Unit 17: Electrical Circuits and their Applications

Unit code: M/502/5558

QCF Level 3: BTEC National

Credit value: 10

Guided learning hours: 60

Aim and purpose

The aim of this unit is to enable learners to develop an understanding of the principles which underpin the main aspects of electricity by means of a theoretical and practical approach to study. Learners will be taught principal electrical terms, quantities and relationships and the differences between AC and DC circuits and the importance of working safely with electricity. They will learn to measure electrical values on series and parallel circuits.

Unit introduction

Despite the complexities of modern day electronic devices, fundamental electrical principles still form the basis of sustained electrical and electronic development in all aspects of life.

During the study of this unit, learners could explore questions such as:

- How does electrical current 'flow' in a circuit and in which direction?
- What are the most suitable measuring devices?
- How can we make use of series and parallel circuits in everyday life?
- How does industry make use of conductors and insulators?
- How can we prevent and treat electric shocks?
- How have transducers affected our lives?

Science technicians working in industry, education, health or modern research laboratories must frequently demonstrate a clear understanding of electrical concepts and feel confident in the use of instruments and measuring devices. This unit will provide learners with the knowledge and skills necessary to undertake essential tasks related to electrical circuits and their components.

Learning outcomes

On completion of this unit a learner should:

1 Know principal electrical terms, quantities and relationships

2 Be able to measure electrical values by construction of series and parallel circuits

3 Understand the characteristics of AC and DC circuits

4 Understand the health and safety aspects of working with electricity

5 Know the uses of transducers and measurement devices.

Unit content

1 Know principal electrical terms, quantities and relationships

Terminology and units: current (ampere); potential difference (volt); electrical charge (coulomb); resistance (ohm); conductance (siemen); electrical power (watt); definition of current in terms of rate of flow of mobile charge carriers; EMF as measure of ratio of energy supplied per unit charge; conductance and resistance in relation to density of mobile charge carriers

Electrical relationships: energy supplied $\mathrm{W} = \mathrm{VIt}$; use of Ohm's law $\mathrm{V} = \mathrm{IR}$; Kirchoff's laws; power $P = IV$, $P = I^2R$; charge $Q = It$;

conductance $\mathrm{G} = \frac{1}{R}$; *resistivity* $\mathrm{R} = \frac{\rho l}{A}$

Capacitors: charge stored by capacitors $Q = CV$ in operation as a reservoir; use of capacitors as a filter in AC circuits; units of capacitance (farad and sub-units); charging and discharging; calculations of capacitances

($C_T = C_1 + C_2 \ldots$ *for parallel capacitors,* $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ *… for series capacitors)*

Electrical properties of materials: eg conductivity and resistivity, insulators and conductors, Ohmic and non-Ohmic conductors, use of semiconductors, superconductors

2 Be able to measure electrical values by construction of series and parallel circuits

Circuit characteristics: correct assembly of series and parallel resistive circuits using up to three resistors in series, parallel and series – parallel combination; calculation of resistance and conductance

($\mathrm{R_T} = \mathrm{R_1} + \mathrm{R_2} \ldots$ for series circuits, $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ for parallel circuits and similarly for

conductance); use of ammeters and voltmeters (digital and analogue types for simple comparison); nature of voltage drop across components as the energy dissipated per unit charge by a resistor (where the energy dissipated is transferred from electricity into heat); potential divider circuits and potential divider calculation; internal resistance and EMF with use of $E = I\,(R + r)$

3 Understand the characteristics of AC and DC circuits

Mains electricity: domestic ring main circuit; nature of AC voltage as changing polarity with instantaneous values varying sinusoidally, eg mains frequency; root mean square (rms); peak and peak-to-peak voltages

Industrial applications: DC current, eg transport (trams, railways), lifting gear, electrolysis; AC current, eg induction furnace

4 Understand the health and safety aspects of working with electricity

Human physiology and electricity: typical resistance values for current pathways in the body; skin resistance and changes of environment, eg moisture levels of the skin, contact with the ground; heart responses to electric shock; safe levels of DC voltage

Electrical safety devices: earthing; fuses; significance of double insulation; residual current and earth leakage circuit breakers (RCCB and ELCB); variable socket design; isolating transformers (for outside use)

5 Know the uses of transducers and measurement devices

Passive transducers: definition as devices which change the electrical characteristics within a circuit by the influence of external physical sources (sensors); eg light dependant resistor (LDR) and their practical uses, eg light-meters, automatic cameras, alarm systems; thermistors; reed switch; strain gauge; Wheatstone bridge arrangement and potential divider circuits

Active transducers: production of EMF by conversion of energy from external physical source, eg operation and structure of a thermocouple; piezoelectric devices and fundamental principles; understanding of the need for signal amplification for these devices

Measurement devices: uses of oscilloscopes for voltage measurement and AC/DC display; multimeters and range of measurements; data logging devices as those which sense and store information from physical sources for use with visual/audio display and processing, eg pH meters, temperature sensors, moisture sensors, light sensors

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 define principal electrical terms, quantities and relationships	**M1** show, by calculation, the use of electrical terms, quantities and relationships	**D1** analyse, by calculation and graphical representation, fundamental electrical relationships and quantities
P2 assemble series and parallel electrical circuits [TW1,4; EP2,3]	**M2** calculate current, potential differences and resistances in series and parallel circuits	**D2** compare the accuracy of measured values in circuit operation
P3 carry out essential electrical measurements on the assembled circuits [TW1,4; EP2,3; SM2,4]		
P4 review the differences between AC and DC circuits [CT1,2]	**M3** explain the operations of electrical safety practices used to minimise risk	**D3** evaluate the effectiveness of electrical safety practices, suggesting valid improvements
P5 explain the dangers of working with electricity		
P6 list the main types of active and passive transducers used in electrical circuits	**M4** explain the characteristics of active and passive transducers used in typical electrical circuits	
P7 outline the uses of measurement devices in electrical circuits.	**M5** compare and contrast analogue and digital measurement devices.	**D4** analyse the suitability of an electrical measurement device for its intended purpose.

PLTS: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills applicable in the pass criteria. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

Key	IE – independent enquirers	RL – reflective learners	SM – self-managers
	CT – creative thinkers	TW – team workers	EP – effective participators

Essential guidance for tutors

Delivery

Construction of simple circuits and regular circuit measurement should be incorporated wherever possible. Competency in practical circuit building and understanding of how and where to measure voltage, current and resistance should be developed throughout the unit to become almost routine.

Delivery can include discussion, presentations, formal lectures, workplace visits, practical circuit activities, research and guest invitations from industrial speakers. A varied structure is highly recommended and should help to stimulate and enthuse learners.

Learning outcomes 1 and 2 are very closely linked allowing tutors to demonstrate particular electrical relationships using practical activity. Use of voltmeters and ammeters can be extensive and continued practice in practical application will help to reinforce understanding of these relationships. Learners should become familiar with electrical materials and their uses. Tutors should ensure that sufficient focus there is on the characteristics and importance of capacitors in circuits and demonstrate the AC applications.

The differences between series and parallel circuits should be explored practically and learners should develop a clear understanding of the nature of current 'flow' in these circuits.

Learning outcome 3 focuses on differences between AC and DC. Tutors should explain RMS values and DC equivalence, peak voltages and the nature of AC as a sinusoidal waveform. Learners can discuss the systems put in place to reduce risk from mains electricity and progress to a study of the physiological effects of electricity in the body as a means of helping further understanding of prevention of electric shock. Different effects on the heart of AC and DC should be emphasised. Tutors can also explain that circuit resistance (and body resistance), current and time are the important elements that determine the extent of electric shock.

Learning outcome 4 should be delivered using the practical techniques used throughout the unit. It is essential that learners have direct experience of measuring devices, in particular multimeters, oscilloscopes and data logging devices.

For learning outcome 5, transducers in general should be explained in terms of accepted electrical and physical characteristics. The confusion of 'passive' or 'active' depending on text used can be eliminated by attention to usage rather than energy conversion. Generally, real transducers (eg thermocouple, piezoelectric) produce their own EMF. LDRs, thermistors and strain gauges do not and can be more properly referred to as sensors.

As often as possible, learners should use data logging devices, taking information from physical changes. Learners should become familiar with data collection, processing and display. There is no need to explain particular functions in detail – learners just need to appreciate their usefulness as measurement devices.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way in planning the delivery and assessment of this unit.

Topic and suggested assignments/activities and/assessment
Outline unit introduction, content and assignment programme.
1. *Electrical terminology*: definitions and research group work. Correct use of units, electrical relationships. Demonstration of exponential charge/discharge for capacitors. Practical – ohmic/non-ohmic conduction, use of data for calculations and graphical representation. **Assignment 1 – Electricity and Numbers (P1, M1, D1)**
2. *Investigation*: assembly of circuit types, group work. Combination circuits, measurement of quantities using digital and analogue devices (theoretical). Potential divider circuits and associated calculations. **Assignment 2 – Sea of Electrons (P2, P3, M2, D2)** Individual learning time. Comparison of calculated values with experimental measurement (report).
3. *Theoretical*: learners learning from group work and research. Demonstration to show sine wave characteristics on oscilloscope. Difference of AC to DC, value of RMS.
4. *Theoretical*: health and safety exercises based on video evidence. Physiological effects on the body of AC and DC. Characteristics of electric shock, treatment of electric shock. Visit to industrial site (Distribution Company individual learning time. **Assignment 3 – Shocking (P4, P5, M3, D3)** Use of electrical safety devices, evaluation of effectiveness, research work for students, safety audit in industrial context.
5. *Investigation*: circuit construction and report on both types of transducers. Using various passive sensors. Using active transducers. Limitations, need for amplification by experimental measurement, assessment. **Assignment 4 – Sensors at Work (P6, M4)** Link with variety of work places to include electronics manufacturer to view operations of sensors .
Review of unit and assignment programme.

Topic and suggested assignments/activities and/assessment
6. *Investigation and theoretical*: comparison of measurement devices and report. Use of analogue and digital meters. Oscilloscope uses. Active use of data loggers. **Assignment 5 – Tools for the Job (P7, M5, D4)** Individual learning time and assessment of devices as comparative report or demonstration from investigation and use.

Assessment

The strategies for assessment will be linked to the effective writing of assignments within this unit. A variety of forms of evidence such as written, investigative, poster display, graphs, appropriate software presentations etc, should be encouraged.

To achieve P1, learners must comprehensively list all the electrical terms in the *Unit content* section, giving a brief description of each. This may be done by producing a definition catalogue or poster. Practical work can be incorporated to provide evidence of electrical quantities and some relationships. M1 learners need to demonstrate the ability to use correct electrical relationships and calculate values of electrical quantities. Tutors can provide formulae sheets which incorporate many or all examples of standard suitable calculations that can be performed by the learners and assessed. D1 learners must perform unaided calculations of essential electrical quantities using studied relationships in order to meet this criterion. As many graphical representations for electrical relationships should be produced as necessary (eg resistance, power, charge). These should be used to explain relationships within the circuit operation.

For P2 and P3 learners should be able to obtain measurements of voltage, current and resistance from the construction of series and parallel circuits. Circuit construction should incorporate up to three resistors in a variety of configurations. There is no specific number of circuits required, but tutors should ensure that they are varied and that learners are given guidance where necessary. For M2 learners can use the values obtained in their circuit measurements to make accurate circuit calculations using data. Learners should be able to predict values of current, voltage and resistance at various points in circuits by calculation. These predicted values can then be compared to measured values obtained. Both series and parallel circuit construction must be used as evidence. For D2 learners must use data gathered from circuit construction and calculations in M2 to fully assess the comparison made of measured and calculated values. Learners can provide a report or general account of the operation of a suitable circuit and the measured and calculated values obtained. Any discrepancies between these values can be explained by example calculations and circuit understanding.

Learners can generate sufficient evidence for P4 and P5 by carrying out a safety audit. The effects of both AC and DC on the body can be illustrated by artistic work or a simple report which also reviews the differences between the types of circuits. Alternatively, a video presentation or classroom 'lecture' can be produced which would help learners to incorporate the academics of this topic and develop presentation skills. M3grade learners must give valid explanations of how specific safety devices reduce risk from electricity. Each device studied must be described with the aid of clearly labelled diagrams and explanatory notes on how the device is activated within its circuit. Information should also be included as to how organisations maintain health and safety in relation to hazards posed by use of electrical equipment. To achieve D3 learners must show an ability to evaluate electrical safety devices and safety practices to help reduce or eliminate specific risks. The style of critique is unimportant but the emphasis must be on the overall quality and depth of material provided.

For P6 and P7 learners must provide a list of various transducers and the uses of measurement devices commonly in operation. The uses to which these devices are put can be clearly contextualised and evidence for this section could be from a work placement. A large poster can provide enough evidence to meet the criterion for this task. M4 and M5 grade learners need to demonstrate qualitative research capabilities and may use various order catalogues from equipment manufacturers. Learners can produce circuit diagrams of the transducers chosen and explain their characteristics, referring to levels of potential difference, current and resistance. Practical circuit investigation of the device can also provide this evidence, but values obtained must be verified by the tutor or research text. Suitable transducers are thermocouples, thermistors and LDRs. Practical work can also be used as a means for making a detailed comparison of an analogue and digital measurement device, although research information may be used to produce a table of advantages/ disadvantages, for example. D4 grade learners must produce an analytical account of the suitability of a chosen measurement device from those studied in the unit. Evidence can focus on a working example of a device in industry and presented as a case study, outlining its history, development and technological advancement to date.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Electricity and Numbers	Newly appointed science technician in a college science department.	Production of informative booklet as a means of reference for general electrical work.
P2, P3, M2, D2	Sea of Electrons	Fault diagnosis for service, repair and circuit testing in the workplace.	Circuit building: • components • assembly • measurements taken • calculations from values taken and explanations.
P4, P5, M3, D3	Shocking	Electronics laboratory health and safety audit.	Safety audit: • physiological effects of shock • preventative methods • circuit safety devices • AC/DC characteristics.
P6, M4	Sensors at Work	Research magazine for scientific innovation.	Report on transducers: • uses • limitations • developments.
P7, M5, D4	Tools for the Job	Systems monitoring technician in local medical company.	Report on measurement devices in use and comparison of analogue and digital types.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit forms part of the BTEC in Applied Science sector suite. This unit has particular links with the units below in the BTEC Applied Science suite of qualifications:

Level 2	Level 3
Energy and our Universe	Fundamentals of Science
Physical Applications of our World	Scientific Practical Techniques
Electronics in Action	Using Mathematical Tools for Science
	Medical Physics Techniques
	Electronics for Science Technicians
	Medical Instrumentation

Essential resources

- Electrical circuit boards or equivalent.
- Full range of essential electronic and electrical components (including resistors and capacitors).
- Power supplies (12V DC), low voltage and mains AC.
- Measurement devices:
  - voltmeters and ammeters
  - multimeters
  - high impedance oscilloscopes (single or dual trace)
  - signal generator
  - microphones and suitable speakers.
- DVDs on safety and electrical transmission.
- Data logging devices (eg Philips range).
- Various conductive wires.
- Access to ICT facility.
- Rheostats and variable resistor packs.

Tutors should be well qualified in electrical or similar disciplines and fully conversant with components and electrical measurement.

Employer engagement and vocational contexts

Learners should visit electronic or electrical manufacturing companies. Component and circuit assembly plants, heavy industrial complexes and power stations would all be suitable and these industries allow learner visits through a programme of local community links.

Contextualised references to domestic electrical supply and other variations eg schools, hospitals and retail outlets, will enhance the knowledge learned.

Indicative reading for learners

Textbooks

Bird J – *Electrical Circuit Theory and Technology* (Newnes, 2007) ISBN 9780750681391

Breithaupt J – *New Understanding Physics for Advanced Level* (Nelson Thornes, 2000) ISBN 9780748743162

Cogdell J R – *Foundations of Electric Circuits* (Prentice Hall, 1998) ISBN 9780139077425

Duncan T – *Electronics for Today and Tomorrow* (Philip Allan, 1997) ISBN 9780719574139

Ellse M and Honeywill C – *Electricity and Thermal Physics* (Nelson Thornes, 2005) ISBN 9780748776634

Johnson K et al – *Advanced Physics for You* (Nelson Thornes, 2000) ISBN 9780748752966

Journals

Journal of Electrical Systems

New Scientist

The Open Electrical and Electronic Engineering Journal

Websites

www.allaboutcircuits.com	Online textbooks on electricity and electronics
www.energysafety.govt.nz	Energy safety
www.iee.org.uk	The Institution of Engineering and Technology
www.nationalgrid.com	National Grid
www.physicsworld.com/cws/home	Physics World online

Delivery of personal, learning and thinking skills

The table below identifies the opportunities for personal, learning and thinking skills (PLTS) that have been included within the pass assessment criteria of this unit.

Skill	When learners are ...
Creative thinkers	[CT1,2] developing methods to prevent electrical shocks when dealing with AC theory
Team workers	[TW1,4] sharing practical techniques and setting up electrical circuits for measurement within groups
Self-managers	[SM2,4] recording and collating data from experiment on electrical measurement; calculating and comparing electrical values
Effective participators	[EP2,3] setting up electrical circuit safety devices; assessing acceptable voltage levels and taking effective measurements for investigation.

Although PLTS are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

Skill	When learners are ...
Independent enquirers	[IE1,4] taking part in site and workshop visits
Creative thinkers	[CT2,5] assessing the applications of sensor types by research and investigation
Reflective learners	[RL3,5] constructing circuits and correcting component choices or circuit connections
Team workers	[TW2,3] developing a group safety audit and drawing comparisons between two industrial workplaces
Self-managers	[SM1,6] observing correct safety measures in all practical situations and taking care with use of equipment
Effective participators	[EP4,5] taking part in development and presentation with appropriate software for measurement devices.

Functional Skills – Level 2

Skill	When learners are ...
ICT – Use ICT systems	
Select, interact with and use ICT systems independently for a complex task to meet a variety of needs	using data logging systems in circuit measurement and producing corresponding graphical representation methods
Use ICT to effectively plan work and evaluate the effectiveness of the ICT system they have used	producing appropriate software for purposes of equipment comparison
ICT – Find and select information	
Select and use a variety of sources of information independently for a complex task	collating research information and adapting for report
Access, search for, select and use ICT-based information and evaluate its fitness for purpose	researching information for direct comparison to investigative work
ICT – Develop, present and communicate information	
Enter, develop and format information independently to suit its meaning and purpose including: • text and tables • images • numbers • records	developing correct formats – tables, graphs and text
Bring together information to suit content and purpose	forming coherent reports and findings
Present information in ways that are fit for purpose and audience	developing reports and appropriate software presentations
Evaluate the selection and use of ICT tools and facilities used to present information	comparing the suitability of chosen measurement devices, data logging and oscilloscope equipment.