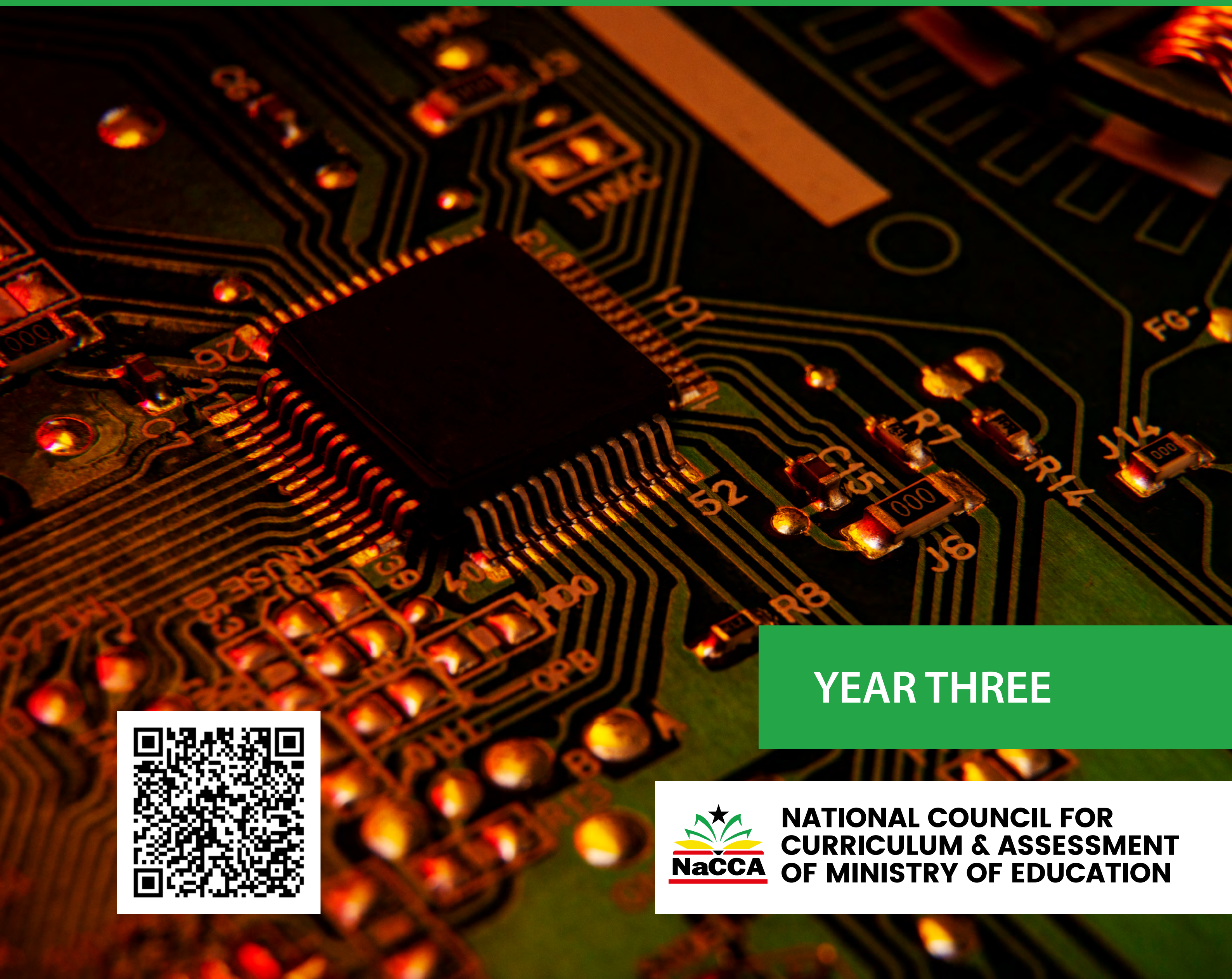
MINISTRY OF EDUCATION

Electrical and Electronics Technology

for Senior High Schools

TEACHER MANUAL



YEAR THREE

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

Electrical and Electronics Technology

for Senior High Schools

Teacher Manual

Year Three

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION
NaCCA

ELECTRICAL AND ELECTRONICS TECHNOLOGY TEACHER MANUAL

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INTRODUCTION

The National Council for Curriculum and Assessment (NaCCA) has developed the third and final set of curriculum materials to support the implementation of the new Senior High School curriculum.

This Year Three Teacher Manual for Electrical and Electronics Technology covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively support learners in their final year of Senior High School. All the necessary information for the Student Assessment Portal has been included in the Year Three Teacher Manual to simplify the development of weekly learning plans, meaning that teachers have a single reference document.

The Year Three Teacher Manual has two main objectives:

- To support learners to consolidate and deepen their understanding of the content, pedagogy, and assessment across all three years of the new Senior High School curriculum in preparation for the West Africa Senior Secondary Certificate Examination (WASSCE).
- To equip teachers with the tools and resources needed to deliver revision-focused, assessment-led lessons that build on the knowledge learners have acquired from Year One to Year Three.

In this third year, teachers will be supporting learners to prepare for the WASSCE. Each section of the Teacher Manual is therefore structured around the highest Depth of Knowledge (DoK) levels, allowing learners to build progressively on knowledge acquired from Year One to Year Three. For each week, learning tasks and pedagogy are built around the assessment, ensuring that classroom activities directly prepare learners for the demands of the examination. Two sets of sample examination papers are also provided; one administered by Week 12 as a first semester practice examination, and one by Week 20 as a mock examination, to gauge learners' competencies and identify areas requiring remediation.

To further support teachers in delivering Year Three, NaCCA, working with the Ghana Education Service, has developed a subject specific App for each subject.

The Year Three PLC sessions have been revised in response to findings from the 2025 annual evaluation survey. The survey confirmed that teachers have made strong progress in lesson planning, use of varied instructional methods, ICT integration and modes of assessment. To address the identified gap in explaining concepts clearly using examples familiar to learners, each PLC session now includes a dedicated Content Exploration segment. This ten-minute segment brings the subject group together to work through one challenging problem or concept from the week's Teacher Manual content, not to plan how to teach it, but to ensure that every teacher in the group fully understands it.

The PLC sessions in Year Three also place particular emphasis on connecting the week's content to equivalent topics taught in Years One and Two. Teachers are encouraged to note the recap weeks signposted throughout the Teacher Manual and to use the App to explore how content across all three years links together.

As in previous years, teachers are expected to integrate National Values, Gender Equality and Social Inclusion (GESI), Social and Emotional Learning (SEL), and 21st-century skills into their learning activities, assessment tasks, and rubrics and mark schemes. The subject-specific App will support teachers in doing this throughout the year.

Ghana Education Service acknowledges the dedication of the teachers who have implemented the new curriculum across Years One and Two and recognises that Year Three represents both the culmination of that effort and a critical moment for learners. The Year Three Teacher Manual and its accompanying resources have been developed to ensure that every learner, regardless of background, ability, or school context, is fully prepared to demonstrate what they know and can do in the WASSCE and to progress confidently to further studies, the world of work, and adult life.

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SECTION 1: AC, DC MOTORS, AND AC, DC GENERATORS

The section covers the following units (strands): Electrical technology and Electronics technology.

In this section, learners will acquire knowledge and understanding of the construction and principles of operation of AC motors, DC motors and the construction and principles of operation of AC Generators as well as the DC Generators. All the above are covered from unit 1 to unit 4.

UNIT 1

Section 1: AC, DC Motors and AC, DC Generators

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical Machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This section looks at AC and DC machines as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, principles of operation and applications of both single-phase and 3-phase motors and generators as well as starting and speed control of the motors.

The unit covers only week 1: ***Describe the construction and principle of operation of AC motors.***

Recap weeks

Year 2	**Week 22:** Explain the principles of measuring instruments through electromagnetism.

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved learners will be actively engaged in practical demonstrations on the various aspects of electrical machines through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section require learners' ability to demonstrate the understanding relating to real-life situations and the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicator	DOK Level	*Assessment Strategy and/or Mode*
Describe the construction and principle of operation of AC motors.	3 (Strategic reasoning)	Mode of Assessment: Class exercise

WEEK 1

Learning Indicator: *Describe the construction and principle of operation of AC motors*

FOCAL AREA: INDUCTION MOTORS AND SYNCHRONOUS MOTORS

Single-phase induction motor

An induction motor requires a rotating magnetic field to operate. This rotating field is obtained when at least two phases are supplied to the stationary pole pieces of the motor. A single-phase supply, however, produces a pulsating field which cannot start the motor because it is not rotating. In the single-phase motor, the phase must be split into what looks like two separate phases, by the introduction of a capacitor or an inductor into a second winding, called the starting winding. Hence, the single-phase induction motor is also known as the split-phase induction motor. The new arrangement ensures that a phase difference of 90^0 degrees exists in the currents of the two windings- the main winding (running winding) and the starting winding (the winding with the capacitor).

1. **Construction**: The machine is made of a *stator* (the stationary part) and a *rotor* (the revolving part). The stator consists of two sets of windings - the starting winding and the main winding. The capacitor or inductor is connected in series with the starting winding, containing a centrifugal switch. However, the main winding is connected directly across the supply as shown in Figure 1.1.

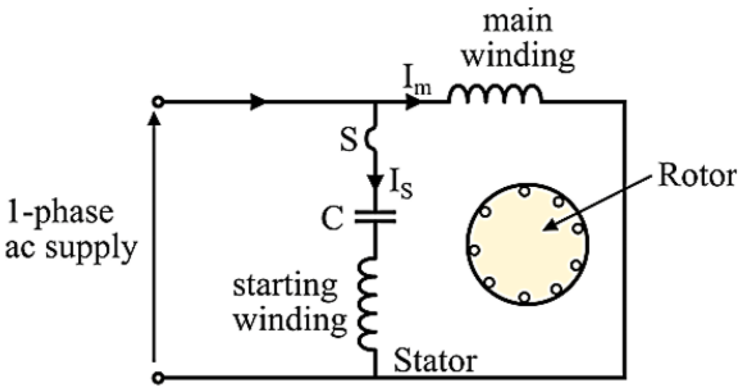

Figure 1.1: *Capacitor start induction motor*

The rotor on the other hand is made up of copper or aluminium bars embedded in a silicon steel core. The ends of these conductors are terminated in rings. These rings short-circuit the conductors. This makes the entire thing look like a cage (Figure 1.2)

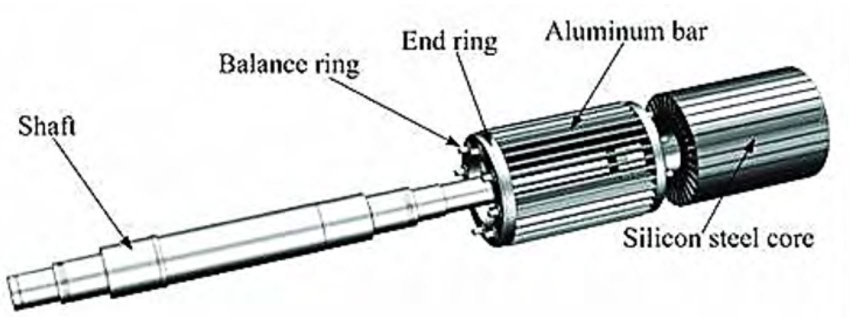

Figure 1.2: *The rotor of an induction motor (exploded view)*

2. **Operation:** Figure 1 shows the circuit diagram of a capacitor start induction motor. The term "capacitor start" here means that the phase difference of 90^0 is achieved by introducing a capacitor into the starting winding to produce a leading current. The effect of two separate phases is thus achieved, and this can affect rotation. When the power supply is switched on, a rotating magnetic field will be created inside the stator as a result of the split phase (as explained earlier). The rotating magnetic field in the stator then cuts the rotor conductors and induces an electromagnetic force (emf) into them. This creates a magnetic field in the rotor, which, by Lenz's law, is opposite to the main rotating field. Since unlike poles attract, the rotor begins to follow the rotating magnetic field. The rotor rotates but not as fast as the rotating field. Note that if the two are running at the same speed the rotating field cannot cut the rotor conductors and there will be no induced emf. After the motor has operated for some time, the starting winding (auxiliary winding) is cut out of the circuit by the centrifugal switch leaving only the main winding in the circuit. The rotor continues to follow the field of this main winding thus ensuring continuous rotation.
3. **Reversal of direction of rotation**: Note that the magnetic field produced by a single phase is like two different fields moving in opposite directions, therefore the induction motor will continue to run in whichever direction it is started. This is determined by the relative phase difference between the two winding currents. Reversing the leads to either of the windings can reverse the direction of rotation.

The Three-phase induction motor

As stated earlier, induction motors operate on the principle of a rotating magnetic field. They have two main parts; a stationary part called stator and a rotating part called the rotor. The three-phase induction motors have their stators supplied from a three-phase supply, which consequently produces the rotating magnetic field needed for its operation. There are two types:

1. The squirrel cage type
2. Wound rotor type

Three-phase squirrel cage type induction motor

This type of induction motor is simple in construction. It is small compared to others, especially with regard to rating in kilowatts and it requires little maintenance. It is relatively cheap and is widely used for most industrial work.

1. **Construction:** Like the single phase one, the 3-phase induction motor has two main parts, a stationary part called the stator and the revolving part called rotor. Unlike the single-phase one, the stator of the three-phase motor has three sets of electrical windings of a fine gauge or size placed 120 degrees apart. These windings can be connected in a star or delta formation and are secured in the stator frame. These windings are connected to a three-phase power supply via a three-pole switch. The revolving part (rotor) is made up of a cylindrical core with copper or aluminium bars embedded in it. The ends of the bars are connected to rings in a manner that forms something like a cage (refer to fig 1.1 of this unit). Figure 1.3 shows the circuit diagram of the 3-phase Squirrel-cage induction motor.

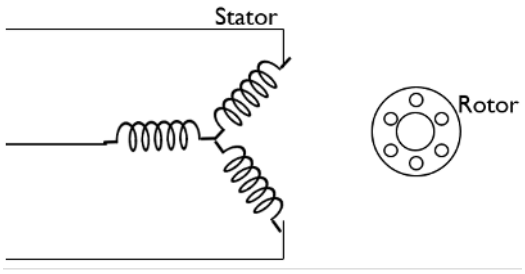

Figure 1.3: *Circuit diagram*

2. **Operation:** When the three sets of stator coils are provided with a three-phase ac supply, a rotating magnetic field is set up inside the stator bore by the stator windings. This rotating field, moving at a speed called the synchronous speed, cuts the rotor conductors and induces an emf in them. This induced emf sets up currents in the rotor bars, which in turn creates another field in the cage rotor. These two fields interact with each other and cause the rotor to rotate. Its speed (the rotor), however, is always less than the synchronous speed. There would not be any motion if the rotor turned at a speed equal to the synchronous speed and the difference between the two speeds is known as *Slip*. The movement of the rotor because of the flux interaction is also known as torque production. Interchanging any two phases can reverse the direction of rotation.

The wound rotor induction motor

1. Construction

Due to the nature of its construction, the speed of the squirrel cage induction motor cannot be varied. It therefore has a constant speed. Another type of induction motor has been developed for variable speed applications in the industry. This is called the wound rotor induction motor. It is similar to the squirrel-cage induction motor in construction. The main difference lies in the fact that its rotor is wound thus providing a speed control/starting arrangement. The principle of operation of this motor is the same as that of the squirrel cage type. But note, however, the rotor windings of this motor are connected to a three-phase variable resistor through a slip ring/ brush arrangement (Figure 1.4).

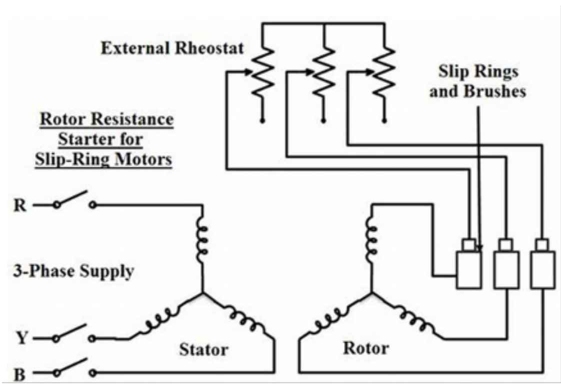

Figure 1.4 Wound rotor induction motor

2. Operation

Before the power is switched onto the motor, the resistance is varied until it is all inserted into the rotor winding circuit. This results in the motor having excellent starting torque. The power is then switched on and the motor starts gradually. The resistance is gradually cut off as speed builds up. Varying the resistance in the rotor circuit can thus also vary the speed of the motor.

Application

Induction motors are widely used in various applications, including:

1. Household appliances (e.g., washing machines, refrigerators).
2. Industrial machinery (e.g., conveyor systems, pumps).
3. Fans and blowers in ventilation and HVAC Systems.
4. Electric vehicles for propulsion.
5. Water pumps for agriculture, irrigation, and domestic use.

The synchronous motor

The synchronous motor works with two electrical inputs provided to it. Its working principle is as follows: The stator is provided with a three-phase AC supply, while the rotor is provided with a DC supply as shown in figure 1.5. The AC supply in the stator winding generates a three-phase rotating magnetic field, while the rotor which has a dc supply that produces a field with fixed polarity.

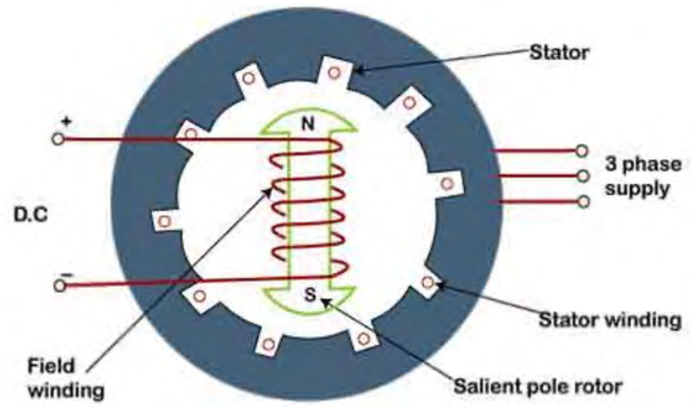

Figure 1.5: *A three-phase synchronous motor*

With this arrangement, the rotor and the stator poles will be of the same polarity (N-N or S-S), at certain instances, causing a repulsive force and then it will be N-S causing an attractive force. As a result of this attractive and repulsive force, the motor cannot rotate in any direction. To ensure rotation the rotor is initially rotated mechanically in the same direction as the rotating magnetic field. After some time, magnetic locking occurs, and the synchronous motor then rotates.

Starting and speed control of ac motors

Certain conditions are necessary if the motors are to start well. For this reason, some starting arrangements are made for the various range of induction motors available, depending on the power rating of the motor and the type of load. Starters such as the direct on-line, the star-delta, and the auto-transformer methods are employed in starting induction motors.

1. **The direct on-line starter**: As the name implies, the direct on-line starter switches the input supply voltage directly on to the motor. Since the supply voltage is applied directly across the motor windings, this method provides a quick start at maximum torque. It is suitable for small motors because the starting current is high and may cause interference with supplies to other consumers on the same system. The use of this method of starting is restricted to motors below 2kw (2½ hp - 3hp). However, if the supply is of the isolated

type or may be the case of stand-by generator, there is no such limit and high motor ratings, of about 100 KW may be used on this starting arrangement.

2. **The star-delta starter**: In this method, two ends of each stator winding of the motor are brought out to a six-terminal box. They are then connected to a double-throw switch. In the *Start* position, the stator windings are connected in a star. This reduces the voltage applied to each winding to 1/1.73 (about 58%) of the line voltage and so the starting current is reduced. This reduces the starting torque to about 33.3% of normal speed. After the speed has built up (closed to full speed), the switch is changed over to the *Run* position, thus applying the full supply voltage to the motor winding. This method of starting is suitable for medium size motors, especially where the load is easy to accelerate.
3. **The auto-transformer starter**: This method consists of a variable auto-transformer with tapping that can obtain 50%, 65% and 80% of the full supply voltage. The motor receives its supply through the auto-transformer and so the voltage applied to the stator winding of the motor is reduced. This subsequently reduces the starting current, so reducing the starting torque. Typical torque values are 25%, 42.2%and 64%. By switching to successive tappings the supply voltage to the motor is gradually increased until the motor's normal speed is attained. The changeover switch is then switched over to the *RUN* position, thus cutting out the auto-transformer and applying the full supply voltage to the motor.

Sometimes there is the need to reverse the direction of rotation, particularly when driving commercial and industrial loads. This is achieved by reversing either of the two lines supplying it. Note however, that this method is not suitable for starting motors against heavy loads. Applications of this method include heavy fans, mixers, centrifugal machines and motor-generator sets.

Speeds of AC motors

1. **Synchronous Speed (*Ns*):** The rotating magnetic field moves at this speed. This speed depends on the frequency of the supply current and the number of poles in the motor. Thus: Ns (RPM) = $(120 \times f) / P$

   Where:

   f = Frequency of the AC supply (in Hz)

   P = Number of poles in the motor
2. **Actual or Rotor speed (*N*):** This is the speed at which the rotor of the motor turns. It is usually slightly less than the synchronous speed due to **slip** in induction motors.

   Thus Slip = $(Ns - N)/Ns$
3. **Rated speed:** This is the speed specified by the manufacturer at full load and rated voltage/frequency.

Application of Synchronous motors

Synchronous motors are mostly used in:

1. Power factor correction systems.
2. Precision timing devices (e.g., synchronous clocks).
3. Industrial processes requiring constant speed.
4. Synchronous generators in power plants

Learning Tasks

1. Explain the construction and operation of the single-phase induction motor.
2. Describe the principle of operation of the wound rotor induction motor.
3. Summarise three methods of starting three-phase motors.

Pedagogical Exemplars

Teachers should consider the following activities:

Talk for learning approaches: Guide learners through discussion to brainstorm the single-phase and three-phase induction motors making sure that every learner takes part in the discussion. Teachers should ask guiding questions during the process to help focus the discussion and ensure clear responses.

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with at least two methods involved in the starting and speed control of AC motors after watching a video (provided by the teacher). Summarise and enumerate the various methods on the board.

Key Assessment Level 3: Class Exercise

1. Compare squirrel-cage and wound rotor induction motors in terms of:

- **a.** Starting characteristics
- **b.** Speed control capabilities
- **c.** Construction complexity
- **d.** Maintenance requirements

Based on your analysis, determine which type would be more suitable for: a) A conveyor belt requiring frequent starts under load and b) A variable-speed pump application.

2. A 3-phase induction motor is wound for 4 poles and is supplied from 50 HZ system. Determine the synchronous speed and, based on the synchronous speed, estimate its rotor speed.

PLC Session 1

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.

2. Use your subject specific app to explore the content before planning. Ask the app to

- **a.** explain the week's concepts in a practical way that will make it easier for learners to understand
- **b.** identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
    a. The key assessment for the week is ***class exercise***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the exercise (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through a similar problem individually for 3–4 minutes
    c. the group then works through the problem together step by step
    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

- **a.** Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
- **b.** After the enactment, ask for structured feedback from the group
  - i. was the concept explained in a way that a learner with no prior knowledge could follow?
  - ii. were the examples grounded in contexts familiar to Ghanaian learners?
  - iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

- **a.** transfer your chats into your learning planner template.
- **b.** read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
- **c.** integrate National Values, GESI, SEL, and 21^{st} century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 1 Review

This unit introduced learners to the construction, operation and methods of starting single phase and three-phase AC motors. The pedagogical exemplars used in this unit include Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 3.

UNIT 2

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This section looks at AC and DC machines as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, principles of operations and applications of both single phase and three-phase motors and generators as well as starting and speed control of the motors.

The unit covers only week 2: ***Describe the construction and principle of operation of D.C motors***

Recap week

Year 2	Week 22: Explain the operation of electrical measuring instruments through the principles of electromagnetism.

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved learners will be actively engaged in practical demonstration on the various aspects of electrical machines through a wide range of pedagogical exemplars such as, Collaborative learning, Experiential learning, project–based learning, research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section require the learners' ability to demonstrate the understanding relating to real life situations hence the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can also consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the construction and principle of operation of DC motors.	3 (Strategic reasoning)	Group discussion

WEEK 2

Learning Indicator: Describe the construction and principle of operation of D.C motors

FOCAL AREA: D.C MOTORS

Definition of DC Motor: A DC Motor is an electrical machine which, when provided with direct current electrical energy, converts it into mechanical energy. It is based on the idea that when a current carrying conductor is placed in a magnetic field, it produces mechanical force. Figure 1.6: shows a diagram of a DC Motor.

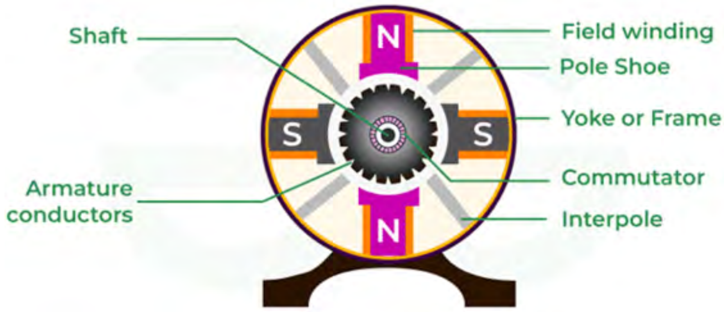

Figure 1.6: *DC Motor*

Types of DC Motors

DC Motors can be classified into various categories based on the application and winding connections. Based on the winding of the armature a DC Motor is of two types:

1. **Self-Excited DC Motor:** DC motors that excite themselves have a part and coil of field connected in series or partly so, same for parallel connection. They can also have a combination of series and parallel connections. They also get power from only one place. Three types of self-excited DC motors exist:

   a. **Series DC Motor:** Is a motor in which the field is in series with the armature and its starting torque is extremely high. This means that the same flow of current goes through both the coil and armature. Series motors always go in one direction and the physical load affects their speed.

   Figure 1.7: shows a diagram of a Series-Wound DC motor.

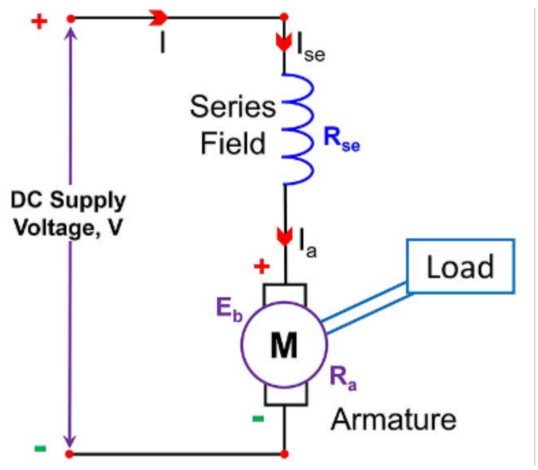

Figure 1.7: *Series Wound DC motor*

Current and Voltage Equations involving a series motor are as follows;

i. I = Ise = Ia

ii. V = Eb +Ia (Ra+Rse)

Where I = total current, Ise = series field current, Ia = armature current

and Eb = back emf

b. Shunt DC Motor: A shunt motor is a DC motor in which the field is joined in parallel to the armature and its starting torque is less than that of series motor. Inside the shunt motor, the field winding is connected parallel to the armature winding. The field winding is made of more turns of thin wire. Shunt motors are used in applications where continuous speed is required.

Figure 1.8: *Shows a diagram of a DC shunt motor.*

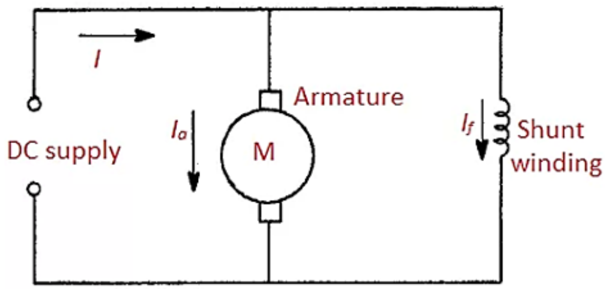

Figure 1.8: *DC shunt motor*

Current and voltage Equations involving a DC shunt motor

i. IL – Ia – If = 0

ii. V = Eb + Ia Raf

Compound DC Motor: A **c**ompound DC Motor is a motor in which both series and parallel fields are added. Compound DC motors use both parallel and connected field windings. In the armature winding, everything is in series. However, field coils can be shunt or series types.

Figure 1.9: shows a DC compound motor.

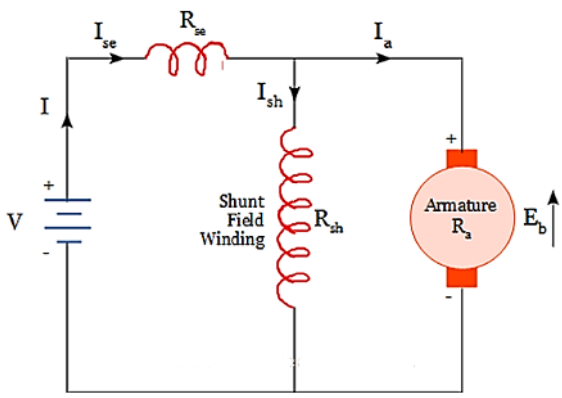

Figure 1.9: *DC compound motor*

2. **Separately Excited DC Motor:** In DC motors with a separate excite, fields coil to make permanent magnets. The armature and field coils are not connected electrically to each

other. They work separately and do not interfere the other one. But the result of the engine is added up with both.

Construction

A DC motor has basic components such as a stator (the stationary part of the element producing a magnetic field) and a rotor part that rotates carrying winding or coil.

A DC machine has the following main parts:

1. **Field System or Stator**
   a. Armature
   b. Commutator
   c. Brushes
2. **Field Coil or Stator:** As the name suggests, the field coil or stator is the non-moving or stationary part of the DC motor around which coil is wound and produces a magnetic field. The stator consists of various parts:
   a. **Yoke:** The structure of a DC machine works to create the magnetic circuit between the poles.
   b. **Pole Core:** Pole Core is usually made of laminated iron or other magnetic material. Its function is to serve as a passage for the magnetic flux generated by the field winding.
   c. **Pole Body:** Pole body works with the pole core. When an electric current passes through the field winding, a magnetic flux is established not only in the pole core but also around it. The poles and their bearings are known as the pole body.
   d. **Shoe:** Shoe is a synonym for one of the brushes inside an electric motor. DC motors have brushes that contact the rotating armature, and typically they are sodded.
   e. **Field Winding:** Field winding is on the pole core next to the stator. Field winding uses insulated copper wire. An insulated copper coil is wound round the pole core. If this coil on the pole core is excited with direct current, we get magnetic flux.
   f. **End Plates:** End plates encapsulate the entire motor. They provide a casing for all the internal parts, the armature, commutator and brushes, and sometimes include field windings.
3. **Armature:** Armature is the rotating part of the motor which generates mechanical energy. The armature core has windings and is made of 0.3 to 0.5 mm thick high magnetic strength (silicon steel lamination) and a thin layer of varnish is applied on each sheet.
4. **Commutator:** Commutators are used in DC appliances such as DC Motors and DC Generators. A commutator periodically reverses the current between the armature and the circuit and produces steady torque
5. **Brushes:** Brushes, often called Carbon Brushes, are made of graphite. In DC Motors, brushes supply current to the winding of the armature.

DC Motor Working Principle

When a current carrying conductor is placed in a magnetic field, a mechanical force acts on it, which can be determined by Fleming's left-hand rule. Due to this force the conductor becomes mobile in the direction of the force.

DC Motor Characteristics

If length of conductor = L metre, field intensity = B weber per square metre (Bwb/m2) and current flowing in the conductor = i ampere, then the force experienced by the conductor will be F = iBL Newton.

F= B.L.I.Sinθ

Where

1. **B =** flux density (in Tesla).
2. **L =** length of conductor (in metres).
3. **I =** current flowing in the conductor.
4. **Sinθ =** angle between the conductor and magnetic lines of force.

DC Motor Torque Formula

Torque, also known as moment or moment of force, is the force that tends to rotate or move an object around a central axis. A force is a push or pull, similarly, torque creates twisting to an object. Mathematically, torque is given as $T = F \times r$.

For DC Motor, the torque is given as:

T = (0.159PΦNZ/A)Ia

Where

a. **T is** Torque of Armature
b. **Ia** is the armature current
c. **P** is Number of Poles
d. **Φ** is Flux per pole
e. **N** is Speed of motor in (RPM)
f. **Z** is Number of conductors
g. **A** is Number of parallel paths

DC Motor EMF Equation

EMF or the electromotive force is responsible for flow of current in electrical appliances. EMF is not a force but the electric potential. In the case of a DC Motor, a back EMF is produced which counters the armature current. The direction of this back EMF is given by Lenz Law. The formula of back emf is given as:

Eb = PΦNZ/60A

Where

a. **P** is Number of Poles

b. **Φ** is Flux per pole

c. **N** is Speed of motor in (RPM)

d. **Z** is Number of conductors

e. **A** is Number of parallel paths

DC Motor Speed

The formula for DC Motor speed is given as:

N = KEb/Φ

Where

a. **N** is speed in RPM

b. **K** is constant proportionality which is equal to 60A/ZP

Application of DC Motor

A 'DC motor' is used to refer to any rotary electrical machine that converts direct current electrical energy into mechanical energy. DC motors can vary in size and power, ranging from small motors in toys and appliances to large mechanisms that power vehicles.

1. DC motors are very versatile as follows: DC motors are used in traction work, machine tools, industry, elevators etc.
2. DC motors have the widest variation in speed (compared to other motors).
3. A DC series motor has extremely high starting torque and is commonly used to start high inertia loads such as trains, elevators or hoists.
4. Shunt DC Motors are used in drilling machines, centrifugal machines etc.

Learning Tasks

1. Explain the concept of DC motors.
2. Describe the principle of operation of a DC motor.
3. Summarise the applications of a DC motor

Pedagogical Exemplars

Teachers should consider the following activities

Talk for learning approaches: Guide learners through a discussion to brainstorm the concept of DC motors making sure that every learner takes part in the discussion. Teachers should ask guiding questions during the process to help focus the discussion and ensure clear responses.

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with various types of DC motors, the construction of DC motors, the principles of operation of DC motors and applications of DC motors after watching a video (provided by the teacher). Finally, the teacher should summarise everything on the board.

Key Assessment Level 3: Group Discussion

1. A DC motor runs normally at no load, but when connected to its intended load, it slows down significantly and draws excessive current.

Analyse how the following aspects of motor construction might contribute to this problem:

a. Field winding configuration

b. Armature winding resistance

c. Brush positioning

For each aspect, explain the specific mechanism by which it affects motor performance under load.

2. Assess the role of back emf in the starting of DC shunt motors.

PLC Session 2

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.

2. Use your subject specific app to explore the content before planning. Ask the app to

a. explain the week's concepts in a practical way that will make it easier for learners to understand

b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

a. The key assessment for the week is ***group discussion***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the discussion (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

    b. all teachers in the group work through a similar problem individually for 3–4 minutes

    c. the group then works through the problem together step by step

    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

    b. After the enactment, ask for structured feedback from the group

        i. was the concept explained in a way that a learner with no prior knowledge could follow?

        ii. were the examples grounded in contexts familiar to Ghanaian learners?

        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

    a. transfer your chats into your learning planner template.

    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 2 Review

This unit introduces learners to the concept of house wiring and the processes involved in wiring a new house. The pedagogical exemplars used in this unit include Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 1,2 and 3.

Resources: Pictures, Videos, real objects (DC motors)

UNIT 3

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome:. *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This section looks at AC and DC machines as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, principles of operation and applications of both single phase and three-phase motors and generators as well as starting and speed control of the motors.

The unit covers only week 3: ***Describe the construction and principle of operation of AC generators****.*

Recap weeks

Year 2	**Week 22:** Explain the principles of measuring instruments through electromagnetism

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved learners will be actively engaged in practical demonstrations on the various aspect of electrical machines through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section require learners' ability to demonstrate the understanding relating to real life situations hence the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the construction and principle of operation of AC Generators	3 (Strategic reasoning)	Assessment mode: Group discussion

WEEK 3

Learning Indicator: *Describe the construction and principle of operation of AC generators*

FOCAL AREA: SINGLE PHASE AND THREE-PHASE GENERATORS

The single-phase AC generators

An AC generator or alternator is an electrical machine that converts mechanical energy into electrical energy in the form of alternating current (AC). It is also known as a **synchronous generator** (there are other types of AC generators). It generates a specific voltage at a specific frequency. The outputs of alternators are sinusoidal in nature (changes in magnitude and in direction) and could be single-phase or three-phase. For large-scale power supplies AC generators are often used because AC voltage can be transformed.

1. **Construction of a simple AC generator:** Figure 1.10 shows the construction of a single loop AC generator.

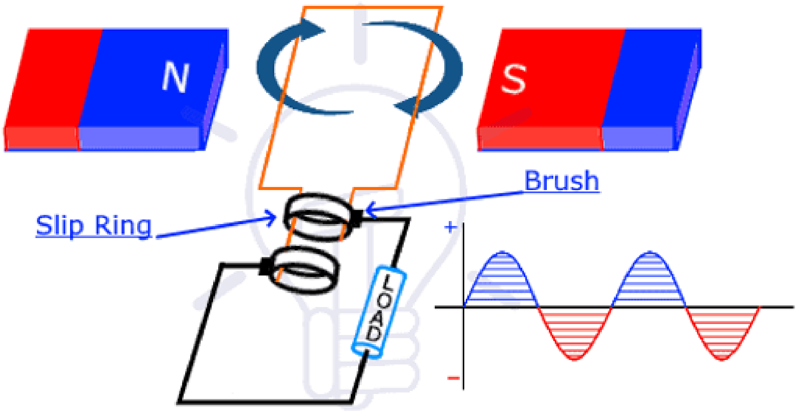

Figure 1.10: *Single loop AC generator*

It consists of the following parts:

a. **Permanent magnetic pole pieces**: The permanent magnetic pole pieces are the North Pole and South Pole. These provide the needed magnetic lines of force, which move from the North Pole to the South Pole.

b. **The conductor**: The conductor is made of copper and constructed in a loop form. It suspends between the two magnetic pole pieces and its ends terminate in two copper slip rings. In the bigger form of generator, the conductors consist of many turns on a laminated silicon steel core called a rotor.

c. **Slip Rings:** The slip rings are made of copper. Each one is connected to one end of the copper conductor.

d. **Carbon Brushes**: The carbon brushes are square or rectangular cakes of carbon positioned on each slip ring. They press tightly against the split rings with the aid of springs. Power from the generator is tapped through these brushes by means of circuit conductors, which are then connected to the external load.

e. **Operation**: The conductor or rotor which is suspended between the pole pieces, is rotated by a prime mover. As it rotates, it cuts the magnetic lines of force and an emf is induced into the conductor.

2. **Variation of induced emf with time:** Figure 3.*2*, sums up how the induced emf into the conductor will vary with time.

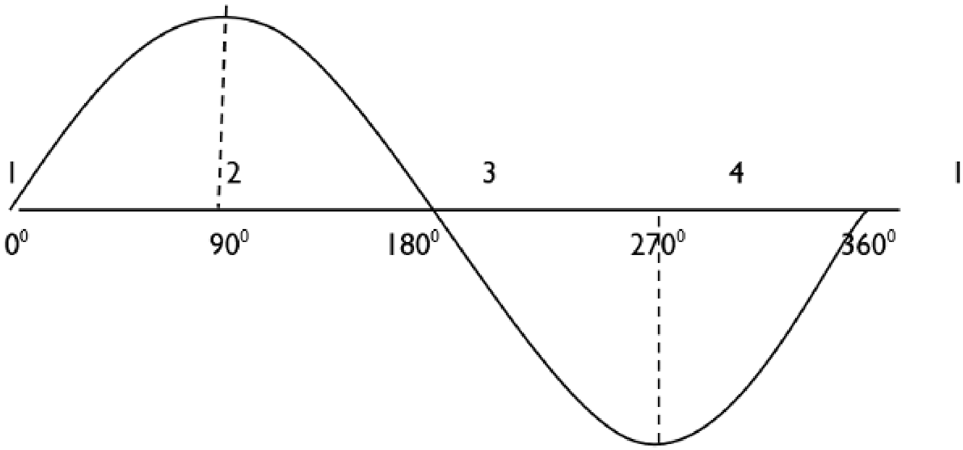

Figure 1.11: *Variation of induced emf with time*

Figure 1.11: Wave form of induced emf into the conductor. This wave form is referred to as sinusoidal wave. Note however that *position1* is at an angle of 00, *position 2* at 900, *position 3* at 1800 and *position 4* is at 2700. The output of this generator is tapped through two wires, a live and a neutral, and referred to as a single phase

3. **The three-phase generator (alternator):** Remember in the single-phase AC generator, it was a single loop that rotated in the magnetic field. In the three-phase, however, three different loops are used and are positioned at 120^0 to one another as shown in Figure 1.12. Note that the loops are windings of copper conductors on a laminated core. Also note that in this type the windings are called the stator and the rotating member is called rotor and carries the magnetic field. This arrangement is made to minimise losses and increase efficiency.

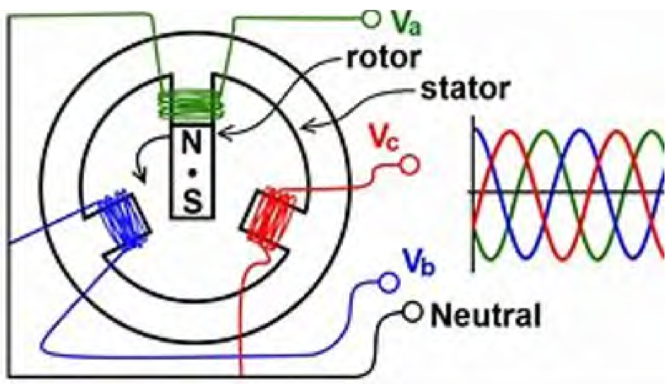

Figure 1.12: *3-phase alternator with revolving field*

In most cases, instead of a permanent magnet, the field is provided from a DC source as shown in the equivalent circuit diagram and phasor diagram in Figure 1.13. This arrangement makes it possible to vary the field current and vary the output of the alternator.

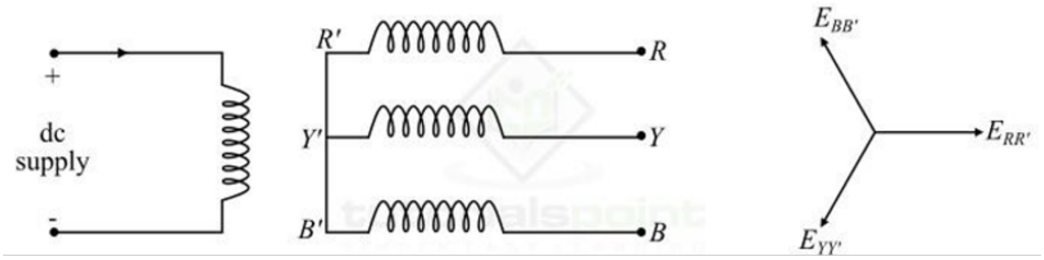

Figure 1.13: *3-phase alternator*

The rotor is turned by a prime mover, which can be a diesel engine, water turbine and the like. This causes the magnetic field to rotate and cut the stator windings in turns thus inducing an emf into them. Even though the output of each individual conductor or winding is the same as that of the single-phase one, they do not start or end at the same time. Consequently, the output of the three-phase alternator is as shown in Figure 1.14.

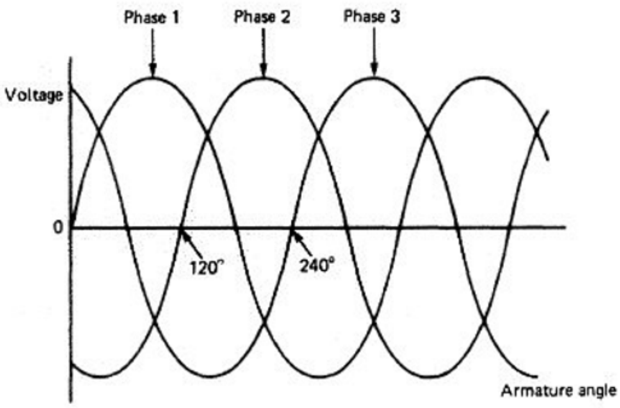

Figure 1.14: *Output wave-form of a 3-phase alternator*

4. **Relationship between line and phase voltages:** Line voltage (VL) exists between two separate lives of a 3-phase supply. Its value is about 415V in some countries including Ghana. Phase voltage (Vph) on the other hand is the voltage between any line and neutral. Its value is about 240v in some countries including Ghana and 110v in the United States.

For a star-connected alternator, the line voltage V_L is $\sqrt{3}$ times the phase voltage:

$V_L = \sqrt{3}\ V_{ph}$

EMF equation of the alternator

The following symbols are critical to the equation:

P = No. of poles

T = number of coils or turns per phase (each turn or coil has two ends or sides)

Z = No. of conductors or coil sides in series/phase i.e. **Z = 2T**

f = frequency of induced EMF in Hz

Φ = Flux per pole (Weber)

N = rotor speed (RPM)

Average EMF per conductor = φNP/60 = (φP/60) x (120f/P) = 2fφ volts

If Z = No. of conductors per phase, then the emf per phase becomes:

$EMF\ per\ phase = 2f\varphi\ x\ Z = 2f\varphi Z$

If T = No. of turns (two conductors per turn), therefore $Z = 2T$. The equation then becomes:

$EMF\ per\ phase = 2f\varphi Z = 2f\varphi(2T) = 4f\varphi T$

If the induced EMF is sinusoidal, then its form factor, kf = 1.11.

Note that Form factor = RMS value/ Average value

And RMS value = form factor x Average value

So, RMS value per phase = 1.11 x 4fφT

Therefore, V_{rms} per phase = 4.44 fφT volts

For the actual induced EMF per phase, 'coil span factor k_c' and 'distribution factor k_d' have to be introduced.

Therefore: V_{rms} per phase = $V_{ph} = 4.44\ k_c k_d f\varphi T\ volts$

or

$V_{ph} = 2.22\ k_c k_d f\varphi Z\ volts$

Where

- **a.** $\mathbf{V_{ph}}$ = Actual induced EMF per phase
- **b.** $\mathbf{K_c}$ = Coil span factor
- **c.** $\mathbf{K_d}$ = Distribution factor
- **d.** ***f*** = Frequency
- **e.** **φ** = Flux per pole (Weber)
- **f.** **Z** = No. of conductors

Advantages of alternators

The following are some advantages of an alternator:

1. In most alternators, brushes and slip rings are eliminated consequently, brush contact friction losses are eliminated
2. The machine requires little maintenance since there is no wear and tear or sparks due to friction between the slip ring and brushes.
3. Increased output voltage due to the absence of brush voltage drop
4. Higher efficiency than a DC generator.
5. It is simple and robust in construction and cheaper than a DC generator.

Disadvantages

Some disadvantages of an alternator are:

1. The large current drawn tends to cause overheating thus reducing its performance. As a result, the machine requires an efficient cooling system.
2. It requires a diode rectifier to convert AC into DC for its field excitation or a separate DC exciter is needed.

Applications of Alternators

Some common applications include:

1. Power plants to generate electricity.
2. Battery charging and powering the electrical system in vehicles.
3. Alternators are used in aircraft to generate electricity for onboard systems,
4. Various industrial applications to provide electrical power for machinery, equipment, and other systems.
5. They are used as standby and emergency power systems.
6. Employed in some renewable energy systems, like wind turbines and hydroelectric plants, for the generation of electricity from natural energy sources

Learning Tasks

1. Explain the construction and principles of operation of the alternator
2. Why is it more advantageous using the alternator instead of a DC generator?
3. Discuss some typical applications of alternators and explain the impact and consequences of overloading them.

Pedagogical Exemplars: Teachers should consider the following activities:

Talk for learning approaches: Guide learners through discussion to brainstorm the construction, operation and application of alternators, making sure that all learners actively take part in the discussion. Teachers should ask guiding questions during the process to help focus the discussion and ensure clear responses.

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with typical applications of alternators and the impact of load on the output of alternators after watching a video (provided by the teacher). Summarise and enumerate the various processes on the board.

Key Assessment: Group Project

1. An AC generator's output voltage drops significantly when connected to a heavy load, even though it maintains proper rotation speed.

Analyse three potential causes related to the generator's construction, explaining for each:

   a. What specific component or design aspect might be responsible
   b. How this element affects voltage regulation under load
   c. A practical method to verify this as the cause of the problem.

2. A three-phase AC generator is producing power at 52 Hz instead of the required 50 Hz.

Analyse:

   a. How this frequency deviation affects devices connected to the generator.

b. What aspects of the generator's construction determines its frequency.
c. What specific adjustments could bring the frequency to the correct value.
d. How these adjustments might affect other operational parameters.

Hint

Assign Group Project to learners and give them reasonable time to complete it. Use the SS App to generate the project as well as the rubric. Learners' projects should be marked immediately and scores entered into the SAP.

PLC Session 3

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).
   a. The key assessment for the week is ***group project***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the project (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through the problem individually for 3–4 minutes
   c. the group then works through it together the problem, step by step
   d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 3 Review

This unit introduced learners to the construction, operation and application of single- phase and three-phase alternators. The pedagogical exemplars used in this unit includes Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 1,2 and 3.

UNIT 4

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at AC and DC machines as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, Principle of operation and application of both single phase and three-phase motors and generators motors and generators as well as starting and speed control of the motors.

The unit covers only week 4: ***Describe the construction and principle of operation of DC Generators***

Recap week

Year 2	**Week 22:** Explain the operation of electrical measuring instruments through principles of electromagnetism

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved learners are to be actively engaged in practical demonstrations on the various aspects of electrical machines through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section require learners' ability to demonstrate the understanding relating to real life situations hence the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the construction and principle of operation of DC generators.	3 (Strategic reasoning)	*Class Exercise*

WEEK 4

Learning Indicator: *Describe the construction and principle of operation of DC Generators*

FOCAL AREA: DC GENERATORS

Definition of DC Generator: A DC generator is the type of electrical generator that converts mechanical energy into direct current electricity. Figure 1.15 shows a sectional view of a DC Generator.

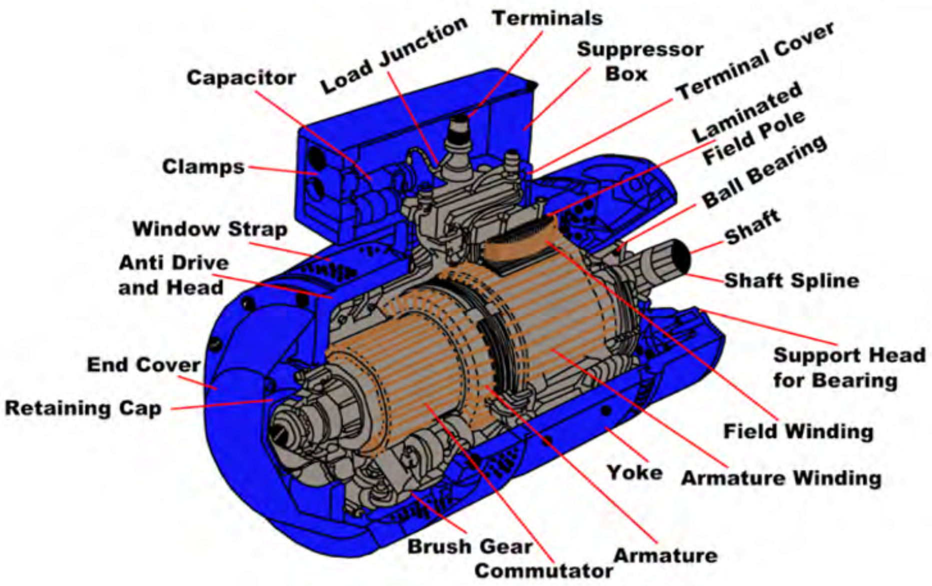

Figure 1.15: *Sectional view of a DC Generator*

A DC Generator consists of the following parts:

1. **Stator:** A stator is a set of two magnets placed in such a way that opposite polarities face each other. The purpose of the stator is to provide a magnetic field in the region where the coil spins.
2. **Rotor:** A rotor is a cylindrical laminated armature core with slots.
3. **Armature Core:** The armature core is cylindrical in shape and has grooves on the outer surface. These slots accommodate the armature winding.
4. **Armature Winding:** These are the insulated conductors placed in the armature core. Because of them, the actual conversion of power takes place.
5. **Field Coils:** To produce the magnetic field, field coils are placed over the pole core. The field coils of all the poles are connected in series. When current flows through them, adjacent poles acquire opposite polarity.
6. **Yoke:** The outer hollow cylindrical structure is known as the Yoke. It provides support to main poles and inter poles and gives a low reluctance path for the magnetic flux.
7. **Poles:** The main function of the poles is to support the field coils. It increases the cross-sectional area of the magnetic circuit, which results in a uniform spread of magnetic flux.
8. **Pole Shoe:** To protect the field coil from falling and to enhance the uniform spread of magnetic flux, a pole shoe is used. The pole shoe is fixed to the Yoke.

9. **Commutator:** The commutator is cylindrical in shape. Several wedge-shaped, hard drawn copper segments form a commutator.

    i. **The functions of a commutator:** To connect stationary external circuits to the rotating armature conductors through brushes and to convert induced alternating current into direct current.

Types of DC generators

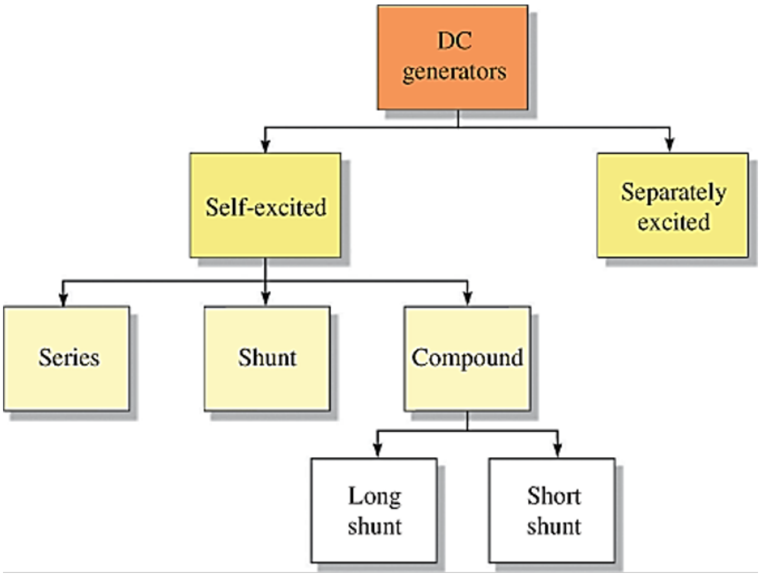

Figure 1.16: *DC Generator Types by Electromagnetic Field Windings*

DC generators are classified by how they obtain current for the field electromagnets (called excitation current).

Methods of Excitation

Note**:** nearly all DC generators use an electromagnet to create the required magnetic field (very small generators can use a permanent magnet). An electromagnet requires current to produce the field (except for a small residual field). Current can be provided for the field in one of two ways**:** (1) use a separate source for field current (Separate Excitation) or (2) use a portion of the generator's own output to supply current for the field (Self-Excitation).

1. **Separately Excited DC Generator:** The separately excited DC generator has the field voltage connected to an external DC source. It is controlled by varying the source current, which can be useful in renewable energy systems such as wind turbines, in which the shaft speed may vary. Controlling the excitation can help maintain a constant DC output. The disadvantage of this method is that a separate source of DC must be available, which adds to the cost.

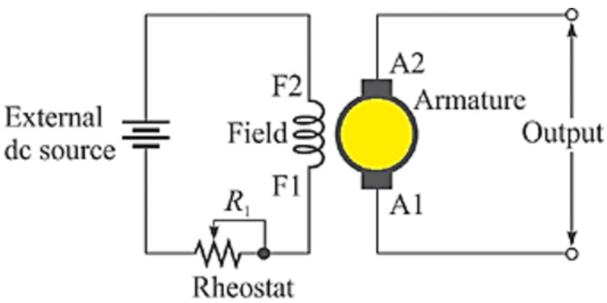

Figure 1.17: *Separately Excited DC Generator*

2. **Self-Excited Series DC Generator:** A self-excited generator is one in which some of the output is used to provide current for the field. The self-excited series DC generator has the field winding in series with the armature; thus, the armature current, field current, and load current are the same. When the generator is started, a small residual magnetism produces a field, and the output is small. As current is supplied to the load, the increased current causes the output voltage to increase. Thus, the voltage varies with load current, an undesirable characteristic for generators. Although a series-wound DC generator has a limited application by itself, series-field coils are especially useful in compound generators. The generator starts from residual magnetism in the stator's poles. This is a case where a small amount of hysteresis is an advantage because the core "remembers" the last state it was in and begins to output a small voltage. If the generator has not been used for a long time, it may be necessary to apply an external source to the field windings to start it; this is called flashing the fields.

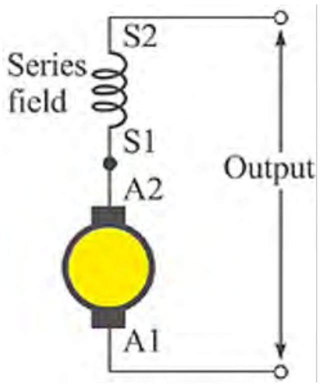

Figure 1.18: *Self-Excited Series DC Generator*

Most DC generators are self-excited because the method is simpler; they use the residual magnetism in their fields to produce the required field at start-up. Once the voltage is produced, the self-excited generator can tap some portion of the output current to control the generator's output. The voltage regulation tends to be less efficient than that found in separately excited generators.

3. **Self-Excited DC Shunt Generator:** The majority of DC generators are self-excited shunt generators. A self-excited shunt generator is a generator that supplies voltage from its armature to create the field current. The field and armature windings are parallel. The self-excited shunt DC generator has the field winding and field rheostat parallel to the armature and load (not shown). The field winding has a fixed resistance, so the field current is proportional to the applied voltage. An increase in field current increases the magnetic field up to the point at which core saturation occurs.

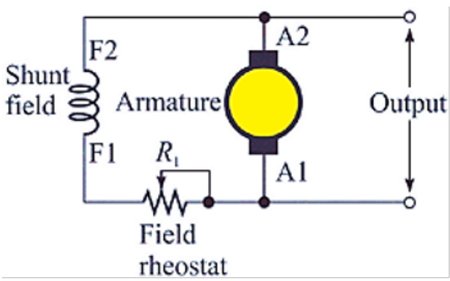

Figure1.19: *Self-Excited Shunt Generator*

Saturation is the point where an increase in magnetic field intensity (H) in a core does not increase flux density. The rheostat can control the output voltage by adjusting the field current up to the point of saturation. When a self-excited shunt generator is turned at a constant speed, the output voltage remains constant. Because the field is connected in parallel with the armature, the voltage applied to the field also remains constant. This equilibrium continues as long as the load is constant and it remains at a constant speed. If the voltage is used for charging a bank of batteries, a small change in voltage is not a problem.

4. **Long-Shunt and Short-Shunt Compound Generators:** A flat compounded generator uses both a series field and a shunt field to maintain constant output voltage over a range of loads. The series field consists of a few turns of very large wire, and it is connected in series with the armature, whereas the shunt field consists of many turns of smaller-diameter wire. The shunt field coil can be connected in one of two ways. The first is to connect field coils, armature, and rheostat. In this configuration, the combination of the shunt field coil and its series rheostat across are both parallel with the combination of the armature coil and the series field coil. This configuration is called a long-shunt generator.

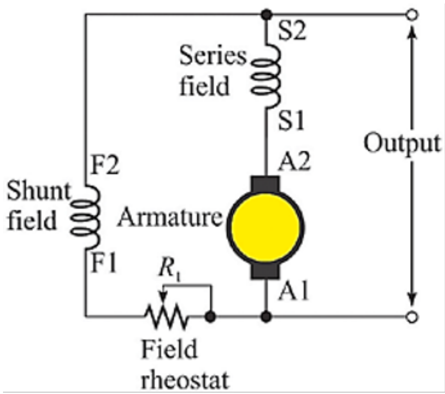

Figure1.20: *Long-Shunt Compound Generator*

The **second way** to connect the coils is the combination of the shunt field with its series rheostat connected across the armature only. This arrangement is called a short-shunt generator. In both the long-shunt and short-shunt configurations, the coils can be wound on the same pole pieces.

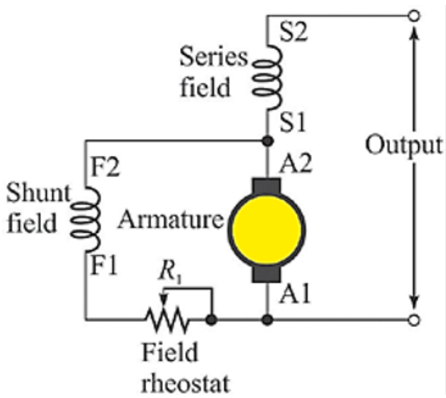

Figure 1.21: *Short-Shunt Compound Generator*

5. **Working principle of a DC Generator:** A DC generator operates on the principle of Faraday's laws of electromagnetic induction. According to Faraday's law, whenever a conductor is placed in a fluctuating magnetic field (or when a conductor is moved in a magnetic field) an EMF is induced in the conductor. If the conductor is guided with a closed path, the current will be induced. The direction of the induced current (given by Fleming's right-hand rule) changes as the direction of movement of the conductor changes.

EMF Equation of a DC Generator

The EMF equation for DC generator is expressed as:

E = (PØNZ)/60A

Where

E = Generated EMF across any parallel path

P = Total number of poles in the field

N = Rotational speed of armature (rpm)

Z = Total number of armature conductors in the field.

Ø = Magnetic flux produced per pole

A = number of parallel paths in the armature.

Losses in DC Generators

While converting the mechanical energy into electrical energy, there are losses of energy, i.e. whole input is converted into output. These losses are classified into four types:

1. **Copper Loss:** These losses occur while current flows through windings and are of three types: armature copper loss, field copper winding loss and losses because of brush resistances.
2. **Iron Losses:** Due to the induction of current in the armature, eddy current losses and hysteresis losses occur. These losses are also called Core losses or Magnetic losses.
3. **Mechanical Losses:** Losses which occur because of friction between the parts of the generator are called mechanical losses.
4. **Brush contact losses:** This loss is due to the resistance at the interface between the brushes and the commutator, which generates heat.

Applications of DC Generators

The applications of DC generators are as follows:

1. The separately excited type of DC generator is used for power and lighting purposes using the field regulators.
2. The series DC generator is used in arc lamps for stable current generator, lighting and as a booster.
3. Level compound DC generators are used to supply power to hostels, offices, lodges etc.
4. Compound DC generators are used for supplying power to DC welding machines.
5. A DC generator is used to compensate for the voltage drop in the feeders.

Learning Tasks

1. Explain the concept of DC Generators.
2. Summarise the principles of operation of a DC Generator.
3. Illustrate the various applications a DC generator can be used for.

Pedagogical Exemplars

Teachers should consider the following activities:

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with the concept of DC Generators, the various types of DC motors, the construction of DC Generators, the principles of operation of DC Generators and application of DC Generators after watching a video on these provided by the teacher. Summarise everything on the board.

Key Assessment Level 3: Class Exercise

1. A shunt-wound DC generator and a series-wound DC generator of identical physical construction are being considered for a small hydroelectric installation.

Compare how each type would respond to the following:

   - **a.** Sudden increases in mechanical input speed
   - **b.** Variations in load demand
   - **c.** Short circuit conditions

Based on your analysis, recommend which would be more suitable for this application and justify your choice.

2. A DC generator needs to produce more voltage without changing its physical size or rotation speed. Analyse how modifications to the following construction elements would affect the output:

   - **a.** Number of armature conductors
   - **b.** Number of parallel paths
   - **c.** Field winding configuration

Explain which modification would be most effective and why.

PLC Session 4

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   - **a.** explain the week's concepts in a practical way that will make it easier for learners to understand
   - **b.** identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   - **a.** suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

   a. The key assessment for the week is ***class exercise***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the exercise (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

   b. all teachers in the group work through a similar problem individually for 3–4 minutes

   c. the group then works through the problem together step by step

   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?
ii. were the examples grounded in contexts familiar to Ghanaian learners?
iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 4 Review

This unit introduced learners to the concept of DC Generators. The pedagogical exemplars used in this unit includes Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 3.

Resources: Pictures, Videos, real objects (DC Generators)

MARKING SCHEMES FOR THE KEY ASSESSMENTS

UNIT 1

Question 1 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs improvement (1mark)
Starting Characteristics Comparison	Comprehensively compares starting torque, current, and performance characteristics of both motor types with technical accuracy	Provides good comparison of starting characteristics with minimal technical errors	Provides basic comparison of starting characteristics	Limited description of starting characteristics

Speed Control Capabilities Analysis	Thoroughly analyses speed control methods for both motors with detailed explanation of technical principles	Identifies speed control differences for both motors with moderate technical explanation	Identifies basic speed control differences with some technical explanation	Limited explanation of speed control capabilities
Construction Complexity Evaluation	Detailed comparison of construction elements with specific reference to rotor designs and manufacturing considerations	Clear description of construction differences with some technical language used	Basic description of construction differences	Superficial description of construction
Maintenance Requirements Assessment	Comprehensive analysis of maintenance needs, including slip rings, brushes, and reliability factors	Clear comparison of maintenance requirements with some technical language used	Basic comparison of maintenance requirements	Minimal maintenance information provided
Application Selection - Conveyor	Well-reasoned selection with comprehensive technical justification based on starting characteristics and load requirements	Correct selection with good justification and using some technical language	Correct selection with basic justification provided	An initial selection has been identified
Application Selection - Pump	Well-reasoned selection with comprehensive technical justification based on speed control requirements	Correct selection with good justification and using some technical language	Correct selection with basic justification provided	An initial selection has been identified

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Understanding of Motor Principles	Comprehensive understanding with clear connection to practical applications	Good understanding of 3-phase induction motor principles	Basic understanding of induction motors	Limited understanding of induction motor principles

Calculation of Synchronous Speed	Precise calculation with explanation of formula derivation	Correct formula used and calculation with proper units	Correct formula used with some calculation attempted	Limited understanding of formula used
Estimation of Rotor Speed	Detailed explanation of relationship between synchronous speed, slip, and rotor speed	Correct approach to estimating rotor speed with accurate calculations	Recognises need for slip with some application attempted	Limited understanding of slip concept
Mathematical Accuracy	Accurate and precise calculations with verification steps included	Calculations are accurate	Minor calculation errors present	Limited attempt at calculations
Presentation of Solution	Well-structured solution with labelled steps and units	Clear, logical solution sequence and clear layout	Organisation and layout of solution present	Basic layout of work attempted

UNIT 2

Question 1 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Understanding of DC Motor Principles	Comprehensive understanding with clear explanation of relationship between motor components and load performance	Good understanding of DC motor principles with some connection to load characteristics	Basic understanding of DC motor components and function	Limited understanding of DC motor operation
Field Winding Configuration Analysis	Detailed analysis of how field winding configuration directly relates to motor performance under load with specific mechanisms explained	Clear explanation of field winding's impact on torque and speed	Basic description of how field winding affects motor operation	Minimal explanation of field winding's role
Armature Winding Resistance Analysis	Comprehensive analysis of armature resistance effects with reference to voltage drop, heating, and efficiency changes under load	Clear explanation of how armature resistance impacts torque and current under load	Identifies that armature resistance affects current but with limited explanation	Limited recognition of armature resistance as a factor

Brush Positioning Analysis	Detailed analysis of how improper brush positioning leads to commutation problems, arcing, and torque reduction under load conditions	Clear explanation of how brush positioning impacts on commutation, torque and current	Basic explanation of brush positioning importance	Minimal understanding of brush function
Integration of Concepts	Comprehensive systemic analysis showing how all factors interact to create the observed symptoms	Clear explanation of how factors interact to affect commutation, torque and current	Some connections between factors	Discusses some factors in isolation

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Understanding of Back EMF	Comprehensive explanation including mathematical relationship ($E = k\Phi\omega$) and physical principles	Clear explanation of back EMF as counter voltage proportional to speed	Basic definition of back EMF as counter voltage	Limited definition of back EMF
DC Shunt Motor Characteristics	Detailed analysis of shunt motor characteristics including torque-speed relationships	Clear explanation of shunt motor field and armature circuit relationships	Basic understanding of shunt motor construction and operation	Limited understanding of DC shunt motor construction
Starting Current Analysis	Comprehensive analysis with calculations demonstrating how current varies with back EMF during starting	Clear explanation of inverse relationship between back EMF and armature current	Identifies that starting current is excessive due to low/zero back EMF	Minimal recognition of high starting current issue
Starting Methods & Protection	Detailed comparative analysis of starting methods with their advantages/disadvantages related to back EMF management	Clear explanation of multiple starting methods to address back EMF issues	Basic explanation of one starting method related to back EMF	Lists a starting method; limited connection to back EMF

Application to Motor Protection	Comprehensive analysis of protection systems designed specifically to address back EMF-related starting issues	Clear explanation of how back EMF-related starting issues affect motor components	Basic understanding of how back EMF relates to motor protection	Limited connection to motor protection

UNIT 3

Question 1(20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Understanding of AC Generator Principles	Comprehensive understanding with detailed explanation of generator operation under varying load conditions	Clear understanding of voltage generation principles and load effects	Basic understanding of generator components and function	Limited understanding of AC generator operation
Cause Identification: Component/Design Aspects	Identifies precise components with detailed explanation of their design parameters and potential failure modes	Clearly identifies specific components that could cause voltage drop	Identifies basic components but with limited connection to the problem	Identifies som components unrelated to problem
Analysis of Voltage Regulation Mechanisms	Sophisticated analysis of load-dependent voltage regulation with reference to electrical principles and equations	Clear explanation of how each component affects voltage regulation under load	Basic explanation of component/ voltage relationship	Minimal explanation of how components affect voltage
Diagnostic Method Recommendations	Proposes comprehensive diagnostic protocol with sequential testing and expected results for each cause	Proposes specific, practical tests to verify each cause	Suggests basic tests with some relevance to cause	Suggests generic or unrelated tests
Technical Communication	Exceptionally clear, precise technical explanations with professional terminology	Well- organised text with accurate technical content	Basic organisation of text with some technical content	Limited explanation with minimal relationship to causes

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Effects of Frequency Deviation on Connected Devices	Comprehensive understanding with detailed explanation of generator operation under varying load conditions	Clear understanding of voltage generation principles and load effects	Basic understanding of generator components and function	Limited understanding of AC generator operation
Generator Construction and Frequency Determination	Identifies precise components with detailed explanation of their design parameters and potential failure modes	Clearly identifies specific components that could cause voltage drop	Identifies basic components with limited connection to the problem	Identifies some components unrelated to problem
Frequency Adjustment Methods	Sophisticated analysis of load-dependent voltage regulation with reference to electrical principles and equations	Clear explanation of how each component affects voltage regulation under load	Basic explanation of component/voltage relationship	Minimal explanation of how components affect voltage
Impact Analysis of Adjustments	Proposes comprehensive diagnostic protocol with sequential testing and expected results for each cause	Proposes specific, practical tests to verify each cause	Suggests basic relevant tests	Suggests generic or unrelated tests
Technical Accuracy and Communication	Exceptionally clear, precise technical explanations with professional terminology	Well organised with accurate technical content	Basic organisation with some technical content	Limited organisation of text

UNIT 4

Question 1 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Knowledge of Generator Types	Comprehensively describes the electrical characteristics and operating principles with correct technical terminology	Explains the construction and connection configurations of both generator types	Identifies basic differences between shunt-wound and series-wound DC generators	Limited understanding of the differences between shunt-wound and series-wound DC generators
Response to Input Speed Changes	Analyses with equations/graphs how each generator responds to sudden speed changes and the implications for stability	Explains how speed changes affect voltage output in each generator type	States basic effects of speed changes on each generator type	Limited knowledge of basic effects of speed changes on each generator type
Response to Load Variations	Provides detailed analysis of load-voltage curves and self-regulation properties with technical justification	Explains voltage regulation characteristics under varying loads	States simple load-voltage relationships for each type	Limited knowledge of simple load-voltage relationships
Response to Short Circuit	Analyses the short-circuit current paths, magnitudes, and consequent effects on the generator components	Explains the current behaviour during short circuit for each type	Identifies which generator is more vulnerable to short circuits	Limited knowledge of which generator is more vulnerable to short circuits
Recommendation & Justification	Delivers comprehensive recommendation with detailed justification based on all analysed conditions and hydroelectric application requirements	Provides recommendation with some supporting technical reasons	Makes a basic recommendation with some technical reasons	Limited ability to make a basic recommendation

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Analysis of Armature Conductors	Provides detailed analysis with reference to the EMF equation ($E \propto Z\Phi N/A$) and discusses practical limitations within fixed physical size	Explains the proportional relationship between number of conductors and generated EMF	States that increasing conductors affects output voltage	Limited ability to state the effect of increasing conductors on output voltage
Analysis of Parallel Paths	Analyses mathematically how changing parallel paths (A) affects terminal voltage while maintaining the same physical size, with consideration of current-carrying capacity and commutation issues	Explains that reducing parallel paths increases voltage	Identifies that parallel paths affect voltage	Limited ability to identify effects of parallel paths on voltage
Analysis of Field Winding Configuration	Provides comprehensive analysis of how modifications to field windings (turns, material, configuration) affect magnetic flux and consequent voltage, considering saturation effects	Explains how field winding configuration affects flux density	Describes basic field winding types (series, shunt, compound)	Limited ability to describe basic field winding types (series, shunt, compound)
Comparative Effectiveness	Critically evaluates all three modifications, identifying the most effective approach with thorough technical justification, considering practical constraints and trade-offs	Compares the effectiveness of each modification with some technical reasoning	Selects a modification with minimal justification	Limited ability to select a modification
Technical Communication	Demonstrates mastery of technical terminology with precise engineering language and may include relevant equations/diagrams	Uses technical terminology with minor errors	Uses basic technical terminology with some errors	Limited ability to use basic technical terminology

SECTION 2: TRANSFORMERS AND MAINTENANCE

The section covers the following unit (strands); Electrical technology and electronic technology.

In this section learners will acquire knowledge and understanding of the construction and principles, losses and efficiency, methods of cooling and classification of the operation of a transformer. All the above are treated from unit 5 to unit 8.

UNIT 5

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits.*

INTRODUCTION AND SECTION SUMMARY

This Section looks at AC and DC machines as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, Principle of operation and application of transformers as part of electrical machines.

The unit covers only week 5: ***Describe the construction and principle of operation of the transformer****.*

Recap weeks

Year 2	**Week 22: Explain** the principles of measuring instruments through electro-magnetism

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved, learners will be actively engaged in practical demonstrations on the various aspects of transformers through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project–based learning, research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section require learners' ability to demonstrate the understanding relating to real life situations hence the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively

Indicators	**DOK Level**	***Assessment Strategy and/or Mode***
Describe the construction and principle of operation of a transformer.	3 (Strategic reasoning)	Assessment mode: Group discussion

WEEK 5

Learning Indicator: *Describe the construction and principle of operation of the transformer*

FOCAL AREA: SINGLE PHASE AND 3-PHASE TRANSFORMER

Construction of a transformer

A transformer changes ac supply from a lower value to a higher one or vice versa. Figure 2.1 shows the basic construction of a simple transformer. It consists of two coils wound on a laminated core. One is called the *Primary Winding* and it is on this that the input supply is connected. The other is called *Secondary Winding,* and that is where the load is connected. Note that the two windings are not electrically connected but only share a common magnetic circuit.

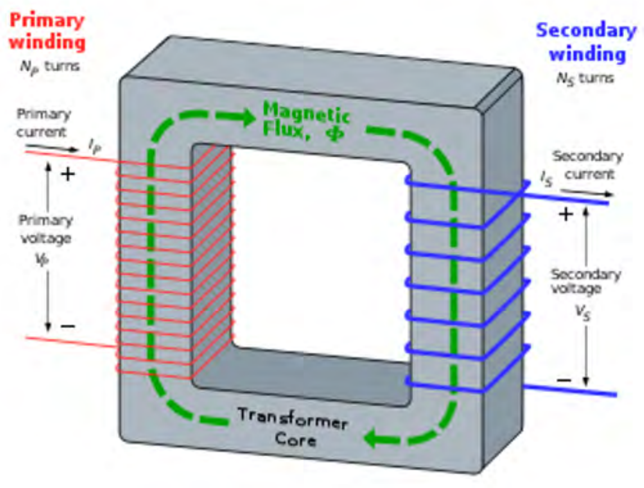

Figure 2.1: *Basic construction of a transformer*

Figure 2.2 shows a diagrammatic representation of the transformer. It represents a single-phase transformer. In other types however, there can be more than two windings.

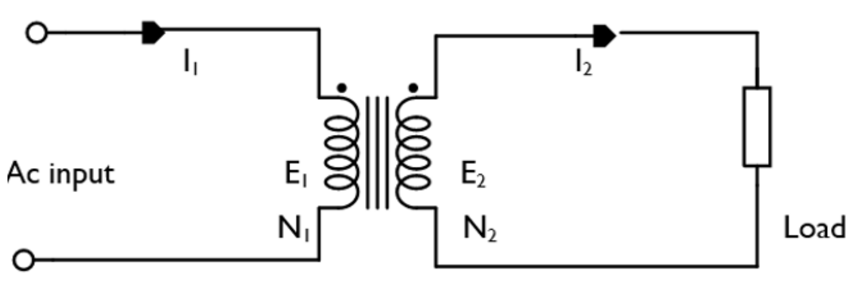

Figure 2.2: *A simple transformer*

Principle of operation

Transformers operate on the basis of mutual induction. That is the magnetic field of one coil linking a second coil and inducing an emf into that second coil. Note, however that the most important condition required for the induced emf to take place is that the magnetic flux linking the coils must change. This is in accordance with Faraday's Laws of electromagnetic induction.

For this reason, transformers can be used to change only ac voltages from one value to another. DC does not change and so cannot bring about induction. This means that the transformer cannot operate on DC. When an alternating voltage is applied to the primary side, a current is generated in the primary coil, which in turn produces a changing magnetic flux, which links both the primary and secondary coils. The linkage of the flux causes an emf to be induced in the coils. The emf induced 'e' in a coil of *N* turns is given by:

$$e = N\frac{d\phi}{dt}$$

This implies that, the rate of change of the flux, which links with the turns

N, is $\frac{d\phi}{dt}$

Example

A coil of 200 turns is linked by a magnetic flux of 4mWb. Calculate the induced emf if the flux doubles in a time of 20ms.

Solution

Initial flux = 4mWb, final flux = 8mWb

Flux change = 8-4 = 4mWb

Induced emf, $E = N\frac{d\phi}{dt} = (200) \times \frac{0.004}{0.02} = 40V$

If the coils are having *Np* and *Ns* as the number of turns in the primary and secondary windings respectively and their respective rms voltages induced in the windings are *Ep* and *Es* then:

$$\frac{E_P}{N_P} = \frac{E_s}{N_s} \text{ and } \frac{E_p}{E_s} = \frac{N_p}{N_s}$$

Note that in the transformer, current is inversely proportional to voltage therefore a general equation becomes;

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$$

In an ideal transformer, the induced voltage in the secondary winding (V_S) is in proportion to the primary voltage (V_P), and is given by the ratio of the number of turns in the secondary *Ns* to the number of turns in the primary *Np* as follows:

$$\frac{V_s}{V_P} = \frac{N_s}{N_P}$$

A transformer can be a step up or step down by the appropriate selection of the ratio of turns. A step-up transformer is obtained by making N_S greater than N_P, and vice versa for a step down. In the construction of power transformers (heavy-duty transformers) however, steps are taken to ensure that all the flux produced in the primary links with the secondary winding. This is to obtain high efficiency operation.

Three phase transformer construction

The three-phase transformer has three interconnected single-phase transformers on a single laminated iron-core. Instead of connecting three single-phase transformers together (bank transformers), the three windings are combined onto a single magnetic circuit as shown in figure 5.3.

Figure 2.3 A typical 3-phase transformer

A three-phase transformer has three magnetic circuits that are interlaced to give a uniform distribution of the dielectric flux between the high and low voltage windings. The primary and secondary windings of a three-phase transformer can be connected in different configuration such as delta-star, star-delta, star-star or delta-delta to meet any electrical requirement. A typical delta-star connection is shown in Figure 2.4.

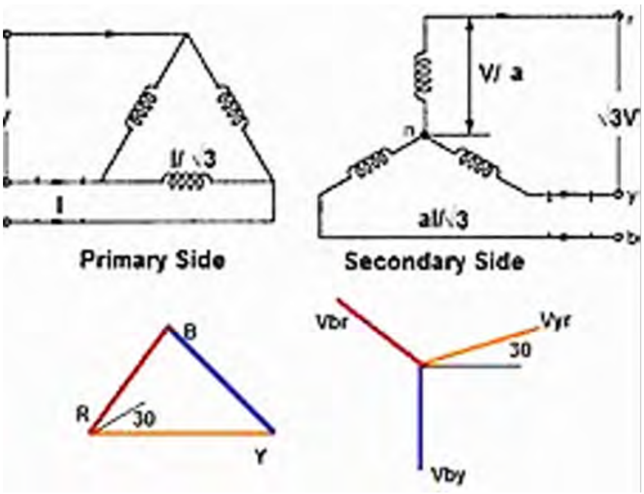

Figure 2.4: *Delta–star connection of a 3-phase transformer*

Note that the working of the 3-phase system is like a single-phase transformer, and they are normally employed in power generation plants.

EMF equation of transformer

Note the following symbols:

$\mathbf{N_1}$ – Number of turns in the primary

$\mathbf{N_2}$ – Number of turns in the secondary

$\mathbf{\Phi_m}$ – Maximum flux in weber (Wb)

T – (period) Time taken to complete 1 cycle.

Note that the flux formed is an alternating (sinusoidal wave). It rises to Φ_m in the positive region and falls to Φ_m in the negative region. Maximum flux is therefore attained in 1/4 of a cycle. The time taken is equal to T/4.

Average rate of change of flux = $\Phi_m/(T/4) = 4f\Phi_m$

Where, **f** = frequency

T = 1/f

- Induced EMF per turn = Rate of change of flux per turn
- Form factor = RMS value / average value
- RMS value = $1.11\ (4f\Phi_m) = 4.44\ f\Phi_m$ where 1.11 is form factor of a sine wave
- RMS value of EMF induced in winding = RMS value of EMF per turn x No. of turns

In the primary winding, RMS value of induced EMF = $E_1 = 4.44\ f\Phi m * N_1$

In the secondary winding, RMS value of induced EMF = $E_2 = 4.44\ f\Phi m * N_2$

Consequently, the EMF equation for an ideal transformer at no load condition is as follows:

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44f\,\Phi m$$

Where

E_1 = Supply voltage on the primary winding

E_2 = Terminal voltage (theoretical or calculated) on the secondary winding

Advantages of a three-phase transformer

Here are some advantages of a three-phase transformer

1. Needs less space to install and it is easier to install
2. Less weight and reduced size
3. Higher efficiency
4. Low cost
5. Transportation cost is low

Disadvantages of a three-phase transformer include the following

These include:

1. The entire unit shuts down if a fault or loss occurs in any one unit of a transformer, as a common core is shared by all three units.
2. Repair costs are higher
3. Cost of spare units are high

Applications of transformers

1. Employed in the transmission and distribution of electricity
2. Multiple secondary output transformers are used in radio and TV receivers, which require several different voltages.
3. Transformers are used as voltage regulators.

Learning Tasks

1. Outline the construction and principles of operation of the transformer
2. Justify why you think it's advantageous using the transformer
3. Discuss some typical applications of transformers and illustrate the impact of overloading them

Pedagogical Exemplars

Teachers should consider the following activities:

Talk for learning approaches: Guide learners through discussion to brainstorm the construction and operation as well as application of transformers, making sure that all learners take part in the discussion. Teachers should ask leading questions to streamline the discussion for the responses to be clear.

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with the typical applications of transformers as well as advantages and disadvantages of transformers after watching a video (provided by the teacher) on the impact of loading on the output of alternators. Summarise and enumerate the various processes on the board.

Key Assessment Level 3: Group Discussion

1. A 240V to 24V transformer needs to be modified to provide a 12V output as well.

Analyse the following two possible approaches to this modification:

- **a.** Adding a centre tap to the secondary winding
- **b.** Adding a separate 12V secondary winding

Compare these approaches in terms of:

- **a.** Impact on transformer efficiency
- **b.** Construction complexity
- **c.** Effect on voltage regulation
- **d.** Cost implications

2. A step-down transformer designed for 240V to 12V operation has been experiencing overheating issues despite operating within its rated load. Analyse how the following construction elements might contribute to this problem:

- **a.** Core material and lamination thickness
- **b.** Primary and secondary winding insulation
- **c.** Transformer oil or cooling medium

For each element, explain the specific mechanism by which it could cause overheating and suggest how to verify if it is the actual cause.

PLC Session 5

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   - **a.** explain the week's concepts in a practical way that will make it easier for learners to understand
   - **b.** identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

- **a.** suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
- **b.** suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
- **c.** review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

- **a.** The key assessment for the week is ***group discussion***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the discussion (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

- **a.** use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
- **b.** all teachers in the group work through a similar problem individually for 3–4 minutes
- **c.** the group then works through the problem together step by step
- **d.** highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).

a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 5 Review

This unit introduced learners to the construction, operation and application of single phase and three-phase transformers. The pedagogical exemplars used in this unit include Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 3.

UNIT 6

Section 2: Transformers

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at transformers as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, Principles of operation of transformers, losses in transformers and methods of cooling transformers.

*The unit covers only week 6: **Explain losses that occur in a transformer and how they affect the operation of the transformer**.*

Recap week

Year 2	**Week 22:** Explain the operation of electrical measuring instruments through Principles of electromagnetism.

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved learners are to be actively engaged in practical demonstration on the various aspect of Electrical machines through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section require learners' ability to demonstrate the understanding relating to real life situations hence the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively

Indicators	DOK Level	Assessment Strategy and/or Mode
LI: Explain losses that occur in a transformer and how they affect the operation of the transformer.	4 (Extended critical thinking and reasoning)	Group Presentation

WEEK 6

Learning Indicator: *Explain losses that occur in a transformer and how they affect the operation of the transformer*

FOCAL AREA: LOSSES AND EFFICIENCY OF TRANSFORMERS

PREAMBLE: Transformers are used in the power system to efficiently transfer electrical energy between different voltage levels. Like other electrical machines, transformers are not 100% efficient because various losses occur during operation. The transformer losses are called transformation losses, which impact on the performance and efficiency of transformers. It is important to understand these losses in the transformer to optimise the transformer performance and minimise energy wastage**.** Figure 2.5 shows a breakdown of transformer losses.

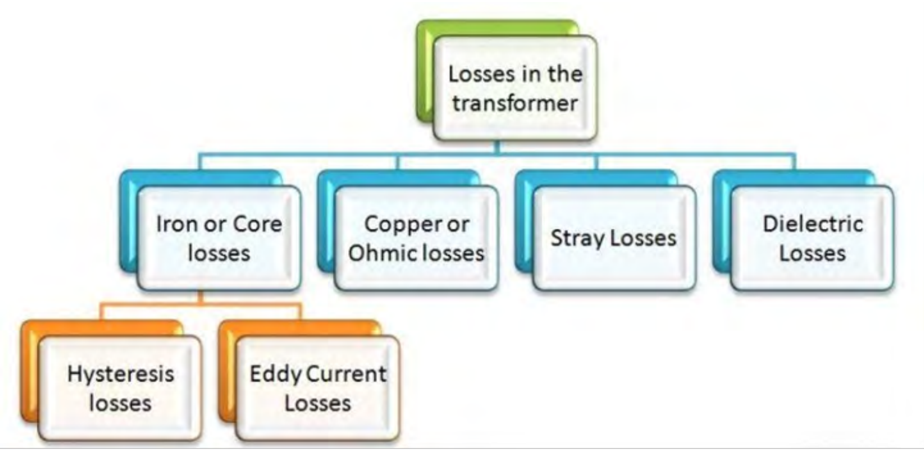

Figure 2.5: *Types of transformer losses*

Types of Losses in a Transformer

Transformer losses are broadly categorised into **Core Losses** (or Iron Losses) and **Copper Losses**. Additionally, Stray Losses and Dielectric Losses also contribute to the overall **l**oss in transformers.

1. **Iron Losses:** Iron losses occur in the magnetic core of the transformer. When the primary winding of the transformer receives alternating voltage, the current in the primary winding sets up the alternating magnetic flux in the transformer core, which causes losses in the core of the transformer. This loss is also called **core loss**. These losses are constant under specified operating conditions and have two main components: **Hysteresis Loss** and **Eddy Current Loss**.

    a. **Hysteresis Loss:** The transformer core magnetises and demagnetises during each cycle of the alternating current (AC). After demagnetisation, the magnetic domains realign in the positive cycle and consume energy. The energy consumed in the process of realignment of the magnetic domain causes hysteresis loss in the transformer, and it depends on the magnetic properties of the core material and the frequency of the AC supply.

    b. **Eddy Current Loss:** In a transformer, the alternating magnetic flux flows in the closed magnetic circuit. The varying magnetic flux induces an electromotive force (EMF) and causes current to flow in the core. The magnitude of this current depends on the EMF generated and the resistance of the magnetic core. The induced EMF causes current to circulate within the core material, and this circulating current is called Eddy Currents. However, these circulating currents do not perform any useful work. Instead, they cause energy dissipation in the form of heat, commonly referred to as **I^2R loss**, which is known as **Eddy Current Loss** in magnetic materials. The solid piece of the core has a higher resistance and therefore it has higher eddy current loss. To minimise these losses, the core is constructed using thin laminations. These laminations are insulated from each other which restricts the path of eddy current and as a result, reduces energy loss and improves the efficiency of the transformer.

2. **Copper Loss (Ohmic Loss):** Copper loss in the transformer is load-dependent and occurs due to resistance of primary and secondary windings. The loss occurs due to the resistance of the winding; therefore, it is also called **ohmic loss**. The copper loss in the primary and secondary winding depends on the resistance and the current in the respective winding. Thus, the copper loss of the transformer is the sum of losses in the primary and secondary winding. For example, if the resistance and current in the primary winding are R_1 and I_1 and, the secondary winding resistance and current are R2 and I2, then the copper loss in the primary is $I_1^2R_1$, and the copper loss in the secondary is $I_2^2R_2$.
3. **Stray Loss:** In an ideal transformer, it is assumed that all the flux produced in the winding links to the primary and secondary winding and there is no flux leakage. However, in a practical transformer, the flux produced in the primary does not 100% link to the windings and some parts of the flux leak from the winding and core. Leakage flux induces circulating currents in the windings or nearby metallic parts, leading to additional I^2R losses. Stray magnetic fields can cause localised heating in parts of the core or structural elements which contribute to energy loss. These losses are relatively minor compared to core and copper losses but can still impact overall efficiency. The stray losses can be minimised by ensuring proper insulation selection, optimised core design, precise placement of winding & components, and use of high-resistivity materials. Dielectric loss occurs in the transformer due to the movement of charges and dipoles in the insulating materials under an AC voltage. The primary causes of this loss are conduction loss, caused by the minute conductivity of the insulating material, and **Polarisation Loss** which occurs due to the lag in the polarisation of the dielectric material compared to the applied alternating electric field.

How Losses Affect the Operation of a Transformer

Losses are a significant factor that affects the operation of a transformer. When a transformer operates, it generates heat due to the opposition of the electrical current flow. If the temperature of the transformer increases beyond its maximum allowable limit, it can cause damage to the insulation, reducing the transformer's lifespan. Losses can also result in reduced efficiency as the resistance of the transformer's windings increases, causing more energy to be lost as heat. This can lead to decreased voltage regulation and increased energy consumption, making the transformer less cost-effective to operate. Various factors can also impact the insulating properties of a transformer, including overloading, moisture, insulation type, and extreme temperatures.

How Can the Efficiency of a Transformer Be Increased?

Minimising loss can help increase the efficiency of transformers. While you may benefit from a more efficient generator that produces lower amounts of heat waste, it's important to remember that transformers may experience temperature increases based on the level of transformer heat output. If you want to boost your transformer's efficiency, the following are some ways to reduce transformer losses and improve performance:

1. **Loop area:** The loop area in a transformer must prevent heat loss in the form of hysteresis loops.
2. **Insulation:** Sufficient insulation will help prevent the formation of eddy currents and dielectric loss.
3. **Primary and secondary coil resistance:** Minimise electrical resistance using stable primary and secondary coils.
4. **Flux coupling:** Transformers must contain wound coils that facilitate efficient power transfer between coils.

Learning Tasks

1. Outline the concept of Transformer Losses
2. Analyse the effects of transformer losses on the performance of transformers.
3. Illustrate how a transformer's efficiency can be increased

Pedagogical Exemplars

Teachers should consider the following activities:

Talk for learning approaches: Guide learners through discussion to brainstorm the concept of Transformer losses and the effects of these losses on transformer performance making sure that every learner takes part in the discussion. Teachers should ask leading questions to streamline the discussion of transformer losses and their effect on transformer performance to ensure clarity.

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with the concept of transformer losses, the effects of transformer losses on transformer performance and how to increase the efficiency of a transformer after watching a video provided by the teacher on these aspects. Summarise everything on the board.

Key Assessment: Mid-Semester Examination

Explain losses that occur in a transformer and how they affect the operation of the transformer.

1. A manufacturing plant experiences frequent overheating in their 50 KVA distribution transformer. Analyse the possible causes of the transformer overheating, relating each to specific type of loss.
2. Critically analyse how the losses of a transformer can affect the efficiency of that transformer.

Hint

*Conduct **Mid-semester Examination**. It should cover contents taught from Week 1 to 5. Refer to the **Table of Specification and Structure of the Paper** to guide you. Learners' papers should be marked immediately and scores entered into the SAP.*

Structure

Section A = 25 Multiple Choice Questions

Section B = 2 Essay Questions

Table of specification for item construction for section A and B

Week	Focal area	Types of questions	DoK Levels				Total
			1	2	3	4	
1	Induction motors and synchronous motors	MCQs	2	2	-		4
		ESSAY	-	-	-		-
2	D.C motors	MCQs	2	2	2		6
		ESSAY	-	-	1		1
3	Single phase and three-phase generators	MCQs	-	2	1		3
		ESSAY	-	-	-		
4	DC generators	MCQs	3	2	1		6
		ESSAY					
5	Single phase and 3-phase transformer	MCQs	1	3	2		6
		ESSAY			1		1
		Total	**8**	**11**	**8**		**27**

PLC Session 6

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).

a. The key assessment for the week is ***mid-semester examination***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the mid-semester examination (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through the problem individually for 3–4 minutes

c. the group then works through it together the problem, step by step

d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).

a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 6 Review

This unit introduced learners to the construction, principles of operation of transformers, losses in transformers and methods of cooling transformers. The pedagogical exemplars used in this unit includes Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 1,2 and 3.

Resources: Pictures, Videos, real objects (transformer)

UNIT 7

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of transformers

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This section looks at AC and DC machines as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, Principle of operation and application of transformers as part of electrical machines

The unit covers only week 7:

1. *Describe the methods of cooling transformers.*
2. Calculate voltage regulation of transformers

Recap weeks

Year 2	**Week 22: Explain** the principles of measuring instruments through electro-magnetism

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved learners will be actively engaged in practical demonstrations on the various aspects of transformers through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project–based learning, research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situations hence the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the methods of cooling transformers	3 (Strategic reasoning)	Assessment mode: Group discussion
Calculate voltage regulation of transformers	4 (Extended critical thinking and reasoning	Assessment mode: Group discussion

WEEK 7

Learning Indicators

1. *Describe the methods of cooling transformers*
2. *Calculate voltage regulation of transformers*

FOCAL AREA 1: METHODS OF COOLING TRANSFORMERS

COOLING OF TRANSFORMER

As transformers supply power to loads, heat is produced in the coils and the core because of the losses that occur, with the major contributor being copper loss. Since the high temperature, which the insulation can safely withstand, binds the rating of any electrical system, effective cooling is important. Cooling of a transformer is the process by which heat generated in the transformer is dissipated or treated to a safe value to increase efficiency. This involves two types of transformers, the dry type and the oil-filled type. Some of the methods used in cooling are as follows:

1. **Dry type transformer**
   - **a.** Air Natural (AN)
   - **b.** Air Blast or Forced (AF)
2. **Oil filled transformers**
   - **a.** Oil Natural Air Natural (ONAN)
   - **b.** Oil Natural Air Forced (ONAF)
   - **c.** Oil Forced Air Forced (OFAF)
   - **d.** Oil Natural Water Forced (ONWF)
   - **e.** Oil Forced Water Forced (OFWF)

Process for cooling dry type transformers: Dry type transformers are cooled by air natural and air forced:

1. **Air Natural (AN):** This method makes use of natural air for the cooling process and so it is also referred to as the self-cooled method. The process is by the circulation of natural air (convection) where cooler air replaces the warm air that surrounds the transformer. This method is employed in cooling smaller transformers that are less than 1.5 Mega Volts Ampere (MVA).
2. **Air Forced (AF) or Air Blast:** In this method, the transformer is cooled by forced air circulation at high velocity. Fans and blowers are automatically turned on as the transformer temperature reaches a pre-determined level. This forces air at high velocity on the core and the windings of the transformer. Since the cooling rate is much faster here, this method is employed in cooling transformers up to 15MVA.

Process of cooling Oil filled transformers

The following are the processes of cooling oil-filled transformers:

1. **Oil Natural Air Natural (ONAN**): The ONAN method uses the natural convection process of cooling. Both the core and winding of the transformer are immersed in the oil-filled tank of the transformer and so as they heat during the working of the transformer, the heat is transferred to the oil thus raising the temperature of the oil. Through the convection process, the hot oil rises to the top and is replaced by cool oil. The hot oil at the top dissipates heat to the surrounding air and cools down. After cooling, it goes through the radiator again and returns to the transformer to replace other heated oil inside. Transformers up to **30 MVA** capacity make use of this method of cooling. Fig 2.6 shows the type of transformer that utilises this method.

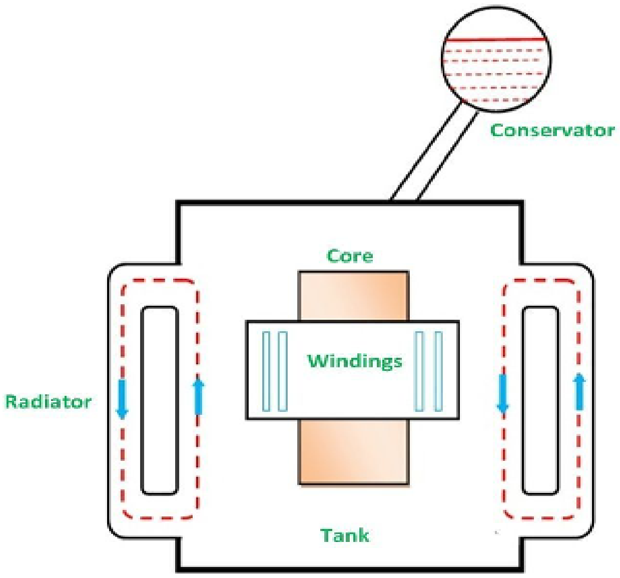

Figure 2.6: *Oil Natural Air Natural cooling method*

2. **Oil Natural Air Forced (ONAF):** The ONAF method works in the same way as the ONAN. The difference here is that the former has fans and blowers mounted, which blow air at high velocity on the radiator, thus cooling the oil in the radiator and tower, at a very fast rate. Since the cooling rate is fast and more efficient, this method is used for cooling transformers of up to 60 MVA in capacity**.** It is, however, more expensive than the ONAN because of the fan and blower attached. Figure 2.7 shows a typical ONAF cooling system.

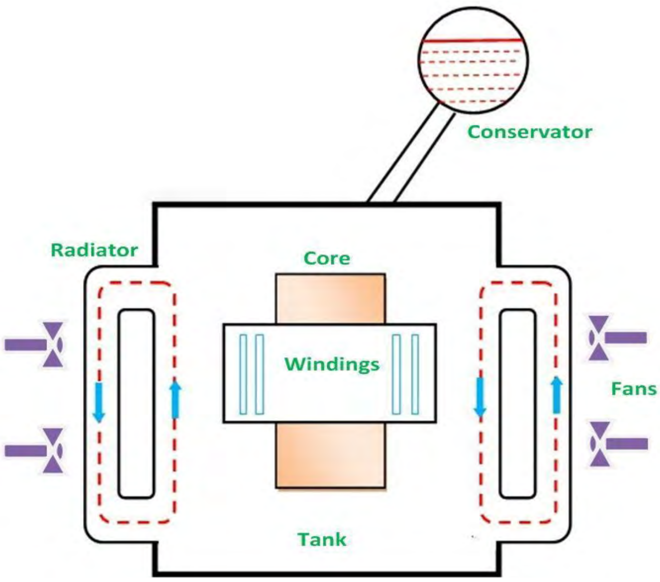

Figure 2.7: *Oil Natural Air Forced method of cooling*

3. **Oil Forced Air Forced (OFAF):** The features of this method include a heat exchanger through which hot oil flows with the aid of a pump and a high-speed fan which forces air onto the heat exchanger to cool the oil. Obviously, both oil and air are applied by force for the cooling of the transformer, hence the name OFAF. During off-peak periods, when the load is small, both fan and the pump are off and the cooling is done naturally just as an ONAN. However, during peak periods, a lot of heat is generated because of the huge load, and this raises the temperature of the oil. As soon as the temperature reaches a pre-determined level, sensors send a signal to both fan and pump and they switch on automatically, and from that moment the OFAF method kicks in. Figure 2.8 shows a diagram of Oil Forced Air Forced Cooling of Transformer.

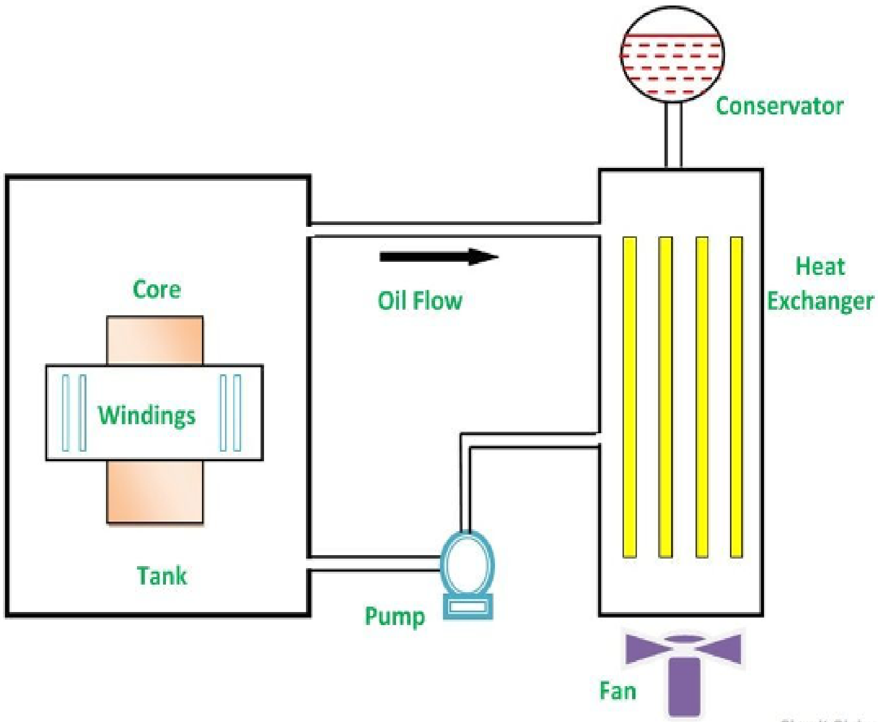

Figure 2.8: *Oil Forced Air Forced Cooling of Transformer*

4. **Oil Natural Water Forced (ONWF):** The ONWF method uses the same principle as ONAF. In the Oil Natural Water Force cooling method, however, the hot oil is cooled in the radiator by means of forced water instead of forced air. Normally, the transformer has a radiator installed outside the tank. However, the transformer core and the windings are immersed in the oil inside the tank. As the oil heats up owing to rising temperature, it moves upwards thus dissipating the heat through the convection process. Water is then pumped through which cools the oil.

5. **Oil Forced Water Forced (OFWF):** In this method, both oil and water are passed through a heat exchanger with the assistance of pumps. The transformer core and windings are immersed in the oil inside the tank. The temperature of the oil rises as it absorbs the heat from the core and windings. The hot oil is circulated between the tank and the heat exchanger by means of a pump. Water is also pumped through the heat exchanger which cools the hot oil that comes into contact with it. The level and pressure of the oil are always kept higher than that of water so that if any leakage occurs in the system the oil mixes with the water, but water does not get mixed up with the oil. A typical OFWF method is shown in Figure 2.9. This method is applied on transformers of several hundreds of MVA. It can also be employed where banks of transformers are installed.

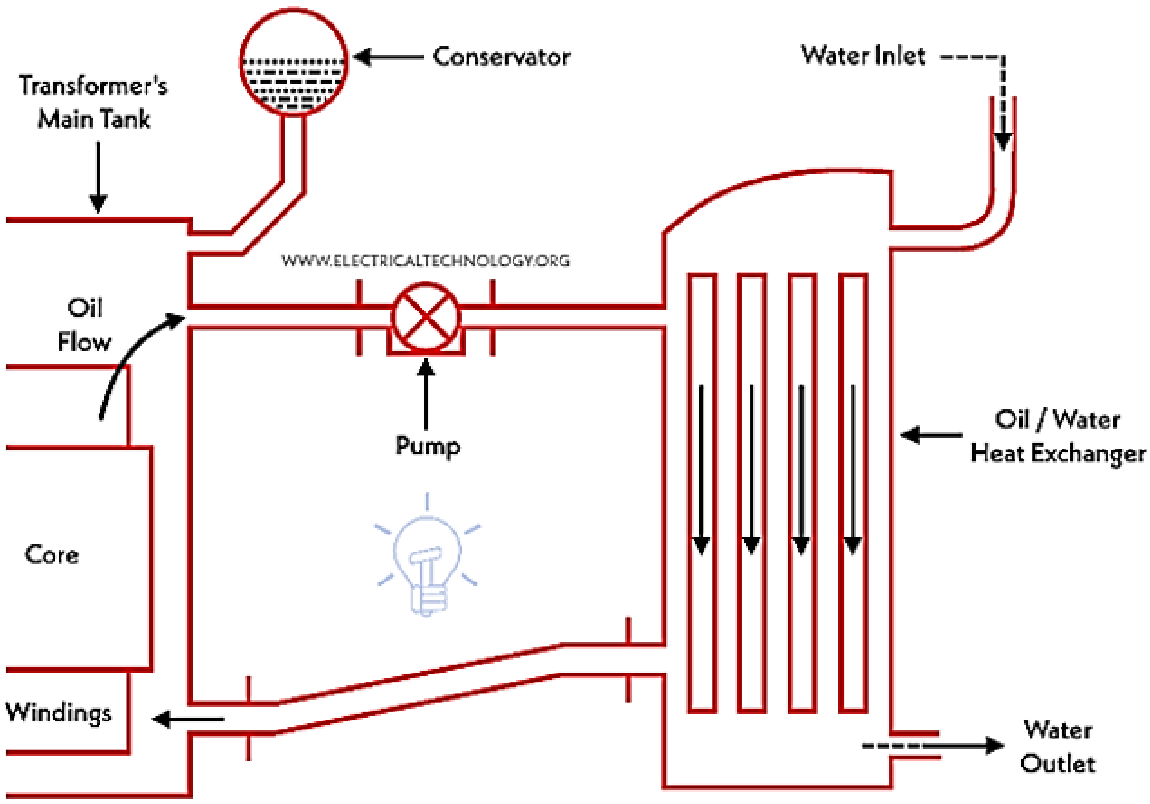

Figure 2.9: *Oil Forced Water Forced Cooling of Transformer*

FOCAL AREA 2: VOLTAGE REGULATION IN TRANSFORMERS

Voltage regulation in a transformer

Every transformer has its secondary voltage of E_2. This voltage varies as current is drawn from the transformer. It should be noted that the current drawn from the transformer, varies as the load varies. Therefore, the voltage at the secondary also varies as load conditions change. The voltage regulation in a transformer therefore refers to the ratio of the change in terminal voltage of the secondary between no-load and full-load to the no-load secondary voltage. It is the difference between the no-load output voltage and the full-load output voltage, divided by the no-load secondary voltage and expressed in *per unit*. If the no-load secondary voltage is E2 and the full-load secondary voltage is V2, then the voltage regulation of the transformer will be;

$$\text{Voltage regulation} = \frac{E_2 - V_2}{E_2} \text{ per unit}$$

Example 1:

The no-load secondary voltage of a transformer is 380V. When the transformer was operating at full-load, the terminal voltage was found to be 368V. What is the voltage regulation of the transformer?

Solution:

E_2=380V and V_2=368V.

$$\text{Voltage regulation} = \frac{380 - 368}{380} = \underline{0.0316} \text{ per unit}$$

Voltage regulation can also be expressed in percentage by multiplying equation 2.4 by 100%. In example 1, therefore, the voltage regulation can be written as 3.16%

Learning Tasks

1. Illustrate two methods of cooling dry-type transformers and recommend one of them for transformers up to 15MVA capacity.
2. Explain voltage regulation as it applies to transformers.
3. Discuss three methods of cooling oil-filled transformers

Pedagogical Exemplars

Teachers should consider the following activities:

Talk for learning approaches: Guide learners through a discussion to brainstorm on voltage regulation as well as various methods of cooling transformers, making sure that all learners take part in the discussion, Teachers should ask leading questions to streamline the discussion for the responses to be clear.

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with methods of cooling dry-type transformers and oil-filled transformers after watching a video provided by the teacher on the various methods. Summarise and enumerate the various methods on the board.

Key Assessment Level 3: Group Discussion

1. A 500 KVA transformer is to be installed in a confined space with limited ventilation. The operating temperature is expected to exceed normal limits. Compare the effectiveness of ONAN (Oil Natural Air Natural) and ONAF (Oil Natural Air Forced) cooling methods for this application.
2. A 20:1 step-down transformer supplies power to a facility with varying load conditions. The primary voltage is maintained at 240 Vrms. If the no-load secondary voltage is 12Vrms and the full-load secondary voltage drops to 11.4 Vrms determine the voltage regulation of the transformer.

PLC Session 7

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

   a. The key assessment for the week is ***group discussion***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the discussion (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

   b. all teachers in the group work through a similar problem individually for 3–4 minutes

   c. the group then works through the problem together step by step

   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 7 Review

This unit introduced learners to various methods of cooling transformers as well as voltage regulation in transformers. The pedagogical exemplars used in this unit includes Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learner's skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 3.

UNIT 8

Section 3: Common Faults with Home Appliances

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This section looks at common faults with home appliances as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the classification of electrical appliances into resistive loads and inductive loads and troubleshooting and repairing of common faults in home appliances.

The unit covers only week 8: ***Identify and troubleshoot common faults in electrical home appliances.***

Recap week

Year 2	**Weeks 13-15:** Passive Components (Resistors, capacitors and Inductors).

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be achieved learners are to be actively engaged in practical demonstrations on troubleshooting of common faults and repair of home appliances through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section require learners' ability to demonstrate the understanding relating to real life situations hence the assessment should cover all the levels. Teachers should employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teachers can consult the Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	Assessment Strategy
Classify home appliances under resistive and inductive loads and outline faults associated with them.	4 (Extended critical thinking and reasoning)	Group Discussion.

WEEK 8

Learning Indicator: *Classify home appliances under resistive and inductive loads and outline faults associated with them*

FOCAL AREA: CLASSIFICATION OF ELELCTRICAL APPLIANCES AND COMMON FAULTS ASSOCIATED WITH THEM

An Electrical Appliance is a device or item of equipment that uses electricity to perform a specific function e.g., a refrigerator, ceiling fan, an air conditioner etc. A load could be a device or circuit that consumes electrical power. All electrical appliances are loads but not all loads are technically electrical appliances. Loads can be broadly categorised as follows:

1. Resistive Loads
2. Inductive Loads

Figure 2.10: *shows a picture of a pressing Iron (An example of a resistive load).*

Figure 2.10: *Pressing Iron*

Figure 2.11: *Water Heater (An example of a resistive load)*

1. **Resistive load:** A type of load which consumes only active power is called a resistive load. If you look at the voltage and current waveforms of this type of load, the voltage and current are perfectly in phase with each other. Figure 2.12 shows a diagram of a Resistive load.

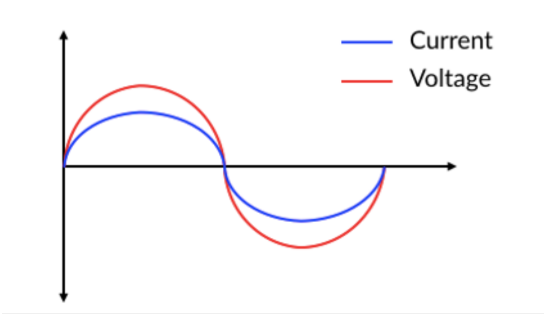

Figure 2.12: *Resistive load*

This means both the waveforms reach their peak value at the same time. They also reach their zero value at the same time. As this type of load only consumes active power, the power flows from the source to the load only. There will be no power flowing from load to source. In some cases, power can also flow from load to source.

Example of resistive load are:

- **a.** Pressing Iron
- **b.** Water Heater
- **c.** Kettle
- **d.** Electric stoves

Properties of Resistive Load:

- **a.** These loads consume only active power
- **b.** Voltage and current waveforms of such loads are perfectly in phase with each other.
- **c.** Power factor of such a load is unity
- **d.** Power always flows from the source to the load.

2. **Inductive Load:** A load which consumes only reactive power is called an inductive load. The voltage and current waveforms of this type of load, are out of phase with each other by 90 deg.

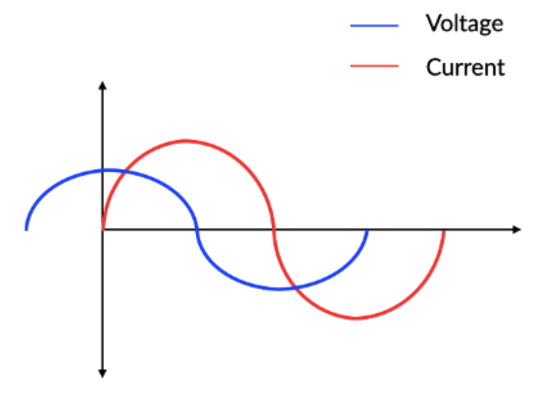

Figure 2.13: *Resistive load*

This means both the waveforms reach their peak value at different times. They also reach the zero value at different times. When looking at the waveform it's noticeable that voltage has a head start and then the current. We can also say current is lagging behind the voltage. Examples of inductive load:

a. Electric Motor

a. Fan

b. Washing machine

c. Drill machine

d. Blender

Figure 2.14 shows a picture of a Blender and a washing machine (Examples of an Inductive load).

Figure 2.14: *Blender*

Figure 2.15 *Washing Machine*

Properties of Inductive loads:

a. This load consumes only reactive power

b. Voltage and current waveform of such loads are out of phase with each other by 90 deg.

c. Power factor of such load is lagging

d. Power flows from source to load and load to source.

Faults associated with Electrical Appliances

An electrical fault is a condition which can cause equipment failures (in transformers, transmission lines, alternators, busbars, etc.) and disturbs the normal working of the system. The faults can also lead to the death of humans, birds, and animals along with equipment failure and electric power supply interruption.

Classification of faults: The faults can be classified as:

1. **Open Circuit faults:** The open-circuit faults are caused when there is a break in the conducting path. Due to this the path of current flow in the phases gets interrupted, making the current equal to zero. These faults are also known as **series faults.**

   Causes

   a. joint failures of cable and overhead lines

   b. failure of one or more phase of circuit breaker

   c. melting of a fuse in one or more phases

2. **Short-Circuit Faults:** The short circuit fault results in an abnormal connection of very low impedance between two points of different potential, whether made accidentally or intentionally. These faults are also known as **shunt faults**, heavy current flow in the case of short-circuit faults.

   Causes

   a. insulator puncture due to lightning or switching surges
   b. accumulation of dirt or dust or foreign particles on the surface of insulators which result in flashover
   c. broken conductor falls to the ground
   d. short circuit of phases.

Note**:** There are other types of electrical faults apart from the two main types listed above such as the ground fault.

Effects of faults

1. **Effects of open-circuit faults:** The effect of open circuit faults can lead to the reduction of actual loading of the alternator. This will cause acceleration of the alternator and hence it runs slightly greater than synchronous speed. This over speed can cause over frequency.
2. **Effects of short-circuit faults**

   a. The equipment can be damaged due to overheating caused by heavy current associated with short-circuits faults.
   b. There may be fire hazards caused by arcing in the faulty element. There is a chance of spreading of the fire to other parts of the system.
   c. There may be a reduction in the supply voltage of healthy feeders.

Learning Tasks

1. Differentiate between Resistive loads and Inductive loads.
2. Analyse the effects of faults on electrical appliances.

Pedagogical Exemplars

Teachers should consider the following activities:

Talk for learning approaches: Guide learners through discussion to brainstorm the concepts of Resistive and Inductive loads, classification of electrical appliances as resistive and inductive loads, making sure that all learners take part in the discussion. Teachers should ask leading questions to streamline the discussion for the concepts to come out clear.

Group work/Collaborative learning: Place learners into mixed-ability groups and ask each group to come up with the types of electrical faults and analyse the effects of these faults on electrical appliances after watching a video provided by the teacher. Summarise everything on the board.

Key Assessment Level 4: Group Discussion

1. A household reports that whenever their air conditioner turns on, the lights in the same circuit dim momentarily. However, when electric heaters are used, this dimming does not occur despite drawing similar current. Explain the electromagnetic principles causing this phenomenon.
2. Apply the concept of resistive and inductive loads to classify the following items and indicate the common faults that may occur in them: Blender, electric cooker, standing fan, water heater, electric iron, washing machine, refrigerator, air conditioner, hair dryer

PLC Session 8

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   - **a.** explain the week's concepts in a practical way that will make it easier for learners to understand
   - **b.** identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   - **a.** suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   - **b.** suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   - **c.** review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   - **a.** The key assessment for the week is ***group discussion***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the discussion (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 8 Review

This unit introduced learners to the concept Classification of Electrical appliances and common faults associated with them. The pedagogical exemplars used in this unit includes Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to instil in learner's skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 1,2 and 3.

Resources: Pictures, Videos, real objects (DC motors)

MARKING SCHEMES FOR THE KEY ASSESSMENTS

UNIT 5

Question 1 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Centre Tap Analysis	Provides comprehensive technical analysis including load balancing considerations and electromagnetic effects	Analyses centre tap implementation with reference to turns ratio and magnetic coupling	Explains how centre tap provides 12V output with basic principles	Describes basic concept of centre tap
Separate Winding Analysis	Provides detailed technical analysis with consideration of magnetic circuit design and coupling coefficients	Analyses separate winding approach with reference to flux linkage and core utilisation	Explains how separate winding operates using transformer principles	Describes basic concept of additional secondary winding
Efficiency Comparison	Provides detailed comparative analysis with quantitative reasoning about relative efficiency impacts	Analyses efficiency factors including copper losses, core losses, and flux leakage for both approaches	Explains basic efficiency implications of both approaches	States which approach might affect efficiency
Construction Complexity	Provides expert-level analysis of manufacturing processes, materials, and technical constraints	Analysesspecific construction challenges and considerations for both modifications	Describes construction requirements for both approaches	States which approach seems more complex

Voltage Regulation	Provides comprehensive analysis of regulation characteristics with load interactions and mutual inductance effects	Analyses regulation factors including leakage reactance and resistance effects	Explains how each modification affects voltage drop under load	States basic effects on voltage regulation
Cost Implications	Provides detailed cost-benefit analysis with consideration of both immediate and long-term economic factors	Analysesspecific cost elements including materials, labour, and design	Describes basic cost factors for both approaches	Mentions cost differences without detail

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Core Material and Lamination Thickness	Provides comprehensive analysis of how core material properties (permeability, saturation) affect heating; explains eddy current formation in detail with mathematical relationships; clearly links lamination thickness to eddy current losses; suggests precise testing methods with expected measurements.	Correctly explains how core material affects heating with specific examples; describes eddy current formation and its relationship to lamination thickness; provides logical verification methods.	Basic explanation of core material impact on heating; mentions eddy currents but with limited detail; suggests general verification approach without specifics.	Minimal explanation of core materials; limited understanding of eddy currents and verification methods.
Primary and Secondary Winding Insulation	Detailed analysis of insulation materials and their thermal properties; explains relationship between insulation degradation and heat generation; discusses impact of voltage stress and thermal cycling; provides specific tests (resistance, polarisation index) to verify issues.	Good explanation of insulation properties and their role in heat dissipation; describes how insulation breakdown leads to heating; suggests appropriate verification tests.	Basic understanding of insulation's role in heating; mentions some mechanisms superficially with some verification methods suggested.	Minimal understanding of insulation's role simple descriptions of mechanisms and limited verification methods.

Transformer Oil or Cooling Medium	Comprehensive analysis of cooling medium properties and circulation patterns; detailed explanation of how viscosity, contamination, and level affect cooling efficiency; links specific cooling failures to overheating symptoms; suggests detailed oil testing protocol (dielectric strength, moisture content, acidity).	Clear explanation of cooling medium's role with specific properties mentioned; good description of how cooling medium problems cause overheating; suggests appropriate verification tests.	Basic description of cooling medium's purpose; mentions some problems that could occur; suggests general verification approaches.	Limited understanding of cooling medium's function; simple explanation of relationship to overheating and verification methods.
Technical Accuracy and Depth	Analysis demonstrates exceptional understanding of transformer principles; all explanations align with electromagnetic and thermal theory; mechanisms are explained at both macro and micro levels; verification methods are of industry-standard and practical.	Analysis shows strong understanding of transformer operation; explanations are technically sound with; mechanisms are well-explained and verification methods are appropriate.	Analysis shows adequate understanding of basic principles; some technical information present and core concepts are correct; verification methods are generally appropriate.	Analysis contains limited understanding of transformer principles; simple verification methods are present

UNIT 6

Question 1 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Core Losses (Hysteresis and Eddy Current)	Comprehensive analysis of both hysteresis and eddy current losses with precise explanations of their physical mechanisms. explains how manufacturing environments with harmonic-rich loads amplify these losses accurately calculates magnitude of losses using appropriate formulas, connects core material properties directly to loss characteristics provides detailed mitigation strategies specific to 50 KVA transformers.	Clear distinction between hysteresis and eddy current losses with good explanation of both mechanisms; relates these to manufacturing environment conditions; explains how harmonics contribute to increased core losses; suggests appropriate mitigation strategies.	Basic explanation of core losses with some distinction between types; mentions relationship to heating; suggests general solutions few plant-specific considerations.	Minimal explanation of core losses; simple attempt to distinguish between hysteresis and eddy current losses; limited connection to transformer heating; simple solutions proposed.
Copper/Winding Losses (I^2R Losses)	Detailed analysis of I^2R losses with mathematical explanation; connects load profiles in manufacturing settings to winding temperature rise; explains skin effect at higher frequencies; discusses unbalanced loading effects on neutral conductors; provides quantitative analysis of how overloading affects losses exponentially; suggests monitoring and mitigation strategies specific to plant operation cycles.	Good explanation of how current flow creates heat in windings; relates manufacturing load characteristics to increased losses; explains impact of overloading and unbalanced loads; provides logical mitigation approaches.	Basic understanding of winding losses; mentions relationship between current and heat generation, provides some connection to manufacturing context and offers general mitigation suggestions.	Limited understanding of winding losses and I^2R relationship; minimal connection to manufacturing context; simple solutions proposed.

Dielectric and Stray Losses	Comprehensive explanation of dielectric losses in insulation materials with aging factors; includes detailed analysis of stray flux patterns and resulting losses in transformer tank and structural components; explains how these connect to manufacturing environment conditions (vibration, electromagnetic interference); details frequency dependency of these losses provides specific testing methods to identify these losses.	Clear explanation of both dielectric and stray losses; good understanding of how these contribute to overall heating; relates to a manufacturing environment; suggests appropriate detection methods.	Basic description of dielectric and/or stray losses; mentions their contribution to heating with limited detail; suggests general verification approaches.	Minimal explanation of these loss types and how they contribute to heating; simple testing or verification methods given.
Cooling System Analysis	Detailed analysis of cooling system types applicable to 50 KVA transformers including a comprehensive explanation of how manufacturing environments impact cooling efficiency (dust, ambient temperature, airflow restrictions); quantifies thermal resistance concepts through an explanation of ONAN and ONAF cooling approaches; provides detailed maintenance protocol with specific intervals and procedures.	Good explanation of cooling system functions; clear description of how cooling inadequacies lead to overheating by considering manufacturing environmental factors; suggests appropriate maintenance and improvement approaches.	Basic understanding of cooling system role; mentions some factors affecting cooling efficiency; suggests general maintenance practices.	Limited understanding of cooling systems with minimal connections given to cooling inadequacies and overheating; simple maintenance routine attempted. .

Technical Accuracy and Solutions	Exceptional understanding of transformer loss mechanisms with precise technical language; correctly prioritises likely causes based on manufacturing context; proposes comprehensive monitoring system (temperature, load, harmonics); provides cost-effective, practical solutions with implementation timeline; includes load management strategies specific to manufacturing processes.	Strong technical understanding with minor gaps; good prioritisation of likely causes; proposes suitable monitoring and solutions with consideration of manufacturing constraints.	Adequate technical understanding of basic concepts; reasonable identification of possible causes; proposes workable solutions with limited manufacturing context consideration.	Limited technical understanding; provides simple solutions

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Types and Mechanisms of Transformer Losses	Comprehensive identification and explanation of all transformer losses (core losses - hysteresis and eddy current, copper/winding losses, stray losses, dielectric losses) with an accurate illustration of the physical mechanisms behind each loss type; precise technical terminology uses clearly distinguishes between load-dependent and load-independent losses; provides examples of how specific transformer designs experience different loss profiles.	Correctly identifies and explains major transformer losses with good technical accuracy; distinguishes between core and copper losses with a clear explanation of their mechanisms; recognises load-dependent vs. load-independent losses; provides some examples.	Basic identification of main transformer losses (core and copper); provides a simple explanation of how each occurs; a limited distinction between load-dependent and load-independent losses is given.	Simple identification of transformer losses; limited explanation about loss mechanisms;

Relationship Between Losses and Efficiency	Sophisticated analysis of how each loss type directly impacts efficiency with precise cause-effect relationships explains how losses vary under different loading conditions (no-load, partial load, full load, overload); provides insightful explanation of how transformer rating and design affect the loss-efficiency relationship; discusses temperature effects on losses and subsequent efficiency impacts.	Clear analysis of how major losses affect efficiency explaining efficiency variations under different loading conditions; recognises design factors that influence the loss-efficiency relationship; mentions temperature effects.	Basic explanation of how losses reduce efficiency; recognises that efficiency varies with load; mentions some design factors that affect losses; limited discussion of other influencing factors.	Simple explanation of how losses relate to efficiency; minimal understanding of load-dependent efficiency and important design factors
Mathematical Analysis and Calculations	Provides comprehensive mathematical framework for efficiency calculation (η = Pout/Pin = Pout/(Pout+Plosses) ; accurately expresses individual loss components in formulas demonstrates how to calculate efficiency at different loads with worked examples; includes correct analysis of all-day efficiency for varying load profiles; includes transformer equivalent circuit analysis.	Correctly provides efficiency formula with clear explanation showing how different losses contribute to the formula; includes basic calculations showing efficiency at different loads; recognises the concept of all-day efficiency.	Presents basic efficiency formula that shows simple calculation of efficiency; limited mathematical analysis of how different losses affect the calculation; minimal worked examples given.	Minimal number of efficiency formulas presented with few worked examples provided

Critical Evaluation of Efficiency Improvement Methods	Comprehensive critical evaluation of multiple methods to improve efficiency by addressing specific losses; detailed analysis of core material selection (silicon steel, amorphous materials) along with quantified an in-depth discussion of conductor sizing and materials; sophisticated analysis of cooling methods including economic evaluation of efficiency improvements vs. Cost and clear links to details of emerging technologies and materials.	Good evaluation of several methods to improve efficiency; explains how specific design choices address different losses; discusses material selection and design considerations with clear reasoning; includes some economic considerations.	Basic description of common methods to improve efficiency; mentions material selection and design factors; limited critical analysis of effectiveness; minimal economic considerations included.	Limited description of efficiency improvement methods; little connection to specific loss types; some economic links attempted.

UNIT 7

Question 1 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Understanding of ONAN and ONAF Cooling Methods	Comprehensive explanation of both cooling methods with precise technical details; accurately describes the physical principles of heat transfer (conduction, convection, radiation) in each method; explains detailed construction features including radiator design, oil flow patterns, and air circulation paths; correctly identifies the cooling class designations and their meanings per IEC/IEEE standards.	Clear explanation of both cooling methods with good technical detail; correctly describes the main heat transfer mechanisms; explains key construction features for both methods good understanding of cooling class designations.	Basic explanation of both cooling methods with minimal technical errors; describes general heat transfer concepts; mentions basic construction elements; shows some understanding of cooling classifications.	Simple explanation of cooling methods with some information about heat transfer principles; limited information given around construction features and cooling classifications.

Comparative Analysis of ONAN vs ONAF	Sophisticated point-by-point comparison with quantitative analysis of cooling capacity differences (typically 25-30% improvement with ONAF); includes a comprehensive comparison of heat dissipation rates, temperature gradients, and cooling efficiency; detailed analysis of fan system requirements including power consumption, control systems, and reliability factors; thorough examination of cost implications for both initial and operating expenses.	Effective comparison highlighting key differences in cooling capacity; provides good analysis of heat dissipation capabilities; explains fan system requirements and basic control mechanisms; addresses cost differences between systems.	Basic comparison identifying main differences; mentions increased cooling capacity of ONAF; basic description of fan requirements; mentions cost differences with minimal analysis.	Minimal comparison between types that shows few key differences and little mention of fan systems or costs.
Analysis for Confined Space Application	Exceptional analysis of how confined space affects cooling performance for both methods; details how limited ventilation creates specific challenges for each cooling type specifically for 500 KVA; includes a sophisticated thermal analysis considering ambient temperature rise in confined spaces; considers maintenance accessibility in confined installation.	Good analysis of confined space implications for both cooling methods; explains how limited ventilation affects performance; includes heat buildup concerns; relates to 500 KVA capacity to cooling needs; covers maintenance considerations.	Basic analysis of confined space considerations recognises that limited ventilation poses challenges; mentions that higher capacity transformers generate more heat; limited discussion of maintenance aspects.	Limited analysis of confined space factors with few links to address ventilation limitations; minimal consideration of transformer capacity

Technical Accuracy and Depth	Exceptional technical accuracy throughout; uses precise engineering terminology; demonstrates deep understanding of thermodynamics principles; includes specific temperature rise calculations; references to appropriate standards (IEC 60076-2, IEEE C57.12.00); includes thermal modelling concepts and hotspot temperature monitoring.	High ; uses appropriate terminology; demonstrates solid understanding of thermal principles; mentions of temperature rise considerations; references to relevant standards and temperature monitoring.	Generally accurate and uses basic terminology correctly; shows fundamental understanding of thermal concepts; mentions temperature concerns with limited analysis; some reference to standards.	Limited understanding of technical aspects; some use of terminology and reference to standards
Recommendations and Practical Solutions	Comprehensive, well-justified recommendation with a sophisticated decision matrix; proposes innovative solutions to overcome space constraints (e.g., directional airflow design, temperature monitoring systems); includes detailed implementation considerations; discusses hybrid or modified cooling approaches; addresses contingency planning; considers future load growth implications.	Clear recommendation with good justification; proposes viable solutions for the space constraints; includes implementation considerations; suggests monitoring approaches and considers some alternative options.	Basic recommendation with simple justification; mentions some solutions for space constraints, includes limited implementation details and basic consideration of alternatives.	Limited recommendations using minimal details and some solutions or alternatives provided.

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Conceptual Understanding	Demonstrates comprehensive understanding of voltage regulation as a transformer performance metric; precisely explains why voltage drops under load conditions; thoroughly explains the relationship between transformer impedance and voltage regulation; connects voltage regulation to power quality and equipment performance; identifies factors that influence regulation in real-world applications.	Shows clear understanding of voltage regulation concept; correctly explains the relationship between no-load and full-load voltages; recognises the factors that cause secondary voltage to drop under load; makes good connections to transformer performance.	Basic understanding of voltage regulation concept; recognises that it involves comparing no-load and full-load voltages; limited explanation of why voltage drops under load; minimal connection to transformer performance.	Limited understanding of voltage regulation; with minimal connection to transformer performance.
Formula and Approach	Correctly identifies and clearly presents the voltage regulation formula with proper notation-VR% = ((VNL-VFL)/VFL) × 100%-; explains the rationale behind using full-load voltage as the denominator; demonstrates understanding of alternative formulations and when they might be used; shows awareness of how the formula relates to transformer equivalent circuit.	Correctly identifies the voltage regulation formula; presents it with proper notation; understands why this formula is used; applies it appropriately to the problem; shows good understanding of the mathematical relationship.	Identifies the basic voltage regulation formula with some notation and explanation; generally applies it correctly; some limited explanation of why this formula is used.	Limited inclusion of details around formulas; simple calculation of voltage regulation; some details covering mathematical relationships.

Calculation Process	Executes calculations with perfect accuracy and clear systematic approach; clearly substitutes values VR% = ((12-11.4)/11.4) × 100% = 5.26%; includes appropriate units throughout, shows all steps with logical progression; verifies result through alternative method or estimation; presents final answer with appropriate precision (two decimal places).	Executes calculations with accuracy and a clear approach; correctly substitutes values; includes units and shows key steps in calculation to present final answer with appropriate precision.	Completes basic calculation showing main calculation steps; reaches approximately correct answer with some accuracy. .	Limited calculation details throughout process; some details covering mathematical relationships
Interpretation of Results	Provides comprehensive interpretation of the 5.26% voltage regulation value; evaluates whether this is acceptable for typical applications; compares with industry standards for different load types; discusses implications for equipment operation; explains how voltage regulation relates to transformer efficiency and loading; connects to power quality considerations.	Provides good interpretation of the calculated value; discusses whether the result is acceptable; relates to typical transformer performance, mentions implications for equipment operation; shows understanding of practical significance.	Basic interpretation of calculated value; limited discussion of whether result is acceptable; minimal connection to practical applications; shows some understanding of significance.	. Limited understanding of voltage regulation; minimal attempts to discuss results and practical applications.
Relationship to Transformer Parameters	Demonstrates sophisticated understanding of how transformer parameters affect voltage regulation; explains the roles of winding resistance, leakage reactance, and core losses, discusses how the 20:1 turns ratio influences regulation; analyses how varying load conditions (resistive, inductive, capacitive) would affect regulation; explains how to improve voltage regulation through design modifications.	Shows good understanding of how transformer parameters affect voltage regulation; mentions the influence of winding resistance and leakage reactance; relates turns ratio to voltage transformation; discusses basic load effects; mentions methods to improve regulation.	Shows basic understanding of some factors affecting voltage regulation; mentions resistance or reactance, recognises that load type affects regulation; limited discussion of improvement methods.	Minimal understanding of factors affecting voltage regulation limited knowledge of links of transformer parameters to regulation, load effects or improvement methods.

UNIT 8

Question 1 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Load Classification and Characteristics	Comprehensive analysis correctly identifying air conditioners as inductive loads (motor-driven) and heaters as resistive loads; precisely explains their different electromagnetic properties; provides detailed explanation of power factor concepts (air conditioner with lagging power factor vs. heater with unity power factor); explains how these properties fundamentally affect circuit behaviour; includes accurate technical parameters (typical power factors, circuit models).	Clear distinction between inductive and resistive loads with good technical explanation; correctly identifies air conditioner motors as inductive and heaters as resistive; explains power factor differences; discusses how these different characteristics affect circuit operation.	Basic identification of air conditioners as motor loads and heaters as resistive loads; mentions that motors have different electrical characteristics; limited explanation of power factor; basic connection to the observed phenomenon.	I Minimal distinction between load types; minimal understanding of inductive vs. resistive characteristics ; little connection to the observed phenomenon.
Inrush Current Analysis	Sophisticated explanation of inrush/starting current in AC motors (5-7 times running current); explains the electromagnetic principles causing high starting current (locked rotor condition, low initial back-EMF); relates inrush current directly to voltage drop using circuit analysis principles; explains time-dependent nature of the phenomenon; discusses how motor design affects inrush characteristics; may include mathematical relationships (V=IR for circuit, L*di/dt for inductors).	Clear explanation of inrush current phenomenon in motors; correctly identifies that motors draw significantly higher current when starting; explains basic electromagnetic principles involved; makes clear connection to momentary voltage drop; quantifies approximate inrush current magnitude.	Basic recognition that motors draw higher current when starting; mentions this causes voltage drop; limited explanation of electromagnetic principles; makes simple connection to the dimming lights; minimal quantification.	Minimal explanation of motor starting current; limited recognition of inrush current as the primary cause; limited understanding about electromagnetic principles; simple connection to light dimming.

Circuit Analysis	Comprehensive circuit analysis applying Ohm's law and Kirchhoff's laws to explain voltage drop; precisely explains how shared impedance in home wiring creates voltage drop affecting lights; calculates or estimates percentage voltage drop during motor start-up; explains how circuit impedance interacts with different load types; discusses how wiring gauge, circuit length, and connection quality affect the phenomenon; may include equivalent circuit diagrams.	Good circuit analysis explaining voltage drop principles; correctly applies Ohm's law to explain shared circuit effects; explains how momentary high current creates voltage drop affecting lights; discusses circuit impedance considerations; makes clear connections between theory and observed effects.	Basic application of voltage drop concepts; mentions that high current causes voltage reduction in the circuit; simple explanation of why lights dim; limited discussion of circuit impedance or wiring factors; basic connection between theory and observation.	Limited application of electrical theory and circuit principles; simple explanation of voltage drop ; ; minimal connection between circuit behaviour and observed dimming.
Comparative Analysis	Sophisticated comparison of air conditioner vs. heater behaviour with precise technical explanation; explains how resistive loads draw consistent current from startup while inductive loads have distinctive starting characteristics; analyses how reactive power affects circuit differently than real power; explains why similar steady-state current ratings still produce different startup behaviours; discusses implications for circuit design and load management.	Effective comparison of air conditioner and heater electrical behaviour; correctly explains why similar rated devices affect circuits differently; discusses inductive vs. resistive start-up characteristics; makes clear connections to observed household phenomenon; provides good technical explanation.	Basic comparison of the two appliances; recognises that motors start differently than resistive loads; mentions that current draw patterns differ despite similar ratings; limited technical explanation of differences; simple connection to observation.	Minimal comparison between appliances; limited explanation why similarly rated devices behave differently; ; little connection to the observed phenomenon and load characteristics.

Solutions and Applications	Comprehensive discussion of multiple practical solutions with technical justification (dedicated circuits, soft starters, larger gauge wiring, power factor correction); explains how each solution addresses specific electromagnetic principles; analyses cost-benefit considerations; discusses relevant electrical codes; explains how solution principles apply to other situations; may include specific component recommendations with technical specifications.	Clear discussion of practical solutions with good technical basis; suggests appropriate modifications to reduce dimming effect; explains how solutions address the electromagnetic principles involved; makes good connections between theory and practical application.	Basic suggestions for addressing the problem; mentions some solutions like separate circuits; limited explanation of how solutions relate to the electromagnetic principles; minimal discussion of broader applications.	Few or impractical solutions offered; solutions not clearly connected to the electromagnetic principles involved; limited knowledge about appropriate remedies; minimal practical application.

Question 2 (20 marks)

Criteria	Excellent (4 marks)	Very good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1mark)
Load Classification Accuracy	Precisely classifies all 9 appliances with perfect accuracy: Resistive loads (electric cooker, water heater, electric iron, hair dryer) and Inductive loads (blender, standing fan, washing machine, refrigerator, air conditioner); recognises and explains dual-nature appliances (e.g., washing machines have both heating elements and motors); provides technical justification for each classification based on electrical principles.	Correctly classifies 7-8 appliances; recognises most dual-nature appliances; provides good justification for classifications with minor technical gaps; demonstrates clear understanding of the difference between load types.	Correctly classifies 5-6 appliances; basic recognition of some dual-nature appliances; provides simple justification for classifications; shows adequate understanding of load types with some misconceptions.	Correctly classifies fewer than 5 appliances; little recognition of dual-nature appliances; provides limited justifications; little knowledge about load types.

Load Characteristics Analysis	Comprehensive explanation of load characteristics with precise technical details: explains how resistive loads convert electrical energy directly to heat with unity power factor; details how inductive loads create magnetic fields with lagging power factor; explains starting vs. running current differences; discusses power consumption patterns; analyses harmonic generation; includes typical values (power factors, starting currents) for specific appliances.	Clear explanation of key load characteristics: distinguishes between resistive and inductive energy conversion; explains power factor differences; mentions starting current for motors; discusses general operational characteristics with good technical accuracy.	Basic explanation of main characteristics: mentions that resistive loads produce heat while inductive loads use motors; limited discussion of power factor; simple explanation of operational differences; some technical accuracy provided.	Minimal explanation of load characteristics; limited ability to distinguish fundamental differences between load types; little knowledge about electrical principles; simple technical accuracy.
Fault Identification - Resistive Appliances	Comprehensive identification of specific faults for each resistive appliance with technical detail: electric cooker (element burnout, thermostat failure, insulation breakdown, switch failure); water heater (element scaling, thermostat failure, pressure relief valve issues, anode rod corrosion); electric iron (element burnout, thermostat sticking, cord damage, auto-shutoff failure); hair dryer (element burnout, thermal cutout failure, switch failure, fan motor issues); includes causes and symptoms for each fault.	Identifies multiple specific faults for each resistive appliance with good detail; covers major common issues for each appliance; provides some information about causes or symptoms; demonstrates good understanding of failure mechanisms.	Identifies basic common faults for resistive appliances but with limited specificity to each appliance; mentions general issues like "element failure" without detailed differentiation; limited discussion of causes or symptoms.	Identifies few faults for resistive appliances; limited appliance-specific detail; little understanding of failure mechanisms; limited knowledge in fault identification.

Fault Identification – Inductive Appliances	Comprehensive identification of specific faults for each inductive appliance with technical detail: blender (motor bearing failure, coupling breakage, winding burnout, speed control failure); standing fan (motor winding failure, oscillation mechanism breakdown, capacitor failure, bearing wear); washing machine (motor carbon brush wear, door lock failure, belt breakage, transmission issues); refrigerator (compressor relay failure, refrigerant leakage, thermostat failure, defrost timer malfunction); air conditioner (compressor failure, refrigerant leakage, fan motor issues, control board failure); includes causes, symptoms and typical lifespan considerations.	Identifies multiple specific faults for each inductive appliance with good detail; covers major common issues for each appliance; provides some information about causes or symptoms; demonstrates good understanding of electromechanical failure mechanisms.	Identifies basic common faults for inductive appliances but with limited specificity to each appliance; mentions general issues like "motor failure" without detailed differentiation; limited discussion of causes or symptoms.	Identifies few faults for inductive appliances; limited appliance-specific detail; little understanding of failure mechanisms; limited knowledge in fault identification.
Technical Explanation and Diagnostics	Sophisticated explanation of the relationship between load type and typical failure modes; explains why inductive loads experience specific failures (high starting current stressing components, mechanical wear); details why resistive loads fail in characteristic ways (thermal cycling, oxidation); provides comprehensive diagnostic approaches for each appliance type with specific test procedures; includes safety considerations during diagnostics; references ohmmeter, continuity, and insulation resistance testing methods.	Good explanation of relationship between load type and failure patterns; explains some key failure mechanisms related to load characteristics; provides solid diagnostic approaches with some specific procedures; mentions important safety considerations; includes some testing methods.	Basic explanation of some connections between load type and failures; limited explanation of failure mechanisms; provides general diagnostic approaches without specific details; mentions basic safety concerns; limited testing methods.	Simple explanation of relationship between load type and failures; limited understanding about failure mechanisms; little understanding of diagnostic approaches; minimal testing methods included.

SECTION 3: MAINTENANCE, ELECTRICAL MACHINE FAULT AND CIRCUIT, AMPLIFIER, LOGIC GATES

The section covers the following units (strands): Electrical technology and Electronics technology.

In this section, learners will acquire knowledge and understanding of troubleshooting and servicing electrical appliances, detecting faults in electrical machines, operation of Integrated Circuits (Timers), operation of Operational Amplifiers, as well as types of logic gates and determine the output function of the various gates. All the above are covered from unit 9 to unit 13.

UNIT 9

Section 3: Common faults with electrical appliances

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at common faults that occur in electrical appliances as well as electrical wiring circuits as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in identifying, troubleshooting common faults that occur in electrical appliances and wiring circuits and repairing them.

The unit covers only week 9:

1. *Describe the process of trouble shooting and servicing of electrical appliances*
2. *Describe the process of troubleshooting and servicing electrical wiring circuits*

Recap weeks

Year 2:	**Week 22:** Explain the principles of measuring instruments through electromagnetism

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on the various faults in appliances and electrical circuits through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the process of trouble shooting and servicing electrical appliances	Level,4 (Extended Strategic reasoning)	Assessment mode: Group Project
Describe the process of troubleshooting and servicing electrical wiring circuits	Level,4 (Extended Strategic reasoning)	Assessment mode: Group project

WEEK 9

Learning Indicators

1. *Describe the process of trouble shooting and servicing of electrical appliances*
2. *Describe the process of troubleshooting and servicing electrical wiring circuits*

FOCAL AREA 1: TROUBLE SHOOTING AND SERVICING OF ELECTRICAL APPLIANCES

Troubleshooting home appliances

It is not easy to troubleshoot problems with home appliances. However, if we have the right knowledge and resources, we can gain some success. A wiring diagram is a blueprint which can provide very useful information on the components that are in a system, how these components are wired, and how the current flows in the system. We need to always refer to a wiring diagram when troubleshooting any system because the information on a wiring diagram helps us understand the components, wiring, and the flow of current. Consequently, it is not easy to start troubleshooting without a wiring diagram.

Note that every wiring diagram has an input side (line side), control side and load side. It is therefore helpful to break the circuit into these parts during troubleshooting, because each part presents a different problem altogether. The voltage at the line side of the circuit is usually about 240V. That of the control side of the circuit could be lower, depending on the system.

The following are the initial steps to be taken during troubleshooting any appliance:

1. **Check socket outlets for proper functioning**. This can be done by:
   - **a.** Using a voltage tester.
   - **b.** Plugging in another device to see if it is functioning.

If the outlet seems to be the problem, consult an electrician to fix the problem or replace it altogether.

2. **Inspect the Electrical Cord and Plug for Damage.** Note that damaged cords can cause intermittent breaks in power supply of a complete failure of the appliance altogether
   - **a.** Look for signs of damage such as burnt marks and frayed wires
   - **b.** Inspect the plug for blown fuses

If damage is detected in the cord or plug, replace it immediately with one that matches your appliance's specifications. Remember to unplug the appliance before making any repairs and exercise caution while handling electricity.

3. **Consult the User Manual**
   - **a.** Obtain useful guidance by studying the user manual provided with your appliance.
   - **b.** The manual often contains troubleshooting tips specific to your model that can help you diagnose common problems quickly.

   c. It may also provide step-by-step instructions for basic repairs that you can carry out yourself if confident enough.

4. Check for Warranty Coverage

   a. Never attempt any repairs without first checking if your appliance is still covered by warranty.

   b. If covered by warranty, refer the problem to the supplier, or you would bear repair costs that would otherwise have been covered.

Once you are certain that the fault is within the appliance itself, you now have to proceed deeper into it.

Electric Burner Not Working: Possible causes include;

1. damaged heating element,
2. faulty switch,
3. loose wiring.

Solution: Conduct continuity test on each of them to identify the faulty one and replace it.

Electric Iron not heating: Possible causes include;

1. burned out heating element,
2. faulty thermostats or
3. broken wiring connections.

Solution: Conduct continuity test on each of them to identify the faulty one. Then replace it.

Iron too hot or cold

1. Possible cause: thermostat likely has physical damage or disconnected wiring.

Solution: Replace faulty thermostat. Note that thermostat wiring requires professional replacing and calibration to fix inaccurate temperatures.

FOCAL AREA 2: TROUBLE SHOOTING AND SERVICING OF ELECTRICAL WIRING CIRCUITS

Troubleshooting Electrical Circuits

Tools and equipment: Before you can successfully troubleshoot an electrical circuit, make sure you have all appropriate tools and equipment. It is critical to ensure that all the tools and equipment are in good working condition since damaged or faulty tools are dangerous and can cause electrical accidents.

Safety Precautions

Working with electricity can be dangerous, and it is essential to take the necessary precautions to ensure your safety and the safety of others. Some safety measures you should adhere to during troubleshooting electrical circuits are as follows

1. Use personal protective equipment (PPE)

2. Turn off the power
3. Ground the circuit
4. Avoid working alone
5. Keep work areas clean and tidy

Common Electrical Circuit Problems: Some common circuit problems that can arise are as follows:

Table 3.1: *Techniques for troubleshooting electrical wiring*

Problem	Solution
Blown Fuse	Replace the fuse with one that has the same amperage rating.
Tripped Circuit Breaker	Reset the circuit breaker by turning it off and on again.
Faulty Switch	Replace the switch with a new one.
Loose Connection	Tighten the connection or replace the faulty component.
Ground Fault	Identify and repair the damaged insulation or replace the faulty component.

Troubleshooting Circuit Breakers

Circuit breakers are protective devices that protect electrical circuits against overloads and short circuits but these circuit breakers can develop problems thus failing to protect the circuits. Some steps in troubleshooting circuit breakers are as follows:

1. Turn off power to the circuit by switching off the breaker for that circuit. If you are not certain which breaker controls the circuit, turn off the mains switch.
2. Remove the cover of the circuit breaker panel to access the breakers.
3. Inspect the circuit breaker for any signs of damage or burn marks, or if it appears to be tripped. If the breaker is damaged, it will need to be replaced by a qualified electrician.
4. Reset the circuit breaker if it is tripped and if it trips again, it could be due to an overload or a short circuit in the circuit.
5. Test the circuit to check if it is working correctly using a multimeter. Test between live and neutral to see if voltage is the right value.
6. Call an electrician if you are not sure of the problem

Troubleshooting Electrical Wiring

Electrical wiring issues can be frustrating and dangerous. The following are some techniques for troubleshooting electrical wiring

Table 3.2: *Techniques for troubleshooting electrical wiring*

Technique	Description
Visual Inspection	Visually inspect the wiring for signs of damage, such as fraying, corrosion, or loose connections.

Continuity Testing	Test for continuity in the wiring with an ohmmeter, to identify breaks in the circuit.
Voltage Testing	Test for voltage in the wiring with a voltmeter, to determine if there is power and whether the voltage level is appropriate.

The problem may be damaged wiring, loose connections, or one that calls for rewiring to make the circuit safe. So, after identifying it, ensure the necessary steps are taken to fix it.

Maintenance of electrical circuits

Electrical circuits consist of various accessories such as cables, switches, lamp holders and outlets that need to be inspected and maintained regularly to ensure proper functioning. Regular maintenance is therefore very crucial for their reliability and safety. Some essential steps involved in maintaining electrical circuits are as follows:

1. Regular visual inspections of electrical circuits can help identify potential issues. Check for any signs of wear and tear, such as frayed wires or loose connections, which can cause electrical problems.
2. Regular cleaning of accessories and other electrical components can help remove dirt and dust which collect on them and affect their performance.
3. Loose connections can cause malfunctioning of electrical circuits and equipment. Therefore, check and tighten all electrical connections regularly to ensure proper functioning.

It is essential to hire a licensed electrician for any electrical repairs or maintenance work. Additionally, any repairs or maintenance work should be done only with the power off and using proper safety equipment such as gloves and goggles.

Learning Tasks

1. Explain how to troubleshoot an electric iron that is not heating and how to solve the problem
2. Explain how to troubleshoot an electrical circuit with a non-functioning lighting system
3. Outline a maintenance plan for an electrical system to keep it working safely

Pedagogical Exemplars

Teachers should consider the following activities:

Talk for learning approaches: Guide learners through discussion in order to brainstorm on types of appliances and the faults that may develop in them making sure that every learner take part in the discussion, Teachers in the process should be asking leading questions to streamline the discussion for the responses to be clear

Research and Collaboration: Organise the learners into mixed ability and gender inclusive groups and task them to undertake the following practical activities:

a. Identify the type of gadget/circuit to be diagnosed and describe its operation and function e.g., Iron, kettle and blender and final circuits

b. Distinguish between a faulty appliance/circuit and a functioning one teaching learners to be honest and sincere in their diagnosis.

c. Describe how to test each appliance/circuit to diagnose the fault.

d. Explain how to solve the problem identified

Key Assessment Level 4: Group project

1. A customer reports that their electric pressing iron heats excessively and does not regulate temperature properly. Design a comprehensive troubleshooting flowchart that identifies at least four (4) possible causes of this problem.
2. A household experiences frequent tripping of an MCB on a specific circuit. Evaluate all possible causes of this issue and categorise them as either immediate safety hazards or non-critical faults.

PLC Session 9

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

    a. explain the week's concepts in a practical way that will make it easier for learners to understand

    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

    a. The key assessment for the week is ***group project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 9 Review

This unit exposed learners to various methods troubleshooting electrical appliances and electrical circuits. The pedagogical exemplars used in this unit includes Talk for learning approaches and Groupwork/Collaborative learning. These strategies are expected to inculcate in learners skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 3.

UNIT 10

Section 10: Common Faults with Home Appliances

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electrical system design

Content Standard: Apply knowledge and understanding of electrical machines

Learning Outcome: *Demonstrate knowledge and understanding of electrical machines and appliances and apply the knowledge in servicing electrical appliances and circuits.*

INTRODUCTION AND SECTION SUMMARY

This Section looks at common faults with home appliances as they apply to electrical technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in detecting faults in electrical machines and applying maintenance principles to maintain faults in electrical machines.

The unit covers only week 10: ***Detect fault in electrical machines***

Recap week

Year 2	**Weeks 13-15:** PASSIVE COMPONENTS (Resistors, capacitors and Inductors).

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration in detecting faults in electrical machines and applying maintenance principles to maintain faults in electrical machines through a wide range of pedagogical exemplars such as Research and Collaborative learning, Experiential learning, Project – based learning.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy*
Detect fault in electrical machines.	3	*Group Presentation.*

WEEK 10

Learning Indicator: *Detect fault in electrical machines*

FOCAL AREA: FAULT IN ELECTRICAL MACHINES

An **electrical fault** *is a condition which can cause equipment failures (in transformers, transmission lines, alternators, busbars, etc.) and disturbs the normal working of the system.* The faults can also lead to the death of humans, birds, and animals along with equipment failure and electric power supply interruption.

Types of faults in electrical machines

Faults in electrical machines can broadly be categorised into two areas, namely **mechanical faults** and **electrical faults**. The most common faults arise from normal wear and tear, manufacturing defects, environmental factors, and improper operation or maintenance. Identifying and addressing these faults early can significantly improve the lifespan and efficiency of the machine, as well as prevent costly repairs. Mechanical faults are typically caused by the physical wear of moving parts, poor maintenance, or improper installation. The most common mechanical faults, causes and their possible symptoms are as follows;

1. **Bearing Failures**: Bearings are essential components that support the rotating shaft of a motor or machine. Bearing failures are caused by insufficient lubrication, contamination, or overloading. Worn-out bearings can lead to excessive vibrations, noise, and eventually, motor failure.
2. **Broken rotor bars**: Broken rotor bars is a common issue in induction motors and other electrical machines, and are usually caused by operational stress, inadequate material quality, high ambient temperatures or aging, which can lead to performance issues like reduced efficiency, speed fluctuations and overheating.
3. **Vibration Issues**: Excessive vibrations can occur due to misalignment of the rotor, unbalanced rotors, or improper bearing installation. Vibration issues not only reduce the efficiency of the machine but can also lead to damage to other components, increasing maintenance costs.
4. **Misalignment**: Misalignment occurs when the rotor and stator of the motor are not properly aligned. This can cause uneven wear, increase friction, and result in overheating, leading to premature failure of components like bearings and windings.
5. **Overheating**: Overheating of the motor, typically due to insufficient ventilation or excessive load, can lead to mechanical stresses that affect the bearings, insulation, and other parts of the machine. This may lead to reduced performance and eventual failure.

Figure 3.1 shows different types of bearing faults in electrical machines., Figure 3.2 shows a broken rotor bar while Figure 3.3 shows failure in a three-phase stator winding of an electrical motor

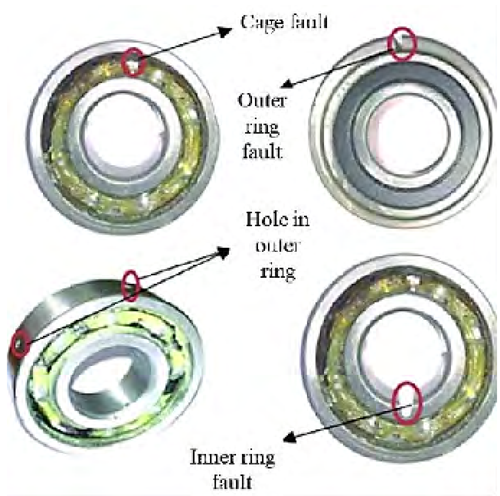

Figure 3.1: *Types of bearing faults in electrical machines*

Figure 3.2: *Broken rotor bar*

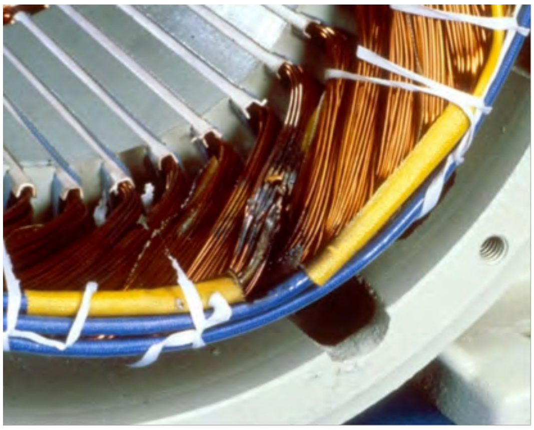

Figure 3.3: *Failure in a three-phase stator winding of an electrical motor*

Electrical Faults

Electrical faults are caused by issues in the electrical components of the machine, such as the stator windings, rotor windings, insulation, and power supply. Some common electrical faults, causes, and their possible symptoms are as follows;

1. **Short Circuits**: A short circuit occurs when two conductors, which should be kept separate, encounter each other, causing a direct path for current flow. This can result in overcurrent, overheating, and possible damage to the windings or insulation. Short circuits can occur due to insulation failure or physical damage to the windings.
2. **Open Circuits**: Open circuits occur when there is a break in the electrical path, often caused by damaged wires or faulty connections. This prevents the flow of current, causing the motor to fail or operate inefficiently.

3. **Insulation Failures**: Insulation failures in the windings are one of the most common causes of electrical faults in machines. Over time, insulation can deteriorate due to heat, moisture, or aging, leading to short circuits or ground faults. In severe cases, insulation breakdown can result in complete motor failure.
4. **Overloading**: Overloading occurs when the motor is asked to operate beyond its designed capacity. This results in excessive current flow, leading to overheating and potential damage to the windings, bearings, and other electrical components.
5. **Voltage Surges**: Voltage spikes or surges caused by lightning strikes, power line issues, or faulty power supply can damage the motor's electrical components. Surge protectors and voltage regulation are important for preventing such issues.
6. **Ground Faults**: A ground fault occurs when an unintended path is created between a machine's electrical system and the ground. This can cause short circuits, electrical shocks, and equipment failure. It is important to ensure proper grounding to avoid such issues.

Learning Tasks

1. State the two main categories of faults that occur in electrical machines.
2. Analyse the effects of four types of faults on electrical machines.

Pedagogical Exemplars

Teachers should consider the following activities:

Research and Collaboration: Organise the learners into mixed-ability and gender inclusive groups and task them to undertake the following practical activities: Outline major faults in electrical machines and associated symptoms. Describe diagnostic methods used to identify these faults.

Key Assessment Level 3: Group Presentation

1. A three-phase induction motor is drawing excessive current while producing less than rated torque. The motor also exhibits unusual patterns of heating in one phase winding. Analyse the possible causes of this fault.
2. A DC motor starts normally but gradually slows down and eventually stops after 15 minutes of operation despite receiving proper input voltage. What systematic troubleshooting approach would you use to identify the fault? Justify each step in your reasoning process.

PLC Session 10

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand

   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***group presentation***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
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Note

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30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

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ii. were the examples grounded in contexts familiar to Ghanaian learners?

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5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 10 Review

This unit exposes learners to the types of faults in electrical machines, causes and their possible symptoms. The pedagogical exemplars used in this unit includes Group presentation /Collaborative learning. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 3.

Resources: Pictures, Videos, real objects (DC motors)

UNIT 11

Section 3: Integrated Circuits

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic components and circuits

Content Standard: Demonstrate knowledge and understanding of electronic components and use them to design and construct electronic circuits.

Learning Outcome: *Demonstrate knowledge and understanding of electronic components and use them to design and construct electronic circuits.*

INTRODUCTION AND SECTION SUMMARY

This Section looks at integrated circuits as they apply to electronics technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques as regards timers such as 555 and 556 and operational amplifiers such as 471 and 4558, and how they can be used to design electronic circuits.

The unit covers only week 11: ***Describe the features and principle of operation of integrated circuits (timers)***

Recap weeks

Year 2	**Week 16:** Illustrate the construction and operation of the Bipolar junction transistor

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on the operation and designing with timers and operational amplifiers through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the features and principles of operation of Integrated Circuits (Timers)	Level,4 (Extended Strategic reasoning)	Assessment mode: Group Project
Apply the principle of operation of Timers in designing circuits	3 (Strategic reasoning)	Assessment mode: Group project

WEEK 11

Learning Indicators

1. *Describe the features and principles of operation of integrated circuits (timers)*
2. *Apply the principle of operation of timers in designing circuits*

FOCAL AREA 1: FEATURES AND PRINCIPLE OF OPERATION OF TIMERS

Features of the 555 time IC

The 555 timer is an integrated circuit (IC) widely used in various electronic circuits because of its robust and stable properties. It generates a square-wave with a duty cycle varying from 50% to 100% when used as an oscillator. It can also be used in circuits to provide time delay. Figure 3.4 shows the 555 timer with its pin connections

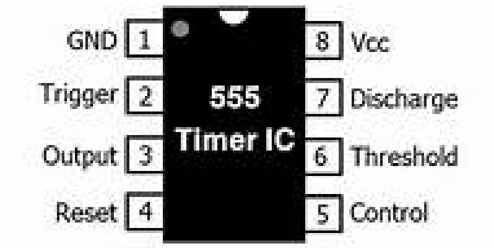


Figure 3.4: *The 555 timer IC*

The 555 timer comes as 8 pin DIP (Dual In-line Package) device. A dual version of the 555 timer is the 556 and consists of two complete 555 timers in 14 DIP as shown in Figure 3.5.

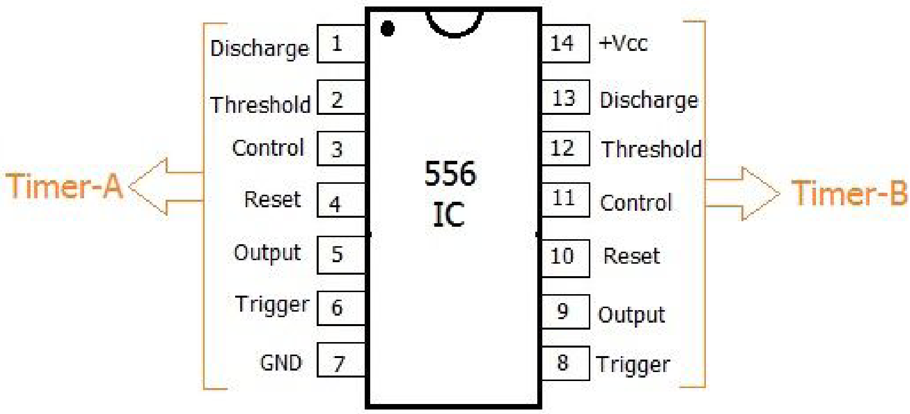


Figure 3.5: *The 556 timer IC*

The internal circuit connections of the 555 timer are shown in Figure 3.6. Note that this is a simplified version for better understanding, as the full internal circuit consists of over 16 resistors, 20 transistors, 2 diodes, a flip-flop and many other circuit components.

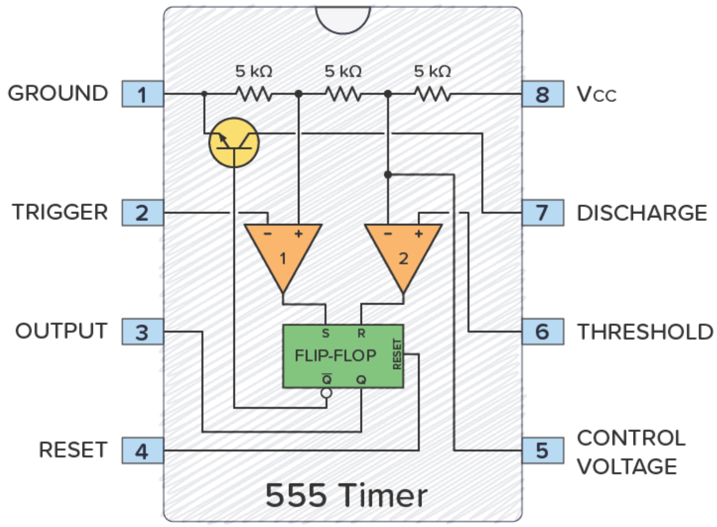


Figure 3.6: *Internal circuit connection of the 555 timer*

Function of the various pins

1. **Pin 1. Ground**: This pin is connected to ground of the power supply and provide a zero voltage to the IC. It enables the supply voltage, (Vcc), to be shared equally among the three series resistors shown in the diagram. Therefore, each resistor takes 1/3 of Vcc.
2. **Pin 2. Trigger**: This acts by comparing voltages. Note that the voltage at the non-inverting input of operational amplifier 1 (comparator 1) is Vcc/3. So, the trigger input is used to set the output of the flip-flop (F/F) to 'high' state with the application of a voltage equal to or less than Vcc/3 or any negative pulse, as the voltage at the non-inverting input of the comparator is Vcc/3.
3. **Pin 3. Output**: This is the output pin of the IC. It is always connected to the load it drives.
4. **Pin 4. Reset**: This pin resets the output of the F/F regardless of the initial state. It is also an active low pin and so to avoid any noise interference, it is connected to "high" state, unless a reset operation is required. Consequently, it is always connected to the Vcc.
5. **Pin 5: Control Voltage**: This pin is connected to the inverting input of comparator 2 and so it has a voltage level of (2/3) Vcc. It is used to override the inverting voltage thus changing the width of the output signal regardless of the RC timing network.
6. **Pin 6. Threshold**: This pin is connected to the non-inverting input of comparator 2. The output of the comparator will be high whenever the threshold voltage is more than (2/3) Vcc. This resets the output of the F/F from 'high' to 'low'.
7. **Pin 7. Discharge**: This pin is used to discharge the timing capacitors to ground when the output of pin 3 is switched to 'low'. Note that these capacitors are connected in the external circuit to ensure that the IC is able to generate a square wave
8. **Pin 8. Supply Voltage (Vcc)**: This pin enables the IC to be connected to supply voltage required for its operation

FOCAL AREA 2: DESIGNING CIRCUITS WITH TIMERS

1. **Applications of 555 timers:** The 555 timer has wide applications in electronics, such as monostable for the generation of a one-shot pulse, bistable to produce a flip/flop type action and astable as in an oscillator. It is also used in designing many other types of circuit for various purposes such as follows:

   a. **Timing Applications**

      i. Delay Timer: This principle is used in circuits to create a delay before an action occurs, such as turning on a light after a specified period.

      ii. Pulse Width Modulation (PWM): PWM is employed in motor speed control, dimming lights, and controlling the brightness of LEDs.

   b. **Oscillator Applications**

      i. Frequency Generator: The timer is used to generate a square wave for audio tones, clock pulses or signal modulation.

      ii. Tone Generator: Here, the timer is employed in sound-producing devices like alarms, buzzers, and musical instruments.

   c. **Flashing Lights**

      i. LED Flasher: The timer is used to create blinking LED circuits for decorative lighting or indicators.

      ii. Light Chasers: Employed in circuits that light up LEDs in a sequence, such as in decorative displays.

   d. **Timer Circuits**

      i. One-Shot Timer: The IC is used to generate a single pulse of a predetermined period in response to a trigger signal. A typical application is a timer for an appliance.

      ii. Interval Timer: Employed in situations that require a definite time interval between events.

   e. **Pulse Generation**

      i. Square Wave Generator: The IC is used to produce a square wave for testing and signal processing applications.

      ii. Random Pulse Generator: The timer is capable of being configured to produce random pulses for various applications.

   f. **Bistable Applications**

      i. Flip-Flop: The timer can be used as a bistable multi-vibrator, which maintains a state until triggered. This is useful in memory and control applications.

      ii. Switch Debouncing: This principle is used to stabilise signals from mechanical switches to prevent multiple triggering.

g. Control Systems

Motor Control: applied in motor control circuits for controlling the speed and direction of DC motors.

Temperature Control: Used in temperature control systems, such as regulating the temperature of heating elements.

h. Tone and Sound Generation

i. Alarm Systems: Used to generate sound for alarms and security systems.

ii. Music Synthesizers: Used in simple synthesizer circuits for producing audio tones.

2. Connecting the timer in various modes

a. Monostable Mode: A monostable circuit is one that has one stable state. When switched to its unstable state (high or low), it will stay there for a pre-determined time and switch over to its stable state. This is achieved by a resistor capacitor circuit arrangement. Figure 3.7 shows a typical monostable connection mode.

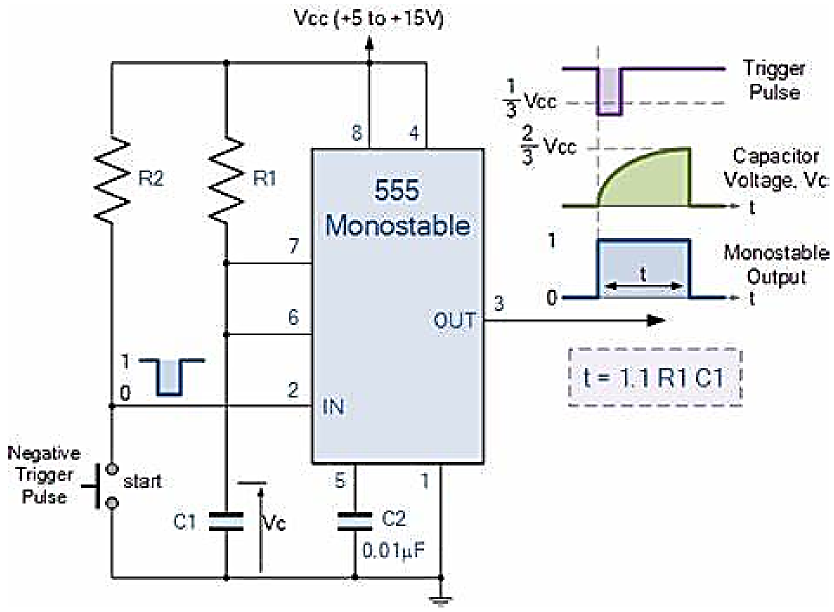


Figure 3.7: *Monostable mode of a 555 timer*

Notice from the figure that Pin 2 of the 555 timer is kept HIGH by resistor R2, the timing starts from the moment the pin 2 goes LOW. At that moment, the output, pin 3 goes HIGH and remains in that condition for a period determined by the values of resistor R1 and capacitor C1. This period is calculated using the equation: $t = 1.1 \times R1 \times C1$.

As soon as this period ends, pin 3 goes LOW again. This is only true for input pulses longer than t. As pin 3 goes HIGH, the instant pin 2 goes LOW, and if pin 2 stays LOW for longer than t, pin 3 will stay HIGH until pin 2 goes HIGH again. Such circuits can be employed in cleaning up a pulse of unreliable length by forcing it to be a known length, such as a pulse stretcher in a burglar alarm vibration sensor or a momentary push-button circuit.

b. Bistable Mode: A bistable circuit is one that has two stable states, either on or off. Typical applications of bistable circuits are memory cells, flip flop circuits, and switch debouncers. Figure 3.8a shows a typical bistable circuit.

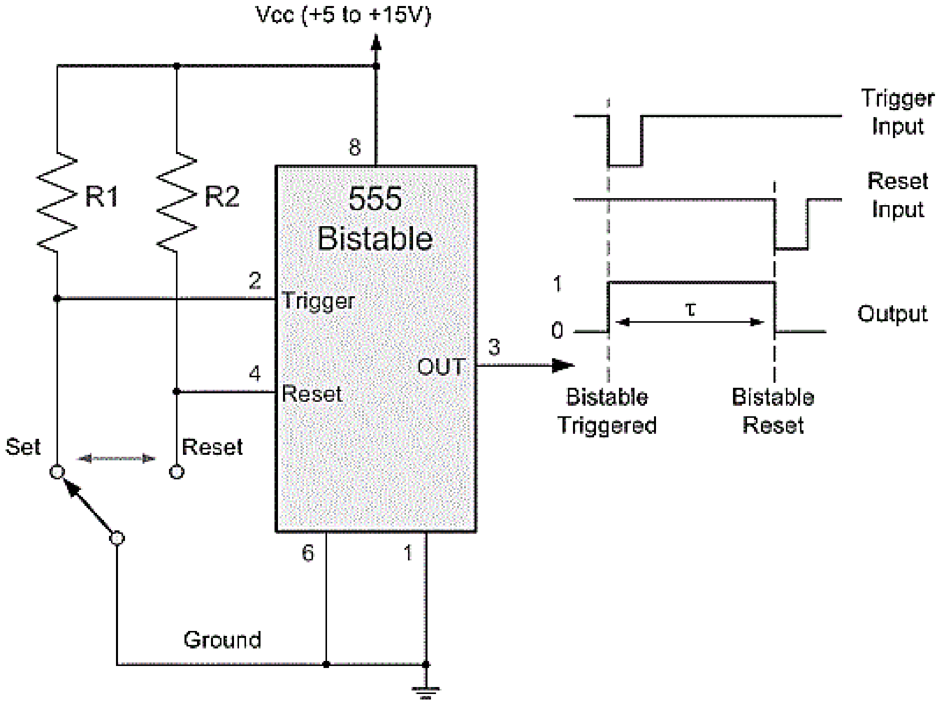


Figure 3.8a: *Bistable mode with change-over switch trigger*

Notice from the figure that there are no timing capacitors since it is only on or off. The set and reset conditions are obtained through a double throw switch. In the set state, a LOW signal is sent to pin 2 causing the output to change state. In the reset state, a low signal is sent to pin 4, causing the output to change state again. It is worth noting that the output pin 3 will be HIGH on boot up if pin 2 is LOW. The same results can be obtained by replacing the double throw switch with two separate push-button switches as shown in Figure 3.8b.

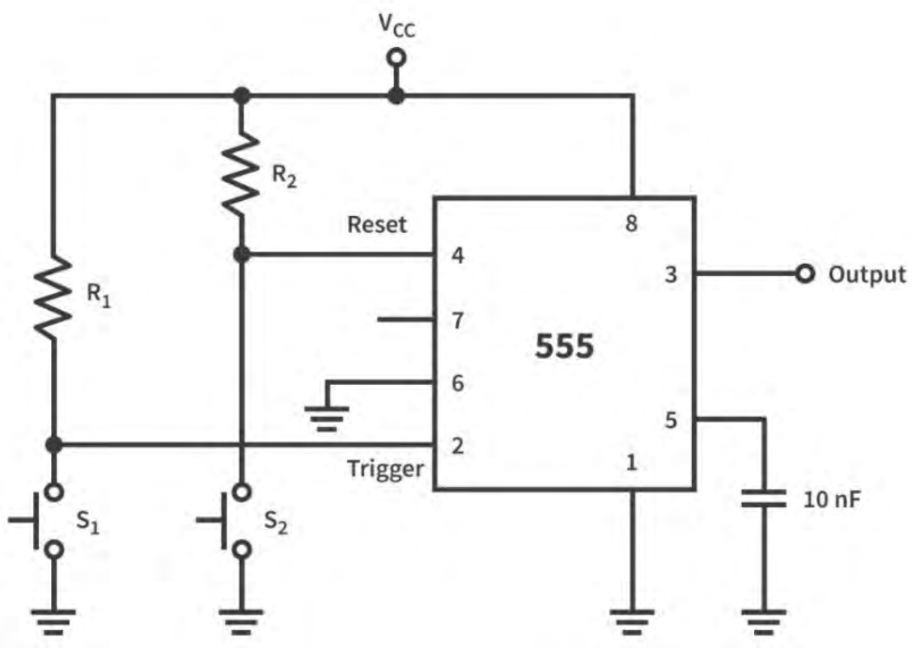


Figure 3.8b: *Bistable mode with two push button trigger*

c. **Astable Mode:** The 555 timer acts as a square wave oscillator in the astable mode. A wide range of frequencies can be obtained and the duty cycle can equally be varied. Figure 3.9 shows a typical astable circuit.

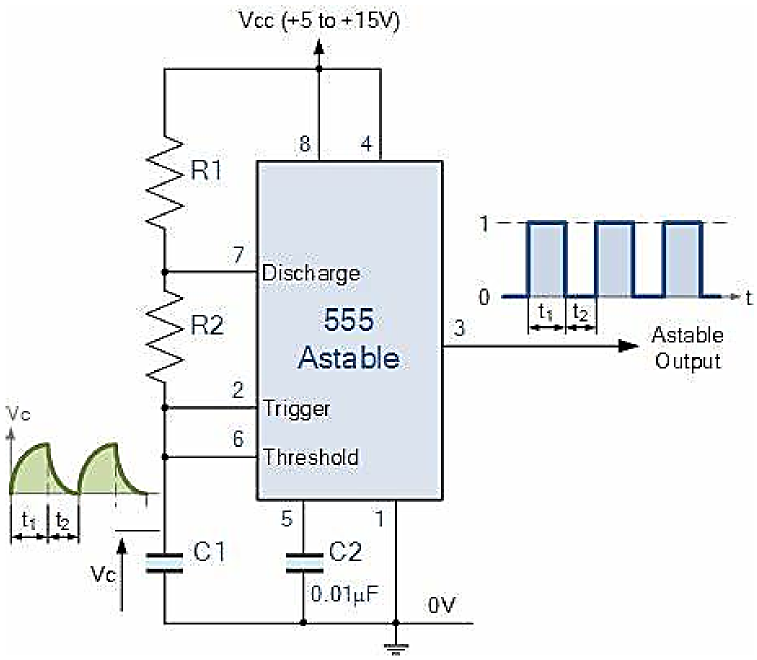


Fig 3.9: *Astable mode of a 555 timer*

In this circuit, resistors R1, R2, and capacitor C1 control the on and off periods' timing and that generates the frequency. The frequency can be varied by replacing R1 with a variable resistor. The duty cycle can also be varied.

d. Duty cycle: Duty cycle is the ratio of the ON time (duration the output is in the HIGH state or pulse width) to the total time period of a cycle. For an astable multivibrator, the duty cycle is given by TON/ TON + TOFF. Generally, the duty cycle of an astable multivibrator is **50%**. This means that for 50% of the cycle time, the output is "HIGH" and the remaining 50% of the cycle time, the output is "OFF". Figure 3.10 shows the output wave of the astable.

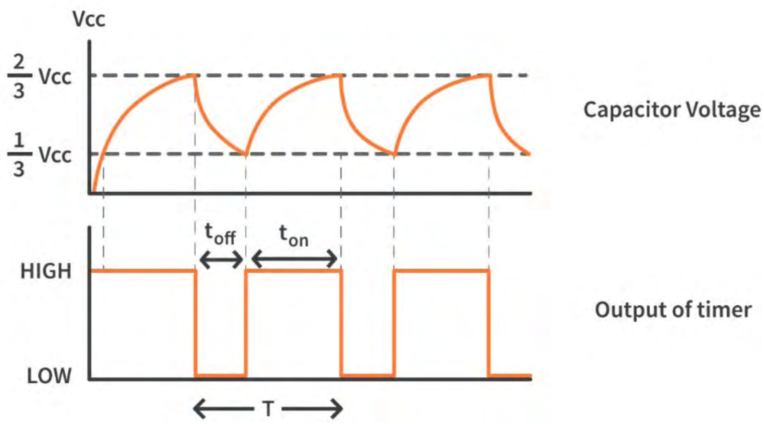


Figure 3.10: *Output wave of an astable mode of a 555 timer*

From Figure 3.8b, if toff = 12mS and ton =17ms, then the period (T) is 12+17 = 29ms. Since frequency is 1/T, then the frequency = 1/29ms = 34.48Hz.

The duty cycle = 12/29 = 0.38 = 38%

We can always set each of the widths independently using the following two equations

i. Period (T) = 0.7 x (R1+2R2) x C1

ii. Frequency = 1/T

This will affect the pulse frequency as well as the duty cycle.

3. **A practical application of timers:** Figure 3.11 is a clap switch circuit. It is a typical example of the application of the 555 timer.

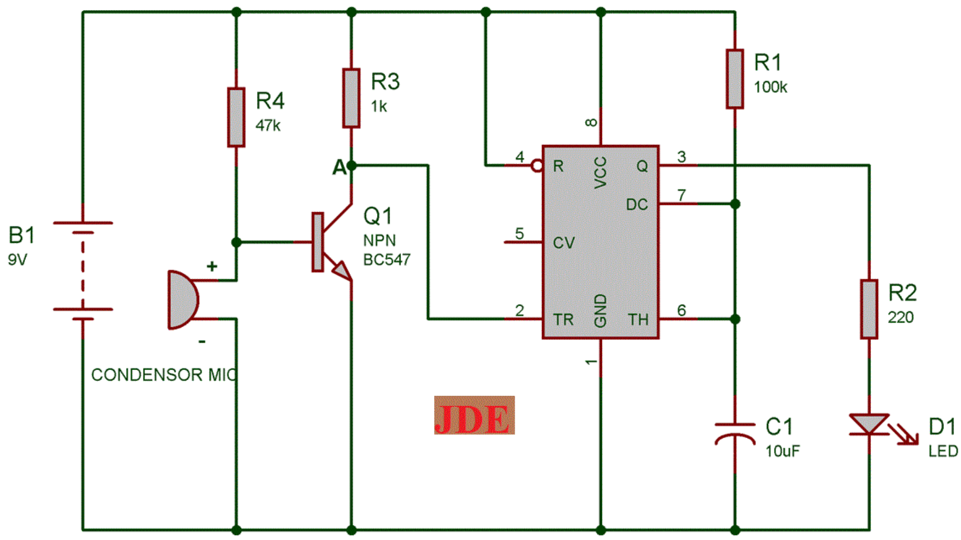


Figure 3.11: *A clap switch circuit involving a timer*

a. **Components required:** The components required to build this clap switch circuit are shown in table 3.3.

Table 3.3: *Components required for building the clap switch circuit*

S/N	Component	Quantity
1	NE 555 Timer IC	1
2	NPN transistor (BC 547)	1
3	10uF capacitor	1
4	Condenser mic	1
5	LED (5mm)	1
6	100K resistor	1
7	47K resistor	1
8	1K resistor	1
9	220 Ω resistor	1
10	9 V battery	1
11	Breadboard	1

b. **Connection of the circuit:** The procedure for connecting the circuit is as follows:

i. Place IC on breadboard

ii. Connect pins 4 and 8 of the 555 timer to Vcc.

iii. Connect pin1 to GND.

iv. Connect the 100KΩ resistor (R1) between pin 7 and Vcc

v. Connect the 10uF electrolytic capacitor (C1) between pin 7 and GND

vi. Link pin 6 to pin 7 using a jumper wire.

vii. Connect the LED between pin 3 and GND through the 220Ω resistor (R2).

viii. Connect the positive side of the condenser mic to Vcc through the 47K resistor (R4) and the negative to GND.

ix. Connect the base of the transistor to the positive of the condenser mic.

x. Connect the collector of the transistor to Vcc. through the 1kΩ resistor (R3) and the emitter to GND.

xi. Connect pin 2 of the IC to the collector of the transistor

xii. Power the circuit with a 9V battery, making sure that the positive goes to Vcc point and negative to GND point of the circuit.

c. **Operation:** Note that the input component of the clap switch is the condenser mic. It is a sound sensor and converts sound energy into electrical energy. This action of the mic increases the base voltage of the transistor and turning it (the transistor) on. The transistor then amplifies the electrical signal and then applies it to pin 2 of the 555 timer, triggering it in the process. This sends a signal to the LED connected to the output (pin 3). Since this is a monostable mode, the LED remains in that state for a period of time, determined by the values of R1 and C1.

After this period, the LED will be turned off automatically. To change the time duration of the LED, the values of resistor R1 and capacitor C1 have to be changed. Test the circuit by clapping your hands loudly. This circuit can be adapted to many situations. For example, it can be used to switch on light in dark places. Note that in situation like that a relay will have to be used since the voltage of the lighting system is very high. The timer turns on the relay which in turn, turns on the light. The circuit also has the advantage of eliminating the possibility of electric shock since one does not need to have physical contact with the circuit.

4. **Troubleshooting of timer Circuits:** The following are some common timer circuit issues and some troubleshooting tips:

a. **Incorrect Timing:** In case the output frequency or pulse duration falls below expectation, double-check the resistor and capacitor values and ensure that the components are connected to the correct pins. Also ensure that the formulas are used correctly.

b. **Unstable Output:** Noise or improper power supply decoupling can be the cause of unstable output. Ensure that the power supply is clean and that decoupling capacitors are placed close to the timer. Also, check for any loose connections or damaged components.

c. **No Output:** In case the timer does not produce an output voltage, check to ensure that the trigger signal is applied correctly and that the reset pin is not inadvertently pulled low.

Learning Tasks

1. Compare the monostable and the astable timers in terms of their construction and operation
2. Explain how the principle of a monostable timer can be adapted to design a circuit to control a standing fan

Pedagogical Exemplars

Teachers should consider the following activities:

Research and Collaboration: Organise the learners into mixed-ability and gender groups and task them to research on google search engine and the U-Tube to undertake the following activities and do group presentation on their findings:

- **a.** Identify the pin connections of the 555 and 556 timer IC and state typical voltage supply for the IC
- **b.** Explain the principle of operation of each and how each can be connected in a circuit

Independent learning: Task learners to draw the block diagrams of 555, 556 timers and indicate the pin connections of each of them. Encourage them to really do independent work and be hard working as well

Collaborative Learning: Work in pairs to; Explain how each IC can be connected in a circuit for a typical function e.g., timer,

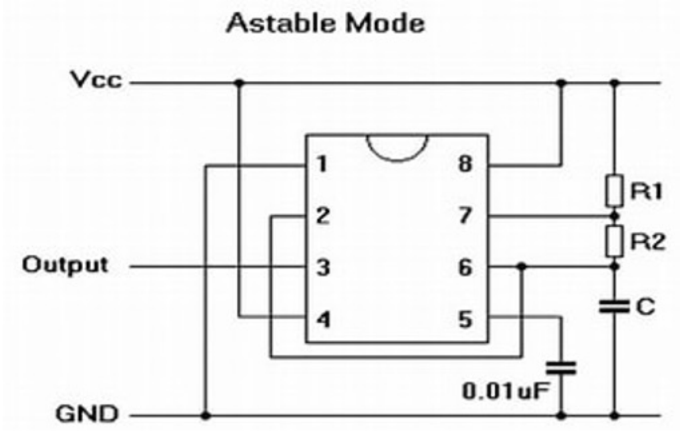
Independent project work: Task learners individually to design and construct multi-vibrators and encourage them to really do independent work as well as exhibiting a sense of responsibility when working with tools in the workshop (in terms of theft).

Project based learning and collaboration: Engage learners in mixed gender groupings to: design and simulate multi-vibrators (monostable, bi-stable and a stable) with 555 and 556 timer IC using multisim if possible

Key Assessment Level 4: Group Project

1. Analyse the timer circuit shown in Figure 3.12, which fails to produce reliable timing intervals:

- **a.** Identify three potential sources of timing inaccuracy in this circuit
- **b.** Calculate the correct component values to achieve stable operation
- **c.** Propose circuit modifications to improve temperature stability
- **d.** Evaluate whether a stable or monostable configuration would be more appropriate for controlling a school bell system



R1= 1KΩ, R2 = 3KΩ , C = 22µF

Figure 3.12

2. The school laboratory needs an automated plant watering system that applies water at different intervals based on environmental conditions. Design a timer-based system using 555 timers that:

   a. Waters plants every 48 hours when soil is moist

   b. Increases to every 24 hours when soil is dry

   c. Activates a pump for exactly 30 seconds during each watering cycle

Your answer must include:

   a. Complete circuit diagram with component values

   b. Calculations justifying your timing component selections

   c. Analysis of potential failure modes and safeguards

   d. Evaluation of how your design balances reliability, cost, and functionality

PLC Session 11

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

   a. explain the week's concepts in a practical way that will make it easier for learners to understand

   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

a. The key assessment for the week is ***group project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

a. transfer your chats into your learning planner template.

b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

UNIT 11 REVIEW

This unit exposed learners to timers such as the 555 and 556. The pedagogical exemplars used in this unit includes Research and collaboration, Group work/Collaborative learning and Group projects. These strategies are expected to instil in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 4.

UNIT 12

Section 12: Integrated Circuits

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic devices and circuits.

Content Standard Demonstrate knowledge and understanding of electronic components

Learning Outcome: *Apply knowledge and understanding of electronic components to design and construct electronic circuits.*

INTRODUCTION AND SECTION SUMMARY

This Section gives exposition on integrated circuits they apply to electronic technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, Principle of operation and applications of integrated circuits.

The unit covers only week 12:

1. *Describe the features and principles of operation of Operational Amplifiers*
2. *Apply the principle of operation of op-amps in designing circuits*

Recap week

Year 2	**Week 13:** Meaning of passive electronic components.

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on the various aspect of Integrated Circuits through a wide range of pedagogical exemplars such as, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the construction and principle of operation of DC motors.	4 (Extended critical thinking and reasoning)	Group project Practice Paper 1

WEEK 12

Learning Indicators

1. *Describe the features and principles of operation of Operational Amplifiers*
2. *Apply the principle of operation of op-amps in designing circuits*

FOCAL AREA 1: FEATURES AND PRINCIPLES OF OPERATION OF OP-AMPS 741 AND 4558

FOCAL AREA 2: DESIGNING WITH OP-AMPS

Operational amplifiers

The term operational amplifier is the full form of op-amp: it is one type of IC (Integrated Circuit) and is a DC-coupled high-gain electronic voltage amplifier with a differential input and usually a single-ended output. As the name suggests, it is basically an amplifier, whose job is to amplify the input signals. The reason behind it being called "operational" is that, in the early days when digital computers were not developed, the basic "mathematical operations" like addition, subtraction, differentiation and integration were performed by them. Today, operational amplifiers have become a popular building block in electronic circuits.

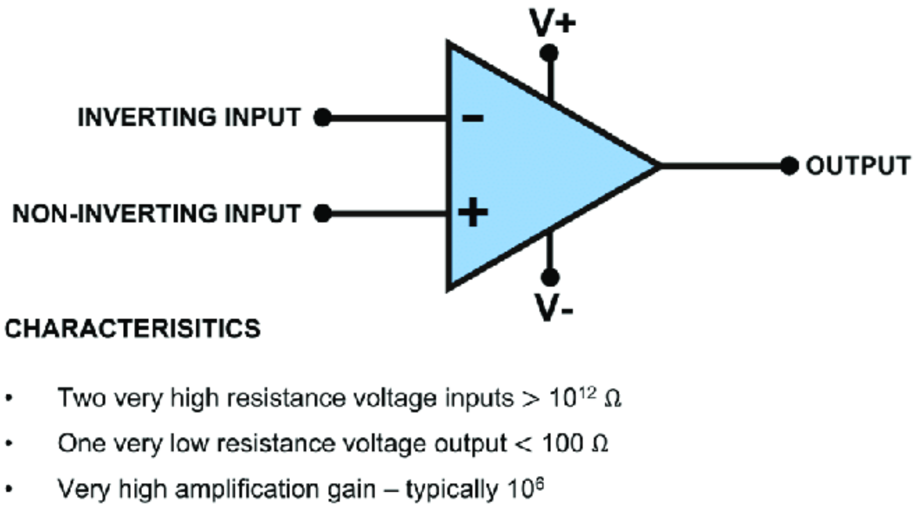


Figure 3.13: *Schematic representation of an Op-Amp*

The positive terminal of the input is called the "non-inverting" input and the negative terminal is called the "inverting" input. They have their names according to the functions they perform.

1. **Inverting Input:** A positive voltage applied to this input terminal will lead to a negative swing at the output.
2. **Non-Inverting Input:** A positive voltage applied to this input terminal will lead to a positive swing at the output.

The OP-Amp has basically five (5) terminals namely

1. Inverting input terminal
2. Non-inverting input terminal

3. Output terminal
4. Positive bias supply terminal
5. Negative bias supply terminal

Pin Description of 741 IC Op-amp

1. **Pin4 & Pin7 (Power Supply):** Pin7 is the positive voltage supply terminal and Pin4 is the negative voltage supply terminal. The IC draws in power from these pins. The voltage between these two pins lies between 5V and 18V.
2. **Pin6 (Output):** This is the output pin for the IC. The voltage at this pin depends on the input signal and the feedback mechanism used.
3. **Pin2 & Pin3 (Input):** These are input pins. Pin2 is the inverting input and Pin3 is the non-inverting input. If the voltage at inverting input is higher than non-inverting input, the voltage at the output signal stays low. Likewise, if the voltage at the non-inverting input is high, the output goes high.
4. **Pin1 & Pin5 (Offset Null):** Because of high gain provided by Op-Amp, even slight variations in voltages at the inverting and non-inverting inputs, caused due to irregularities in the manufacturing process or external disturbances, will affect the output. To nullify this effect, an offset voltage can be applied at pin1 and pin5 and is typically done by employing a potentiometer.
5. **Pin8 (N/C):** This pin is not connected to any circuit inside 741 IC. It's just a dummy lead used to fill the void space in standard 8 pin packages.

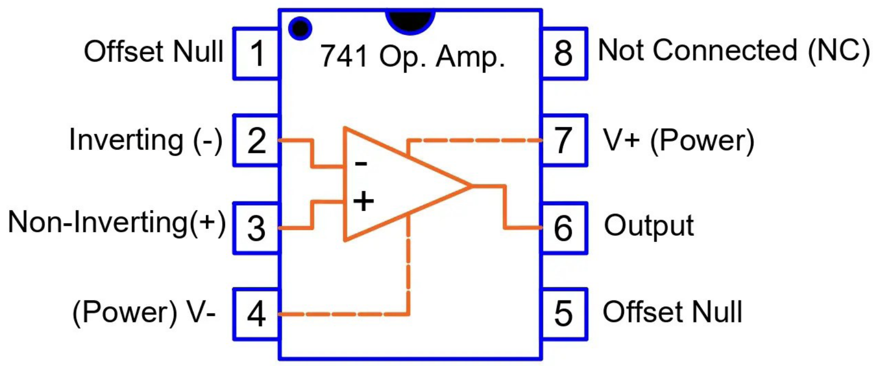


Figure 3.14: *Diagram showing the pin connections of IC 741 Op-amp*

Functions of the various pin connections

1. **Power Supply Pins: Pin 4 and 7:** Pin 4 and pin 7 are the negative and positive voltage power supply terminals respectively. The power which is required for the IC to function is received from these pins. The voltage level between these pins can be in the range of 5V – 18V.
2. **Output Pin: Pin 6:** The output which is delivered from the IC 741 op amp is received from this pin. The output voltage that is received at this pin is based on the feedback approach that is used and the voltage level at the input pins. When the voltage value at pin 6 is high, this means that the output voltage is similar to the +ve supply voltage. In the same way,

when the voltage value at pin 6 is low, this means that output voltage is similar to the -ve supply voltage.

3. **Input Pins: Pin 2 and Pin 3:** These are the input pins for the operational amplifier. Pin 2 is considered as the inverting input while pin 3 is considered as the non-inverting input pin. When the voltage value at pin 2 exceeds pin 3 (which means that the inverting input has a higher value of voltage), then the output signal will be **low.** In the same way, when the voltage value at pin 3 exceeds pin 2 which means that non- inverting input has a higher value of voltage, then the output signal will be **high.**
4. **Offset Null Pins: Pin 1 and Pin 5:** The offset Null pins basically allow you to adjust the input offset voltage and also minimise the output offset voltage which is the voltage present at the output when the input signals are zero. This is generally achieved through the use of a potentiometer in order to reduce errors and improve accuracy.
5. **Not Connected Pin: Pin 8:** Pin 8 is a dummy pin that is used to fill up the empty pin in the IC 741 Op Amp. It has no connection with any of the internal or external circuits.

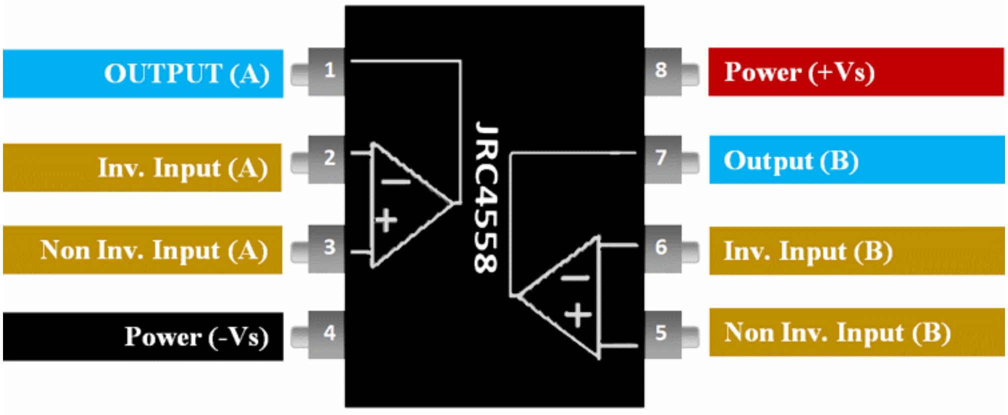


Figure 3.15: *Diagram showing the pin connections of 4558 IC Op-amp*

NOTE: The 4558 IC Op-am houses two operational amplifiers within its internal circuit, providing dual operational amplifiers in a single package.

Table 3.4: *Pin configuration description of IC 4558 Op-amp*

Pin No.	Pin Name	Pin Description
1	OUT (A)	The output pin of Op-amp A
2	Inverting Input (A)	The Inverting input pin of the Op-Amp A
3	Non- Inverting Input (A)	The Non - Inverting Input Pin of Op-Amp A
4	Power (-Vs)	Ground or Negative supply terminal
5	Reference	The non-inverting Input Pin of Op-Amp B
6	Output	The Inverting input pin of the Op-Amp B
7	Power (+Vs)	The output pin of Op-amp B
8	+VS	Positive supply terminal

Features of Op-Amps

1. **High Gain:** Op-amps typically have very high open-loop voltage gain, meaning they amplify the input voltage difference significantly.
2. **Differential Input:** Op-amps respond to the difference in voltage between their two input terminals (inverting and non-inverting).
3. **High Input Impedance:** Ideally, op-amps have very high input impedance, minimising the effect of the op-amp on the input signal source.
4. **Low Output Impedance:** Op-amps ideally have very low output impedance, allowing them to deliver a strong signal to a load without being affected by the load's characteristics.
5. **Feedback:** Op-amps are often used in conjunction with feedback networks, which can be negative or positive, to modify their gain and stability.
6. **Versatile Applications:** Op-amps are used in various applications, including amplification, signal processing, filtering, and analogue-to-digital conversion.

Principles of Operation (Op-amps):

1. **Input Voltage Amplification:** The op-amp's core function is to amplify the voltage difference between its two input terminals (V+ and V-).
2. **Open-Loop Gain:** In the absence of feedback, the op-amp's output voltage is determined by its open-loop gain, which is the ratio of output voltage to input voltage difference.
3. **Feedback:** When feedback is added, the gain is reduced, but the output voltage becomes more predictable and stable.
4. **Negative Feedback:** Negative feedback reduces gain and improves stability, making op-amps useful in applications where a precise output voltage is required.
5. **Positive Feedback:** Positive feedback can be used to create oscillators or comparators, where the output voltage can be switched between two states based on the input signal.

Open Loop Operation

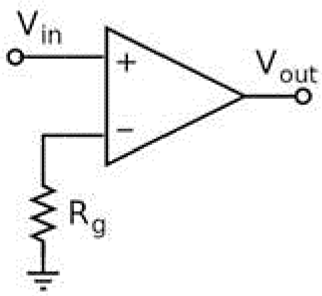


Figure 3.16: *Open Loop Operation*

An ideal op-amp amplifies the difference between the two applied input signals (i.e., at the inverting and the non-inverting) signals. This difference between the two input signals is called the **differential input voltage**. The equation below gives the output of an operational amplifier.

$V_{out} = A_{OL} (V_+ - V_-)$

where, AOL = open-loop gain (which means, the gain of the op-amp component all by itself, with all the different components removed and significantly with the feedback element removed).

In open loop, the op-amp can work only as a comparator. The open-loop gain of an op-amp is very high. Hence, an open-loop operational amplifier amplifies a small applied differential input voltage to a huge value, but this significant value at the output cannot go beyond the supply voltage of the op-amp. Hence, it does not violate the law of conservation of energy.

Closed-Loop Operation

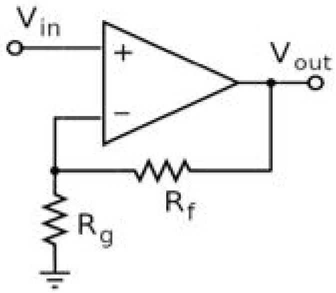


Figure 3.17: *Closed Loop Operation*

Feedback is introduced in the closed-loop configuration. This feedback path feeds the output signal back to the input. Hence, at the inputs, two signals are simultaneously present. One of them is the original applied signal, and the other is the feedback signal. The equation below shows the output of a closed-loop op-amp.

$V_{out} = A_{CL}\ (V_+ - V_-)$

> **where, A_{CL} is the closed-loop gain. The feedback circuit connected to the op-amp determines the closed-loop gain A_{CL}.**

The gain of an inverting amplifier (Closed loop gain) is,

ACL= $\frac{-RF}{R1}$, where RF=Feedback Resistor and R1=Input Resistor,

The gain of the non -inverting amplifier (Closed loop gain) is,

ACL = 1 + $\frac{RF}{R1}$, where RF=Feedback Resistor and R1 = Input Resistor,

Feedback is said to be positive if the feedback path feeds the signal from the output terminal back to the non-inverting (+) terminal. Positive feedback is used in oscillators. The feedback is negative if the feedback path feeds the part of the signal from the output terminal back to the inverting (-) terminal. Negative feedback to the op-amps is used in amplifiers**.**

Op-Amp Characteristics

Input Impedance (Z_{in})

It is the ratio of input voltage to the input current. It is assumed to be infinite to prevent any current flowing from the supply into the op-amp circuit (Iin=0). An ideal op-amp has infinite input impedance. But practically, when op-amp is used in linear applications, some negative feedback is provided. Due to this negative feedback, the input impedance becomes:

Zin = (1 + AOL β) Z_i

where, Z_i = input impedance without feedback

A_{OL} = open-loop gain

β = feedback factor

Output Impedance (Z_{out})

An ideal op-amp has zero output impedance acting as a perfect internal voltage source with zero internal resistance, so that maximum current can be driven to the load. Practically, the output impedance of the op-amp is given by:

$$Z_{out} = \frac{Z_o}{(1 + A_{OL}\,\beta)}$$

where, Z_o = output impedance of op-amp without feedback

A_{OL} = open-loop gain

β = feedback factor

Open-Loop Gain (A_{OL})

It is defined as the gain of the op-amp when there is no feedback in the circuit. For an ideal op-amp, the gain will be infinite, but practically the value ranges from 20,000 to 200,000.

Bandwidth (BW)

Ideally, an op-amp can amplify any frequency signal from DC to the highest AC frequencies, thus it has an infinite frequency response. Hence, the bandwidth of an ideal op-amp should be infinite but practically it is limited by the Gain-Bandwidth product (GB).

Examples of applications of the op-amp are;

1. Inverting amplifier
2. Non inverting amplifier
3. Differentiator
4. Integrator
5. Summing amplifier
6. Differential amplifier
7. Instrumentation amplifier

Learning Tasks

1. Explain the concept of operational Amplifiers.
2. Discuss the principle of operation of the Operational Amplifier.
3. An operational Amplifier has a gain of -10 and an input resistance of 10kΩ.

Determine the value of the feedback resistor.

Pedagogical Exemplars

Teachers should consider the following activities:

Research and Collaboration: Organise the learners into mixed-ability and gender groups and task them to research on Google search engine and the U-Tube to undertake the following activities and do group presentation on their findings:

- **a.** Identify the pin connections of the 741 and 4558 and state typical voltage supply for the IC
- **b.** Explain the principle of operation of each and how each can be connected in a circuit

Independent learning: Task learners to draw the block diagrams of 741 and 4558 and indicate the pin connections of each of them. Encourage them to really do independent work and be hard working as well

Collaborative Learning: Work in pairs to; Explain how each IC can be connected in a circuit for a typical function e.g., comparator, Inverting amplifiers

Independent project work: Task learners individually to Design and construct inverting and non-inverting amps and encourage them to really do independent work as well as exhibiting a sense of responsibility when working with tools in the workshop (in terms theft).

Project based learning and collaboration: Engage learners in mixed gender groupings to: Design and simulate comparators, inverting and non-inverting amplifiers and summing amplifiers with 741 and 4558 op-amps. using Multisim

NB: Ensure all learners participate in all varieties of practical activities and project work given and also when practical wiring is being carried out. Ensure that all learners have the opportunity to be made group leaders. Learners who may be physically challenged should be given enough time to complete the project work.

Key Assessment: Practice Paper 1

1. The ideal op-amp model assumes infinite gain, infinite input impedance, and zero output impedance.

Select a practical application (such as an audio amplifier, sensor interface, or filter) and:

- **a.** Analyse how real op-amp limitations affect performance in your chosen application.
- **b.** Evaluate which non-ideal characteristics are most problematic.
- **c.** Design circuit modifications that compensate for these limitations.
- **d.** Discuss situations where these limitations might actually be beneficial

2. Design a water level monitoring system for a school water tank using operational amplifiers that:

- **a.** Sounds an alarm when water level is too low
- **b.** Automatically starts a pump when level falls below 25%
- **c.** Stops the pump when level reaches 90%
- **d.** Indicates current water level on a simple LED display

Your answer must include:

- **a.** Complete circuit diagram with all necessary op-amp stages
- **b.** Explanation of how each op-amp configuration functions in your design
- **c.** Analysis of potential failure modes and how your design addresses them
- **d.** Evaluation of power consumption considerations

Hint

Conduct ***Practice Paper 1****. It should cover contents taught from Year 1 to 3. Refer to the* ***Table of Specification and Structure of the Paper*** *at the end of this section. Learners' papers should be marked immediately and scores entered into the SAP.*

PRACTICE PAPER 1

TABLE OF SPECIFICATION

PAPER 1 (Multiple Choice Questions)

STRAND	LEARNING INDICATORS	LEVEL OF ASSESSMENT				TOTAL
		1	2	3	4	
Electrical Technology	Discuss safety in the use of electricity.		1	1		2
	Describe the process of electrical Power Transmission and distribution.	1				1
	Apply the concept of power transmission and distribution in electricity supply		1			1
	Explain house wiring and provide reasons for doing good wiring		1			1
	Describe tools and equipment used for house wiring			1		1
	Identify the various materials and accessories used for house wiring	1				1
	Describe how a circuit is protected against Excess current	1				1
	Earth an installation work in accordance with rules and regulations		1			1
	Conduct relevant tests on an installation work that has been complete		1			1
	Describe the construction and principle of operation of AC motors			1		1
	Describe the construction and principle of operation of DC motors.	1				1
	Describe the construction and principle of operation of DC generators.			1		1

	Describe the construction and principle of operation of a transformer		1			1
	Explain losses that occur in a transformer and how they affect the performance of the transformer			1		1
	Classify home appliances under resistive and inductive loads and outline faults associated with them		1			1
	Detect fault in electrical machines			1		1
Electronics Technology	Explain the concept of electrical and electronic circuits		1			1
	Describe the principles and operation of the various Diodes	1				1
	Describe types of resistors as passive electronic components			1		1
	Describe types of capacitors as passive electronic components		1			1
	Describe types of inductors as passive electronic components	1				1
	Describe the types of cells and their functions in circuits.			1		1
	Illustrate the principles of operation of the various transistors.		1			1
	Apply the principle of operation of Timers in designing circuits			1		1
	Describe the features and principles of operation of Operational Amplifiers		1			1
	Apply the principle of operation of operational amplifiers in designing circuits			1		1
	Describe types of logic gates	1				1
	Solve problems on Boolean Algebra			1		1
	Describe the various types of modulation in communication		1			1
	Describe AM and FM transmitters in electronic communication	1				1

	Describe AM and FM receivers in electronic communication			1		1
Building Construction Technology	Explain what setting out is	1				1
	Explain how the locations of temporal structures are specified, as well locations of Services, welfare facilities and Equipment at the new construction Site to ensure		1			1
Woodwork	Classify the two main types of wood species	1				1
	Outline the processing phases of timber in the woodwork industry		1			1
Automotive Technology	Demonstrate safety measures applied to servicing, repairs and maintenance of engine systems.	1	1			2
Metal Technology	Explain health and safety related to workshop, tools, materials and machines	1				1
	Explain ferrous and non-ferrous metals with engineering applications and state the uses of non-metallic materials.		1			1
Total		**12**	**16**	**12**		**40**
		30%	**40%**	**30%**		**100%**

PAPER 2 (Essay)

STRAND	**LEARNING INDICATORS**	**LEVEL OF ASSESSMENT**				**TOTAL**
		1	**2**	**3**	**4**	
Electrical Systems Design	Classify home appliances under resistive and inductive loads and outline faults associated with them	**3**				**3**
	Describe the process of servicing electrical wiring circuits					
	Describe the construction and principle of operation of AC Generators					
	Describe the construction and principle of operation of DC generators.					
	Describe the sequence of Supply-control equipment					

Electronics Technology	Apply the principles of Diodes in designing circuits	3	3
	Apply the principles of operation of transistors in designing circuits		
	Describe the features and principles of operation of Operational Amplifiers		
	Apply the principle of operation of operational amplifiers in designing circuits		
Total		6	6
			100%

PAPER 3 (Practical test)

STRAND	LEARNING INDICATORS	LEVEL OF ASSESSMENT				TOTAL
		1	2	3	4	
Electrical Systems Design	Explain the concept of electrical and electronic circuits	1				1
	Analyse dc circuits and solve problems on them by applying various circuit laws					
	Explain the effects of alternating current on RLC circuits					
Electronics Technology (Practical Test)	Describe types of resistors as passive electronic components	1				1
	Describe types of capacitors as passive electronic components					
	Describe types of inductors or as passive electronic components					
	Describe the types of cells and their functions in circuits.					
	Illustrate the construction of Diodes					
Total		2				2
						100%

PLC Session 12

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   - **a.** explain the week's concepts in a practical way that will make it easier for learners to understand.
   - **b.** identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   - **a.** suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   - **b.** suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   - **c.** review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).
   - **a.** The key assessment for the week is ***practice paper 1***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   - **a.** use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   - **b.** all teachers in the group work through the problem individually for 3–4 minutes
   - **c.** the group then works through it together the problem, step by step
   - **d.** highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?

- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

UNIT 12 REVIEW

This unit exposed learners to the concept of Operational Amplifiers and the processes involved in using the concept of Operational Amplifiers in designing circuits. The pedagogical exemplars used in this unit includes Research, collaborative learning and independent project work. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 1,2 and 3.

Resources: Pictures, Videos, real objects (DC motors)

UNIT 13

Section 5: Digital Electronics

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic devices and circuits

Content Standard: Demonstrate knowledge and understanding of electronic components

Learning Outcome: *Apply knowledge and understanding of electronic components to design and construct electronic circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at digital electronics as they apply to electronics technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques as regards logic gates and how they can be used to design electronic circuits.

The unit covers only week 13: ***Describe types of logic gates and determine the output function of the various gates***

Recap weeks

Year 2	**Week 21:** Solve problems on binary numbers

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on logic gates through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe types of logic gates and determine the output function of the various gates	Level,4 (Extended Strategic reasoning)	Assessment mode: Group Project
Describe the truth table for the various logic gates and determine the output function of the various gates.	**3 (Strategic reasoning)**	Assessment mode: Group project

WEEK 13

Learning Indicators

1. *Describe types of logic gates*
2. *Describe the truth table for the various logic gates and determine the output function of the various gates*

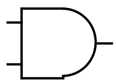
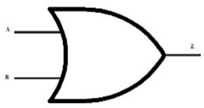
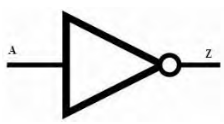
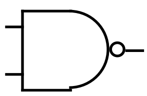
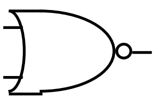
FOCAL AREA 1: TYPES OF LOGIC GATES AND THEIR PROPERTIES

Definition of logic gates: A logic gate is a digital electronic circuit designed with components like diodes, transistors, resistors and more, for performing logical operations. Mostly, the entire circuit is built into a single chip and so a gate can equally be defined as an electronic component which has one or more inputs but with a single output. A gate provides a logical output that is either high (1) or low (0), depending on the inputs supplied to it.

Types of Logic Gates

Basically, logic gates can be grouped into three main categories: These are AND, OR, and NOT gates. However, there are also NAND and NOR, but these are derived from the first two. For instance, NAND stands for Not AND and it is the inverse of the AND gate. NOR also stands for Not OR, and it is the inverse of the OR gate. Table 3.5 shows the symbols of the various gates.

Table 3.5: *Symbols of logic gates*

S/N	Symbol	Name
1		AND gate
2		OR gate
3		NOT gate
4		NAND gate
5		NOR gate

Properties of logic gate

Logic gates have certain properties that guide their operations. The following are the properties of each gate

1. **AND gate**
   - **a.** This gate can accept two or more input values at a time.
   - **b.** When all the inputs are High (logic 1), the output of this gate will be High (logic 1).
   - **c.** It can perform logical multiplication of binary inputs.
2. **OR gate**
   - **a.** This gate can accept two or more input values at a time.
   - **b.** When all of the inputs are logic 0, the output is logic 0.
   - **c.** It can perform logical additions of binary inputs.
3. **NOT gate**
   - **a.** It has only one input and one output
   - **b.** Its output is the inverse of the input
   - **c.** When the input is logic 0, the output of this gate is logic 1 and vice versa.
4. **NAND gate**
   - **a.** This gate can accept two or more inputs at a time
   - **b.** Its output is logic 0, only when all inputs are at logic 1
   - **c.** It performs the inverse operations of the AND gate.
5. **NOR gate**
   - **a.** This gate can accept two or more input values at a time.
   - **b.** Its output is logic 1 only when all inputs are logic 0
   - **c.** It performs the inverse operations of the OR gate.

Truth table of logic gates

A Truth table shows the output for every possible combination of a logic gate's input(s).

1. **The NOT gate:** The NOT gate is also called an inverter. It has a single input and an output. It performs logical inversion operation, inverting 1 to 0 and vice versa. That is, if the input is A, then the output is NOT A, written as $\bar{A}$. The output of an inverter is the opposite of the input. Figure 3.18 shows the symbol of an inverter

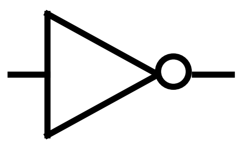


Fig 3.18: *NOT Gate*

Notice the small circle at the output of the inverter. This circle indicates inversion in logic circuits. Using the binary digits, if the input is 1, then the output will be 0 and vice versa. The behaviour of a NOT gate can be summarised in the truth table (Table 3.6).

Table 3.6: *Truth table of a NOT gate*

Input A	Output F = *A*
0	1
1	0

Where F represent the output function of the gate.

2. **The AND gate:** The AND gate consist of two or more inputs terminals and a single output terminal as shown in figures 3.19a and 3.19b.

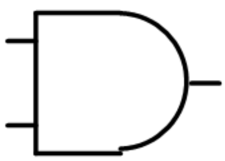


Figure 3.19a: *Two input AND gate*

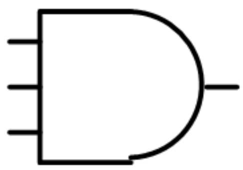


Figure 3.19b: *Three input AND gate*

The output of an AND gate is true if all the inputs are in the true state. This can be illustrated by connecting switches in series as shown in Figure 3.20.

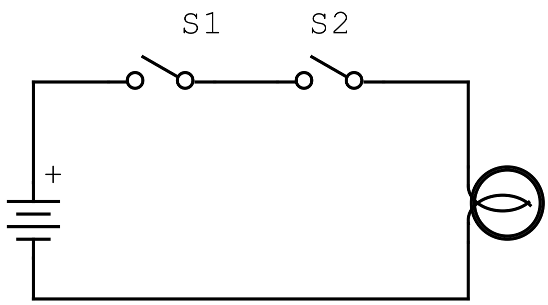


Figure 3.20: *Switches in series*

If switch A is on and switch B is off, the bulb (output) will be off. In the same way if A is off and B is on, the bulb will be off. However, if both switches are on, the bulb will be on, and if both are off, the bulb will be off. Note that the binary digit 1 normally represents the ON while 0 represent OFF. The behaviour of an AND gate can thus be summarised in the truth tables shown in tables 3.7a and 3.7b.

Table 3.7a: *Truth table for 2-input AND gate*

INPUT		OUTPUT
A	B	F = A.B
0	0	0
0	1	0
1	0	0
1	1	1

Table 3.7b: *Truth table for 3 input AND gate*

INPUTS A	B	C	OUTPUT F = A. B. C
0	0	0	0
0	0	1	0
0	1	0	0
1	0	0	0
0	1	1	0
1	0	1	0
1	1	0	0
1	1	1	1

3. **The OR gate:** The OR gate also consists of two or more inputs and a single output. Figures 3.21a and 3.21b shows the symbols for a 2 input and 4 input OR gates.

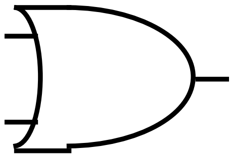


Figure 3.21a: *2-input OR gate*

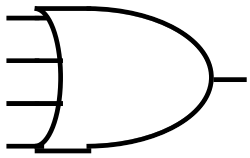


Figure 3.21b: *4 input OR gate*

The output of an OR gate is true if either or any of the inputs is true. This behaviour is be illustrated by connecting switches in parallel as shown in Figure 3.22.

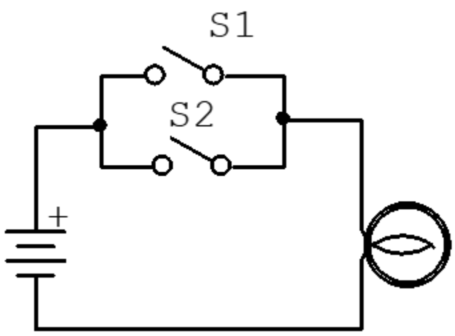


Figure 3.22: *Switches in parallel*

In this circuit, either or both switches will complete the circuit. The bulb will only be off if both switches are off. The truth table for an OR gate is shown in tables 3.8a and 3.8b

Table 3.8a: *2 input OR gate*

INPUT A	B	OUTPUT F = A + B
0	0	0
0	1	1
1	0	1
1	1	1

Table 3.8b: *3 Input OR gate*

INPUT A	B	C	OUTPUT F= A+B+C
0	0	0	0
0	0	1	1
0	1	0	1
1	0	0	1
0	1	1	1
1	0	1	1
1	1	0	1
1	1	1	1

4. **NAND gate:** The NAND gate is derived from an AND gate followed by a NOT gate or inverter as shown in Figure 3.23a. The output of a NAND gate is the binary inverse of AND. Thus, the NAND gate simply means Not AND.

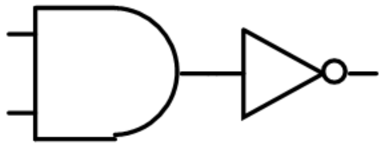


Figure 3.23a: *AND followed by NOT*

The symbol of the NAND gate is an AND gate with a small circle at the output indicating inversion as shown in Figure 3.23b. The truth table for the NAND gate is also shown in table 3.9.

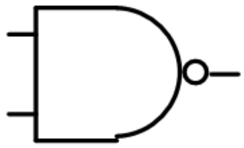


Fig 3.23b: *NAND gate*

Table 3.9: *Truth table of 2 input NAND gate*

INPUT		OUTPUT
A	B	F = (A . B)’
0	0	I
0	I	I
I	0	I
I	I	0

.

5. **The NOR gate:** The NOR gate is also derived from an OR gate followed by an inverter, as shown in Figure 3.24a

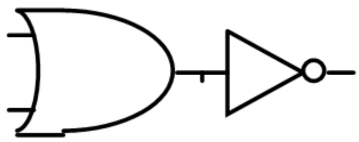


Figure 3.24a: *OR followed by NOT*

The output of a NOR gate is the binary inverse of OR, that is. Not OR. The symbol is an OR gate with an inversion sign as shown in Figure 3.24b. Its truth table is shown in table 3.10.

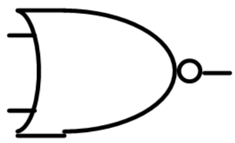


Figure 3.24b: *NOR gate*

Table 3.10: *Truth table of a NOR gate*

INPUTS		OUTPUT
A	B	$F = \bar{A} + B$
0	0	1
0	1	0
1	0	0
1	1	0

FOCAL AREA 2: OUTPUT FUNCTIONS OF LOGIC GATES

The output function of a logic gate depends on the type of gate

Implementation of Digital Logic Gates: Technologies involving components such as diodes, transistors and relays are often used in making digital logic gates. However, diodes and transistors are the most common methods often used. Remember, that diodes are components that pass current in one direction only. In most cases, bipolar junction transistors (BJT) are used. But metal-oxide-semiconductor field-effect transistors (MOSFETs) are equally used. Some digital logic circuits are as follows:

1. **Transistor-Transistor Logic-NOR gate:** TTL logic family uses BJTs to implement digital logic gates. Recall from year 2 that BJTs are made up of three regions: base, emitter and collector. The base controls the current flow between the collector and the emitter. A small current applied to the base turns on the transistor causing a large current to flow from the collector to the emitter. Note that without a base current, the transistor is off. current is applied to the base, no current flows from the collector to the emitter, turning the transistor off. In TTL logic gates a number of transistors are connected in various configurations for the performance logical operations. Normally, the input signal is applied to the bases of the transistors and the output signal is taken from either the collector or the emitter of the transistors. A typical TTL logic circuit is shown in Figure 3.25. This TTL is a typical NOR gate. The output is HIGH only when both inputs are LOW (0 volts).

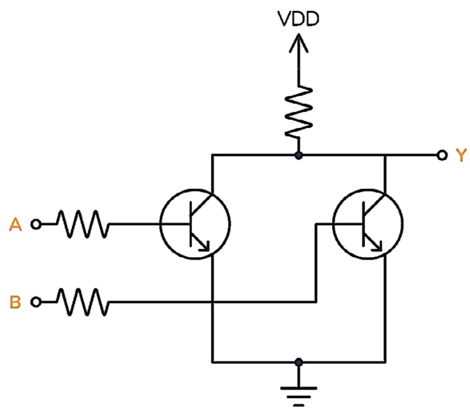


Figure 3.25: *Transistor-transistor logic circuit of a NOR Gate*

When both inputs A and B of the circuit in Figure 3.25 are LOW (logic 0), the base of the two transistors Q1 and Q2 experience low voltage and are therefore OFF and so no current is drawn from the supply. Note that since no current is drawn from the supply, no voltage is dropped across the resistor connected to the power supply VDD. As a result, the output goes High (logic 0).

On the other hand, if any input is HIGH, or both inputs are HIGH, the transistors will switch on, drawing current through their collectors to ground. This makes the resistor connected to VDD, to drop high voltage, The output Y, therefore goes LOW (logic 0). The output will therefore be HIGH, if and only if both inputs are LOW. Table 3.11 shows the truth table. Hence the output function is Y = (A+B)'

Table 3.11: *Truth table of a NOR gate*

INPUTS		OUTPUT
A	B	Y = (A + B)'
0	0	1
0	1	0
1	0	0
1	1	0

Some advantages of TTL logic gates are as follows:

a. They are highly immune to noise

b. They are cheap and readily available.

c. They are fast and reliable.

TTL logic gates have some of disadvantages including the following:

a. High power consumption compared to other logic families.

b. TTL produce more heat than other logic families.

c. Their operating voltage range is limited (between 4.75 and 5.25 volts).

2. Diode Transistor Logic Circuit – AND gate: A 3-input diode transistor logic of an AND gate is shown in Figure 3.26. The circuit consists of a base resistor R1 and an emitter resistor R_E. The base resistor R1 is connected between the power supply (5v) and the base of the transistor at point B. The output Y, is taken between the emitter of the transistor and the emitter resistor, consequently, the output voltage is equal to the voltage across RE.

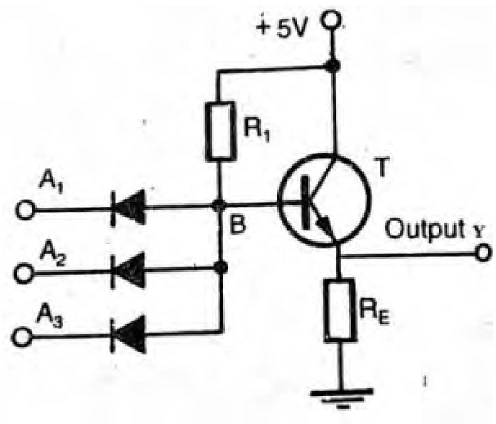


Figure 3.26: *A 3-input diode transistor logic of an AND gate*

Operation: Whenever all the three inputs A1, A2, and A3 are LOW, (logic 0), the diodes are forward biased, (Remember diodes allow current to flow in one direction only).

Therefore, they conduct current from the supply (5v) through R1 to ground. This causes R1 to drop a high voltage. Because of that, the base of the transistor does not have enough voltage to turn it on so no collector current flows and by extension, no emitter current. Therefore, no voltage flows across RE which is also the output voltage and Output is LOW (logic 0) Note that it is the same effect, if any of the input is LOW.

On the other hand, if all three inputs are HIGH, (logic 1), all three diodes will be reverse biased and will not conduct current. Base voltage of the transistor increases and turns it (the transistor) on. This results in current flowing through the emitter causing a voltage to be established across it. Output goes HIGH (logic 1). The truth table is shown in table 3.12. The output function F = A.B.C

Table 3.12: *Truth table for 3 input AND gate*

INPUTS			OUTPUT
A	B	C	F = A. B. C
0	0	0	0
0	0	I	0
0	I	0	0
I	0	0	0
0	I	I	0
I	0	I	0
I	I	0	0
I	I	I	I

3. **Diode-transistor logic-NAND gate:** The diode-transistor logic circuit of a 3-input NAND gate is shown in Figure 3.27. This is a 3-input diode transistor logic NAND gate circuit. This circuit is designed with three diodes, D1, D2 and D3 and a transistor Q1. Notice that the transistor receives its input at the base through R1. The voltage across the collector-emitter region of the transistor forms the output and receives power through RL. Capacitor 'C1' is used to give an overdrive current throughout the switching time and this decreases the switching time to some level.

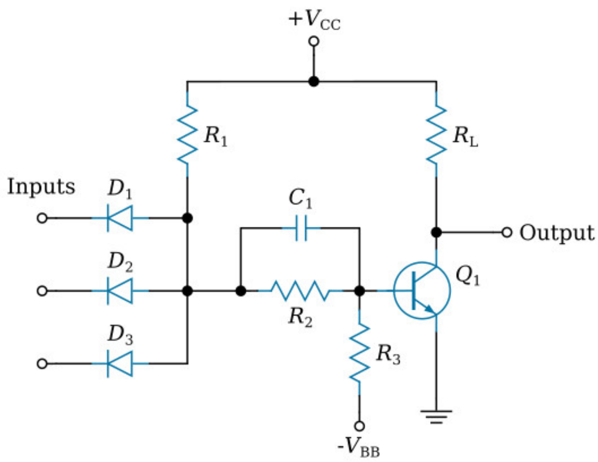


Figure 3.27: *Diode transistor logic circuit of a 3 input NAND gate*

Operation: Whenever all three inputs of the circuit are LOW (logic 0), then all three diodes D1, D2 and D3 will be forward biased, and thus conducting current from the supply (Vcc) through R1 to GND. This causes a high voltage to be dropped across R1 and so the voltage supply to the base of the transistor Q1 becomes too low that it cannot trigger it (the transistor) The transistor is thus switched off and does not conduct any current at the collector region. This makes the output of the transistor

HIGH (logic 1), since no voltage is dropped across RL. Note that the output will be HIGH if any one of the inputs is LOW, (logic 0).

On the other hand, whenever all three inputs of the circuit are HIGH, (connected to Vcc), all three diodes D1, D2 and D3 will be reverse biased, and cannot conduct current from the supply (Vcc) through R1 to GND. Voltage at the base region of the transistor becomes high and the transistor switches on, conducting collector current in the process. This causes a high voltage to be dropped across RL making the output to be LOW. Table 13.9 shows the truth table for a 3-input NAND gate. The output function F = (A.B.C)'.

Table 3.13: *Truth table for 3 input NAND gate*

INPUTS			OUTPUT
A	B	C	F = (A . B . C)'
0	0	0	I
0	0	I	I
0	I	0	I
I	0	0	I
0	I	I	I
I	0	I	I
I	I	0	I
I	I	I	0

4. **Diode logic - OR gate:** A 2-input OR gate circuit based on diode logic is shown in Figure 3.28. For this figure, the output, Z, will be HIGH (logic1) when X is HIGH, or Y is HIGH or both X and Y are HIGH. However, the output is LOW when both X and Y are LOW. The truth table is shown in table 13.14. The output function for this gate is Z= X+Y.

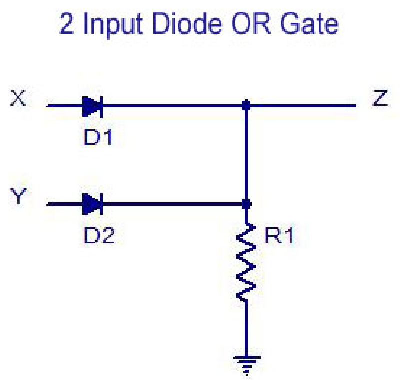


Figure 3.28 A 2-input Diode logic OR gate

Table 3.14: *input OR gate*

INPUT		OUTPUT
X	Y	Z = A + B
0	0	0
0	I	I
I	0	I
I	I	I

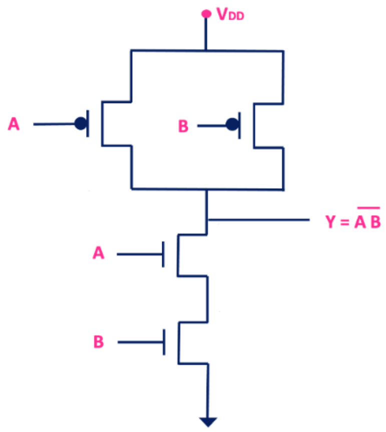
5. **Complementary Metal-Oxide-Semiconductor (CMOS):** CMOS is a logic family that uses MOSFETs to implement. Recall from year 2 that a m**etal Oxide Semiconductor**

Field-effect Transistor (MOSFET) is a field-effect transistor (FET with an insulated gate, where the voltage determines the conductivity of the device. The terminals of MOSFETs are usually the gate, source and drain, and it is the gate which controls the current flow between the source and the drain. Usually, they have the same voltage levels at both and output. CMOS logic gates employ a complementary pair of NMOS (N-channel MOSFETs) and PMOS (P-channel MOSFETs) transistors. The complementary pairs may be connected either in series or in parallel configurations to perform logical operations on the input signals that are applied to them.

Note **that** NMOS logic offers higher density and speed for digital circuits. PMOS Logic, on the other hand, uses positive and negative voltages to perform logic functions. PMOS and NMOS transistor can be used as a switch by controlling the gate to source voltage, as such, they can be used to design a logic gate. Note that, in both NMOS and PMOS transistor, the voltage applied between the gate and source is the control voltage.

For AND operation between the two variables, involving NMOS network, two NMOS transistors will be connected in series, with the output being its complement. Figure 3.29 shows CMOS implemented as NAND gate

NAND Gate



Truth Table

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

Figure 3.29: *CMOS implemented as NAND gate*

For two input NAND gate, if A and B are the inputs then its output Y = (A.B)' or $\overline{A.B}$

Advantages and disadvantages of CMOS

Some advantages of CMOS logic gates are as follows:

1. They consume very low power particularly when they are in a steady state,
2. In a steady state also, they produce little heat
3. They are immune to high noise and fan-out.
4. Their operating voltage range is wide

Some of their disadvantages include:

1. Comparatively, they are slow when switching states.
2. They are easily damaged by electrostatic discharge.
3. They are bulky and so they occupy a lot of space compared to other logic families

Applications of Logic Gates

Logic gates have numerous applications in various fields of engineering and science. They include:

1. Digital circuits
2. Computer architecture
3. Programming languages
4. Error detection and correction
5. Artificial intelligence

Learning Tasks

1. Explain how the BJT can be used to obtain Transistor –transistor logic.
2. Compare the DTL, TTL and COMOS in terms of their design and performance.

Pedagogical Exemplars

Teachers should consider the following activities:

Collaborative Learning: With the use of the internet, engage learners in mixed ability groups to undergo the following activities:

1. Define the term 'Logic Gate '
2. Outline the types of Logic gates that we have and give examples i.e. Basic logic gate e.g., AND, NOT and OR gates and Universal Logic Gates e.g. NAND and NOR gates.

   Experiential Learning/collaborative learning: In mixed-ability groups and with the use of the internet, task learners to describe how each gate operate and outline their applications as well.

   Experiential Learning: Engage learners to work in mixed gender groups to:

1. Construct the truth table for the various logic gates and determine the output functions of the various gates from the Boolean expressions given.
2. Task learners to present their findings from the group work

   Experiential Learning/collaborative learning/ project-based learning: Group learners in mixed-ability groups and guide them to perform experiments on logic gates functions E.g. $F = (A \bullet \overline{B} + \overline{A} \bullet B)$

Key Assessment: Level 4: Group Project

1. Different logic gate families (TTL, CMOS, ECL) have distinctive characteristics.

   a. Analyse how the choice of logic family affects a circuit's power consumption, speed, and noise immunity.

   b. Evaluate which logic family would be most appropriate for: a) A battery-powered medical device b) A high-speed computing system c) A circuit operating in an electrically noisy industrial environment.

   c. Justify your recommendations with technical reasoning.

2. For the Boolean function $F = (A \oplus B) \bullet (B + \bar{C})$. Create four different circuit implementations using:

   a. Only basic AND, OR, and NOT gates

   b. Only NAND gates

   c. Only NOR gates

   d. A mixed approach with minimal gate count

PLC Session 13

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.

2. Use your subject specific app to explore the content before planning. Ask the app to

   a. explain the week's concepts in a practical way that will make it easier for learners to understand

   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

   a. The key assessment for the week is ***group project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS 1a-1b, 1e-1g, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

      i. was the concept explained in a way that a learner with no prior knowledge could follow?

      ii. were the examples grounded in contexts familiar to Ghanaian learners?

      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

   a. transfer your chats into your learning planner template.

   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

UNIT 13 REVIEW

This unit exposed learners to various logic gates and their applications. The pedagogical exemplars used in this unit include Talk for learning approaches and Group work/Collaborative learning. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies, such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 4.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

UNIT 9

Question 1

Criteria	Excellent (4)	Very good (3)	Satisfactory (2)	Needs improvement (1)
Flowchart Structure and Logic	Exemplary flowchart with clear start/end points, logical decision branches, and proper flow direction; uses standard flowchart symbols correctly (process, decision, terminal); implements perfect logical progression from symptoms to causes; includes comprehensive decision points with both "yes" and "no" paths fully developed; flowchart is visually well organised with optimal spacing and connection lines; includes intelligent prioritisation based on likelihood and ease of testing.	Well-structured flowchart with clear decision flow; uses appropriate symbols; demonstrates good logical progression; includes complete decision paths; organised presentation with minor layout issues; shows good prioritisation of likely causes.	Basic flowchart structure with recognisable flow; some use of symbols; reasonable logical progression with occasional gaps; most decision paths complete; adequate organisation with some clarity; some prioritisation of causes.	Simple flowchart structure used; limited number of standard symbols used; limited knowledge of decision paths and cause prioritisation.

Identification of Possible Causes	Identifies all major possible causes with exceptional technical precision: 1) Thermostat failure (contacts fused/stuck, improper calibration); 2) Power control circuit malfunction (faulty Triac/ solid-state relay); 3) Temperature sensor failure (broken or mispositioned); 4) Wiring issues (internal short circuits, damaged insulation); may include additional causes like improper voltage supply or mechanical thermostat positioning problems; demonstrates comprehensive understanding of iron's heating system.	Identifies at least four major causes with good technical detail; includes thermostat failure, control circuit issues, sensor problems, and wiring faults; provides specific details for most causes; demonstrates solid understanding of iron's heating system.	Identifies at least four basic causes with adequate technical explanation; covers main categories with limited specificity; basic understanding of iron's heating system; explanations generally correct but limited depth.	Identifies fewer than four causes ; explanations show minimal understanding of how irons regulate temperature; limited technical knowledge; some causes proposed
Diagnostic Procedures	Exceptional detail in diagnostic procedures, including: precise measurement points; exact test equipment requirements (multimeter settings, temperature probes); specific resistance/voltage values to expect at test points; detailed step-by-step verification methods; includes both powered and unpowered tests where appropriate; diagnostic steps minimise disassembly until necessary; procedures follow logical isolation methodology to pinpoint faults efficiently.	Clear diagnostic procedures with good detail; specifies appropriate test equipment and methods; includes some specific values or ranges to expect; provides step-by-step approach for most tests; balances disassembly requirements with diagnostic needs; follows logical troubleshooting sequence.	Basic diagnostic procedures that would identify major faults; mentions appropriate test equipment; limited specific values or expectations; provides general steps for testing; some logical progression in troubleshooting sequence; may require unnecessary disassembly.	Minimal diagnostic procedures followed; limited test methods used; limited sequences to identify faults; limited use of safe testing approaches.

Technical Accuracy and Detail	Exceptional technical accuracy throughout; demonstrates sophisticated understanding of thermostatic control principles (bimetallic strip operation, solid-state controls); accurately describes electrical principles (Ohm's law applications, power calculation); correct terminology for all components; accurate representation of iron's internal circuitry; includes technical specifications (typical thermostat resistance values, operating temperatures, power ratings).	High level of technical accuracy with minor gaps; demonstrates good understanding of thermostatic control principles; uses correct terminology for most components; accurate electrical concepts; includes some technical specifications or values.	Generally accurate technical information ;basic understanding of thermostatic control; mostly correct terminology; basic electrical concepts generally correct; limited technical specifications.	Limited understanding of thermostatic control, electrical concepts or electrical principles; minimal use of technical terminology and specifications;
Safety Considerations	Comprehensive integration of safety protocols throughout the flowchart; specific warnings at appropriate points (disconnecting power before testing, allowing cooling time, proper handling of exposed elements); includes electrical safety procedures for live testing when necessary; mentions proper tools and personal protective equipment; addresses potential hazards like stored heat, sharp edges during disassembly, and electrical shock risks; includes customer safety considerations for final testing.	Good integration of safety considerations; includes important warnings at key points; addresses electrical safety for most procedures; mentions appropriate tools and precautions; covers major hazards; includes some final safety checks.	Basic safety warnings included with limited integration; mentions main electrical safety concerns; limited discussion of tools or protective equipment; addresses obvious hazards; basic final safety check.	Minimal safety considerations included; unsafe procedures may be suggested; limited warnings about electrical hazards; minimal mention of appropriate tools or protection; few critical safety steps included; basic final safety verification provided

Question 2

Criteria	Excellent (4)	Very good (3)	Satisfactory (2)	Needs improvement (1)
Identification of Possible Causes	Comprehensive identification of 8+ possible causes including: overloaded circuit, short circuit, ground fault, arc fault, loose connections, deteriorated insulation, defective MCB, harmonic distortion, voltage surges, faulty appliances, wet conditions, rodent damage, aging wiring, and incorrect MCB rating; includes rare but possible causes; demonstrates exceptional understanding of electrical systems.	Identifies 6-7 major possible causes including most common ones: overloaded circuit, short circuit, ground fault, loose connections, faulty appliances, and deteriorated insulation; may include some less common causes; demonstrates solid understanding of electrical systems.	Identifies 4-5 basic causes like overloaded circuit, short circuit, ground fault, and faulty appliances; covers most obvious causes but omits some important possibilities; demonstrates adequate understanding of basic electrical faults.	Identifies fewer than 4 causes; omits major common causes; limited understanding of electrical systems and fault mechanisms.
Categorisation of Hazards	Precisely categorises all identified causes with nuanced understanding ; immediate safety hazards included such as short circuits, ground faults, exposed wiring, water ingress, severe insulation damage, direct contact hazards; non-critical faults included such as moderate overloading, intermittent connections, minor insulation aging, nuisance tripping due to sensitivity, incorrect MCB type/rating, harmonic issues; explains rationale for each categorisation with excellent technical justification; recognises that some faults can shift categories based on severity.	Correctly categorises most identified causes with good accuracy: **I:** immediate safety hazards included such as short circuits, ground faults, severe insulation damage; non-critical faults included such as overloading, loose connections; provides good rationale for most categorisations; generally accurate assessment of risk levels.	Basic categorisation of identified causes with some inaccuracies: immediate safety hazards included such as short circuits, ground faults: some non-critical faults included such as overloading, loose connections; Limited explanation for categorisations; some misconceptions about hazard levels.	Minimal categorisation covered; limited critical safety hazards listed as non-critical or vice versa; minimal explanation for categorisations; simple understanding of electrical safety principles.

Technical Analysis	Exceptional technical depth: explains MCB trip curves (B, C, D types) and their implications; describes precise fault mechanisms (impedance calculations, I^2t energy release, thermal vs. magnetic tripping); relates fault currents to circuit parameters; explains time-current characteristics of different faults; references relevant electrical codes (NEC/IEC standards); includes specifics on fault current levels and their effects.	Good technical explanation of major concepts: explains how MCBs detect different faults; describes fault mechanisms with good accuracy; distinguishes between thermal and magnetic tripping; mentions relevant electrical standards; provides some specific technical details on fault detection.	Adequate basic technical explanation: describes fundamental MCB operation; explains basic fault conditions; provides general description of how faults cause tripping; limited reference to standards; minimal specific technical details.	Minimal technical explanation and reference to standards; limited understanding about how MCBs work; simple explanation of fault mechanisms;
Evaluation Methodology	Comprehensive systematic approach to evaluation including: sequential testing methodology; specific instrument requirements (megger, clamp meter, thermal imaging); non-invasive tests before circuit opening; load calculation process; insulation resistance testing protocol; visual inspection checklist; fault current testing approach; appliance isolation method; circuit mapping technique; includes decision trees for diagnostic process.	Well-structured evaluation approach: logical testing sequence; appropriate test equipment identification; good balance of visual inspection and measurement; describes load testing procedure; includes appliance testing method; discusses circuit analysis approach; provides organised troubleshooting steps.	Basic evaluation methods used: mentions main testing approaches; identifies some appropriate tools; includes basic visual inspection; describes simple load testing; mentions isolating appliances; provides general troubleshooting steps without detailed sequence.	Limited use of logical evaluation methods and testing approaches; minimal number of tools specified; simple approach that would not effectively identify the fault.

Safety Understanding and Recommendations	Exceptional safety awareness: comprehensive safety protocols before, during and after testing; detailed lockout/tagout procedures; specific recommendations for emergency measures for different fault types; distinguishes immediate vs. deferred actions based on risk assessment; discusses documentation requirements; recommends appropriate qualification levels for different repair actions; includes follow-up testing protocol; addresses liability and compliance considerations; provides clear homeowner vs. professional scope differentiation.	Strong safety awareness: good safety protocols for testing; clear recommendations for immediate actions; distinguishes between DIY-safe and professional-only repairs; includes important warnings for high-risk situations; discusses verification testing after repairs; provides good guidance on when to call professionals.	Basic safety awareness covered: mentions main safety precautions; includes some recommendations for homeowner actions; identifies when professional help is needed; includes basic warnings about electrical hazards; mentions post-repair verification; limited discussion of compliance issues.	Minimal safety awareness and few critical safety warnings; basic recommendations only; inadequate distinction between homeowner-safe and professional-only repairs; limited post-repair verification steps; recommendations that could create additional hazards.

UNIT 10

Question 1

Criteria	Excellent (4 marks)	Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Technical Understanding	Demonstrates comprehensive understanding of three-phase induction motor principles; correctly identifies relationship between current, torque, and heating; shows exceptional knowledge of motor construction	Shows solid understanding of three-phase motor operation; correctly relates most aspects of the fault symptoms to motor principles	Displays basic understanding of motor operation; partially connects symptoms to causes	Shows limited understanding of motor principles; limited concepts explored

Fault Analysis Methodology	Presents systematic, logical approach to fault diagnosis; considers electrical, mechanical, and thermal aspects; demonstrates excellent diagnostic reasoning	Shows organised approach to fault analysis; considers multiple aspects of the problem; demonstrates good diagnostic reasoning	Shows somewhat organised approach but logical steps omitted; limited consideration of different fault aspects	Presents illogical fault analysis; limited coherent diagnostic approach
Identification of Possible Causes	Identifies multiple relevant potential causes including: single-phase condition, winding fault, voltage imbalance, rotor issues; comprehensive coverage of possibilities	Identifies several relevant potential causes with good coverage of main possibilities	Identifies some relevant causes and few key possibilities; limited scope of analysis	Identifies few causes; limited knowledge in fault possibilities
Technical Explanation	Provides precise technical explanations for each cause; clearly explains how each cause produces the specific symptoms; includes quantitative relationships where appropriate	Provides good technical explanations for most causes; connects causes to symptoms with adequate detail	Provides basic explanations with limited technical detail; limited knowledge connecting causes to symptoms	Provides minimal technical explanations; minimal connection between causes and symptoms
Practical Validation	Proposes specific, practical tests to confirm each potential cause; includes expected measurements and results; demonstrates excellent troubleshooting knowledge	Proposes reasonable tests for most causes; includes some specific measurements; demonstrates good troubleshooting knowledge	Proposes some basic tests with limited specificity; demonstrates fundamental troubleshooting knowledge	Proposes few tests; limited troubleshooting knowledge

Question 2

Criteria	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Technical Understanding	Demonstrates comprehensive understanding of DC motor principles; correctly identifies potential thermal, mechanical, and electrical failure modes; shows exceptional knowledge of how these affect motor operation	Shows solid understanding of DC motor operation; identifies most relevant failure modes; connects symptoms to likely causes	Displays basic understanding of motor operation with some knowledge gaps; identifies some relevant failure modes	Shows limited understanding of DC motor principles; makes limited ability in identifying potential causes
Systematic Approach	Presents a highly organised, logical sequence of diagnostic steps; demonstrates excellent troubleshooting methodology; follows clear progression from non-invasive to more invasive tests	Shows organised approach with logical sequence; demonstrates good troubleshooting methodology; generally progresses from simple to complex tests	Shows somewhat organised approach with some logical gaps; demonstrates basic troubleshooting methodology	Presents limited number of diagnostic steps; minimal use of troubleshooting methodology
Safety Considerations	Thoroughly addresses safety precautions at each relevant step; demonstrates excellent awareness of electrical and mechanical hazards	Addresses safety precautions for most steps; demonstrates good awareness of main hazards	Mentions some safety considerations; demonstrates basic awareness of hazards	Minimal mention of safety considerations; demonstrates limited safety awareness
Justification of Steps	Provides thorough, technically precise justification for each diagnostic step; clearly explains why each test is performed and what information it provides	Provides good justification for most steps with adequate technical explanation	Provides basic justification for some steps with limited technical detail	Provides minimal justification for steps; limited use of technical reasoning

Comprehensiveness	Includes all major potential causes relevant to symptom (thermal issues, mechanical binding, electrical problems, load issues); provides complete diagnostic coverage	Includes most major potential causes with good diagnostic coverage	Includes some relevant causes but key possibilities	Identifies few potential causes; limited diagnostic coverage
Technical Understanding	Demonstrates comprehensive understanding of DC motor principles; correctly identifies potential thermal, mechanical, and electrical failure modes; shows exceptional knowledge of how these affect motor operation	Shows solid understanding of DC motor operation; identifies most relevant failure modes; connects symptoms to likely causes	Displays basic understanding of motor operation with some knowledge gaps; identifies some relevant failure modes	Shows limited understanding of DC motor principles; minimal knowledge in identifying potential causes

UNIT 11

Question 1 (16 marks)

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Timing Inaccuracy Analysis	Identifies three precise, technically valid sources of inaccuracy with detailed explanation of how each affects timing; demonstrates exceptional understanding of 555 timer operation	Identifies three valid sources with good technical explanation for most; demonstrates solid understanding of timer operation	Identifies 2-3 sources with basic explanation; demonstrates adequate understanding of timer principles	Identifies fewer than three valid sources and provides minimal analysis; demonstrates limited understanding of timer operation

Component Value Calculation	Performs complete, correct calculations with all steps clearly shown; selects optimal component values considering tolerance, availability, and stability; justifies choices with technical reasoning	Performs correct calculations with most steps shown; selects appropriate component values; provides adequate justification	Performs basic calculations providing limited results; selects workable component values	Limited understanding of calculations required; simple selection of component values
Temperature Stability Improvements	Proposes multiple specific, technically sound modifications to improve temperature stability; explains precisely how each modification works; demonstrates excellent understanding of temperature effects on electronic components	Proposes 2-3 valid modifications with good technical explanation; demonstrates good understanding of temperature effects	Proposes 1-2 basic modifications with limited technical explanation	Proposes vague modifications to improve stability; limited understanding of temperature effects
Configuration Evaluation	Provides comprehensive comparative analysis of stable vs. monostable for bell system; considers multiple relevant factors (timing precision, reset capabilities, power consumption, failure modes); makes well-justified recommendation	Provides good comparative analysis considering several factors; makes appropriate recommendation with adequate justification	Provides basic comparison with limited factors considered; makes reasonable recommendation with minimal justification	Provides limited comparison with simple consideration of relevant factors; recommendation has limited justification

Question 2 (24 marks)

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Circuit Design Completeness	Comprehensive circuit diagram with all necessary subsystems: moisture sensing, dual timing control (24/48hr), 30-second pump activation, power supply protection; all components properly labelled with values	Complete circuit with all major subsystems; minor omissions in component details; proper integration of subsystems	Basic functional circuit with some subsystem integration issues; missing several component details	Simple circuit proposed; limited integration included; minimal component details
555 Timer Implementation	Excellent implementation of multiple 555 timers with proper configuration for long-interval timing and 30-second control; innovative solutions for extending timing range; correct interconnection	Good implementation of 555 timers for required functions; appropriate configuration choices; proper connection between stages	Basic implementation with functional timing circuits and simple design; some connection issues between stages	Simple implementation with limited knowledge about 555 timer operation; minimal configurations included
Component Calculations	Comprehensive calculations for all timing components with clear methodology; excellent selection of practical component values; consideration of tolerance and temperature effects; complete justification	Accurate calculations for most timing components; good selection of practical values; some consideration of component limitations	Basic calculations with minor errors; workable component selection; limited consideration of real-world factors	Limited use of accurate calculations; minimal knowledge of component values and limitations
Moisture Sensing Integration	Sophisticated moisture sensing circuit with excellent threshold control; perfect integration with timing control; clear explanation of how sensing affects timing	Effective moisture sensing with good integration to timing control; adequate explanation of interaction	Basic moisture sensing with simple and functional integration; limited explanation	Simple moisture sensing proposed; limited integration with timing circuit

Failure Mode Analysis	Comprehensive analysis of multiple potential failure modes (power issues, sensor failure, component drift, pump problems); specific circuit-level safeguards for each; excellent preventative design features	Good analysis of several failure modes with appropriate safeguards for most; consideration of major system vulnerabilities	Basic analysis of obvious failure modes with some safeguards proposed; limited preventative features	Minimal inclusion pf failure analysis; few safeguards included
System Evaluation	Exceptional evaluation of design trade-offs; insightful analysis of reliability factors; detailed cost considerations; thorough functionality assessment; well-reasoned overall evaluation	Good evaluation of main design trade-offs; reasonable analysis of reliability, cost and functionality; sound overall assessment	Basic evaluation with consideration of some trade-offs; limited analysis of one or more key factors	Limited evaluation with minimal consideration of design trade-offs; superficial analysis

UNIT 12

Question 1

Criteria	Excellent (4 marks)	Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Application Selection & Description	Selects highly appropriate application with comprehensive description of circuit requirements and operating conditions; clearly connects application needs to op-amp performance	Selects appropriate application with good description of circuit requirements; establishes connection between application and op-amp performance	Selects reasonable application with basic description; connection to op-amp performance identified	Selects simple application and provides minimal description; limited connection to op-amp requirements

Op-Amp Limitations Analysis	Comprehensively Analyses multiple non-ideal characteristics (finite gain, bandwidth, slew rate, input/output impedance, offset, bias current, CMRR, PSRR) with precise technical explanation of how each affects the specific application	Analyses several non-ideal characteristics with good technical explanation of effects on application	Analyses some basic limitations with adequate explanation of general effects	Provides minimal analysis of limitations; limited understanding of effects
Prioritisation of Limitations	Provides insightful evaluation of which limitations are most critical for the application with excellent justification; demonstrates exceptional understanding of performance trade-offs	Evaluates relative importance of limitations with good justification; demonstrates solid understanding of trade-offs	Provides basic evaluation of limitation importance with limited justification	Provides simple evaluation of limitation importance; f limited application to justify prioritisation
Compensation Design	Designs multiple, technically sound circuit modifications to address each critical limitation; provides detailed schematics with component values; thoroughly explains how each modification compensates for specific limitations	Designs several appropriate modifications with good technical explanation and component information	Designs basic modifications with adequate explanation but limited detail	Provides minimal compensation designs
Beneficial Limitations Discussion	Provides highly insightful, original discussion of how certain “limitations” can be beneficial in specific scenarios; demonstrates exceptional creative thinking and technical depth	Discusses several scenarios where limitations provide benefits with good technical reasoning	Provides basic discussion of beneficial aspects with limited technical support	Offers minimal discussion of beneficial limitations

Technical Accuracy	Demonstrates exceptional technical accuracy throughout; precise use of terms, calculations, and circuit principles	Demonstrates good technical accuracy with minor errors; mostly correct use of terms and principles	Shows adequate technical understanding	Limited understanding of technical requirements

Question 2 (32 marks)

Criteria	Excellent (4 marks)	Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Circuit Design Completeness	Comprehensive circuit with all required subsystems: water level sensing, threshold detection, pump control, alarm circuit, and LED display; all components properly specified	Complete circuit with all major subsystems; minor omissions in component details; proper integration of subsystems	Basic functional circuit with some integration issues between subsystems; missing several component details	Limited circuit design presented; little system integration included; minimal component details
Op-Amp Implementation	Excellent use of multiple op-amp configurations (comparators, amplifiers, buffers) with proper circuit parameters; optimal op-amp selection for each function	Good implementation of op-amps for required functions; appropriate configuration choices; proper connection between stages	Basic implementation with functional op-amp circuits limited in design; some connection issues between stages	Limited implementation of op amps; little mention of op amp configurations
Water Level Sensing Approach	Sophisticated sensing design with excellent noise immunity; appropriate sensor interface to op-amps; calibration capabilities; consideration of tank material and water conductivity	Effective sensing design with good interface to op-amps; some consideration of environmental factors	Basic sensing design with functional but limited interface; minimal environmental considerations	Limited sensing design approach; minimal coverage of interface to op-amps; little mention of environmental aspects

Control Logic Implementation	Precise threshold detection for 25% and 90% levels; excellent hysteresis implementation to prevent oscillation; fail-safe logic design; proper isolation between control and power circuits	Good threshold detection with appropriate hysteresis; adequate isolation between circuits; proper pump control logic	Basic threshold detection with functional control logic; limited consideration of oscillation prevention	Minimal threshold detection in place; Limited mention of hysteresis; simple pump control logic
LED Display Design	Innovative, clear level display using op-amps to drive multiple LEDs or bar graph; excellent scaling of sensor input to display output; intuitive visual indication	Good display implementation with appropriate op-amp drivers; clear visual indication of water levels	Basic functional display with limited resolution; adequate op-amp interface	Simple display implementation; limited use of op-amps for display
Functional Explanation	Comprehensive explanation of each circuit stage with precise technical detail; clear description of signal flow; excellent explanation of op-amp configuration choices	Clear explanation of most circuit stages with good technical detail; adequate description of configuration choices	Basic explanation of main functions with limited technical detail; some gaps in explanation	Minimal explanation of circuit operation; limited understanding of op-amp configurations
Failure Mode Analysis	Thorough analysis of multiple potential failure modes (sensor failure, op-amp failure, power issues, mechanical failures); specific circuit-level safeguards for each; excellent preventative design features	Good analysis of several failure modes with appropriate safeguards for most; consideration of major system vulnerabilities	Basic analysis of obvious failure modes with some safeguards proposed; limited preventative features	Minimal or superficial failure analysis; few inappropriate safeguards mentioned

Power Consumption Evaluation	Comprehensive evaluation of power requirements for all circuit components; excellent low-power design considerations; detailed analysis of battery vs. mains power options; power-saving features	Good evaluation of power requirements with reasonable low-power considerations; adequate analysis of power source options	Basic power evaluation with limited consideration of efficiency; some awareness of power constraints	Minimal power consumption analysis; little consideration of efficiency or constraints

UNIT 13

Question 1

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Technical Knowledge of Logic Families	Demonstrates comprehensive understanding of all three logic families with accurate technical details about their construction and operation	Shows solid understanding of the logic families with mostly accurate technical details	Displays basic understanding of logic families with some technical inaccuracies	Shows limited understanding of logic families and concepts
Analysis of Power Consumption	Provides detailed analysis of power requirements for each family with specific technical factors (static vs. dynamic power, supply voltage ranges, etc.)	Correctly analyses power consumption differences with adequate technical detail	Provides basic comparison of power needs with limited technical explanation	Offers minimal analysis of power characteristics
Analysis of Speed Characteristics	Thoroughly analyses propagation delay, rise/fall times, and switching characteristics with precise technical explanation	Correctly explains speed differences with good technical detail	Provides basic explanation of speed characteristics with limited technical support	Provides minimal analysis of speed factors

Analysis of Noise Immunity	Comprehensively analyses noise margin, input/output voltage levels, and immunity mechanisms with detailed technical reasoning	Accurately describes noise immunity differences with appropriate technical terms	Provides basic explanation of noise immunity with limited technical detail	Offers minimal analysis of noise immunity
Application Evaluation: Medical Device	Provides insightful evaluation with multiple relevant factors considered (power efficiency, reliability, etc.) leading to well-justified recommendation	Offers good evaluation with consideration of key factors leading to appropriate recommendation	Provides basic evaluation with limited consideration of relevant factors	Offers minimal evaluation simple recommendation
Application Evaluation: High-speed Computing	Provides insightful evaluation with multiple relevant factors considered (propagation delay, fan-out, etc.) leading to well-justified recommendation	Offers good evaluation with consideration of key factors leading to appropriate recommendation	Provides basic evaluation with limited consideration of relevant factors	Offers minimal evaluation with simple recommendation
Application Evaluation: Noisy Environment	Provides insightful evaluation with multiple relevant factors considered (noise margins, input protection, etc.) leading to well-justified recommendation	Offers good evaluation with consideration of key factors leading to appropriate recommendation	Provides basic evaluation with limited consideration of relevant factors	Offers minimal evaluation with simple recommendation
Technical Justification	Justifications are comprehensive, technically precise, and directly connect logic family characteristics to application requirements	Justifications are logical, technically sound, and connect characteristics to requirements	Justifications show basic reasoning with limited technical connection	Simple justifications provided

Question 2

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Implementation with Basic Gates	Perfect implementation using AND, OR, and NOT gates only; correctly implements XOR using basic gates; circuit is optimised and logically organised	Correct implementation with minimal inefficiencies or organisational issues; XOR correctly implemented	Mostly correct implementation; Limited presence of logic organisation	Limited implementation present and functions attempted
Implementation with NAND Gates Only	Perfect implementation using only NAND gates; demonstrates thorough understanding of NAND equivalents for all required operations; optimised gate count	Correct implementation with only NAND gates but with minor inefficiencies; good understanding of NAND equivalents	Basic implementation with some errors; limited understanding of NAND universality	Limited attempt to include NAND gates for functions
Implementation with NOR Gates Only	Perfect implementation using only NOR gates; demonstrates thorough understanding of NOR equivalents for all required operations; optimised gate count	Correct implementation with only NOR gates but with minor inefficiencies; good understanding of NOR equivalents	Basic implementation with some errors; limited understanding of NOR universality	Limited attempt to include NOR gates for functions
Mixed Approach with Minimal Gates	Achieves provably minimal gate implementation; creative approach to optimisation ; excellent understanding of which gates to use for maximum efficiency	Good optimisation with near-minimal gate count; sensible selection of gate types	Basic optimisation attempt with moderate gate reduction; some understanding of efficient gate selection	Minimal coverage of optimisation; limited attempt at gate count

Circuit Diagram Clarity	Perfectly clear diagrams with proper symbols; logical signal flow; well-labelled inputs/outputs; easy to follow	Clear diagrams with minor presentation issues; good signal flow; adequate labelling	Basic diagrams that communicate the implementation but with minor organisational or clarity issues	Simple attempt to create and label signal flow diagrams
Technical Accuracy	All implementations correctly realise the exact Boolean function; demonstrates perfect understanding of logical equivalence	Implementations correctly realise the function with minor inaccuracies in one version	Some implementations correctly realise the function, others have functional errors but	Limited attempt to realise correct function

SECTION 4: ALGEBRA, CIRCUIT, MODULATION, TRANSMITTERS AND RECEIVERS

The section covers the following units (strands); Electrical technology and Electronics technology.

In this section, learners will acquire knowledge and understanding of Boolean algebra, principles of logic gates in designing electronic circuits, various types of modulation in communication, AM and FM transmitters in electronic communication, as well as AM and FM receivers in electronic communication. All the above are covered from unit 14 to unit 18.

UNIT 14

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic devices and circuits

Content Standard: Demonstrate knowledge and understanding of electronic components

Learning Outcome: *Apply knowledge and understanding of electronic components to design and construct electronic circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at Logic gates and Boolean algebra as they apply to electrical and electronics technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in the construction, Principle of operation of Logic gates and Boolean algebra in designing circuits and solving problems.

The unit covers only week 14:

1. *Solve problems on Boolean Algebra*
2. *Manipulate and simplify Boolean Algebra*

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on the various aspect of Boolean algebra through a wide range of pedagogical exemplars such as Experiential learning, Research and Collaborative learning.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Solve problems on Boolean Algebra	4 (Extended Strategic reasoning)	Class Exercise
Manipulate and simplify Boolean Algebra	3 (Strategic reasoning)	*Class Exercise*

WEEK 14

Learning Indicators

1. *Solve problems on Boolean Algebra*
2. *Manipulate and simplify Boolean Algebra*

FOCAL AREA 1: PROBLEMS ON BOOLEAN ALGEBRA

1. Elements of Boolean algebra
2. Operations or functions of Boolean algebra
3. Basic rules for each of the operations of Boolean algebra
4. Basic Axioms

FOCAL AREA 2: SOLUTION OF SIMPLE COMBINATIONAL AND SEQUENTIAL LOGIC

Solving problems on Boolean Algebra

1. Redundancy theorem
2. Race-Hazard theorem
3. De-Morgans Theorem

Preamble: Boolean algebra is named after George Boole (1815-64), an English mathematician who developed the basic rules and laws of mathematics and applies them to solve problems on logic. Boolean algebra, just like any other algebra consists of Elements, operations and a set of rules called axioms.

Elements: The elements of Boolean algebra consist of variables and constants. Capital letters such as A, B and C are used to represent the variables. A variable in Boolean algebra can either have a value of 1 or 0. The constants have fixed values of either 1 or 0.

Operation or functions: The operations in basic algebra are addition (+), subtraction (-), division (÷) and multiplication (x). However, in Boolean algebra, only 3 functions or operations are permitted. These are AND, OR and NOT operation. The AND operation. The AND operation between two Boolean variables A and B is written A.B, read A and B.

The table below shows the operation A.B

Table 4.1

A	B	A.B
0	0	0
0	1	0
1	0	0
1	1	1

The following rules can thus be derived from the truth table above.

$A \bullet 1 = A$

PROOF: when A = 0

$0.1 = 0$

When A = 1

$1.1 = 1$

$A \bullet 0 = 0$

PROOF: when A = 0

$0.0 = 0$

When A = 1

$1.0 = 0$

$A \bullet B = B.A$

PROOF: if A = 1 and B = 0

then $1.0 = 0$

$0.1 = 0$

$\therefore A.B = B.A$

$A \bullet \bar{A} = 0$

PROOF: if A = 1 then $\bar{A} = 0$ and if A = 0 then $\bar{A} = 1$

$1.0 = 0.1 = 0$

$A \bullet A = A$

PROOF: if A = 0

then $0.1 = 0$

$0.0 = 0$

if A = 1

$1.1 = 1$

The OR operation. The OR operation between two Boolean Variables A, B written A + B and read A or B. Notice that the + sign is read 'or' not addition. The tables bellow shows the OR operation on the Boolean variables A, B

Table 4.2

A	B	F = A+B
0	0	0
0	1	1
1	1	1

Truth table for OR operation

Can you derive the rules or postulates for this operation?

$A + 1 = 1$

PROOF: when $A = 0$

$0 + 1 = 1$

when $A = 1$

$1 + 1 = 1$

$A + 0 = A$

PROOF: when $A = 0$

$0 + 0 = 0$

when $A = 1$

$1 + 0 = 1$

$A+B = B + A$

PROOF: when $A = 1$ and $B = 0$

$0 + 1 = 1$

when $A = 1$

$0 + 1 = 1$

$\therefore A + B = B + A$

$A + \overline{A} = 1$

PROOF: when $A = 1$, then $\overline{A} = 0$ and vice versa

But $1 + 0 = 0 + 1 = 1$

$A+A = A$

PROOF: when $A = 0$

$0 + 0 = 0$

when $A = 1$

$1 + 1 = 1$

The NOT operation. The NOT operation is also called the negation or complementation and is denoted by a bar over the variable. Thus, the complement of $A = \overline{A}$ and vice versa. Also, if $A = 1$, then $\overline{A} = 0$. It should be obvious that a double inversion leaves the value unchanged.

i.e. $\overline{\overline{B}} = B$

$\overline{\overline{A}} = A$

Summary

Below is a summary of the basic laws derived in this section.

Commutative property (law)

$A + B = B + A$

$A.B \quad = B.A$

Associative property

$(A + B) + C = A + (B + C)$

$(A.B).\ C = (A.B).C$

Identity law

$A + A = A$

$A \bullet A = A$

Negation law

$(\overline{A}) = \overline{A}$

$\overline{\overline{A}} = A$

Algebraic simplification and manipulation

Simplifying an equation in mathematics simply means reducing the equation to its simplest form. Complex logic expressions are therefore simplified to enable us produce cheaper versions of logic circuits. In this section, you will study how Boolean algebra is used to simplify Logical expressions.

Basic axioms

Do you still remember the basic axioms of Boolean algebra? Below is a summary.

NOT ALGEBRA	AND ALGEBRA	OR ALGEBRA
$\overline{0} = 1$	$0.0 = 0$	$0 + 0 = 0$
$\overline{1} = 0$	$0.1 = 0$	$0 + 1 = 1$
	$1.0 = 0$	$1 + 0 = 1$
	1.1	

Boolean operations on a constant and a variable

NOT OPERATION	AND OPERATION	OR OPERATION
$\overline{\overline{A}} = A$	$0.A = 0$	$0 + A = A$
$1.A = A$	$1 + A = 1$	
$A.A = A$	$A + A = A$	
$A.\overline{A} = 0$	$A + \overline{A} = 1$	

The basic laws or properties of Boolean algebra led to three theorems which are very useful for simplifying Boolean expressions. These include the Redundancy theorem, the Race Hazard theorem and De Morgan's theorem.

The redundancy theorem

When 2 binary variables are AND operated and then OR operated on any of the variables, the result is the variable. (The variable makes the other 2 AND operated variables redundant).

i.e. $(X \bullet Y) + Y = Y$

also $(X \bullet Y) + X = X$

PROOF

(1) $X \bullet Y + Y = Y(X + 1)$

$= Y \bullet 1$

$= Y$

Since $X + 1 = 1$

$Y \bullet 1 = Y$

(2) $(X \bullet Y) + X = X(Y + 1)$

$= X \bullet 1$

$= X$

If the operations are exchanged the result is the same

i.e. $X \bullet (X + Y) = X$

$Y \bullet (X + Y) = Y$

PROOF

(1) $X (X+Y) = X \bullet X + X \bullet Y$

$= X + X \bullet Y$

$= X (1 + Y)$

$= X \bullet 1$

$= X$

Since $X \bullet X = X$

(2) $Y \bullet (X + Y) = Y \bullet X + Y \bullet Y$

$= Y \bullet X + Y$

$= Y(X + 1)$

$= Y \bullet 1$

$= Y$

Since $Y \bullet Y = Y$

The redundancy theorem can also be applied on operations involving more than 2 variables as shown below.

$(X+Y) \bullet (X + Y + X) = X + Y$

$(X \bullet Y) + (X \bullet Y \bullet Z) = X \bullet Y$

Example

Simplify the Boolean expression

F = (A + B)•(A + C)

Solution

F = (A + B)•(A + C)

= A•A + A•C + A•B + B•C (Expanding)

(A•A = A)

= A + A•C + A•B + B•C

= A + A•B + B•C (A•C is redundant with respect to A)

= A + B•C (A•B is also redundant with respect to A.)

The Race-hazard theory

The Race-hazard theorem allows you to add redundant terms to an expression.

Example

A•B + $\overline{A}$ C =A•B+ $\overline{A}$ •C+B•C

This may sometime be the first step in the simplification of an expression before the redundancy theorem is applied.

Example

Simplify the following expressions.

a. F = $\overline{X}$ •Y + X•Y•Z

b. F = A •C + $\bar{A}$•B•C

Solution

a. F = $\bar{X}$•Y + X•Y•Z

= $\bar{X}$•Y + X•Y•Z + Y•Y•Z

= $\bar{X}$•Y + X•Y•Z + Y•Z

= $\bar{X}$•Y + Y•Z

Adding the redundant elements; Y•Y•Z, Y from the first term and Y•Z from the second term)•

(Y•Y = Y)

(X•Y•Z is redundant with respect to Y•Z

b•F = A•C + $\bar{A}$•B•C

= A•C + $\bar{A}$•B•C + C•B•C

= A•C + $\bar{A}$•B•C + B•C

= A•C + B•C

= C(A+B)

(Add redundant terms)

(C•C = C)

(Applying redundant theorem)

De Morgan theorem

When designing circuits, NAND gates are normally preferred to AND gates because they operate at higher speeds and can also be built from fewer components when making their integrated circuits. There is therefore the need to change AND to NAND. This is made possible by the use of De Morgan's theorem. De Morgan's theorem states that if you want to invert an expression, then you replace AND (.) with OR (+) and each variable with its inverse.

i.e. $(\overline{X + Y}) \;= \overline{X}\bullet\overline{Y}$

$(\overline{X \bullet Y})\ \overline{X}\ \overline{Y}$

Note that $(\overline{X + Y}) \neq \overline{X} + \overline{Y}$

Examples: Use De Morgan's theorem to simplify the following expressions.

a. $F = A\bullet B + A\bullet C$

Solution

a. $F = A\bullet B + A\bullet C$

$F = \overline{AB + AC}$ (applying De Morgan's theorem)

$= (\overline{A} + \overline{B})\bullet(\overline{A} + \overline{C})$

$= \overline{A}\bullet\overline{A} + \overline{A}\bullet\overline{C} + \overline{A}\bullet\overline{B} + \overline{B}\bullet\overline{C}$

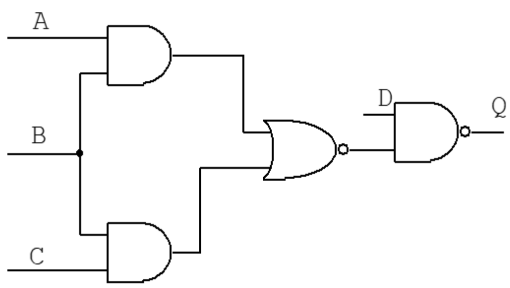
$= \overline{A} + \overline{A}\bullet\overline{C} + \overline{A}\bullet\overline{B} + \overline{B}\bullet\overline{C}$ (since $\overline{A}\bullet\overline{A} = \overline{A}$)

$= \overline{A} + \overline{B}\bullet\overline{C}$ (applying redundancy theorem)

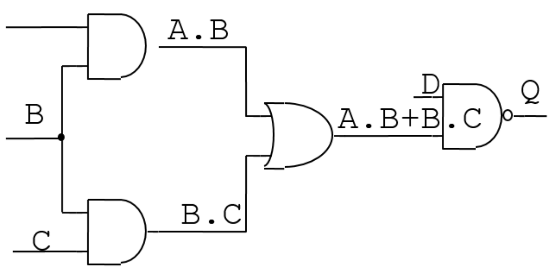
Obtaining logic expressions from circuits

You should be able to obtain logic expressions when the logic circuit is provided and also draw a logic circuit for a given logic expression. The following examples will guide you.

Example: The diagrams below are circuits designed using logic gates. Obtain the logic expression for each circuit.



Solution



Therefore, $Q = \overline{(A\,B + B\bullet C)\bullet D}$

Learning Tasks

1. Explain the concept of Boolean algebra
2. Describe the 3 basic operations of Boolean algebra
3. Use De Morgan's theorem to find F if

$$F = (X + Y).(\overline{W} + Z)$$

4. Write the Boolean expression for the circuit below;

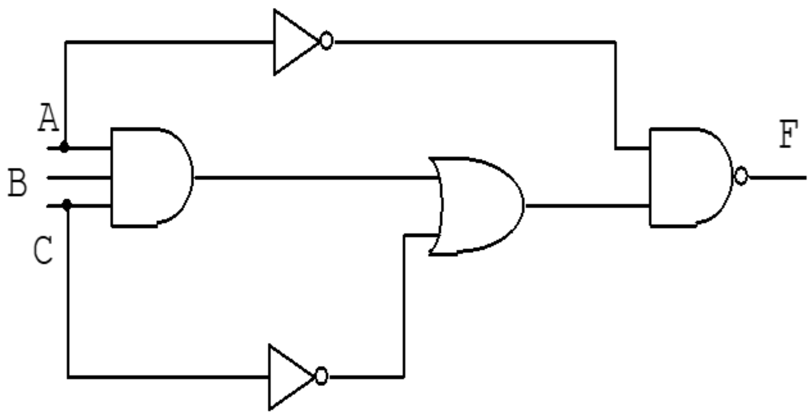


Figure 14.1

Pedagogical Exemplars

Teachers should consider the following activities:

Collaborative Learning: Engage learners in mixed ability groups to undergo the following activities:

Come out with rules of Boolean Algebra

Come out with the basic axioms

Discuss the elements of Boolean Algebra

Experiential Learning/collaborative learning: In mixed-ability groups and with the use of the internet, task learners to: Solve operations on Boolean Algebra

Collaborative Learning: Engage learners in mixed ability groups to undergo the following activities:

Explain redundancy theorem

Explain Race-Hazard theorem

Explain De-Morgans Theorem

Experiential Learning/collaborative learning: In mixed-ability groups and with the use of the internet, task learners to:

Solve problems on Redundancy theorem

Solve problems on Race-Hazard theorem

Solve problems on De-Morgans Theorem

NB. Ensure all learners participate in all varieties of practical activities and project work given mixed gender groupings as well and also ensure mixed gender grouping when practical work such as constructing

Key Assessment Level 3: Class Exercise

1. You are given this Boolean expression: F = AB + AC + BC
    a. Simplify this expression using Boolean algebra
    b. Implement the original and simplified expressions using logic gates
    c. Compare both implementations in terms of gate count and performance
    d. Explain the practical importance of circuit minimisation in real electronic devices
    e. Discuss why engineers might sometimes choose a non-minimised circuit
2. In the hardware in fig 14.2, derive the Boolean expression for the function F, and compute the value of the function F if A = 0, B = 1, C = 0 and D = 1.

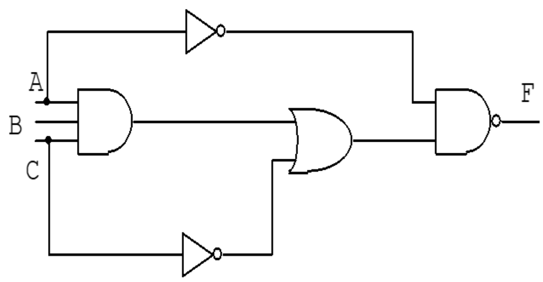


Figure 14.2

PLC Session 14

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

a. The key assessment for the week is ***class exercise***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the exercise (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

b. After the enactment, ask for structured feedback from the group

i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 14 Review

This unit exposed learners to the concept Boolean algebra, particularly the elements of Boolean algebra, operations of Boolean algebra and solving of problems on Boolean algebra using the Redundancy theorem, the Race Hazard theorem and the De-Morgans theorem. The pedagogical exemplars used in this unit includes Collaborative learning approaches and Experiential learning. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 4.

Resources: Pictures, Videos, real objects (DC Generators)

UNIT 15

Section 5: Digital Electronics

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic devices and circuits

Content Standard: Demonstrate knowledge and understanding of electronic components

Learning Outcome: *Apply knowledge and understanding of electronic components to design and construct electronic circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at digital electronics as they apply to electronics technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques as regards logic gates and how they can be used to design electronic circuits.

The unit covers only week 15: Apply principles of logic gates in designing electronic circuits

Recap weeks

Year 2	**Week 21:** Solve problems on binary numbers

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on logic gates through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Apply principles of logic gates in designing electronic circuits	Level,4 (Extended Strategic reasoning)	Assessment mode: Group Project

WEEK 15

Learning Indicator: *Apply principles of logic gates in designing electronic circuits*

FOCAL AREA: LOGIC EXPRESSIONS FROM CIRCUITS

Let's begin our design process by first understanding how to obtain expressions from logic circuits. Logic expressions can be obtained from logic circuits by obtaining the output function of each gate, beginning from the input side (left hand side) towards the output. Note that the output of each gate becomes the input of the next. This process continuous until you get to the last logic gate at the right-hand side. The output of the last gate becomes the expression for the circuit. Take Figure 15.1 as an example.

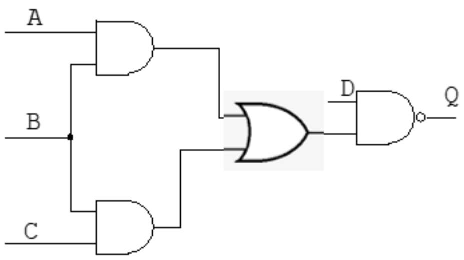


Figure 15.1

The output of the circuit, in Figure 15.1 is Q. The solution is as follows:

- **a.** The first gate is an AND gate. Its output is A.B
- **b.** Next is another AND gate with an output of B.C
- **c.** Note that the outputs of the first two gates become the inputs of the third gate, which is an OR gate. Thus, one input of the third gate is A.B and the second input is B.C
- **d.** The output of the third gate then becomes A.B + B.C (since it is an OR gate).
- **e.** One input of the fourth gate is D and the other input is AB+BC, but note that the fourth gate is a NAND gate. Therefore, its output, $Q = \overline{(A\,B + B{\bullet}C){\bullet}D}$ is as shown in figure 4.3

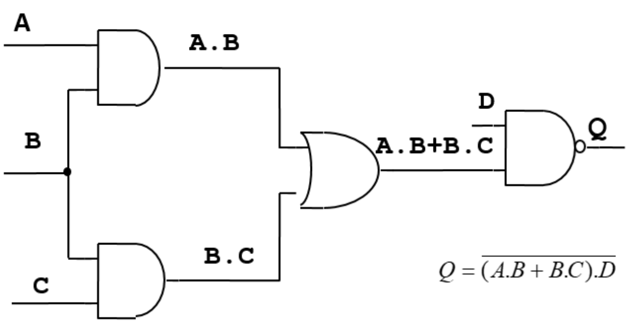


Figure 15.2: *Output expression of a logic circuit*

Let us find the logic expression for the circuit shown in figure4.4

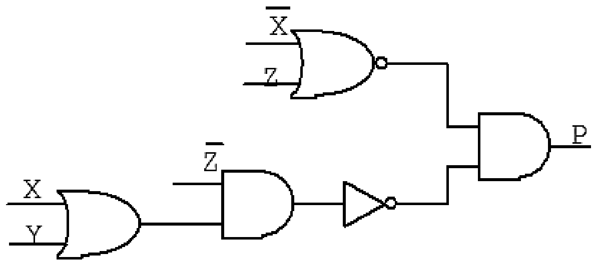
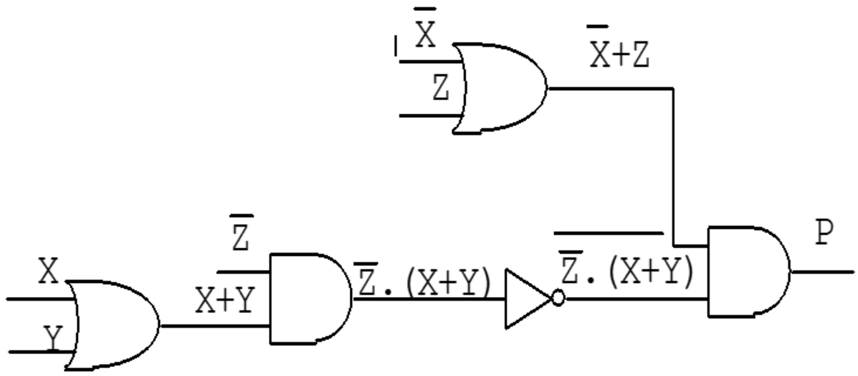


Figure 15.3: *Logic circuit*

Using the same process as in the first circuit in figure 15.1, the output expression P, of the circuit in fig 15.3 therefore is $P = (\bar{X} + X)\bullet(Z + \bar{X}\bullet\bar{Y})$, as shown in figure 15.4. Note that the final expression has been simplified using De Morgan's theorem



$$P = (\overline{X} + Z).(Z + \overline{X}.\overline{Y})$$

Figure 15.4: *Output expression of Logic circuit*

Designing with logic Gates

Logic gates can be combined in various forms to produce very useful circuits, such as multi-vibrators.

Astable multivibrator using NAND gates: An astable multi-vibrator is a circuit with no stable state. It is in fact an oscillator. Figure 15.5 shows a typical astable circuit using two NAND gates. It involves two LEDs for the viewing of the output status of each gate.

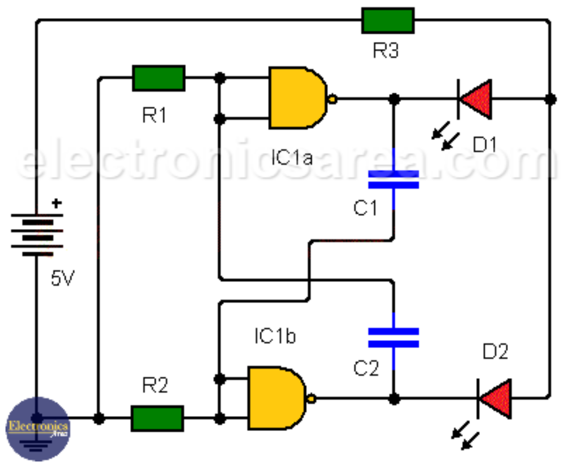


Figure 15.5: *An astable multivibrator using NAND gates*

Note that the cathodes of the LEDs are connected to the output of the gates and so each LED will turn on when the output of the gate is LOW. Also, note that you need to connect the circuit to a power source before oscillation can start. The values of resistors R1 and R2 and capacitors C1 and C2 determine the frequency of oscillation.

Table 4.1: *Components required*

S/N	Component	Quantity
1	TTL 4011 IC	1
2	10K resistors (R1, R2)	2
3	220 ohm resistor (R3)	1
4	100 uF (microfarads) capacitors (C1, C2)	2
5	LEDs of any colour (D1, D2)	2

NOTE: the IC is a 4-NAND component as shown in figure 4.7.

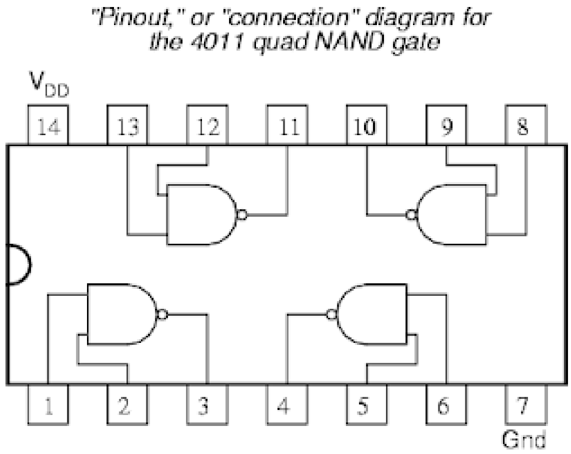


Figure 15.6: *Pin connection of 4011 Quad NAND gate*

Bistable or flip-flop

A bistable has two outputs which are logically opposite (i.e., if the first is 1, then the other is 0) and can be made to change from one state to the other. The outputs are normally denoted by Q and $\bar{Q}$.It also has two inputs: Set and Reset. A block diagram of a flip flop is shown in figure 15.7.

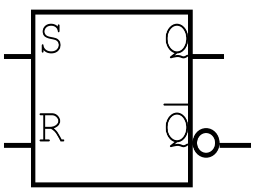


Figure 15.7: *Block diagram of a flip-flop*

Flip-flops can be designed using either NAND gates or NOR gates. Figure 15.8 shows a flip flop

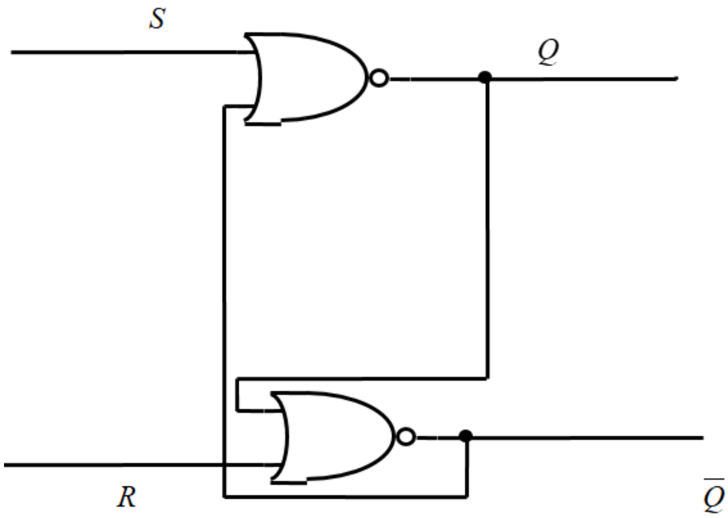


Figure 15.8: *Flip-flop using NOR gates*

When S = 1 and R = 0, the $\bar{Q}$ = 0 resulting in Q = 1.

This is the set state. It will remain in this state until the inputs are changed.

If S is changed to 0 and R = 1, then $\bar{Q}$ = 1 and Q = 0 when both inputs are zero, the circuit remains in its last state: either set or reset (there will be no change).

You should note however that when NOR gates are used to design a flip-flop, both inputs should not be put at 1, otherwise both outputs will be zero which is not acceptable in flip-flops.

The behaviour of this circuit can be summarised in table 4.2

Table 4.2: *Output of the NOR gate flip-flop*

S	R	Q	$\bar{Q}$
1	0	1	0
0	1	0	1
0	0	No change	
1	1	not acceptable	

Figure 15.9 shows a NAND gate flip-flop

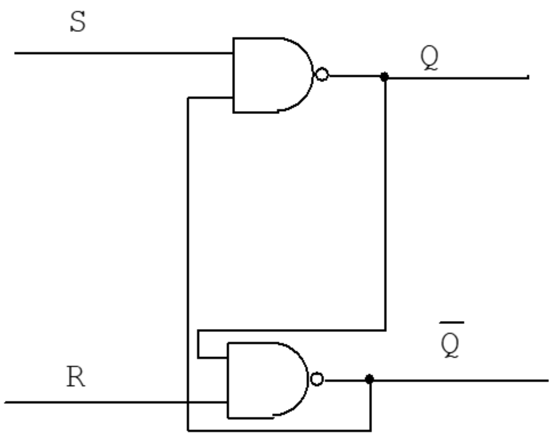


Figure 15.9: *NAND gate Flip-flop*

Operation

If S = 1 and R = 0, then Q = 1 and $\bar{Q}$ = 0, this is the set state.

If S = 0 and R = 1, then Q = 0 and $\bar{Q}$ = 1, this is the reset state.

When S = 1 and R = 1, the outputs remain unchanged, and when S = 0 and R = 0, the outputs are unacceptable (i.e., both will be zero).

This type of flip-flop is called a Set and Reset flip-flop or S-R flip-flop. Its main disadvantage is that only one of its inputs is allowed to go low or 0 (when using NAND gates) or high, 1, (when using NOR gates).

D Flip-flop

Another type of flip-flop known as the D type has only 1 input for data. This input can either be I or 0. So the problem of two inputs going low or high as is the case of the S-R flip-flop does not arise. It has another input called the clock, which controls the action of the flip-flop. A block diagram of a D flip-flop is as shown in figure 15.10a.

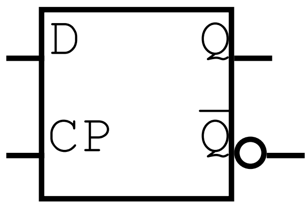


Figure 15.10a: *Symbol of D flip flop*

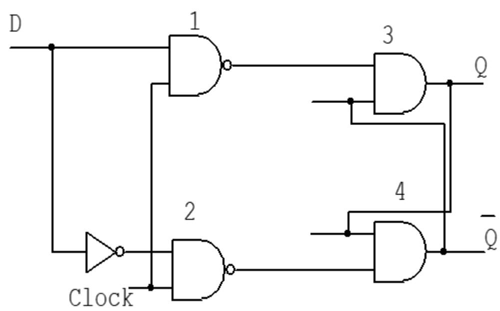


Figure 15.10b: *A logic diagram of D flip-flop*

Operation: When the clock is low or 0, the outputs of NAND gates 1 and 2 will both be 1 whether D is 0 or 1. This is because the NOT gate connected to NAND gate 2 inverts the data into 2. This is illustrated in figure 15.11

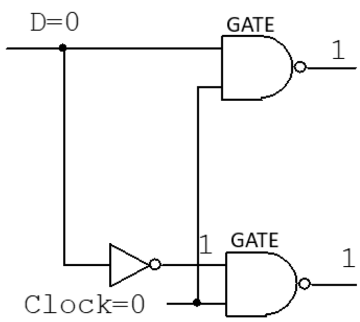


Figure 15.11a: *When D = 0*

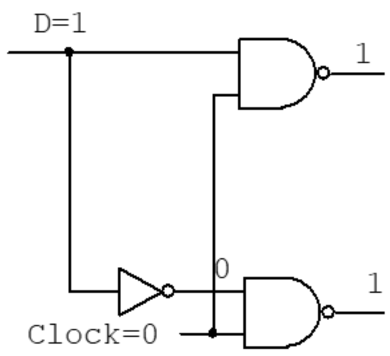


Figure 15.11b: *When D=1*

You may have to refer back to the truth table for the NAND gate if you have difficulty. This therefore means gates 3 and 4, which make up the S-R flip flop, will both receive 1 as the input. Thus, the flip-flop will not change state. It will remain in its previous state. The outputs for gates 1 and 2 when the clock is 1 (with D being either 1 or 0) is shown in figures 15.12a and 15.12b.

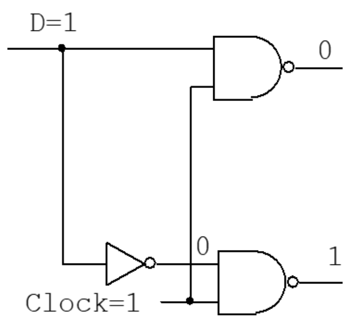


Figure 15.12a

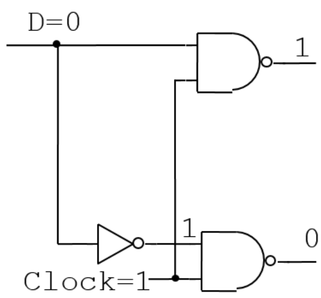


Figure 15.12b: *When D=0*

It can be seen clearly from Figures 2.9a and 2.9b that the gates 3 and 4 will receive 0 and 1 signals respectively when D=1 and 1 and 0 respectively when D = 0. This means that the S-R flip-flop is being Set and Reset each time the clock is 1 and does not change state when the clock is low or 0.

Learning Tasks

1. Explain the processes that take place in a flip-flop during the set state
2. Assess the role of the clock during the operation of the D flip-flop
3. Discuss the difference between the S-R Flip-flop and the D-Flip-flop in terms of their design and operation

Pedagogical Exemplars

Teachers should consider the following activities:

1. **Collaborative Learning:** With the use of the internet, engage learners in mixed ability groups to undergo the following activities:

Outline the types of Logic gates that we have and give examples i.e. Basic logic gate e.g., AND, NOT and OR gates and Universal Logic Gates e.g., NAND and NOR gates.

2. **Experiential Learning/collaborative learning:** In mixed-ability groups and with the use of the internet, task learners to describe how each gate operates and outline their applications as well.
3. **Experiential Learning:** Engage learners to work in mixed gender groups to:
   - **a.** Construct the truth table for the various logic gates and determine the output functions of the various gates from the Boolean expressions given.
   - **b.** Draw circuits with logic gates and obtain their logic expressions.
   - **c.** Design flip-flops using logic gates Task learners to present their findings from the group work.

Key Assessment Level 4: Group project

1. Your school's robotics club needs a circuit that will control a line-following robot.
   - **a.** Design a logic gate circuit that allows the robot to:
   - **b.** Move forward when both sensors detect the line.
   - **c.** Turn right when only the left sensor detects the line.
   - **d.** Turn left when only the right sensor detects the line
   - **e.** Stop when neither sensor detects the line

Draw your circuit using basic logic gates, explain how it works, and discuss how your design would handle potential real-world problems like sensor interference.

2. Design a circuit using the minimum number of logic gates that will light an LED when exactly 2 out of 4 switches are turned on (no more, no less).
   - **a.** Draw your circuit diagram using standard symbols
   - **b.** Provide the Boolean expression for your solution
   - **c.** Explain how you arrived at your design
   - **d.** Evaluate how your solution compares to other possible approaches
   - **e.** Discuss how adding a "3-out-of-4" detection feature would modify your design

PLC Session 15

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.

2. Use your subject specific app to explore the content before planning. Ask the app to

   a. explain the week's concepts in a practical way that will make it easier for learners to understand

   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app

   a. The key assessment for the week is ***group project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

   b. all teachers in the group work through a similar problem individually for 3–4 minutes

   c. the group then works through the problem together step by step

   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.

- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Unit 15 Review

This unit exposed learners to various logic gates and their applications. The pedagogical exemplars used in this unit includes Talk for learning approaches and Group work/ Collaborative learning. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 4.

UNIT 16

Section 4: Electronic circuits and transmitters in electronic communication

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic devices and circuits

Content Standard: Demonstrate knowledge and understanding of electronic components

Learning Outcome: *Apply knowledge and understanding of electronic components to design and construct electronic circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at electronic communication system with emphasis on carrier wave, modulation, transmitters and receivers as they apply to electrical and electronics technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in Principles of operation in AM and FM modulations, Receivers and Transmitters in electronic communication system.

The unit covers only week 16: ***Describe the various types of modulation in communication***

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on the various aspect of Electronic communication system through a wide range of pedagogical exemplars such as Collaborative learning, Research and Collaborative approaches.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation, hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe the various types of modulation in communication	3	*Group discussion*

WEEK 16

Learning Indicator: *Describe the various types of modulation in communication*

FOCAL AREA: TYPES OF MODULATION IN ELECTRONIC COMMUNICATION SYSTEM

1. Carrier Wave,
2. Modulation,
3. Types of Modulation,

Preamble: Electronic communication systems involve various technologies and devices that enable the transmission of information over a distance. These systems can be categorised by the nature of the signal, the direction of communication, and the type of medium used.

Key Components of an Electronic Communication System

1. **Source:** The origin of the information to be transmitted.
2. **Input Transducer:** Converts the information into an electrical signal suitable for transmission.
3. **Transmitter:** Processes and prepares the signal for transmission.
4. **Communication Channel:** The medium through which the signal is transmitted (e.g., wires, radio waves, fibre optics).
5. **Receiver:** Receives and processes the signal.
6. **Output Transducer:** Converts the received electrical signal back into the original form of information.
7. **Destination:** The recipient of the information.

Types of Electronic Communication Systems

The types of electronic communication system can be broadly categorised as follows:

1. **By Signal Nature**
    a. **Analogue:** Signals are continuous and can take on any value within a given range.
    b. **Digital:** Signals are discrete and take on specific values, typically represented as 0s and 1s.
2. **By Direction of Communication**
    a. **Simplex:** Information flows in one direction only.
    b. **Half-Duplex:** Information can flow in both directions, but only one direction at a time.
    c. **Full-Duplex:** Information can flow in both directions simultaneously.
3. **By the type of medium used**

a. **Wired Communication**: uses physical media (cables, wires) for data transmission.

b. **Wireless Communication**: uses electromagnetic waves (radio, microwave, infrared) for data transmission.

c. **Optical Communication**: uses light to transmit data through fibre optic cables

Examples of Electronic Communication Systems

1. **Mobile communication:** Cellular networks allow for mobile devices to connect and communicate wirelessly.
2. **Voice calls:** Telephones and mobile phones use electronic communication for voice transmission.
3. **Text messages:** SMS and other messaging platforms rely on electronic communication to transmit text messages.
4. **Email:** Electronic mail allows for the transmission of messages, attachments, and files between electronic mailboxes.
5. **Video conferencing:** Platforms like Zoom or Skype enable video and audio communication through electronic media.
6. **Social media:** Platforms like Facebook, Twitter, and others use electronic communication to share content, engage with users, and connect with others.
7. **Online forums and chat rooms:** These platforms facilitate electronic communication and discussion among users.
8. **Computer networking:** Networks like the internet enable electronic communication and data exchange between computers.
9. **Radio and television broadcasting:** These systems use electromagnetic waves to transmit audio and video signals.

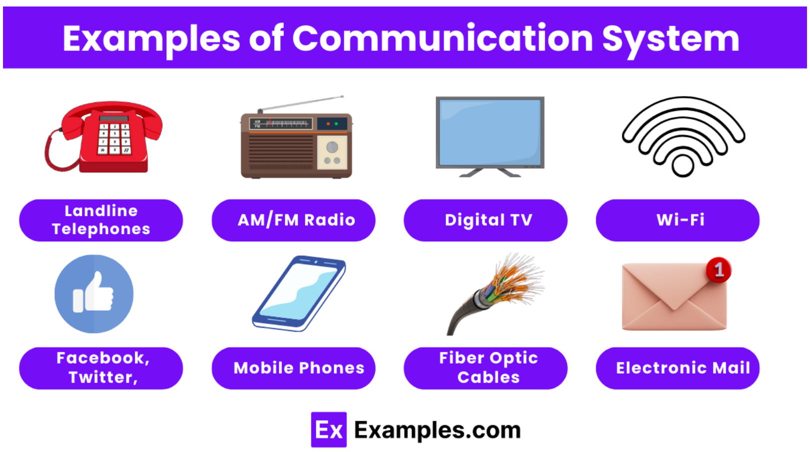


Figure 16.1: *Examples and types of electronic communication systems*

Basic Terminology

1. **Signal:** Information converted into an electrical form.
2. **Transducer:** A device that converts one form of energy into another.
3. **Attenuation:** Loss of signal strength during transmission.

4. **Amplification:** Increasing the signal strength.
5. **Modulation:** Preparing the signal for transmission by altering its characteristics.
6. **Demodulation:** Extracting the original information from the modulated signal.
7. **Repeater:** A device that amplifies and retransmits signals.
8. **Bandwidth:** Bandwidth refers to the frequency range over which the signal is transmitted or the range over which the equipment operates.

Carrier Wave: A Carrier wave is a high frequency, constant amplitude, constant frequency and non-interrupted wave generated by radio-frequency oscillators. These waves are inaudible i.e., by themselves they are not able to produce any sound in the loudspeaker. As their name indicates, their function is to carry the audio or video signal from the transmitting station to the receiving station. The resulting wave (audio signal superimposed on the carrier wave) is called the **modulated wave**.

Modulation: Most of the information/ messages are generated at low frequencies but such frequencies experience heavy attenuation and hence their range is severely hampered. To overcome this problem, the original low-frequency information is superimposed on a high-frequency carrier wave which carries the information. This process is called modulation and there are several types of it, namely AM, FM and PM

Demodulation: The process of extraction of the original information from the modulated signal at the receiver is termed as demodulation. This process is basically the reverse of modulation.

Types of modulation

Types of modulation in communication system are AM, FM and PM:

1. **Amplitude modulation (AM):** Is the type of modulation in which the amplitude of the carrier wave is varied in accordance with the modulating signal, the frequency and phase of the carrier wave unchanged.
2. **Frequency modulation (FM):** Is the type of modulation in which the frequency of the carrier wave varies in accordance with the modulating signal, keeping the amplitude and phase of the carrier wave unchanged.
3. **Phase modulation (PM):** Is the type of modulation in which the phase of the carrier wave is varied in accordance with the modulating signal, keeping the amplitude and frequency of the carrier wave unchanged.

The frequency modulation (FM) has the following advantages over the amplitude modulation (AM)

1. FM receivers may be fitted with amplitude limiters to remove the amplitude variations caused by noise. This makes FM reception a good deal more immune to noise than AM reception.
2. It is possible to reduce noise still further by increasing the frequency deviation. This is a feature which AM does not have because it is not possible to exceed 100 per cent modulation without causing severe distortion.
3. Standard frequency allocations provide a guard band between commercial FM stations. Due to this, there is less adjacent-channel interference than in AM.

4. FM broadcasts operate in the upper VHF and UHF frequency ranges at which there happens to be less noise than in the MF and HF ranges occupied by AM broadcasts.
5. The amplitude of FM wave is constant. It is thus independent of the modulation depth whereas in AM, modulation depth governs the transmitted power. This permits the use of low-level modulation in FM transmitter and use of efficient class C amplifiers in all stages following the modulator. Further since all amplifiers handle constant power, the average power handled equals the peak power. In AM transmitter, the maximum power is four times, the average power. Finally in FM, all the transmitted power is useful whereas in AM, most of the power is carrier power which does not contain any information.

Despite the above advantages of FM over AM, the FM still has the following drawbacks

1. FM transmitting and receiving equipment's particularly used for modulation and demodulation are more complex and more costly.
2. As a much wider channel, typically 200 kHz is required in FM as against only 10 kHz in AM broadcast. This forms serious limitation of FM.
3. In FM, the area of reception is small as it is limited to only one line of sight.

Learning Tasks

1. Explain the concept of electronic communication system.
2. Discuss at least three types of electronic communication system.
3. Differentiate between AM and FM.
4. Enumerate at least four advantages of FM over AM.

Pedagogical Exemplars

Teachers should consider the following activities:

Collaborative Learning: With the use of the internet, engage learners in mixed ability groups to undergo the following activities:

- **a.** Explain Carrier wave
- **b.** Explain modulation
- **c.** Outline the types of modulation e.g.: AM, FM

Research and Collaboration: Organise the learners into mixed-ability and gender groups and task them to research on the internet and YouTube to undertake the following activities and do group presentation on their findings:

- **a.** Amplitude Modulation
- **b.** Frequency modulation

Groups to explain the differences between Amplitude Modulation and Frequency Modulation

Key Assessment Level 3: Group Discussion

1. Examine the AM modulator circuit diagram provided (teacher to provide diagram). Identify the components responsible for:

   a. Carrier signal generation
   b. Modulating signal input
   c. Actual modulation process

Analyse how changing the value of component X would affect the modulation index and the resulting signal quality.

2. An AM radio receiver produces distorted audio output. Analyse three possible causes related to the modulation/demodulation process that could create this problem. For each cause, describe:
   a. The technical issue occurring
   b. How it affects the demodulation process
   c. A method to test if this is the actual problem

PLC Session 16

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***group discussion***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the discussion (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

UNIT 16 REVIEW

This unit exposed learners to the concept of electronic communication system, particularly the types of communication system, carrier wave, modulation and types of modulation, advantages of FM over AM as well as some drawbacks of FM over AM. The pedagogical exemplars used in this unit includes Collaborative learning approaches and Research. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 3.

UNIT 17

Section 5: Communication

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic devices and circuits

Content Standard: Demonstrate knowledge and understanding of electronic components

Learning Outcome: *Apply knowledge and understanding of electronic components to design and construct electronic circuits*

INTRODUCTION AND SECTION SUMMARY

This section looks at electronics communication as it applies to electronics technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques as regards transmitters and receivers.

*The unit covers only week 17: **Describe AM and FM transmitters in electronic communication***

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished, learners are to be actively engaged in practical demonstration on logic gates through a wide range of pedagogical exemplars such as Talk for learning, Collaborative learning, Experiential learning, Project – based learning, Research and collaboration.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively

Indicators	DOK Level	Assessment Strategy and/or Mode
Describe AM and FM transmitters in electronic communication	Level 3 (Strategic Reasoning)	Assessment mode: Group Project

WEEK 17

Learning Indicator: *Describe AM and FM transmitters in electronic communication*

FOCAL AREA: AM TRANSMITTER

Amplitude Modulation (AM) is the process of varying the amplitude of a carrier wave for the purpose of transmitting information. This carrier wave is a high-frequency electromagnetic wave generated by an RF oscillator (radio frequency oscillator). The modulating signal carries the information to be transmitted. This signal is impressed onto the carrier wave, through a process called modulation, to generate the AM signal. Figure 17.1 shows the carrier wave, input signal and modulated signal

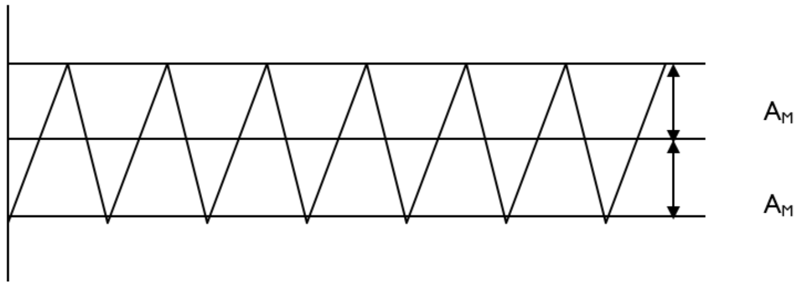


Figure 17.1a: *Carrier wave*

Where A_M = Amplitude of the RF signal

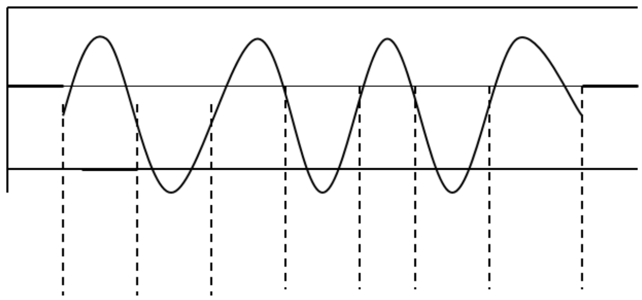


Figure 17.1b: *Input signal*

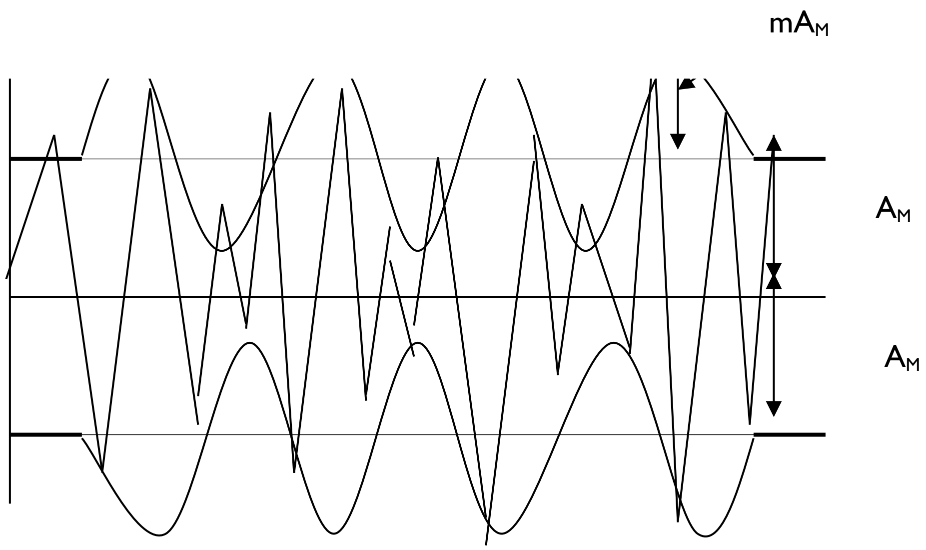


Figure 17.1c: *Amplitude modulated signal*

Where mA_M = modulated index x A_{Mx}

Note that when there is no signal, the RF is not modulated.

Modulation index (Modulating factor)

The modulation index, denoted by M, is a measure of the extent to which a carrier voltage is varied by the input signal. This can be determined by measuring the peak-to-peak voltages at the maximum and minimum points of the modulated wave as shown in figure 17.2. An oscilloscope is used for this purpose.

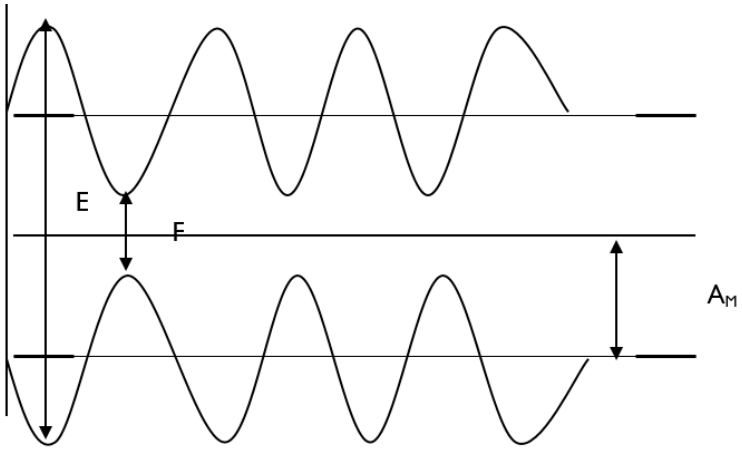


Figure 17.2: *AM modulation index*

From the figure above, the modulation index is given by

$$M = \frac{E - F}{E + F} \times 100\%$$

What happens when E = F? There will be no modulation. For example, if E = F = 10.

$$M = \frac{10 - 10}{10 + 10} \times 100\%$$

$$= \frac{0}{20} \times 100\%$$

$$= 0$$

A block diagram of an AM transmitter is shown in figure 17.3. It consists of a microphone (not included in diagram), a Pre Amplifier (audio amplifier), an AM modulator, Radio frequency oscillator (RF Oscillator) a power amplifier and an antenna.

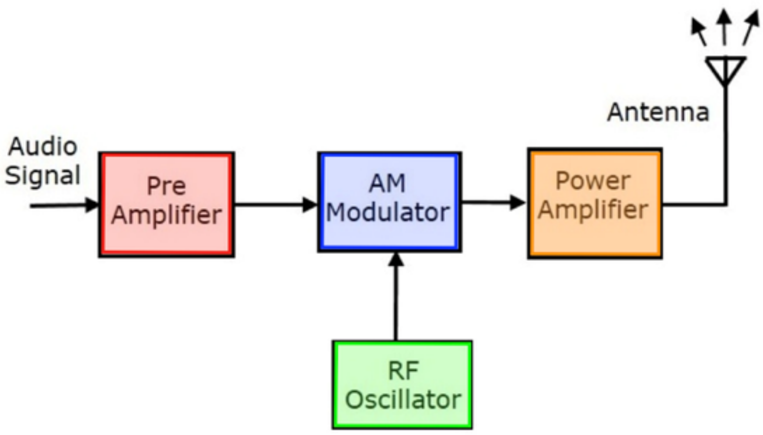


Figure 17.3: *Block diagram of AM transmitter*

The functions of each of the components in the block diagram are as follows:

1. **Pre-Amplifier (Audio amplifier)**: Audio sound waves of low amplitude are fed into the pre-amplifier through a microphone (omitted in the diagram). The microphone converts the sound waves into electric waves. This audio amplifiers which normally operate in a frequency range of between 30 to 18000Hz. Its function is to increase the amplitude of the input wave and feed it into the modulator.
2. **RF Oscillator**: This unit generates a high frequency signal called the carrier wave or Radio Frequency (RF) and also feeds it into the modulator.
3. **The AM modulator:** The modulator impresses the input wave onto the carrier wave by altering the amplitude of the carrier wave and feeds it into the RF power amplifier. At this stage the signal is now referred to as a modulated RF signal.
4. **The power amplifier**: The power amplifier normally operates in the range of 550 to 16000 KHz for the AM broadcast band. Its function is to step up the RF modulated signal to the precise frequency assigned to the radio station and send it out through the antenna.
5. **The antenna: The antenna** converts the RF radiation into electromagnetic radiation and transmits it into the air.

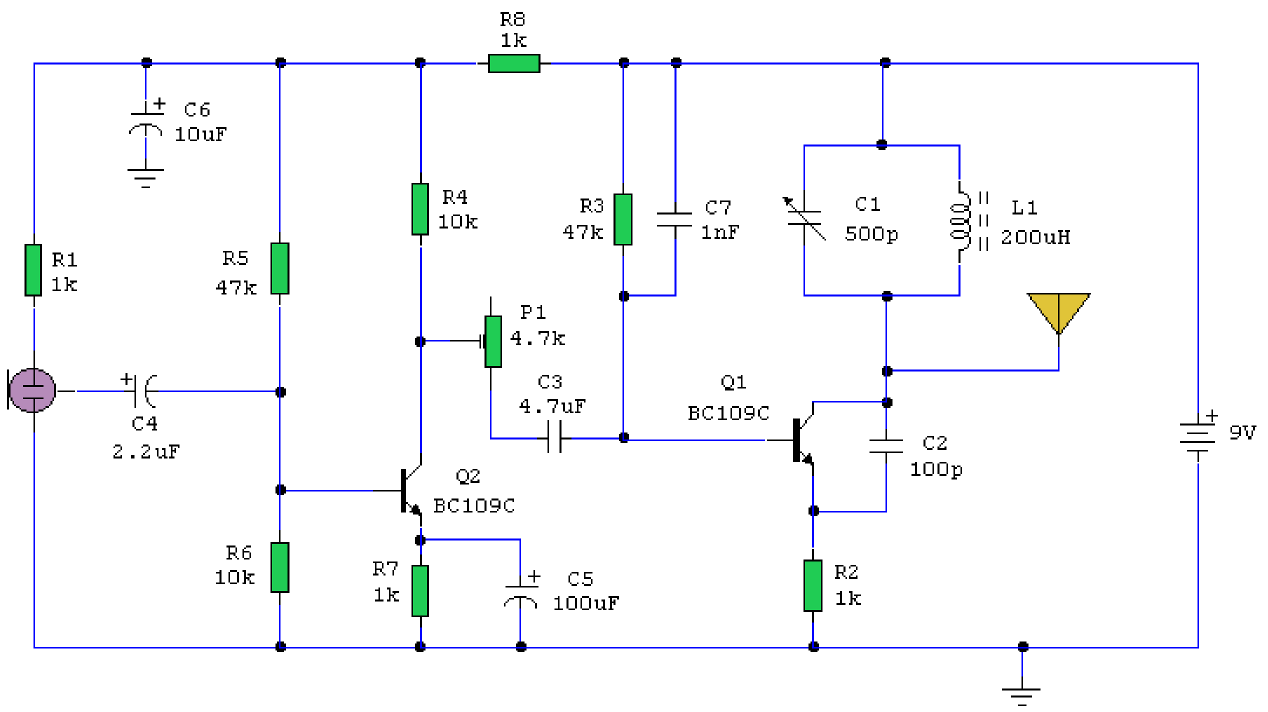


Figure 17.4: *A simple AM transmitter circuit*

Merits of AM

- Easy to transmit and easy to and receive
- Comparatively, its bandwidth requirements are less
- Inexpensive

Demerits of s of AM

- Noise level is high
- Low efficiency
- Small operating range

Fm transmission

An AM transmitter normally transmits a lot of unwanted noise to the receiver as a result of the increase in the amplitude during the amplitude modulation process. Another type of transmission maintains the amplitude of the carrier wave while changing the frequency. It referred to as Frequency modulation.

Figure 17.5 shows a block diagram of an FM transmitter. It is similar to the AM transmitter, however, the difference lies in the method of modulation and the inclusion of a unit called **Limiter**. Frequency Modulation (FM) involves the impressing of a signal wave onto a carrier wave by changing the frequency of the carrier or RF signal. The FM carrier is either VHF or UHF.

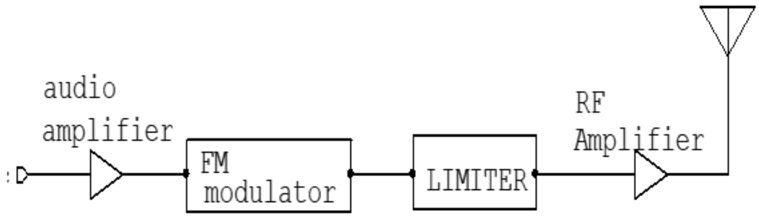


Figure 17.5: *Block diagram of FM transmitter*

The limiter: The limiter removes any amplitude modulation that may result from the frequency modulation before it is fed into the RF amplifier. This helps greatly in eliminating unwanted noise before transmitting. When an input signal is applied, there is a change in frequency either above or below the carrier frequency. This is referred to as Frequency Deviation (Fd). A maximum frequency deviation of 75KHz is allowed for audio signals of up to 15 KHz for commercial FM broadcast. The Commercial FM broadcast range is from 88 to 168 MHz. Figure 17.6a shows an input signal, 17.6b is the carrier wave and 17.6c shows how the carrier wave varies when the input signal is impressed onto the carrier wave.

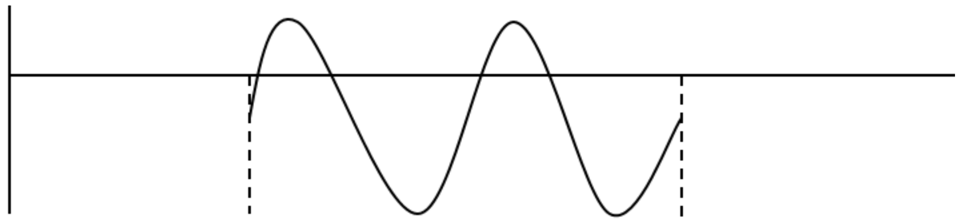


Figure 17.6a: *Input signal*

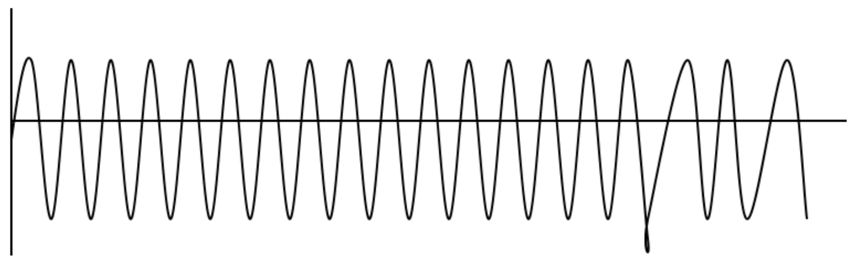


Figure 17.6b: *Carrier wave*

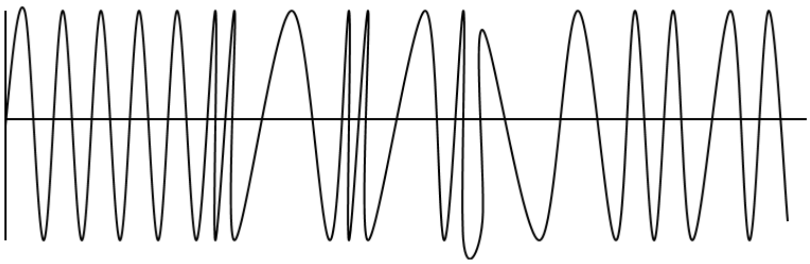


Figure 17.6c: *Frequency Modulated wave*

Modulation index of FM

If the amplitude of the input audio signal is held constant, the FM signal remains at its carrier frequency (Fc), that is, the frequency allocated to the station. The frequency change or deviation (Fd) from the carrier wave is as a result of the amplitude variation of the input signal. The modulation index of an FM is the ratio of the frequency deviation (Fd) to the frequency of the input signal (Fs)

$$M = \frac{Fd}{Fs}$$

It can also be expressed as the ratio of the frequency deviation to the maximum allowable frequency deviation. Note that the modulation index of an FM can be more than one.

Examples

1. An Fm transmission has a frequency deviation of 6 KHz. What will be the modulation index if an input signal of frequency 10 KHz is supplied to it?

Solution:

$$M = \frac{F}{F_S}\,\square 100$$

$$M = \frac{Fd}{Fs} \times 100$$

Given Fd = 6KHZ

$F_s = 10$ KHz

$$M = \frac{6}{10} \times 100$$
$$= 60\%$$

2. An FM transmission has a frequency deviation of 16.25 KHz. What will be the percentage modulation if it is broadcast in the 88 – 108MHz band?

Solution

Frequency deviation Fd = 16.25

Maximum frequency deviation in the 88 – 108MHz band = 175 KHz

$$\text{But Modulation index} = \frac{Fd}{Fm} \times 100$$
$$= \frac{16.25}{75} \times 100$$
$$\mathbf{= 21.67}$$

A simple FM transmitter circuit is shown in figure 17.7

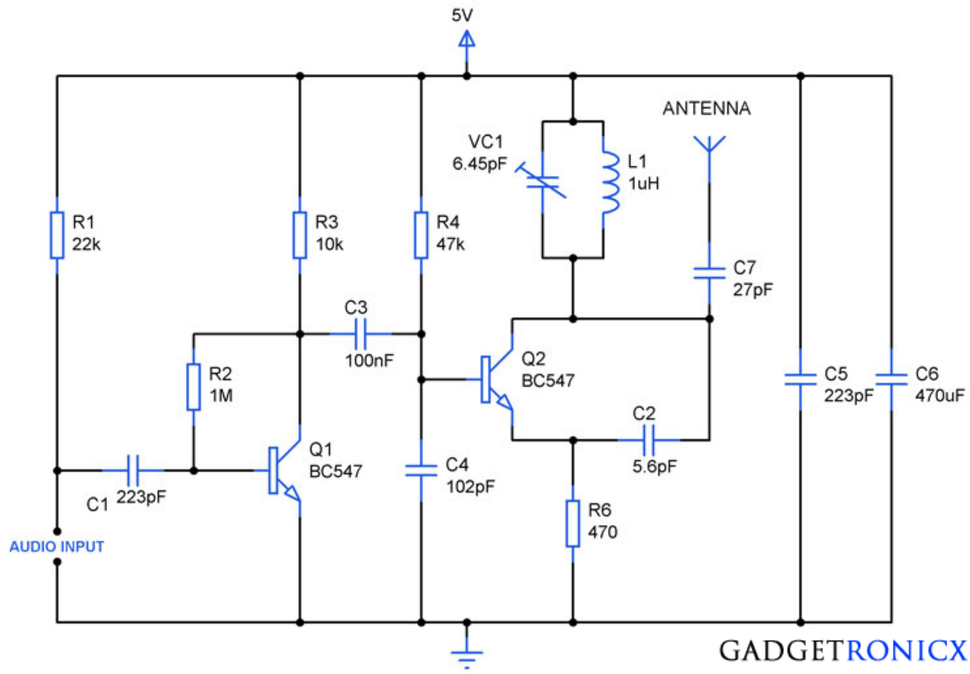


Figure 17.7: *A simple FM circuit*

Uses of FM transmitter

- FM transmitters are used in the homes like sound systems in halls to fill the sound with the audio source.
- They are also used in cars and fitness centres.

Merits of the FM Transmitters

The merits of FM include the following:

- The FM transmitters are cheap and easy to use
- They have very high efficiency
- They have large operating range
- FM transmitters reject noise signals from any amplitude variations.

Demerits of the FM Transmitters

The following are some demerits of FM

- FM transmitters require huge wider channel.
- FM transmitters are more complex than AM

Learning Tasks

1. Explain why an FM transmission has a frequency deviation of 16.25 KHz.
2. What will be the percentage modulation if it is a television broadcast? (HINT: the maximum frequency deviation for T.V transmission is = 25 KHz).
3. Differentiate between AM and FM transmitters in terms of their construction and operation.

Pedagogical Exemplars

Teachers should consider the following activities:

Collaborative Learning: With the use of the internet, engage learners in mixed ability groups to explain the following:

1. AM Transmitter
2. FM transmitter

Research and Collaboration: Organise the learners into mixed-ability groups and task them to research on Google search engine and YouTube to undertake the following activities and do group presentation on their findings: Draw the block diagram of

1. AM Transmitter
2. FM transmitter

Explain the differences between the AM Transmitter and the FM Transmitter

Key Assessment Level 3: Group Project

1. You need to design a communication system for each of the following applications:
    a. Transmitting voice over long distances with limited power
    b. Broadcasting high-quality music to local receivers
    c. Sending digital data between two computers

For each application, identify the most appropriate modulation technique (AM, FM, or digital modulation), and justify your choices by analysing the strengths and limitations of each technique.

2. Two communication systems both operate at the same carrier frequency. System A uses AM modulation while System B uses FM modulation.
    a. Compare how each system would perform during a thunderstorm with atmospheric interference
    b. analyse the bandwidth requirements for each system to transmit the same audio quality
    c. Evaluate which would be more appropriate for a community radio station with limited frequency allocation

PLC Session 17

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week’s concepts in a practical way that will make it easier for learners to understand

   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Plan the week's key assessment with your app
   a. The key assessment for the week is ***group project***. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the project (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

UNIT 17 REVIEW

This unit exposed learners to transmitters in electronic communication. The pedagogical exemplars used in this unit includes Talk for learning approaches and Group work/ Collaborative learning. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 4.

UNIT 18

Section 5: electronic circuits and transmitters in electronic communication

STRAND: ELECTRICAL AND ELECTRONICS TECHNOLOGY

Sub-Strand: Electronic devices and circuits

Content Standard: Demonstrate knowledge and understanding of electronic components

Learning Outcome: *Apply knowledge and understanding of electronic components to design and construct electronic circuits*

INTRODUCTION AND SECTION SUMMARY

This Section looks at electronic communication system with emphasis on AM and FM Transmitters and Receivers, Block diagrams of AM and FM Receivers and the differences that exist between AM and FM receivers as they apply to electrical and electronics technology. It is geared towards equipping the learner with the knowledge, understanding, skills and techniques in Principles of operation of AM and FM Transmitter and Receivers in electronic communication system.

The unit covers only week 18: ***Describe AM and FM receivers in electronic communication***

SUMMARY OF PEDAGOGICAL EXEMPLARS

For this section to be accomplished learners are to be actively engaged in practical demonstration on the various aspect of Receivers in electronic communication system through a wide range of pedagogical exemplars such as Collaborative learning, Research and Collaborative approaches.

ASSESSMENT SUMMARY

The concepts involved in this section requires learners' ability to demonstrate the understanding relating to real life situation hence the assessment should cover all the levels. Teachers should therefore employ a variety of formative assessment strategies both oral and written to collect data from learner's progress and give prompt feedback to them. Teacher can consult Teacher Assessment Manual and Toolkits (TAMTK) (NaCCA 2023) on how to use the assessment strategies effectively.

Indicators	DOK Level	*Assessment Strategy and/or Mode*
Describe AM and FM receivers in electronic communication system	4	*Group work* *Practice Paper 2*

WEEK 18

Learning Indicator: *Describe AM and FM receivers in electronic communication*

FOCAL AREA: AM RECEIVER AND FM RECEIVER

AM Receiver

An AM Receiver- Amplitude modulation radio receiver is an electronic device that captures AM radio signals from a transmitter, demodulates or extracts the original audio information from the AM signal and reproduces the audio content as voice, news or music.

FM Receiver

An FM Receiver- Frequency modulation radio receiver is an electronic device that receives FM radio signals from a transmitter, demodulates or extracts the original audio information from the FM signal and reproduces it as high-quality audio content such as voice. news or music.

Table 4.5: *Comparison between AM Receiver and FM Receiver*

AM Receiver	FM Receiver
In AM, the radio signal is transmitted by varying the amplitude of the signal, keeping the frequency constant.	On the other hand, FM works on the principle of varying the frequency of the carrier, and the amplitude is kept constant.
AM method was first used in 1870.	The FM audio transmission was used in the 1930s by Edwin Armstrong.
When it comes to sound quality, AM has a poorer reputation than FM. However, it is cheaper to use as the bandwidth is lower and can be transmitted to longer distances. In one frequency range, there could be more stations.	FM has a higher bandwidth, making it more reliable, and the sound quality is better than AM. It is only impacted by the physical barriers.
The frequency range for the AM is approximately 1200 bits per second. It ranges from 535 Hz to 1700 Hz.	The frequency range for the FM is a bit higher, ranging from 1200 to 2400 bits per second.
AM is simpler, but synchronisation is needed to maintain the signal as it is received from the transmitter.	FM is complex as the modulating signal needs to be converter after transmission. Voltage to frequency and frequency to voltage while sending or receiving the signals, respectively.
AM is more affected by voice as the amplitude varies in these types of signals.	In FM transmission, noise is not an issue as the amplitude of the transmitted signals doesn't change.

It is important to note that AM offers a longer range and lower cost, while FM provides better sound quality with less interference. The choice therefore between AM and FM depends on the kind of application.

AM and FM Receiver Block Diagrams

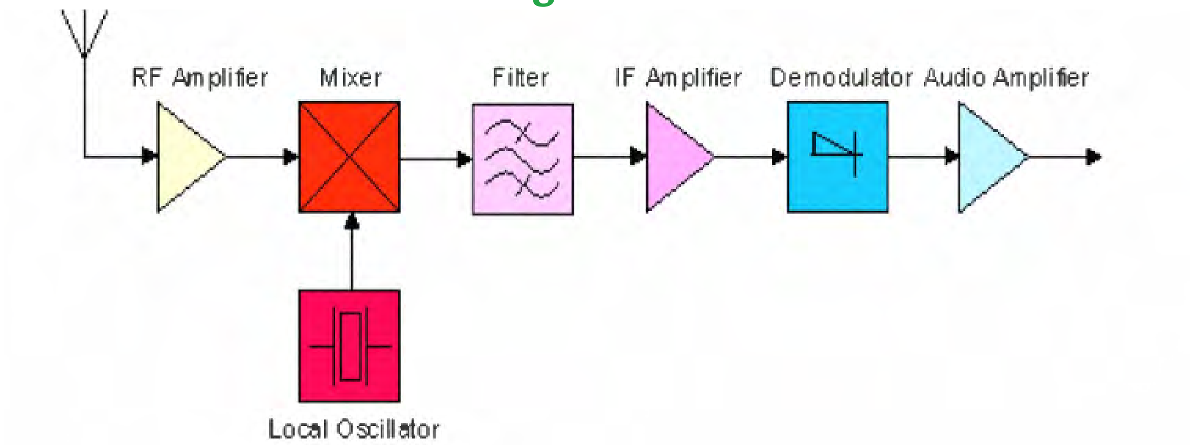


Figure 18.1: *A Block Diagram of an AM Radio Receiver (Superheterodyne)*

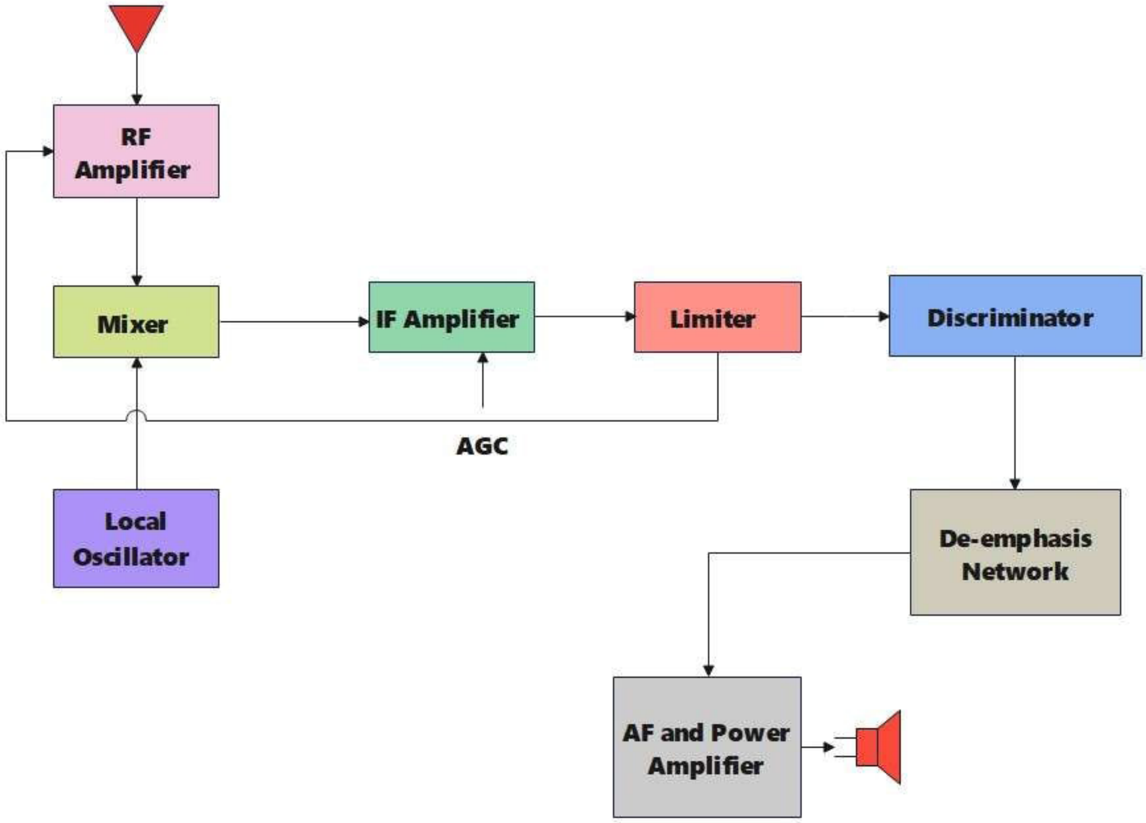


Figure 18.2: *A Block Diagram of an FM Radio Receiver (Superheterodyne)*

Heterodyning: Heterodyning is a signal processing technique where two signals of different frequencies are mixed or combined to produce signals that are of sum component (fo + fs) and difference component (fo – fs).

Learning Tasks

1. Explain the concept of AM and FM Receivers.
2. Discuss at least three differences exist between an AM Receiver and that of FM Receiver.
3. Draw the Block diagrams for AM Receiver and an FM Receiver.

Pedagogical Exemplars

Teachers should consider the following activities:

Collaborative Learning: With the use of the internet, engage learners in mixed ability groups to explain the following:

AM Receiver

FM Receiver

Research and Collaboration: Organise the learners into mixed-ability and gender groups and task them to research on Google search engine and the U-Tube to undertake the following activities and do group presentation on their findings:

Draw the block diagram of

AM Receiver

FM Receiver

Explain the differences between the AM and FM Receivers

Key Assessment: Practice Paper 2

1. A battery-powered portable radio needs to operate for extended periods in areas with both strong and weak signal reception. Design the block diagram of both an AM and an FM receiver for this application, then critically analyse how each design:

- **a.** Handles weak signal reception
- **b.** Manages battery power consumption
- **c.** Maintains audio quality under varying signal conditions

Recommend which receiver type would be more suitable, justifying your recommendation with technical reasoning

2. An old AM radio experiences significant signal fading and interference during evening hours but works well during the day. Analyse the potential causes of this variation in performance related to receiver design and propagation characteristics. Then, propose specific circuit modifications to improve night-time reception while explaining the technical principles behind your solutions.

Hint

*Conduct **Practice Paper 2**. It should cover contents taught from Year 1 to 3. Refer to the **Table of Specification and Structure of the Paper** at the end of this section. Learners' papers should be marked immediately and scores entered into the SAP.*

PRACTICE PAPER 2

TABLE OF SPECIFICATION

PAPER 1 (Multiple Choice Questions)

STRAND	LEARNING INDICATORS	LEVEL OF ASSESSMENT				TOTAL
		1	2	3	4	
Electrical technology	Discuss safety in the use of electricity.		1	1		2
	Describe the process of electrical Power Transmission and distribution.	1				1
	Apply the concept of power transmission and distribution in electricity supply					
	Describe tools and equipment used for house wiring			1		1
	Identify the various materials and accessories used for house wiring	2	1			3
	Describe how a circuit is protected against Excess current	1				1
	Wire final circuits in accordance with IEE regulations					
	Earth an installation work in accordance with rules and regulations		1			1
	Conduct relevant tests on an installation work that has been complete		1			1
	Describe the construction and principle of operation of AC motors	1		1		2
	Describe the construction and principle of operation of DC motors.	1				1
	Describe the construction and principle of operation of DC generators.		1	1		2
	Explain losses that occur in a transformer and how they affect the performance of the transformer			1		1

	Classify home appliances under resistive and inductive loads and outline faults associated with them		1			1
	Detect fault in electrical machines			1		1
	Describe types of resistor as passive electronic components			1		1
	Describe types capacitor as passive electronic components		1			1
	Describe the types of cells and their functions in circuits.			1		1
	Illustrate the principles of operation of the various transistors.		1			1
	Apply the principles of operation of transistors in designing circuits		1			1
	Apply knowledge of electronic components in designing circuits		1			1
	Describe the features and principles of operation of Integrated Circuits			1		
	Apply the principle of operation of Timers in designing circuits			1		1
	Describe the features and principles of operation of Operational Amplifiers		1			1
	Apply the principle of operation of operational amplifiers in designing circuits			1		1
	Solve problems on Binary operations	1				1
	Describe types of logic gates					
	Solve problems on Boolean Algebra			1		1
	Describe the truth table for the various logic gates and determine the output function of the various gates	1				1
	Describe AM and FM transmitters in electronic communication	1				1
Building construction	Explain the stakeholders involved in building construction project		1			1

	Describe the roles of stakeholders in building construction project		1			1
Woodwork	Classify the two main types of wood species	1	1			2
Automotive	Identify types of engines and describe the main components of the engine	1				1
	Demonstrate safety measures applied to servicing, repair and maintenance of engine systems		1			1
Metal	Explain the uses of various types of measuring, marking out, holding, striking and cutting tools	1				1
	Explain ferrous and non-ferrous metals with engineering applications and state the uses of non-metallic materials.		1			1
Total		12	16	12		40
		30%	40%	30%		100%

PAPER 2 (Essay)

STRAND	LEARNING INDICATORS	LEVEL OF ASSESSMENT				TOTAL
		1	2	3	4	
Electrical Systems Design	Identify the various materials and accessories used for house wiring					
	Describe the process of servicing electrical appliances					
	Describe the process of servicing electrical wiring circuits	3				3
	Describe the construction and principle of operation of DC generators.					
	Describe the sequence of Supply-control equipment					
	Apply the knowledge of house wiring in practical situations					

Electronics Technology	Describe the features and principles of operation of Operational Amplifiers	3	3
	Apply the principle of operation of operational amplifiers in designing circuits		
	Illustrate the principles of operation of the various transistors.		
	Apply the principles of operation of transistors in designing circuits		
Total		6	6
			100%

PAPER 3 (Practical test)

STRAND	LEARNING INDICATORS	LEVEL OF ASSESSMENT				TOTAL
		1	2	3	4	
Electrical Systems Design	Explain the concept of electrical and electronic circuits	1				1
	Describe the construction and principle of operation of a transformer					
	Convert moving coil instrument into a voltmeter and ammeter					
	Convert moving iron instrument into voltmeter and ammeter					
Electronics Technology (Practical Test)	Describe the principles and operation of the various Diodes	1				1
	Apply the principles of Diodes in designing circuits					
	Describe types of resistors as passive electronic components					
	Describe the types of cells and their functions in circuits					
Total		2				2
						100%

PLC Session 18

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   - **a.** explain the week's concepts in a practical way that will make it easier for learners to understand.
   - **b.** identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   - **a.** suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   - **b.** suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   - **c.** review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- *Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.*
- *Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.*

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP).
   - **a.** The key assessment for the week is ***practice paper 2***. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   - **a.** use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   - **b.** all teachers in the group work through the problem individually for 3–4 minutes
   - **c.** the group then works through it together the problem, step by step
   - **d.** highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

  a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

  b. After the enactment, ask for structured feedback from the group

    i. was the concept explained in a way that a learner with no prior knowledge could follow?

    ii. were the examples grounded in contexts familiar to Ghanaian learners?

    iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

  a. transfer your chats into your learning planner template.

  b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

  c. integrate National Values, GESI, SEL, and 21^{st} century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

UNIT 18 REVIEW

This unit looks at electronic communication system with emphasis on AM and FM Receivers, Block diagrams of AM and FM Receivers and the differences that exist between AM and FM receivers as they apply to electrical and electronics technology. The pedagogical exemplars used in this unit includes Collaborative learning approaches and Research. These strategies are expected to inculcate in learners' skills in communication, collaboration, critical thinking and problem solving. Various assessment strategies such as Oral/written presentations, class exercises, homework and practical group activities are structured to take care of varied activities of learning. These assessments are classified under DOK Level 4.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

UNIT 14

Question 1

Criteria	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Boolean Algebra Simplification	Performs complete, correct simplification with all algebraic steps clearly shown; reaches most simplified form (e.g., AB + C(A+B))	Correctly simplifies with most steps shown; reaches a simplified but possibly not minimal form	Partially simplifies expression with some algebraic errors	Limited attempt to simplify expression
Original Circuit Implementation	Provides perfect implementation of original expression; uses appropriate gates in logical arrangement; includes all connection details	Provides correct implementation with minimal inefficiencies or presentation issues	Basic implementation with minimal use of logic gates	Limited attempt at implementation
Simplified Circuit Implementation	Provides perfect implementation of simplified expression; optimal gate arrangement; includes all connection details	Provides correct implementation with minor presentation issues	Basic implementation with minimal use of functions and logic gates	Limited attempt at implementation
Comparative Analysis	Provides detailed quantitative comparison of gate count, propagation delay, fan-out issues, and power consumption; analysis is technically precise	Offers good comparison of gate count and at least two performance factors with mostly accurate technical detail	Provides basic comparison of gate count and at least one performance factor with limited technical explanation	Minimal comparison attempted with limited technical details

Practical Importance	Thoroughly explains multiple practical benefits of minimisation (power consumption, chip area, reliability, cost, speed, etc.) with specific technical reasoning	Correctly explains several benefits of minimisation with good technical detail	Explains basic benefits of minimisation with limited technical support	Minimal explanation of minimisation benefits
Non-Minimal Circuit Rationale	Insightfully identifies multiple valid scenarios where non-minimal circuits might be preferred (testability, standardisation, future expansion, etc.) with technical justification	Identifies several valid scenarios with adequate technical explanation	Identifies 1-2 basic scenarios with limited technical support	Provides minimal rationale for non-minimal circuits

Question 2:

Criteria	Excellent (4)	Good (3)	Satisfactory (2)	Needs Improvement (1)
Circuit Analysis Approach	Demonstrates systematic, efficient approach to analysing the circuit; correctly identifies signal flow through all gates; accurately maps connections	Shows logical approach to circuit analysis with minor gaps; correctly traces most signal paths	Shows basic understanding of circuit analysis; follows some signal paths correctly	Limited approach to circuit analysis; little mention of signal flow
Boolean Expression Derivation	Derives the complete and correct Boolean expression for F; uses appropriate notation; shows intermediate steps if complex	Derives mostly correct Boolean expression with limited errors or notational issues	Derives partially correct expression; shows understanding of some circuit components	Limited knowledge of Boolean expressions; simple understanding of circuit operations
Application of Boolean Rules	Correctly applies Boolean algebra rules when combining sub-expressions; simplifies where appropriate	Applies Boolean rules correctly in most cases; limited errors in combining expressions	Applies some Boolean rules correctly; makes errors when combining complex terms	Attempts to apply Boolean rules; little knowledge of operations

Value Computation	Correctly substitutes all input values (A=0, B=1, C=0, D=1); performs perfect step-by-step evaluation; reaches correct final value	Substitutes values correctly; shows most steps; reaches correct final value with minor computational errors	Substitutes most values correctly; shows some working; may reach incorrect final value due to limited calculations	Limited attempt at substitution or calculation; some working out present
Communication of Solution	Solution is presented clearly with logical flow; all steps are shown; proper notation used consistently	Solution is mostly clear with good organisation; adequate steps shown	Solution is understandable but limited organisation or sufficient detail	Minimal attempt to provide clear presentation.

UNIT 15

Question 1

Criteria	Excellent (4 marks)	Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Circuit Design & Functionality	Creates complete, correct circuit that implements all four required behaviours; uses appropriate gates efficiently; includes motor control outputs	Creates mostly correct circuit implementing all behaviours with minor inefficiencies; includes outputs	Creates basic functioning circuit with limited logic present	Simple design of a basic circuit attempted
Logic Implementation Accuracy	Perfect implementation of the four logic conditions; demonstrates optimal approach to decode sensor inputs; includes verification (e.g., truth table)	Correct implementation with good approach; may have minor redundancies; includes basic verification	Basic implementation with functional approach but limited verification	Limited implementation proposed; some understanding of logic
Circuit Explanation	Provides clear, comprehensive explanation of how each part of the circuit works; explains signal flow; connects circuit behaviour to robot movement logically	Provides good explanation of most circuit elements; adequate connection to robot behaviour	Provides basic explanation that covers main functionality but minimal detail present	Explanation is minimal; limited inclusion of concepts

Real-World Problem Analysis	Thoroughly discusses multiple potential real-world issues (sensor variability, interference, threshold problems); proposes specific circuit-level solutions	Discusses several real-world issues with some proposed solutions	Mentions basic real-world issues with limited proposed solutions	Minimal discussion of real-world implementation issues
Technical Communication	Circuit diagram is perfectly clear with proper symbols; excellent organisation ; appropriate technical terminology throughout	Circuit diagram is clear with proper symbols; good organisation ; mostly appropriate terminology	Circuit diagram is understandable but has some clarity issues; basic technical terminology	Simple circuit diagram shown; some organisation present; attempted using terminology

Question 2

Criteria	Excellent (4 marks)	Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Circuit Design Minimality	Achieves provably minimal gate count for 2-out-of-4 detection; uses optimal combination of gate types; demonstrates exceptional understanding of circuit optimisation	Achieves near-minimal gate count; good selection of gate types; shows strong understanding of optimisation	Provides functional design with moderate gate count; some understanding of optimisation	Attempt at adding correct gates provided; minimal understanding of optimisation
Circuit Diagram Quality	Perfect diagram with standard symbols; clear connection paths; excellent organisation ; proper input/output labelling	Clear diagram with standard symbols; goo organisation ; proper labelling with minor issues	Basic functional diagram with minimal symbol or connections present; adequate labelling	Attempted to provide a circuit diagram; minimal labelling present; simple organisation of work
Boolean Expression Accuracy	Provides precise, simplified Boolean expression that exactly implements 2-out-of-4 detection; uses proper notation	Provides correct Boolean expression with minor simplification or notation issues	Provides functional Boolean expression but not fully simplified; limited notations included	Limited knowledge of how to present Boolean expressions; simple notations included

Design Process Explanation	Provides comprehensive, logical explanation of design process; clearly identifies pattern recognition for 2-out-of-4 conditions; demonstrates exceptional problem-solving approach	Provides clear explanation of most design steps; good problem-solving approach	Provides basic explanation that outlines main design decisions; shows adequate problem-solving	Minimal explanation provided; limited logical problem-solving approach
Comparative Evaluation	Thoroughly evaluates multiple alternative implementation approaches; provides insightful technical comparison of gate count, propagation delay, and circuit complexity	Evaluates 2-3 alternative approaches with good technical comparison	Mentions 1-2 alternatives with basic comparison	Minimal evaluation of alternative approaches
Design Extension Analysis	Provides comprehensive analysis of how to add 3-out-of-4 detection; identifies clever ways to leverage existing circuit elements; discusses efficient integration approaches	Provides good analysis of extension requirements with sensible integration suggestions	Provides basic description of how to implement the extension with limited integration considerations	Provides minimal analysis of extension requirements

UNIT 16

Question 1 (20 Marks)

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Carrier Signal Generation Identification	Correctly identifies all components in the carrier generation circuit (likely oscillator circuit); explains their roles precisely; identifies frequency-determining components	Correctly identifies most components in carrier generation; explains their basic functions	Identifies some carrier generation components with partial explanation of function	Limited types of carrier generation components included; provides minimal identification

Modulating Signal Input Identification	Correctly identifies all components in the audio/modulating signal path; explains coupling and pre-processing components; identifies gain control elements	Correctly identifies most modulating signal components with adequate explanation	Identifies some modulating signal components with basic explanation	Provides minimal identification of modulating signal components
Modulation Process Identification	Precisely identifies the modulation stage components (e.g., transistor, transformer, or IC); explains exactly how carrier and modulating signals interact; identifies biasing components	Correctly identifies main modulation components with good explanation of the process	Identifies some modulation stage components with basic explanation	Provides minimal identification of modulating stage components
Component X Analysis	Provides comprehensive analysis of how component X affects modulation index with precise technical explanation; connects to mathematical relationship; predicts specific signal quality impacts	Correctly analyses the relationship between component X and modulation index with good technical detail; describes signal quality effects	Provides basic analysis of how component X affects modulation	Provides minimal analysis of component X's effect on modulation
Technical Understanding	Demonstrates thorough understanding of AM modulation principles; uses precise technical terminology; shows exceptional circuit analysis skills	Shows good understanding of AM modulation; uses mostly correct terminology; demonstrates solid circuit analysis	Shows basic understanding of AM modulation; uses some correct terminology; demonstrates fundamental circuit analysis	Shows limited understanding of AM modulation; some simple terminology used; attempts circuit analysis

Question 2

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Cause Identification	Identifies three distinct, technically accurate causes directly related to modulation/ demodulation; shows comprehensive understanding of receiver operation	Identifies three relevant causes with mostly accurate technical basis; shows good understanding of receiver operation	Identifies 2-3 causes with some partial relevance; shows basic understanding	Identifies fewer than three causes; shows limited understanding
Technical Issue Description	Provides precise, detailed descriptions of each technical issue with specific reference to circuit components or stages; demonstrates exceptional technical knowledge	Provides clear descriptions of each issue with reference to relevant components; demonstrates solid technical knowledge	Provides basic descriptions with some technical details; demonstrates adequate knowledge	Provides vague descriptions; demonstrates limited technical knowledge
Demodulation Effect Analysis	Comprehensively analyses how each issue specifically impacts the demodulation process; explains the exact signal transformation problems; connects to specific audio distortion characteristics	Correctly analyses how issues affect demodulation with good technical detail; makes reasonable connections to audio quality	Provides basic analysis of demodulation effects; makes general connections to audio problems	Provides minimal analysis of demodulation effects; limited ability to connect issues to audio distortion
Testing Method Proposal	Proposes specific, practical testing methods for each cause; includes measurement parameters; describes expected results; demonstrates excellent troubleshooting approach	Proposes reasonable testing methods for each cause with adequate details; demonstrates good troubleshooting approach	Proposes basic testing methods with limited detail; demonstrates fundamental troubleshooting approach	Proposes vague testing methods; demonstrates limited troubleshooting approach

Technical Communication	Uses precise technical terminology throughout; explanations are exceptionally clear and logically organised ; demonstrates professional-level communication	Uses mostly correct technical terminology; explanations are clear and well-organised ; demonstrates good communication skills	Uses some technical terminology correctly; explanations are understandable but limited in scope; demonstrates basic communication	Limited use of correct terminology; simple explanations offered; limited use of communication skills

UNIT 17

Question 1

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Technical Understanding of Modulation	Demonstrates comprehensive understanding of AM, FM, and digital modulation principles with precise technical details about bandwidth, power requirements, and signal characteristics	Shows solid understanding of modulation types with mostly accurate technical descriptions	Shows basic understanding of modulation types with limited technical accuracy	Shows limited understanding about modulation techniques
Long-Distance Voice Application Analysis	Selects most appropriate modulation with comprehensive analysis of power efficiency, bandwidth usage, and distance limitations; excellent consideration of voice communication requirements	Selects appropriate modulation with good analysis of key factors for long-distance voice transmission	Selects reasonable modulation with basic analysis of some relevant factors	Limited selection of correct modulation; provides minimal analysis
High-Quality Music Application Analysis	Selects most appropriate modulation with thorough analysis of audio fidelity requirements, noise immunity, and bandwidth considerations; excellent understanding of music broadcasting challenges	Selects appropriate modulation with good analysis of music broadcasting requirements	Selects reasonable modulation with basic analysis of some relevant factors	Limited selection of correct modulation; provides minimal analysis

Digital Data Application Analysis	Selects most appropriate modulation with comprehensive analysis of data integrity requirements, error rates, and efficiency; excellent understanding of computer data transmission needs	Selects appropriate modulation with good analysis of digital data transmission requirements	Selects reasonable modulation with basic analysis of some relevant factors	Limited selection of correct modulation; provides minimal analysis
Strengths/ Limitations Justification	Provides detailed, technically precise analysis of specific strengths and limitations for each modulation type across all applications; makes excellent comparative evaluations	Provides good analysis of strengths and limitations with adequate technical detail and comparisons	Provides basic analysis of strengths and limitations with limited technical support	Provides minimal analysis of strengths and limitations

Question 2

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Atmospheric Interference Analysis	Provides comprehensive analysis of how AM and FM respond to thunderstorm interference; explains amplitude vs. frequency effects in technical detail; discusses capture effect; includes specific signal-to-noise ratio considerations	Correctly analyses how both systems respond to interference with good technical detail; explains key differences in noise susceptibility	Provides basic comparison with some technical explanation of interference effects on each system	Provides minimal analysis of interference effects
Bandwidth Requirements Analysis	Thoroughly analyses bandwidth formulas for both modulation types; correctly calculates or explains exact bandwidth relationships; precisely explains how audio quality relates to bandwidth in each system	Correctly analyses bandwidth requirements with good technical detail; explains relationship between modulation index and bandwidth	Provides basic analysis of comparative bandwidth needs with limited technical explanation	Provides minimal analysis of bandwidth requirements

Community Radio Evaluation	Provides insightful evaluation considering multiple factors (spectrum efficiency, coverage area, equipment cost, interference resistance); makes well-justified recommendation with excellent technical reasoning	Provides good evaluation with consideration of key factors; makes appropriate recommendation with adequate justification	Provides basic evaluation considering limited factors; makes reasonable recommendation with minimal justification	Provides minimal evaluation with some consideration of relevant factors
Technical Understanding	Demonstrates exceptional understanding of modulation principles; uses precise technical terminology throughout; shows excellent grasp of Carson's rule, modulation index, etc.	Demonstrates good understanding of modulation principles with mostly correct technical terminology	Demonstrates basic understanding with some correct technical concepts but limited depth	Shows limited technical understanding
Communication and Organisation	Presents analysis with exceptional clarity and logical structure; excellent use of technical language; well-organised comparative points	Presents clear analysis with good and appropriate technical language	Presents understandable analysis with adequate organisation and some terminology	Simplistic analysis with some use of terminology

UNIT 18

Question 1

Assessment Rubrics **24 Marks**

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
AM Receiver Block Diagram	Complete, accurate block diagram with all essential stages (RF amp, oscillator, mixer, IF stages, detector, AGC, audio amp); components properly interconnected; signal path clearly indicated	Block diagram includes most essential stages with minor omissions; components correctly connected; signal flow mostly clear	Basic block diagram with some key components identified; fundamental signal path present	Some attempt to draw a diagram; limited use of components; minimal understanding of receiver architecture

FM Receiver Block Diagram	Complete, accurate block diagram with all essential stages (RF amp, oscillator, mixer, IF stages, limiter, discriminator/ratio detector, audio amp); components properly interconnected; signal path clearly indicated	Block diagram includes most essential stages with minor omissions; components correctly connected; signal flow mostly clear	Basic block diagram with some key components missing or misplaced; fundamental signal path present	Some attempt to draw a diagram; limited use of components; minimal understanding of receiver architecture
Weak Signal Reception Analysis	Comprehensive analysis of sensitivity limitations in both receivers; detailed discussion of AGC in AM and limiting/capture effect in FM; includes specific technical considerations for improving weak signal performance in both designs	Good analysis of sensitivity factors in both receivers; discusses key differences in weak signal handling; includes some technical improvement considerations	Basic analysis of how each receiver handles weak signals with limited technical detail	Analysis of weak signal handling attempted; limited understanding of fundamental differences between AM/FM reception
Battery Power Management Analysis	Thorough analysis of power consumption differences; identifies specific high-current stages in each receiver; proposes intelligent power-saving design elements; discusses trade-offs between performance and power consumption	Good analysis of power requirements with identification of major power-consuming stages; proposes some power-saving measures; discusses basic trade-offs	Basic analysis of power consumption with limited technical detail; minimal discussion of power-saving techniques	Minimal analysis of power consumption; limited identification of key differences between receiver types
Audio Quality Analysis	Exceptional analysis of how signal quality varies with reception conditions in both receivers; detailed technical explanation of noise performance differences; thorough discussion of fading, selectivity, and audio bandwidth considerations	Good analysis of signal quality factors with technical explanation of main differences; discusses key quality considerations for both receivers	Basic analysis of audio quality considerations with limited technical depth; some understanding of fundamental differences	Limited analysis of audio quality factors; limited connection of reception conditions to audio performance

Recommendation and Justification	Highly insightful recommendation with comprehensive technical justification; balances all factors (signal handling, power, quality); demonstrates exceptional understanding of application requirements	Clear recommendation with good technical justification; considers most factors; demonstrates solid understanding of requirements	Basic recommendation with limited technical justification; considers some factors; demonstrates adequate understanding	Some recommendations given; minimal consideration of key factors; limited understanding of subject

Question 2 (24 Marks)

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Propagation Analysis	Comprehensive analysis of ionospheric skywave vs. groundwave propagation; detailed explanation of nighttime ionospheric reflection; thorough discussion of how distance affects AM propagation patterns	Good analysis of key propagation differences; explains skywave propagation; addresses main day/night differences	Basic description of propagation differences with some technical explanation; limited understanding of ionospheric effects	Minimal analysis of propagation; limited identification of key day/night differences
Interference Understanding	Thorough analysis of co-channel and adjacent channel interference at night; detailed explanation of how distant stations cause interference; excellent understanding of skip distance and interference zones	Good explanation of increased nighttime interference sources; describes how distant stations become problematic	Basic description of interference issues with limited technical explanation	Limited understanding of interference sources; minimal technical explanation
Receiver Design Analysis	Comprehensive analysis of how specific receiver circuit limitations (selectivity, AGC, IF bandwidth) contribute to nighttime reception problems; identifies exact circuit weaknesses in typical old radios	Good analysis of receiver circuit limitations with identification of key weaknesses; connects circuit design to reception issues	Basic identification of receiver limitations with some connection to reception problems	Limited analysis of receiver design issues; simple connection to the specific problem

Circuit Modification Proposals	Multiple specific, technically sound circuit modifications proposed; includes component values/specifications; modifications directly address identified problems	Several practical circuit modifications proposed with good technical detail; modifications address main issues	Basic modification proposals with limited technical detail; some connection to identified problems	Minimal modification proposals given; limited technical understanding
Technical Principles Explanation	Exceptional explanation of the technical principles behind each proposed modification; precise description of how each modification improves reception; demonstrates deep understanding of AM receiver operation	Good explanation of technical principles for most modifications; clear connection between modifications and improvements	Basic explanation of technical principles with limited depth; some connection between modifications and improvements	Simple explanation of technical principles; limited connection between modifications and improvements
Practical Implementation	Thorough consideration of practical implementation challenges; excellent awareness of component availability/compatibility with vintage equipment; addresses cost and complexity constraints	Good consideration of implementation aspects; addresses main practical concerns	Some consideration of practical implementation with limited detail	Minimal consideration of practical implementation issues

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No	Name of Image	Reference (link)
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2.2	Rotor of an induction motor	https://th.bing.com/th/id/ODF.k-pxizvFukFBB4UyYTNk-kg?pid=ImgDet&w=12&h=12
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4.4	A three-phase synchronous motor	https://tse3.mm.bing.net/th/id/OIP.gdHrLQnHlvB70ga-7tOKh4gHaEa?cb=iwc2&pid=ImgDet&w=191&h=113&c=7
5.1	Diagram of a DC motor	https://th.bing.com/th/id/OIP.GCtW_xmvO-RO3MEAZRkUQ7wHaDt?cb=iwp2&rs=1&pid=ImgDetMain
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12.4	Output wave-form of a three-phase alternator	https://tse3.mm.bing.net/th/id/OIP.pRAu5gQYdKy-70_HJuuQqwAAAA?cb=iw-c2&pid=ImgDet&w=191&h=124&c=7
13.1	Basic construction of a transformer	https://tse1.mm.bing.net/th/id/OIP.uG-WqfTjl7Xr6eoTrZJT22wAAAA?cb=iw-c2&pid=ImgDet&w=191&h=143&c=7
14.2	A typical 3-phase transformer	https://tse2.mm.bing.net/th/id/OIP.Gau-1eYc55WcWpP86NGQGgQHaE8?cb=iw-c2&pid=ImgDet&w=191&h=127&c=7
15.3	Delta – star connection of a 3-phse transformer	https://th.bing.com/th/id/OIP.uq2MOjgTP7TeUht5ZriX_AAAAA?w=307&h=133&c=7&r=0&o=5&cb=iwc2&pid=1.7

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23.7	Short-Shunt Compound Generator.	https://electricalacademia.com/wp-content/uploads/2018/08/Figure-15.png
24.1	Fig 7.1 Oil Natural Air Natural cooling method	https://www.bing.com/th/id/OIP.DhyHpVxd2puFL-BtOA1VizAHaIC?w=162&h=211&c=8&rs=1&qlt=90&o=6&pid=3.1&rm=2
25.2	Fig 7.2. Oil Natural Air Forced method of cooling	https://www.bing.com/th/id/OIP.j8mzDJRjSNXfj5_SIA_LEAHaHu?w=169&h=211&c=8&rs=1&qlt=90&o=6&pid=3.1&rm=2
26.3	Fig 7.3. Oil Forced Air Forced Cooling of Transformer	https://th.bing.com/th/id/OIP.X2wbGj6d0B7u7egCGLSN-3gAAAA?cb=iwc2&pid=ImgDet&w=191&h=127&c=7
27.4	Fig 7.4 Oil Forced Water Forced Cooling of Transformer	https://www.electricaltechnology.org/wp-content/uploads/2022/03/Oil-Forced-Water-Forced-Cooling.png
28.1	A Picture of a pressing Iron (An example of a resistive load)	https://img.freepik.com/premium-photo/modern-electric-iron-isolated-white-background-3d-illustration_943642-6131.jpg?w=2000
29.2	A picture of a Water Heater (An example of a resistive load).	https://as1.ftcdn.net/v2/jpg/01/41/71/02/1000_F_141710214_jVFn37XFSBviYag-F1Ryoccm6DunrGghp.jpg
30.3	A picture of a Blender (An example of an Inductive load).	https://th.bing.com/th/id/OIP.KqrBKEGJwrjNysspZwRnr-gAAAA?cb=iwp2&rs=1&pid=ImgDetMain
31.4	A picture of a Washing Machine (An example of an inductive load)	https://www.lg.com/in/images/washing-machines/md07540887/gallery/FHM1408BDL-Washing-Machines-Right-View-MZ-04-v1.jpg

32.1	A picture showing different types of bearing faults in electrical machines.	https://www.researchgate.net/publication/359414039/figure/fig4/AS:1181552717381656@1658715528107/Some-faults-demonstration-of-ball-element-bearings_Q640.jpg
33.2	A Picture showing a broken rotor bar.	https://www.electricalapparatus.net/wp-content/uploads/rotor-bars.jpg
34.3	A picture showing failure in a three-phase stator winding of an electrical motor.	https://images.squarespace-cdn.com/content/v1/56c20776f699bbc849d-c0a69/1458920265770-J2OWIWOQK5E95CBQA42Z/image-asset.jpeg
35.1	Fig 11.1 The 555 timer IC	https://th.bing.com/th/id/OIP.TaSqichZfNEEc-4BQT-WRkQHaDt?pid=ImgDet&w=191&h=95&c=7
36.2	Fig 11.2 The 556 timer IC	https://www.rantle.com/wp-content/uploads/2020/04/556-Timer-IC.jpg
37.3	Fig 11.3. Internal circuit connection of the 555 timer	https://www.build-electronic-circuits.com/wp-content/uploads/2021/06/Inside-555-timer-sketched.png
38.4	Fig 11.4. Monostable mode of 555 timer	https://th.bing.com/th/id/OIP.j11gRCrgD0h2hOS17USH-6gHaFc?rs=1&pid=ImgDetMain
39.	Fig 11.5a. Bistable mode of 555 timer	https://th.bing.com/th/id/OIP._Reu2IsrbWDEob2pTQbk-9wHaF3?rs=1&pid=ImgDetMain
40.	Fig 11.5b. Bistable mode of 555 timer with 2 push buttond	https://dwma4bz18k1bd.cloudfront.net/tutorials/bistable-multivibrator-555-timer-schematic-diagram.jpg
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45.2	Diagram showing the pin connections of IC 741 Op-amp	https://i0.wp.com/www.electricalvolt.com/wp-content/uploads/2022/12/op4.png?w=1305&ssl=1
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47.3	Open Loop Operation	https://cdn-0.electricalvoice.com/wp-content/uploads/2019/11/open-loop-operation-in-opamp.jpg
48.2	Closed Loop Operation	https://electricalvoice.com/wp-content/uploads/2019/11/closed-loop-operation-in-opamp.jpg
49.1	Transistor-transistor logic circuit	https://www.build-electronic-circuits.com/wp-content/uploads/2022/09/RTL-NOR-gate.png
50.2	Diode Transistor Logic circuit of a 3 input AND Gate	https://www.elprocus.com/wp-content/uploads/Diode-Transistor-Logic-AND-Gate-300x257.jpg
51.3	Diode Transistor Logic circuit of a 3 input NAND Gate	https://ecstudiosystems.com/discover/textbooks/basic-electronics/logic-gates/images/dtl-nand-circuit.jpg
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55.2	Pin connection of 4011 Quad NAND gate	https://1.bp.blogspot.com/_-VwjFK-ofUU/S78NyOWrXoI/AAAAAAAABAU/aOPK13pNhWI/s320/nand3.png
56.1	Block diagram of an AM transmitter	https://images.squarespace-cdn.com/content/v1/554eb-bf2e4b069b360b75a50/b3eb4d57-524c-4d61-adc3-222628864e12/02+-+Block+Diagrams+copy.017.png?format=750w
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58.3	A simple FM transmitter	https://gadgetronicx.com/wp-content/uploads/2014/09/fm-transmitter-circuit-diagram.png
59.1	Block A Diagram of an AM Radio Receiver (Superheterodyne)	https://d3i71xaburhd42.cloudfront.net/2557ce7d0e2ad-f6a3d5578aa066508a6239a7e54/2-Figure4-1.png
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