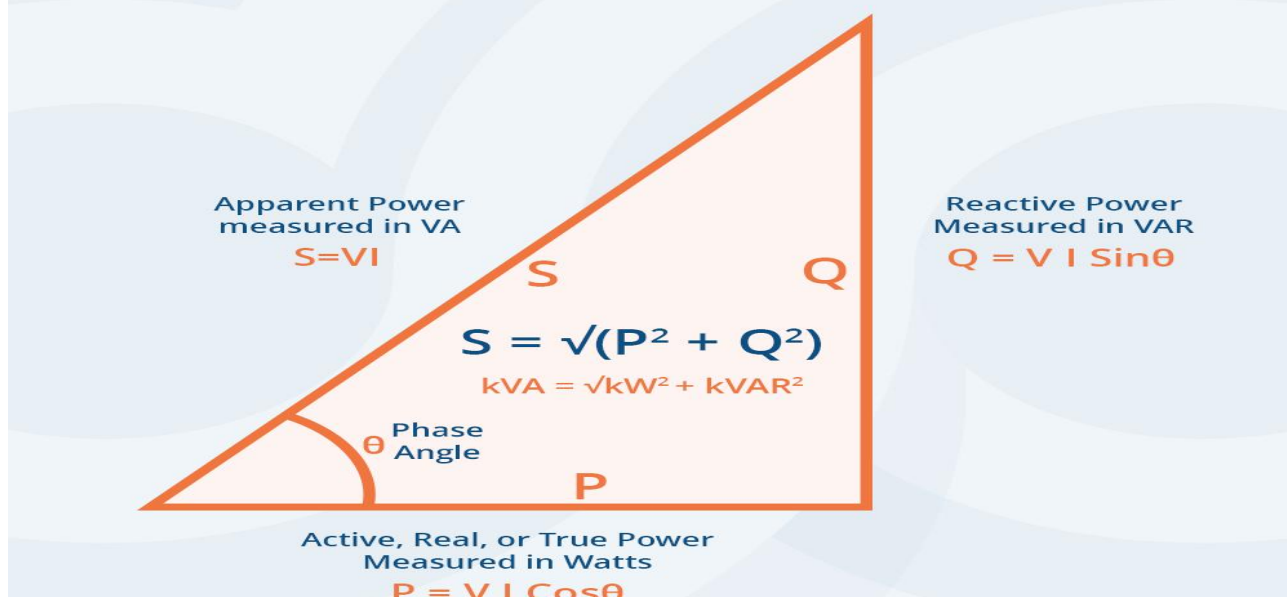


Figure 11: The difference between real power, reactive power, and apparent power

10. How does a three-phase electrical system differ from a single-phase system?

A three-phase electrical system differs from a single-phase system as it provides power through three separate alternating current (AC) waveforms that are 120 degrees out of phase with each other, while a single-phase system only uses one alternating current (AC) waveform, making three-phase systems more efficient for high-power applications such as large motors in industrial settings, whereas single-phase has one alternating current waveform is commonly used for residential power needs such as lighting and small home appliances; basically, three-phase electrical system distributes power more equally across multiple phases, resulting in reduced current fluctuations and more efficiently stable compared to single-phase electrical system see figure 12.

# Single-phase and three-phase electrical power systems

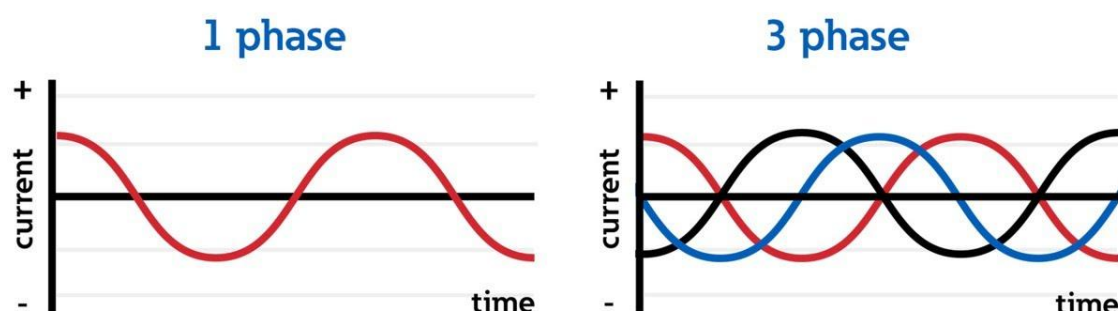


Figure 12: The difference electrical power between single Phase and Three Phase Systems

## 11. What is an RLC circuit?

An RLC circuit is an electrical circuit composed of a resistor (R), an inductor (L) and a capacitor (C), all are connected together in series or parallel; the name RLC simply comes from the symbols representing each component in a circuit diagram. These circuits are often called tuned circuit because they can resonate at a resonant frequency and exhibit resonant behavior, meaning they can oscillate strongly at a specific frequency, making them valuable in basic applications such as radio tuning, oscillators, signal filtering and other electronic devices where precise frequency selection is required see figure 13.

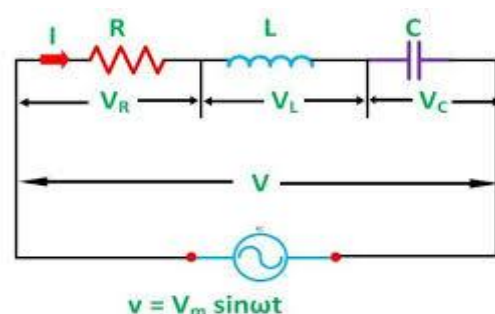


Figure 13: RLC Circuit diagram

And what role do the resistor, inductor, and capacitor play in it?

In an RLC circuit, a resistor controls the current flow by dissipating energy as heat, limiting current flow based on its resistance value, leading to energy dissipation as heat and plays an important role in damping of oscillations in the circuit, while an inductor resists changes in current flow by reserving the energy in a magnetic field, opposes changes in the current by producing a magnetic field when current passes through it, resulting in voltage resisting the change in the current and a capacitor resists changes in the voltage by reserving energy in an electric field, basically creating a dynamic where the circuit will oscillate at a particular resonant frequency depending on the sum of each component, resists changes in the voltage by reserving electrical energy in the electric field, resulting in the current passing when the voltage across it changes see figure 14.

When the inductive reactance of the inductor is even to the capacitive reactance of the capacitor in an electrical system, the circuit will reach resonance, where the impedance is reduced and the current is increased at a specific resonant frequency.

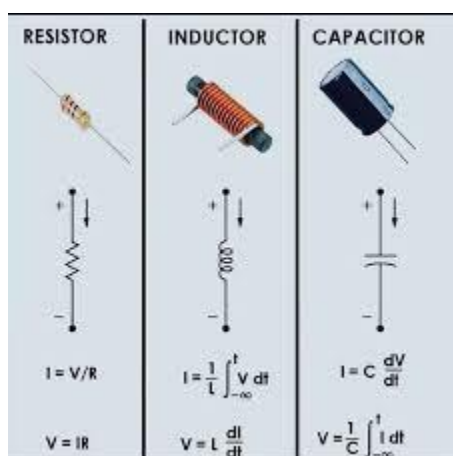


Figure 14: Resistor, Inductor and Capacitor

12. What is the significance of the frequency response in electrical systems?

In electrical systems, the frequency response is significant because it divulges on how a system changes the amplitude and the phase of signals at different frequencies, basically showing how well a system can hold varying signal frequencies, which is important for designing and analyzing components such as amplifiers, filters and sensors ensuring that they

operate precisely across the desired resonant frequency range within the system see figure 15.

Frequency response is fundamental in filter design, as it permits design engineers to accurately control which frequencies are allowed through and which are attenuated, essential for applications such as signal processing, reduction of noise and in feedback control systems, scrutinizing the frequency response in helping identify potential instability issues within the system, as large phase shift at certain specific frequencies can result in oscillations. Mastery in the frequency response allows the engineers to make the best system components to realize the desired performance over the specific frequency spectrum.

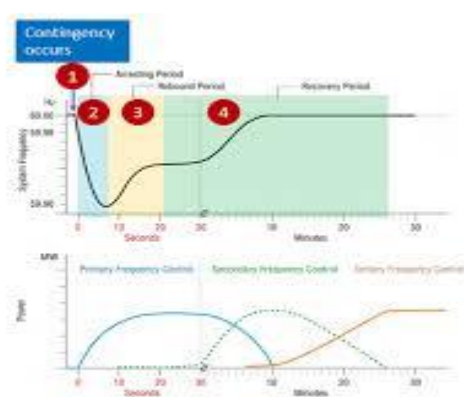


Figure 15: Frequency Response

### 13. How do semiconductors work?

A semiconductor works by permitting electrons to pass through it under particular conditions, controlling switch for electricity, where its conductivity can be controlled by doping impurities to the crystal structure, basically creating holes that allows electron movement and permitting the controlled flow of current subject to the applied voltage; this is attained by utilizing the valence electrons in the outermost shell of atoms within the semiconductor material, which can be electrified to move freely when energy is added, such as heat or light, permitting conduction see figure 16.

In short, semiconductors work by allowing the valence electrons, those located in the outermost shell of an atom, to come together with the valence electrons of other atoms.

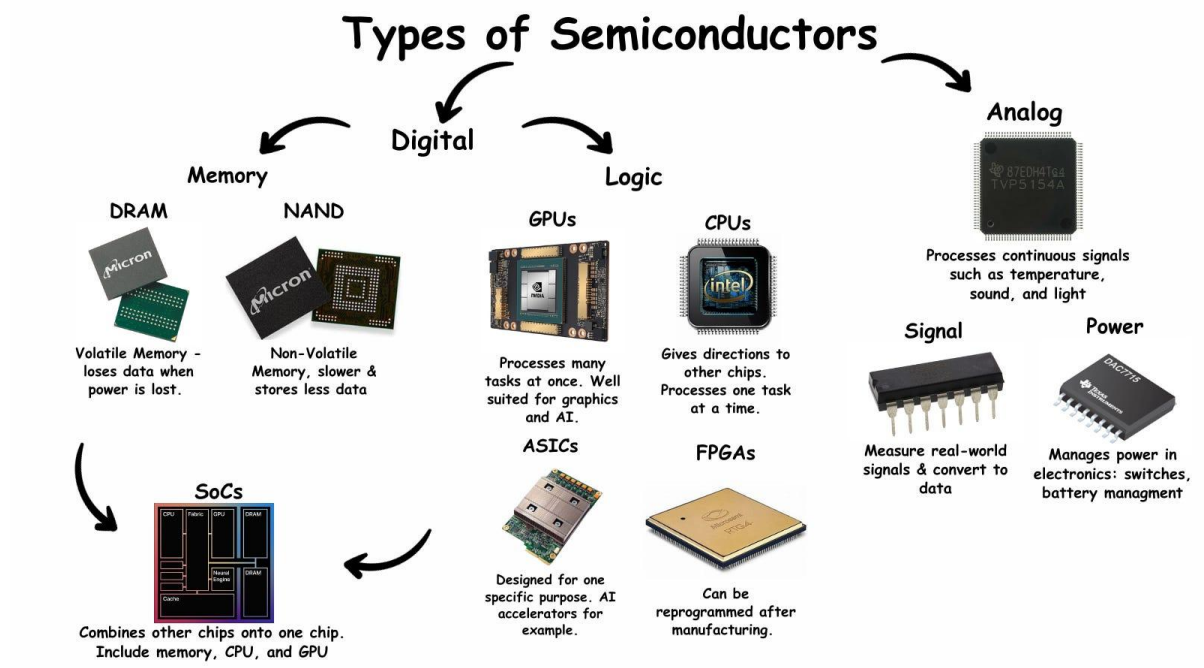


Figure 16: Types of semiconductors

And what role do they play in modern electrical systems?

Semiconductors are materials with electrical conductivity that fall between conductors and insulators. When voltage is applied across them, electrons in the valence band will attain substantial energy to flow into the conduction band, permitting them to flow freely through the material, hence producing an electrical current.

Their unique properties make them crucial in fabrication of transistors, the basically building blocks of current modern electronics.

14. What is the purpose of a circuit breaker?

A circuit breaker is an electrical safety device intended to automatically switch off the flow of electricity in a circuit when there is an over current/overload or short circuit, consequently protecting the electrical circuit system from physical damage, premature failure, overheating and potential fires by switch off the power whenever necessary; basically secure safety mechanism to avert electrical dangers in homes, businesses and industrial settings in safeguarding electrical appliances and wiring see figure 17.



Figure 17: Circuit Breaker

And how does it protect electrical systems?

A circuit breaker protects electrical systems by automatically switching off the flow of electricity in a circuit when the current surpasses safe operation levels, averting damages to the electrical circuits, home appliances and wiring from spikes, over currents/overloads or short circuits, basically offering secure safety mechanism to prevent potential electrical fires and shocks by switching off power supply automatically when required; unlike fuses or circuit breakers which can be reset and replaced after tripping see figure 18.

The internal parts of the circuit breakers manufactured either by bimetallic strip (thermal protection) or electromagnetic coil (magnetic protection), these materials are crucial in detecting excessive current flow or short circuit. When the current surpasses the set limit, the detection mechanism will trigger a mechanism that physically trips the circuit, cutting off the power supply to the circuit.



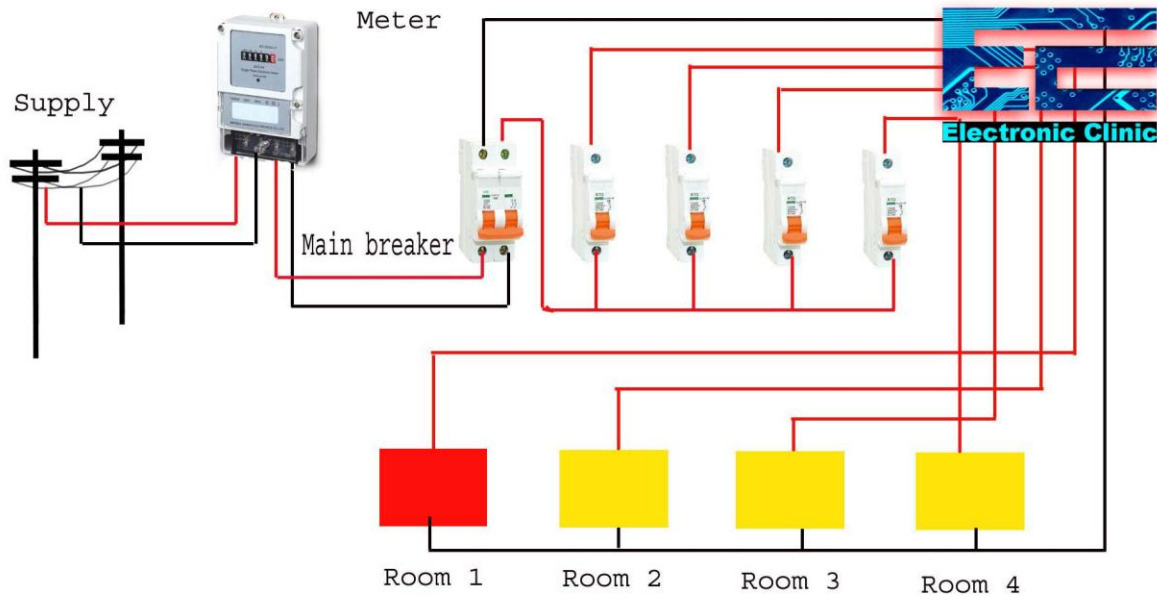


Figure 18: How a Circuit Breaker Protects Electric Circuit

15. Define what an electrical load is?

An electrical load is any electric component, device or that utilizes electrical energy and transforms it into another form such as heat or light.

The electrical load term can also allude to the amount of electricity in a circuit see figure 19.

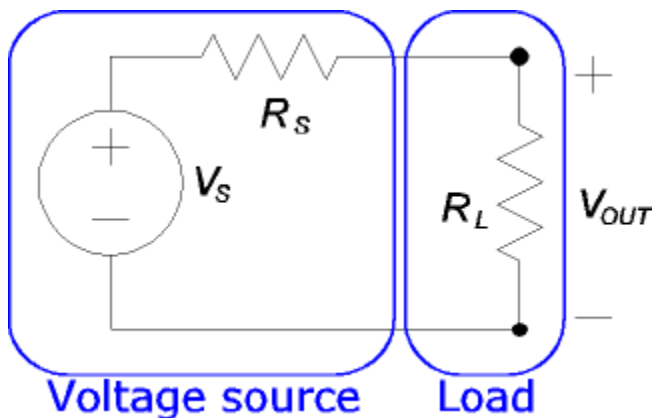


Figure 19: Electrical Load

And give examples of various types of electrical loads?

There are many types of electrical loads, which include resistive, inductive and capacitive loads. These loads can be categorized as active or passive, or by the consumption of the amount of power required see figure 20.

The resistive loads are such as light bulbs which are common resistive loads that convert electrical energy into heat, electric ovens and heating elements which uses constant amount of power.

The inductive loads are electric motors which use winding wire coils to create magnetic fields that convert electric power to mechanical power for appliances and transformers which use winding coils to reserve and release magnetic energy.

The capacitive loads are basically for circuits and substations in improving power factor.

The Reactive loads consume varying amounts of power depending on the specific frequency

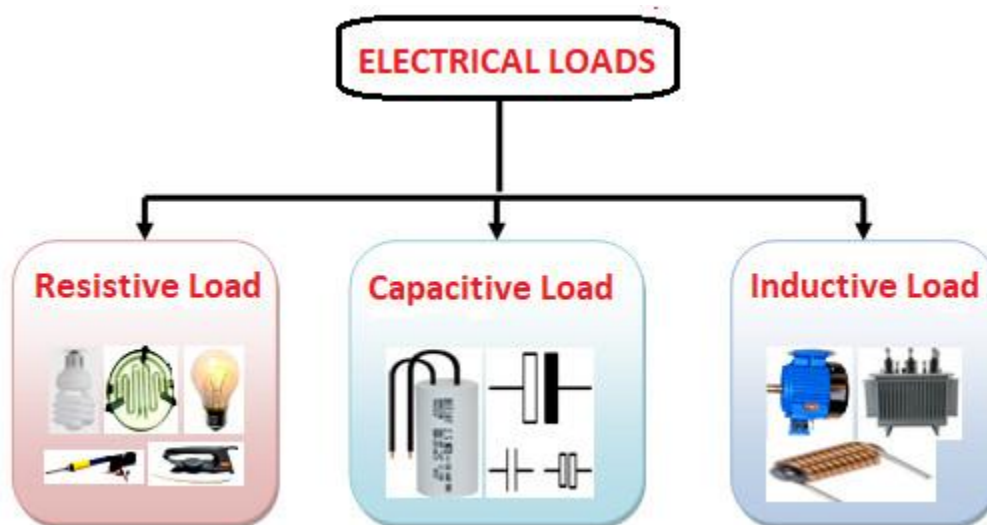


Figure 20: Examples of electrical Loads

16. What is a power factor?

A power factor is the measure of how efficiently electrical power is being utilized in an electrical circuit, expressed as the ratio of the real power (watts) consumed by the load to the apparent power (volt-amperes) drawn from the power source; basically, it indicates how closely the current and voltage waveforms are aligned in an alternating current (AC) circuit, with a value of 1 representing perfect alignment and maximum efficiency, and a value less than 1 indicating wasted power due to reactive components such as motors and transformers.

Power factor is calculated as the cosine of the phase angle between voltage and current ( $\cos(\phi)$ ). An ideal power factor of 1 (unity) is considered ideal, meaning all the power drawn is being used effectively, though it is impossible to get ideal power of 1.

And why is it important in power systems?

Power factor is crucial in power systems because it directly influence on the efficiency of the electrical system, stipulating how effectively electrical power is used; low power factor results in more current drawn to deliver the same amount of real power, resulting in increased energy losses in the system, hence higher electricity bills and likely high penalties from utility companies; hence a high power factor signifies superior efficiency and minimal losses in the electrical system. The majority of inductive loads such as motors, leads to lagging power factor where the current lags behind the voltage, thus to enhance power factor, capacitors can be included in the circuit to restrain the inductive effect see figure 21. Improving the power factor will lead to less current drawn, therefore reduced electricity costs, reduced heat and substantial long life of the electrical system, hence helping to maintain stable voltage supply in the system, ensuring reliability in operation of electrical equipment. .

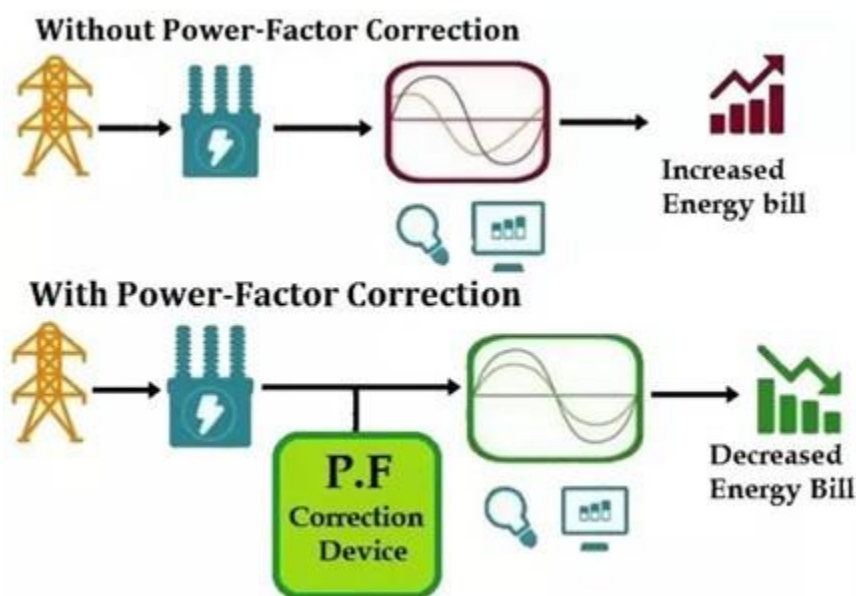


Figure 21: Important of Power Factor in Electrical Systems

## 17. How does an electric motor work?

An electric motor works by transforming electrical energy into mechanical energy through the interaction between the magnetic field and the electric current passing through a conductive coil of wire, which produces a force that causes the coil or squirrel cage rotor to rotate, producing enough torque and leading to rotation of the shaft; basically, when current passes through the coil, it becomes an electromagnet, interacting with permanent magnet to produce rotation see figure 22.

Most electric motors operate through the interaction between the motor's magnetic field and electric current in the winding wire to produce a force in the form of torque applied on the motor's rotor shaft.

The basic principle theory for an electric motor is electromagnetism, where a current carrying conductive wire encounters a force when placed within a magnetic field and because the motor comprises of the stator (the stationary part of the motor, usually containing permanent magnets or insulated laminations or wound units) and the rotor (the rotating part, basically a coil of wire mounted on an axle or squirrel cage Induction rotor).



Figure 22: An Electric Motor

And what are the common types used in electrical engineering?

The common types of electric motors used in electrical engineering include direct current (DC) motors, alternating current (AC) motors, synchronous motors, stepper and servo motors and brushless DC motors see figure 23.

The direct current (DC) motors are simple and reliable motors used in electronic cooling fans, motor vehicles, robotic, industrial applications and fuel pumps.

The compound direct current (DC) integrates characteristics of shunt and series wound motors, in contrary the separate excited direct current (DC) motors have a separate power supply for the field and armature windings, which permits more precise control of the direct current (DC) motor's speed and torque.

Alternating current (AC) motors are more flexible for speed control and their demand for low start up and reduced torque compared to direct current (DC) motors

Stepper motors are common and versatile variety of DC motors with a permanent magnet in the rotor or wound stator. These are motors that are operated using variable speed drive for accurate application.

Other types of electric motors are asynchronous motors and synchronous motors.



# Types of Electric Motors

WWW.ELECTRICALTECHNOLOGY.ORG



**AC Motors**



**DC Motor**



**Special Motors**



**Induction Motor**



**Shunt Motor**



**Stepper Motor**



**Synchronous Motor**



**Series Motor**



**Brushless Motor**



**Commutator Motor**



**PMDC Motor**



**Servo Motor**



**Wound Rotor Motor**



**Compound Motor**



**Universal Motor**



**Squirrel Cage Motor**



**Separately Excited Motor**



**Reluctance Motor**

Figure 23: Common Types of Motors

18. Explain the concept of impedance in AC circuits?

In alternating current (AC) circuits, impedance refers to the total resistance a circuit presents to the flow of alternating current, basically this is a combined measure of both resistance and reactance in the circuit; this is away to expand the concept of resistance to alternating current (AC) circuits where the current is constantly changing direction, and is represented by the symbol  $Z$  and the measurement is in ohms ( $\Omega$ ) see figure 24.

Impedance is the resistance of a conductive material in an alternating current (AC) circuit. This is the rms values of current and voltage in Ohm's Law, by replacing the  $R$  of resistance with  $Z$  for impedance. Hence,  $I = V / R$  becomes  $I_{rms} = V_{rms} / Z$ .

Impedance has two parts: resistance ( $R$ ), which represents the resistance to current flow due to the circuit's intrinsic resistance, and reactance ( $X$ ), which emerges from capacitors and inductors and varies according to the frequency of the alternating current (AC) current. Since resistance and reactance can be considered at different phases in an AC circuit, impedance is often indicated in a complex number, where the real part is the resistance and the imaginary part is the reactance. Different from pure resistance, impedance changes with the frequency of the alternating current (AC) current due to the effect of reactance, which is directly proportional to frequency in inductors and inversely proportional in capacitors. Higher impedance means the circuit offers greater resistance to the flow of current, leading to minimal current for a given voltage.



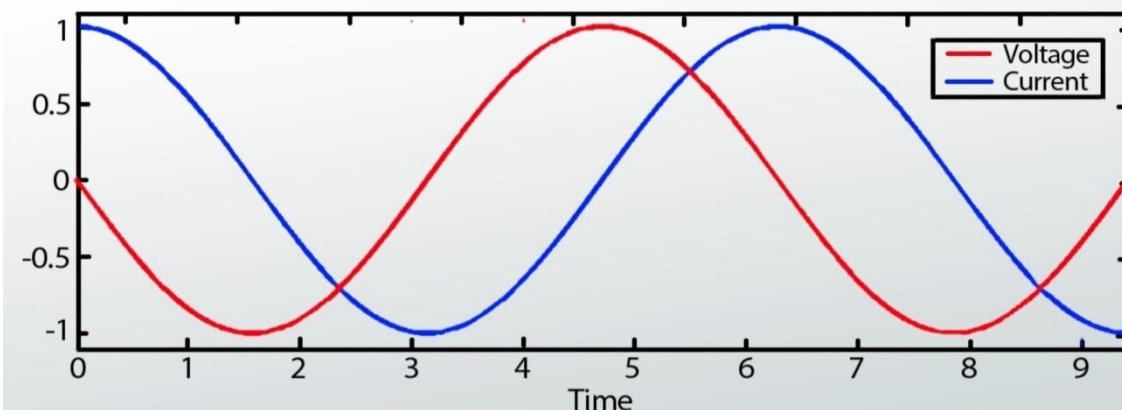


Figure 24: Impedance of AC Circuit

And how is it calculated.

In alternating current (AC) circuits, impedance ( $Z$ ) is calculated utilizing the formula:  $Z = \sqrt{R^2 + (X_L - X_C)^2}$ , where  $R$  is the resistance,  $X_L$  is the inductive reactance and  $X_C$  is the capacitive reactance; basically, it's the square root of the sum of the resistance squared and the difference of reactances squared, constituting the integrated effect of all components in the circuit. The measurement of Impedance is in ohms ( $\Omega$ ), just like resistance.

19. What are the primary differences between analog and digital signals?

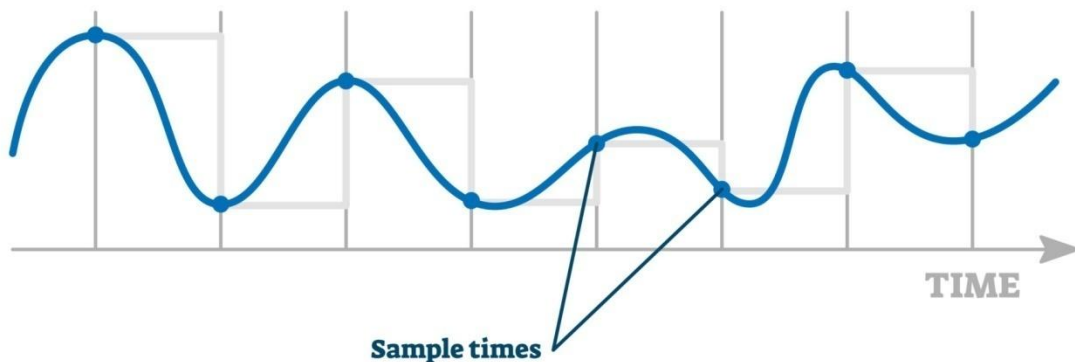
The primary difference between analog and digital signals is that analog signals displays continuous electrical signals, meaning that the signal can measure any value within a range, while digital signals have non-continuous electrical signals, are distinct, representing information as discrete values like "0" or "1" (binary), making them much less susceptible to noise and interference compared to analog signals see figure 25.

Analog signals fluctuate continuously over time, mimicking real world phenomena like sound waves or temperature changes. The amplitude and frequency of an analog signal can vary to represent information and the signals are susceptible to noise, leading to distortion of signals and impacting on its accuracy.

Digital signals are represented by discrete values, typically "0" and "1" in binary form. They are less prone to noise due to their distinct nature, are easier to process and manipulate with computers because of their binary nature.

## **ANALOG VS DIGITAL SIGNAL**

### **ANALOG**



### **DIGITAL**

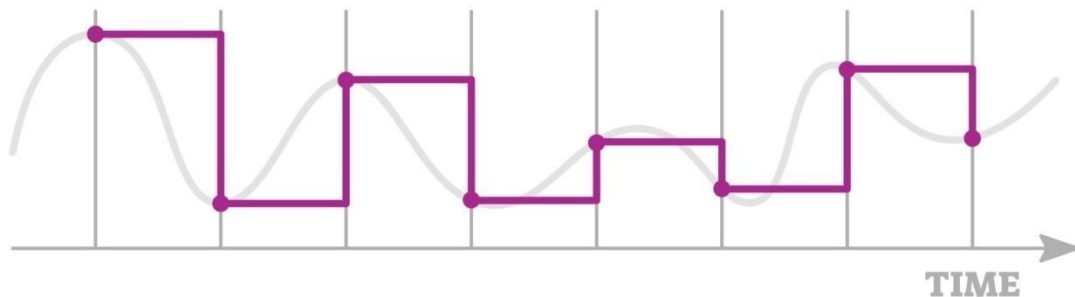


Figure 25: Difference in Analog and Digital Signals

20. What is the role of a diode in a circuit?

A diode in a circuit performs as a one-way valve for electric current, permitting the flow freely in one direction while significantly opposing its flow in the opposite direction; basically operating as a switch that only permits current to pass through in one direction,

making it primarily used for rectifying alternating current (AC) into direct current (DC) application figure 26.

A diode is a semiconducting electrical device with two terminals that ideally permits current to pass easily through in one direction but restricts the flow of current in the opposite direction. A diode can be thought of as a switch that controls the direction of electrons through the electrical circuit.

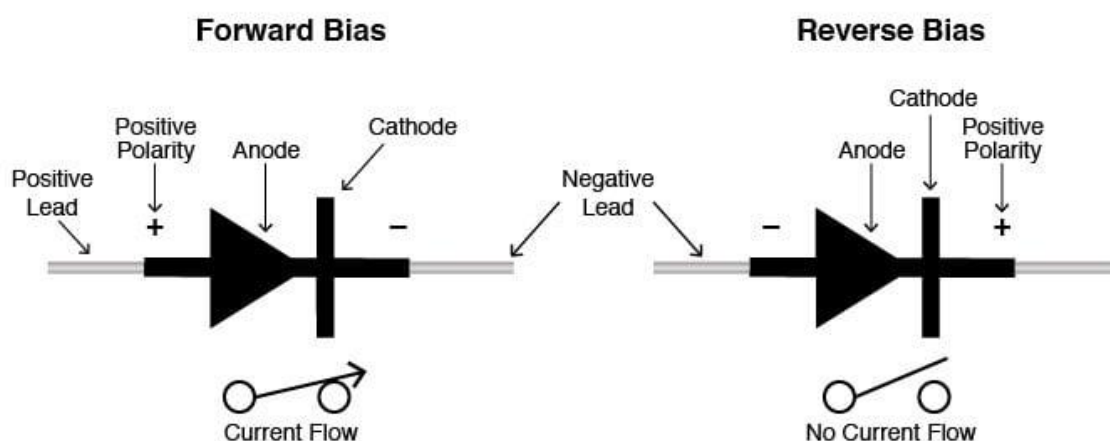


Figure 26: The role of the Diode is to allow current to flow easily through in one direction but restricts the flow of current in the opposite direction.

And how does it allow current to flow in only one direction?

A diode permits current to flow in one direction because of its internal structure and design, called a p-n junction, which creates a barrier that prevents current from passing in the reverse direction when voltage is applied in the opposite polarity basically known as reverse bias, while readily allows current to flow when the voltage is applied in the correct direction, forward bias see figure 27.

A diode permits the current to pass when a voltage is applied in the forward direction (positive voltage to the anode and negative voltage to the cathode). Even if voltage is applied in the reverse direction, no current flows.

Common applications of diodes:

- Rectification: Converting AC power to DC power in circuits like power supplies.
- Signal clipping: Removing unwanted voltage peaks from a signal
- Protection circuits: Protecting sensitive components from reverse current damage
- Voltage regulation: Maintaining a steady voltage level in a circuit
- **Demodulation:** Extracting audio signals from radio waves

How forward bias works:

- When a positive voltage is applied to the anode (p-type) and a negative voltage to the cathode (n-type), the depletion region narrows, allowing electrons from the n-type to easily pass into the p-type, allowing current to flow.

How reverse bias works:

- When the polarity is reversed, the depletion region widens, effectively blocking the movement of charge carriers and preventing current from flowing.

Important terms:

- **Anode:** The positive terminal of a diode, where current is supposed to flow out.
- **Cathode:** The negative terminal of a diode, where current is supposed to flow in.

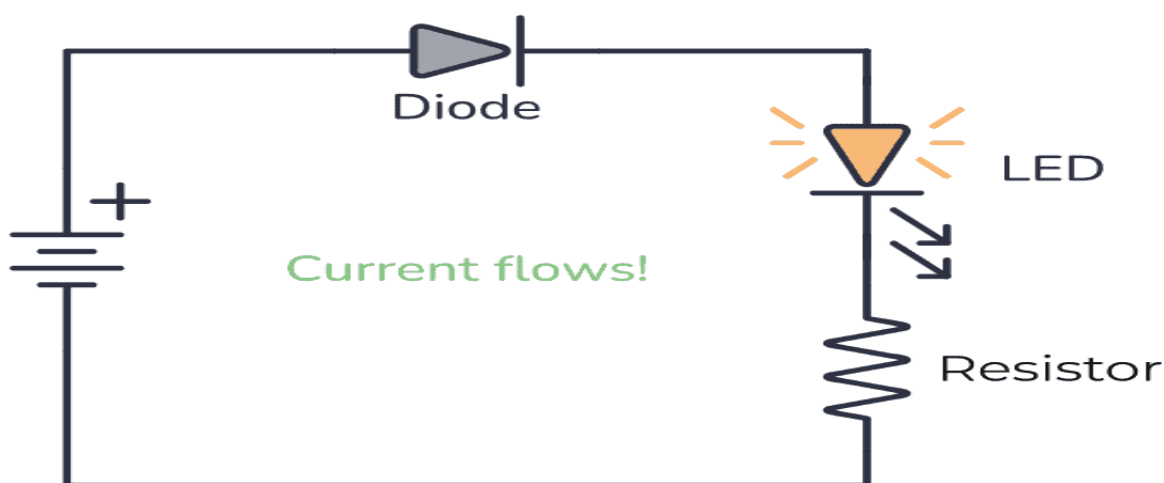


Figure 27: Diode allows Current to Flow in one Direction

Bibliography:

Allan R. Hambley (2016). [Electrical Engineering: Principles & Applications 6 Edition](#), Pearson Education Dorling Kindersley.

Allan R. Hambley (August 1, 2021). [Electrical Engineering Principles and Applications, 7<sup>th</sup> Edition](#). Pearson Education Dorling Kindersley.