Unit 19: Electronic Devices and Circuits

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the operation of electronic devices and their uses in circuits through simulation and practical exercises to build and test physical analogue and digital circuits.

Unit introduction

Electronic analogue and digital devices and circuits are at the heart of familiar household products and high-speed complex operations in industrial applications. For example, they are fundamental to the operation of television remote controllers and to the control of processes in nuclear power stations.

In this unit, you will cover the simulation, construction, testing and evaluation of analogue electronic circuits based on diodes and transistors and combinational and sequential logic digital circuits. As part of the unit you will use software to simulate circuits and use typical bench instruments to test them, since electronic circuit designers make frequent use of software to simulate design ideas before building prototype circuits. Finally, you will reflect on the skills and understanding you have acquired during the unit and the behaviours you have applied.

A wide range of industries, including aerospace, automotive, audio and video, wireless communications, industrial controls and factory automation, employs electronic engineers. This unit helps to prepare you for employment, for example as an electrical/electronic technician, for an apprenticeship and for entry to higher education.

Learning aims

In this unit you will:

A Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits

B Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits

C Review the development of analogue and digital electronic circuits and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits	**A1** Safe electronic working practices **A2** Diode devices and diode-based circuits **A3** Transistor devices and transistor-based circuits **A4** Operational amplifier circuits **A5** Schematic capture and simulation of analogue circuits **A6** Testing physical analogue circuits	A report containing circuit diagrams, photographs, tables of results, sketches, screenshots, calculations and an evaluation of the physical and simulated circuits, supported by observation records and/or witness statements.
B Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits	**B1** Logic gates and Boolean algebra **B2** Combinational logic circuits **B3** Sequential logic circuits **B4** Schematic capture and simulation of digital circuits **B5** Testing physical digital circuits	A report containing circuit diagrams, photographs, tables of results, sketches, screenshots, calculations and an evaluation of the physical and simulated circuits, supported by observation records and/or witness statements.
C Review the development of analogue and digital electronic circuits and reflect on own performance	**C1** Lessons learned from exploring electronic devices and circuits **C2** Personal performance while exploring electronic devices and circuits	The evidence will focus on the skills and knowledge gained when exploring analogue and digital electronic devices and their common applications, reflecting on the ways in which theoretical, simulated and measured values compare. The portfolio of evidence generated while exploring electronic devices and circuits, reflecting on own performance.

Content

Learning aim A: Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits

A1 Safe electronic working practices

- Know how to react in an emergency, including:
  - o isolate power and/or heat supplies
  - o notify the responsible person
  - o follow instructions from the responsible person, including raise the alarm, notify first aider, evacuate the area.
- Safe working practices: awareness and compliance with hazard identification, risk assessments and standard operating procedures associated with electronic-based tasks to include:
  - o construction of electronic circuits
  - o measurement and testing of electronic circuits.

A2 Diode devices and diode-based circuits

- Types of diode to include signal diodes, rectifier diodes, Zener diodes and light-emitting diodes (LED).
- Operation of diodes to include:
  - o semiconductors: materials, intrinsic, extrinsic, doping, p-type, n-type
  - o type: PN-junction
  - o characteristics, e.g. forward and reverse bias.
- Construction of diode-based physical circuits safely, using e.g. bread board or strip board, for different applications, including:
  - o rectification: half wave, full wave
  - o voltage stabilisation
  - o voltage regulation.

A3 Transistor devices and transistor-based circuits

- Types of transistor to include:
  - o bipolar junction transistors (BJT): NPN, PNP
  - o field effect transistors (FET): N channel, P channel.
- Operation of transistors to include:
  - o transistor connections: common base, common emitter, common collector
  - o transistor action, including no collector current (cut off), some collector current (in the active region) and collector current above the emitter current (in saturation)
  - o biasing – operating point of the transistor device.
- Construction of transistor-based physical circuits safely, using e.g. bread board or strip board, for different applications including:
  - o switching including function of components, comparator, digital (set point)
  - o single stage amplifier, including current and voltage gains, phase inversion, bandwidth.

A4 Operational amplifier circuits

- Construction of operational amplifier-based physical circuits safely, using e.g. bread board or strip board, for different applications, including:
  - o voltage comparator
  - o inverting and non-inverting amplifier: negative feedback, gain.
- Characteristics of operation of operational amplifiers to include resonant frequency, cut-off frequency, gain, bandwidth, gain-bandwidth product, dependence on component values.

A5 Schematic capture and simulation of analogue circuits

- Schematic capture of analogue circuits to include electrical circuit drawing standards BS 8888, BS 3939 or other relevant international equivalents.
- Simulation methods and the use of virtual instrumentation extraction of data/measurements, e.g. voltage, current, power, input and output signals, gain, frequency analysis, e.g. Bode plot.

A6 Testing physical analogue circuits

- The safe use of physical test equipment to include multimeters, function generators, oscilloscopes and more complex equipment, e.g. Bode plotters if available.
- Calculations using measured values to include:
  - o transistor current gain $h_{\mathrm{fe}} = \beta = \frac{I_b}{I_c}$
  - o circuit voltage gain (transistor amplifier, non-inverting and inverting op-amp circuits) $A_V = \frac{V_{\mathrm{out}}}{V_{\mathrm{in}}}$
- Cut-off frequency for op-amp filters $f_C = \frac{1}{2\pi RC}$

Learning aim B: Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits

B1 Logic gates and Boolean algebra

- Types of logic gate: AND, OR, NOT, NAND, NOR, XOR.
- Gate symbols, British Standard (BS), International Electrotechnical Commission (IEC), American National Standards Institute (ANSI) or other relevant international equivalents.
- Truth tables for standard logic gates.
- Types of logic family:
  - o transistor-transistor logic (TTL)
  - o complementary metal oxide semiconductor (CMOS).
- Characteristics of logic families: supply voltage, input and output operating voltages, input and output impedance, propagation delay, power.

B2 Combinational logic circuits

Rules of Boolean algebra, including:

- Boolean expressions e.g. sum of products $(A \bullet B) + (C \bullet \overline{D})$
- truth tables for Boolean expressions
- minimisation of combinational logic circuits containing at least three inputs and five gates:
  - o Karnaugh maps for minimisation circuits with at least three inputs
  - o De Morgan’s theorem.

Construction of physical combinational logic circuits safely, using e.g. bread board or strip board.

B3 Sequential logic circuits

- Bi-stable devices (flip-flops), including R-S, D type including clocked D type and JK including master-slave JK.
- Types of sequential logic circuit, including:
  - o three-stage asynchronous counter
  - o three-stage synchronous counter
  - o three-stage shift register.
- Construction of physical sequential logic circuits safely using, e.g. bread board or strip board and R-S, D-type and/or JK bi-stable devices.

B4 Schematic capture and simulation of digital circuits

- Schematic capture of digital circuits to include electrical circuit drawing standards BS 8888, BS 3939, or other relevant international equivalents.
- Simulation methods and the use of virtual instrumentation, e.g. logic probe, logic pulser, logic ‘analyzer’.
- Extraction of data/measurements, e.g. input and output logic states.

B5 Testing physical digital circuits

- The safe use of physical test equipment to include multimeters, logic probes and more complex equipment, e.g. logic ‘analyzers’.
- Calculations using Boolean algebraic and truth tables.

Learning aim C: Review the development of analogue and digital electronic circuits and reflect on own performance

C1 Lessons learned from exploring electronic devices and circuits

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- electronic skills, e.g. schematic capture, simulation, construction methods, use of measurement and test equipment and techniques and semiconductor theory
- general engineering skills, e.g. mathematics, interpreting drawings and using information technology software packages.

C2 Personal performance while exploring electronic devices and circuits

Understand relevant behaviours for exploring the construction, operation and application of electronic devices in analogue and digital circuits, including:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- awareness of the ways in which the skills, knowledge and techniques developed in this unit can be used in further study.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits		
A.P1 Simulate, using captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit. **A.P2** Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one. **A.P3** Explain, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.	**A.M1** Simulate, using accurately captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit. **A.M2** Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one accurately. **A.M3** Analyse, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.	**A.D1** Evaluate, using language that is technically correct and of a high standard, the operation of at least one diode, transistor and operational amplifier circuit, comparing the results from safely and accurately conducted simulations and tests.
Learning aim B: Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits		
B.P4 Simulate, using captured schematics, the correct operation of at least one combinational logic circuit and two sequential logic circuits. **B.P5** Build at least one combinational logic circuit and two sequential logic circuits safely and test the characteristics of each one. **B.P6** Explain, using the simulation and test results, the operation of at least three logic circuits.	**B.M4** Simulate, using accurately captured schematics, the correct operation of at least one combinational logic circuit minimising the gates and at least two sequential bidirectional logic circuits. **B.M5** Build at least one combinational logic circuit minimising the gates and at least two sequential bidirectional logic circuits and test the characteristics of each one accurately. **B.M6** Analyse, using the simulation and test results, the operation of at least three logic circuits.	**B.D2** Evaluate the operation of at least one combinational logic circuit minimising the gates and two sequential bidirectional logic circuits, comparing the results from safely and accurately conducted simulations and tests.
Learning aim C: Review the development of analogue and digital electronic circuits and reflect on own performance		
C.P7 Explain how health and safety, electronic and general engineering skills were effectively applied during the development of the circuits. **C.P8** Explain how relevant behaviours were effectively applied during the development of the circuits.	**C.M7** Recommend improvements to the development of the electronic circuits and to the relevant behaviours applied.	**C.D3** Demonstrate consistently good technical understanding and analysis of the electronic circuits, including the application of relevant behaviours and general engineering skills to a professional standard.

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.M2, A.M3, A.D1)

Learning aim: B (B.P4, B.P5, B.P6, B.M4, B.M5, B.M6, B.D2)

Learning aim: C (C.P7, C.P8, C.M7, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- electronic laboratory and bench top test equipment, including signal generators, low-voltage DC power supplies, dual trace oscilloscopes and digital multimeters. Spectrum analyser/Bode plotter would be advantageous, but is not essential
- physical components for selection and construction using appropriate prototyping approaches such as protoboard (bread board)
- equipment that can support the verification of digital circuit operation to include at the minimum logic probes and ideally access to logic 'analyzer'
- industry-standard SPICE software. A virtual Bode plotter and logic 'analyzer' may be an acceptable alternative to use of real instruments.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will present a balanced evaluation of the different types of analogue electronic circuit that they have captured, simulated, constructed and tested. The circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively. They will include evidence such as circuit schematics and waveform sketches, as well as accurate calculations, from their simulation and testing of physical circuits. For example, the voltage gain of a non-inverting amplifier will be calculated from component values, with estimated upper and lower expected values due to component tolerance.

Learners will compare their results from the simulation and safe construction and testing of physical circuits. The characteristic of device and circuit performance will be more complex than simple output to input ratios in amplifier circuits, for example voltage gain of the amplifier at different frequencies from oscilloscope traces, simulated waveforms and circuit calculations. Small variations may be noted between the results from different sources and attributed to factors such as the simulation using ideal components, but still giving results within acceptable levels considering the preferred values used.

The impact on circuit performance of modifying one criterion will also be evaluated. For example, learners will support their evaluation of changes in bandwidth as a result of increasing or decreasing gain by referring to gain-bandwidth product and its importance in op-amp circuit applications.

Overall the evidence, such as practical and simulation reports, will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct technical engineering terms, with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will capture a circuit schematic accurately and simulate the correct operation of at least one diode-based, one transistor-based and one operational amplifier-based circuit. The circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively.

Learners will construct and test the circuits safely and measure and record the operating characteristics of the circuits safely and accurately, such as instrument controls set to allow the amplitude and frequency of waveforms to be measured accurately, for example time base set to give just over two cycles, and voltage gain to use as much of the vertical scale as possible.

Learners will analyse the operation of the analogue circuits using the simulation and test results from physical circuits, including calculations where appropriate. For example, they will calculate the gain of a non-inverting operational amplifier from measurements and component values at a number of frequencies, but may not make specific reference to the gain-bandwidth product.

Overall, the evidence should be logically structured, technically accurate and easy to understand. For example, schematics will be laid out clearly and logically using standard conventions, with all components appropriately labelled, and virtual instruments connected correctly with controls set to realistic values.

For pass standard, learners will capture a circuit schematic and simulate the correct operation of at least one diode-based, one transistor-based and one operational amplifier-based circuit. These circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively.

Learners will construct and test the circuits safely and measure and record the operating characteristics of the circuits safely. For example, they will construct an inverting operational amplifier and measure input and output voltages to calculate the circuit gain.

Using the simulation and test results from physical circuits, learners will explain the operation of at least one diode-based, transistor-based and operational amplifier-based circuit. For example, an explanation and evidence for the dependence of gain of an inverting operational amplifier on component values at a given frequency would be indicative of pass level achievement. Learners will include calculations where appropriate to do so, for example the voltage gain of the amplifier from amplitude measurements of input and output sinusoidal voltages.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example calculating gain and attenuation as ratios rather than in decibel (dB), and may contain minor technical inaccuracies relating to engineering terminology, such as not differentiating between peak and root-mean squared (RMS) voltages, or inconsistent use of units.

Learning aim B

For distinction standard, learners will present a balanced evaluation of combinational and sequential logic circuits that they have captured, simulated, constructed and tested accurately.

They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format and minimise the number of gates needed using one type of gate, for example NAND. They will verify that the minimised circuit functions as required.

Learners will produce a schematic diagram for two different sequential circuits using D type and/or JK flip-flops and standard logic gates, for example a minimum 3-bit asynchronous up-down counter and a minimum 3-bit bi-directional shift register.

Learners will verify that the circuits function as required, comparing and contrasting simulation and building and testing them accurately.

Overall the evidence, such as practical and simulation reports, will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct technical engineering terms.

For merit standard, learners will capture circuit schematics accurately and simulate the correct operation of at least one combinational and two sequential logic circuits. They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format and minimise the number of gates using a combination of gate types.

Learners will produce a schematic diagram for two different sequential circuits using D type and/or JK flip-flops and standard logic gates, for example a minimum 3-bit asynchronous counter and a minimum 3-bit shift counter. They will verify that the minimised circuits function as required using schematic capture and simulation.

Learners will construct and test the circuits and measure and record the operation of the circuits safely and accurately. For example, they will take suitable precautions when handling integrated circuits and use appropriate instruments such as a logic probe rather than a multimeter.

Overall, the evidence will be logically structured, technically accurate and easy to understand. For example, the schematics will be laid out clearly and logically using standard conventions, with all components appropriately labelled and virtual instruments connected correctly.

For pass standard, learners will capture circuit schematics and simulate the correct operation of at least one combinational logic and two sequential logic circuits. They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format. They will verify that the circuit functions as required using schematic capture and building and testing the circuit.

Learners will produce schematic diagrams for two different sequential circuits, for example a 3-bit asynchronous counter and a 3-bit shift counter using D type and/or JK flip-flops. They will verify that the circuits function as required using schematic capture and simulation software.

Learners will construct and test the circuits and record the operation of the circuits safely.

Using the simulation and test results from physical circuits, learners will explain the operation of the circuits, for example an explanation and evidence for the operation of a shift register.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example not explaining why a shift register shifts in a given direction, and may contain minor technical inaccuracies such as not differentiating between D type and JK flip-flops.

Learning aim C

For distinction standard, learners will demonstrate, during the first two assignments, relevant behaviours and general engineering skills to a professional standard. For example, they will plan all activities in advance and they will meet all deadlines.

Their evidence will show consistently good technical understanding of the analogue and digital electronic circuits during the simulation and construction and testing processes. They will use accurate technical engineering terms and grammar and will clearly differentiate facts from opinion.

The lessons learned evidence, for example a report, will present a good technical understanding of analogue and digital electronic circuits. Overall the evidence will include a balanced view about the actions taken, electronic circuit development (circuit simulation and construction and testing processes), including health and safety compliance, and technical engineering terms used correctly and consistently. The evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will provide in their evidence, such as a logbook, and especially the lessons learned report, examples of where improvements could be made to the:

- development (simulation, construction and testing) of analogue and digital electronic circuits, for example how an understanding of triggering flip-flops can help in deciding whether a shift register will shift left or right
- application of relevant behaviours, for example how listening to instructions has resulted in an activity running smoothly or a circuit operating as intended.

Overall, the suggested improvements should be reasonable and practical. Learners will give professional explanations and use engineering terminology accurately. Some parts of the evidence may have more emphasis than others, making the evidence more difficult for a third party to understand.

For pass standard, learners will give evidence, such as a lessons learned report, that is around 500 words in total and that covers the management of health and safety, analogue and digital electronic skills and general engineering skills, as well as a reflection of personal performance. The evidence will be basic in its approach, with some use of technical language, but it may not be consistent and there may be some errors throughout. The evidence will explain:

- actions taken to manage health and safety in the workplace, for example which personal protective equipment was used and whether any unforeseen issues occurred
- electronic engineering skills, such as identifying components and their characteristics, circuit theory and the skills required to construct and test circuits
- how general engineering skills were used, such as the use of IT to simulate circuits, CAD to capture schematics and interpreting drawings
- the behaviours used, such as time management and planning to ensure the activity was completed within the appropriate time.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 17: Power and Energy Electronics
- Unit 20: Analogue Electronic Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 22: Electronic Printed Circuit Board Design and Manufacture
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electronics and engineering organisations involved with electronic devices and circuits.
- contribution of ideas to unit assignment/project materials.

