

# Unit 5: Electrical and Electronic Principles

NQF Level 3: BTEC National

Guided learning hours: 60

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## Unit abstract

The modern world relies on electrical and electronic devices – from mobile telephones to jet aeroplanes, these devices have had an enormous impact on the way we live today. Without early engineers such as Faraday and Lenz, who studied the then new concept of electricity, many of the inventions we now take for granted would not have been made.

This unit will give any aspiring electrical/electronic engineer an understanding of the underlying physical principles governing the operation of electrical and electronic devices and circuits. The unit aims to build on previous knowledge and give learners a firm foundation for further study of electrical and/or electronic units.

The unit starts by developing and extending learners' understanding of fundamental electrical and electronic principles through analysis of simple direct current (DC) circuits. Learners are then taken through the various properties and parameters associated with capacitance and inductance, before finally considering the application of single phase alternating current (AC) theory. The unit will encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

For learners wishing to follow an electrical/electronic programme this unit is an essential building block that will provide the underpinning knowledge required for further study of electrical and electronic applications.

## Learning outcomes

**On completion of this unit a learner should:**

- 1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits
- 2 Understand the concepts of capacitance and determine capacitance values in DC circuits
- 3 Understand the principles and properties of magnetism
- 4 Understand single-phase alternating current (AC) theory.

## Unit content

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### 1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits

*DC circuit theory:* voltage eg potential difference, electromotive force (emf); resistance eg conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source eg cell, battery, stabilised power supply; resistors eg function, types, values, colour coding; diodes eg types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae eg  $V = IR$ ,  $P = IV$ ,  $W = Pt$ , application of Kirchhoff's voltage and current laws

*DC networks:* networks with one DC power source and at least five components eg DC power source with two series resistor and three parallel resistors connected in a series parallel arrangement; diode resistor circuit with DC power source, series resistors and diodes

*Measurements in DC circuits:* safe use of a multimeter eg setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source, testing a diode's forward and reverse bias)

### 2 Understand the concepts of capacitance and determine capacitance values in DC circuits

*Capacitors:* types (electrolytic, mica, plastic, paper, ceramic, fixed and variable capacitors); typical capacitance values and construction (plates, dielectric materials and strength, flux density, permittivity); function eg energy stored, circuits (series, parallel, combination); working voltage

*Charging and discharging of a capacitor:* measurement of voltage, current and time; tabulation of data and graphical representation of results; time constants

*DC network that includes a capacitor:* eg DC power source with two/three capacitors connected in series, DC power source with two/three capacitors connected in parallel

### 3 Understand the principles and properties of magnetism

*Magnetic field:* magnetic field patterns eg flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops; ferromagnetic materials; reluctance; magnetic screening; hysteresis

*Electromagnetic induction:* principles eg induced electromotive force (emf), eddy currents, self and mutual inductance; applications (electric motor/generator eg series and shunt motor/generator; transformer eg primary and secondary current and voltage ratios); application of Faraday's and Lenz's laws

#### 4 Understand single-phase alternating current (ac) theory

*Single phase AC circuit theory:* waveform characteristics eg sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities eg graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure R, L and C components

*ac circuit measurements:* safe use of an oscilloscope eg setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values); circuits eg half and full wave rectifiers

## Grading grid

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

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 the learner is able to:	To achieve a distinction grade the evidence must show that the learner is able to:
P1 use DC circuit theory to calculate current, voltage and resistance in DC networks	M1 use Kirchoff's laws to determine the current in all the branches of a network containing two voltage sources, five nodes and power dissipated in a load resistor	D1 analyse the operation and the effects of varying component parameters of a power supply circuit that includes a transformer, diodes and capacitors
P2 use a multimeter to carry out circuit measurements in a DC network	M2 evaluate capacitance, charge, voltage and energy in a network containing a series-parallel combination of three capacitors	D2 evaluate the performance of a motor and a generator by reference to electrical theory.
P3 compare the forward and reverse characteristics of two different types of semi-conductor diode	M3 compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram.	
P4 describe the types and function of capacitors		
P5 carry out an experiment to determine the relationship between the voltage and current for a charging and discharging capacitor		
P6 calculate the charge, voltage and energy values in a DC network that includes a capacitor		

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 the learner is able to:	To achieve a distinction grade the evidence must show that the learner is able to:
<p>P7 describe the characteristics of a magnetic field and explain the relationship between flux density (B) and field strength (H)</p> <p>P8 describe the principles and applications of electromagnetic induction</p> <p>P9 use single phase AC circuit theory to explain and determine the characteristics of a sinusoidal AC waveform</p> <p>P10 use an oscilloscope to measure and determine the inputs and outputs of a single phase AC circuit.</p>		

## Essential guidance for tutors

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### Delivery

It is important that *Unit 4: Mathematics for Technicians* has been delivered or is being delivered concurrently with this unit to give learners the necessary mathematical skills. Some level of computer skills may also be necessary to use the computer-based software.

Each of the four learning outcomes of this unit are linked and the delivery strategy should ensure that these links are maintained. Learning outcome 1 is the most likely starting point for delivery, as it will establish much of the underpinning knowledge and skills required for the remaining learning outcomes. The unit could be delivered through a combination of theory lessons and demonstrations, reinforced through practical work in an electrical science laboratory/workshop. It is important that learners have a thorough understanding of circuit theory if they are to be able to recognise, handle and select relevant components (eg power sources, resistors, diodes).

Initially, delivery could use paper-based or computer-based exercises (eg calculate the required value of a second resistance in a series circuit to give a current flow of 2A with a 6V power source). However, even at this stage it may be beneficial to introduce learners to real circuit components. The learners' ability to lay out circuits is an important part of this learning outcome and will support the other outcomes of the unit. Most centres will probably start with paper-based methods of drawing simple circuits (eg power source and series/parallel combination of resistors such as voltage and current divider circuits). It is likely that centres will move on to computer simulation and the use of real circuits/components, using either 'bread boarding' techniques or soldered circuits.

Learners should be given the opportunity to practise using the formulae identified in the unit content but are not required to memorise them. However, they should be expected to select the most appropriate formulae to determine the required circuit values of current, voltage or resistance. In addition, learners should have the confidence to transpose equations to meet their needs (eg use Ohm's law  $V = IR$  and the power equation  $P = IV$  to arrive at  $P = I^2R$ , use  $R = R_1 + R_2$  to arrive at  $R_1 = R - R_2$ ). Clearly, the ability to transpose formulae is a mathematical skill and tutors will need to ensure that appropriate support is provided during both the delivery of this learning outcome and the unit as a whole.

Wherever possible, centres should enable learners to experience a range of multimeters that reflect typical and current industry usage. It would not be appropriate to only use computer-based simulation packages. Tutors should ensure the safe use of multimeters and an awareness of their use in a laboratory/workshop and industrial setting.

The use of computer-based software packages for analysis and simulation of electrical circuits together with practical laboratory work will help to corroborate theoretical results.

Centres are encouraged to relate theory to real engineering applications wherever possible. Industrial visits or work experience could be used to support learning and provide learners with an appreciation of the industrial applications of electrical and electronic principles.

Centres should consider whether it is necessary to deliver the section on diode theory with or without recourse to semi-conductor theory. It should be noted that *Unit 35: Principles and Applications of Electronic Devices and Circuits* does not specify the delivery of semi-conductor theory as a precursor to diode theory. If semi-conductor theory is delivered within this unit it should be focused towards enabling learners to achieve criterion P3.

Note that the use of 'eg' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'eg' needs to be taught or assessed.

## Assessment

Much of the evidence for the pass criteria can be achieved by practical experimentation with real components and circuits and computer-based software packages, where appropriate.

It is likely that at least four assessment instruments will be required for this unit. If practical work and tests are also used then the total number of pieces of assessed work could be even more than this. This should be carefully considered so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Clearly, the ability to safely use a multimeter (P2) will require process evidence, ie, it will need to be observed by the tutor during relevant practical activities. Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The assessment of the use of circuit theory to calculate current, voltage and resistance in DC networks (P1) could be achieved by using a paper-based or computer-based method. However, it is essential that centres combine any testing of this sort with practical hands-on experience of real circuits and components. This could be achieved by prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement. Whichever method is used, centres need to ensure that sufficient product evidence is available of the circuit being used/developed and the formulae selected/used to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where print-outs do not show sufficient detail to meet the criteria.

The comparison of the forward and reverse characteristics of two types of semiconductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box.

For P4, learners will need to describe the full range of types of capacitors (electrolytic, mica, plastic, paper, ceramic, fixed and variable) including typical capacitance values, construction (plates, dielectric materials and strength, flux density, permittivity), their function and working voltages.

P5 requires learners to carry out a laboratory experiment to investigate the charging and discharging of a capacitor through a resistor. A simple but effective way of doing this is to use a power supply unit, a 500 $\mu$ F electrolytic capacitor, a stopwatch or clock and an AVO type multimeter, using the internal resistance of the meter as the resistor. Learners could then be asked to plot the graph of the growth of capacitor voltage against time and evaluate the time constant by comparing the results with standard theory.

P6 involves the calculation of charge, voltage and energy values for DC networks that include a DC power source with two/three capacitors connected in series and a DC power source with two/three capacitors connected in parallel.

The characteristics of magnetic fields for P7 could be demonstrated on an OHP by using magnets and iron filings. Learners could sketch the results and then make appropriate comparisons with expected theoretical results. The other part of P7 is to explain the relationship between flux density (B) and field strength (H) with particular emphasis on BH curves and the use of different materials such as silicon iron and mild steel.

The evidence for P8 will be descriptive and requires learners to provide basic explanations of the principles and concepts of electromagnetic induction such as the movement of a conductor within a magnetic field.

P9 and P10 could link AC theory and practice with learners observing and measuring some of the fundamental characteristics of a single wave AC circuit. This will require the use of a multimeter and an oscilloscope to make appropriate comparisons of frequency, maximum and rms values.

M1 relates to the use of Kirchoff's laws and here again learners should be encouraged to check their results by using a computer software package and/or practical experiment. This criterion naturally follows on from the work on resistors in series and parallel in DC circuits and, as such, could perhaps be incorporated into an assignment covering P1, P2 and M1.

For M2 learners need to evaluate capacitance, charge, voltage and energy for specific capacitors in a series parallel combination. This extends the understanding from the pass grade criterion and could naturally form a next step in an assignment/assessment activity devised for P6.

M3 is intended as an exercise in the graphical addition of two sinusoidal voltages or currents, checking the values theoretically by calculation and also by practical means. This criterion could be linked to *Unit 4: Mathematics for Technicians* and, once learners had been taught the sine and cosine rules, could be used to provide evidence for both units.

For D1 a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of high voltages or currents present. This could be achieved using a function generator as a source of sinusoidal alternating voltage, along with a small isolating transformer, diode rectifiers (half wave and bridge) smoothing capacitors and load resistors.

D2 requires learners to predict the performance of motors and generators by reference to electrical theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines.

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

This unit relates strongly to *Unit 4: Mathematics for Technicians* and it would be useful to study these units concurrently as this unit has a reliance on strong mathematical skills involving problem solving and graphical plots. Data from experiments within this unit can be manipulated mathematically and so provide evidence for both units.

This unit also covers some of the knowledge and understanding associated with the SEMTA Level 3 National Occupational Standards in Electrical and Electronic Engineering, particularly:

- Unit 15: Checking the Compliance of Electronic Components Against the Specification
- Unit 17: Assembling and Wiring Electronic Equipment and Systems
- Unit 18: Testing Post-Production electronic components and Circuits
- Unit 24: Assembling Transformers and Inductors
- Unit 25: Fitting Small Transformer and Inductor Cores
- Unit 26: Assembling Rotor and Armature Windings
- Unit 27: Assembling Stator Windings
- Unit 28: Assembling and Fitting Commutators
- Unit 30: Assembling and Fitting Electrical Rotating Equipment
- Unit 31: Mounting Electrical Components in Enclosures
- Unit 32: Wiring Electrical Components and Equipment in Enclosures
- Unit 33: Selecting and Preparing Materials and Components for Electrical Assembly
- Unit 34: Carrying Out Functional Tests on Electrical Equipment.

The unit provides underpinning knowledge to support the study of all other electrical and electronic units such as *Unit 35: Principles and Applications of Electronic Devices and Circuits* and *Unit 67: Further Electrical Principles*.

## Essential resources

It is essential that learners have access to a well-equipped electrical and electronics laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content, together with the means to physically construct circuits. With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

## Indicative reading for learners

### Textbooks

Bird J O – *Electrical and Electronic Principles and Technology, Second Edition* (Newnes, 2004) ISBN 0750665505

Bird J O – *Electrical Circuit Theory and Technology* (Newnes, 2004) ISBN 0750657847

Robertson C R – *Fundamental Electrical and Electronic Principles* (Butterworth-Heinemann, 2001) ISBN 0750651458

## Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skills evidence are given here. Staff should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

<b>Application of number Level 3</b>	
<b>When learners are:</b>	<b>They should be able to develop the following key skills evidence:</b>
<ul style="list-style-type: none"> <li>planning and presenting their descriptions and explanations when comparing practical and theoretical information</li> <li>solving problems and interpreting results in any of the four learning outcomes using conventional methods and/or computer-based software packages.</li> </ul>	<p>N3.1 Plan an activity and get relevant information from relevant sources.</p> <p>N3.2 Use this information to carry out multi-stage calculations to do with:</p> <ul style="list-style-type: none"> <li>a amounts or sizes</li> <li>b scales or proportion</li> <li>c handling statistics</li> <li>d using formulae.</li> </ul> <p>N3.3 Interpret the results of your calculations, present your findings and justify your methods.</p>
<b>Information and communication technology Level 3</b>	
<b>When learners are:</b>	<b>They should be able to develop the following key skills evidence:</b>
<ul style="list-style-type: none"> <li>researching and using a variety of different sources for product/component information</li> <li>developing and presenting information on electrical and electronic principles to meet the unit criteria/content eg description of capacitors, magnetic field etc.</li> </ul>	<p>ICT3.1 Search for information, using different sources, and multiple search criteria in at least one case .</p> <p>ICT3.2 Enter and develop the information and derive new information.</p> <p>ICT3.3 Present combined information such as text with image, text with number, image with number.</p>

<b>Problem solving Level 3</b>	
<b>When learners are:</b>	<b>They should be able to develop the following key skills evidence:</b>
<ul style="list-style-type: none"> <li>• solving problems in DC and AC circuits using conventional methods and computer-based software analysis and simulation packages.</li> </ul>	<p>PS3.1 Explore a problem and identify different ways of tackling it.</p> <p>PS3.2 Plan and implement at least one way of solving the problem.</p> <p>PS3.3 Check if the problem has been solved and review your approach to problem solving.</p>