Next Generation Higher National Unit Specification

Analogue Electronics: Design and Analysis (SCQF level 8)

Unit code: J7C2 48

SCQF level: 8 (24 SCQF credit points)

Valid from: session 2024 to 25

Prototype unit specification for use in pilot delivery only (version 2.0) December 2024

This unit specification provides detailed information about the unit to ensure consistent and transparent assessment year on year.

This unit specification is for teachers and lecturers and contains all the mandatory information required to deliver and assess the unit.

This edition: December 2024 (version 2.0)

Unit purpose

This unit provides learners with the knowledge of analogue electronics required to design and analyse low frequency circuits. The unit covers:

- analysis of passive circuits using Laplace transforms and direct current (DC) transients
- two-port network theory and small signal analysis of transistor circuits
- non-ideal characteristics of transistors, operational amplifiers and comparators
- active filters and oscillators, including crystal oscillators
- electromagnetic compatibility (EMC) and printed circuit board (PCB) layout

Learners can develop their ability to self-manage and hone their skills in creative problem solving as they identify solutions to real-world problems.

The target group for the unit is learners studying towards qualifications that develop analogue electronics design and analysis skills, to support an industrial career in electronics, or instrumentation and control engineering. It is also aimed at learners who want to develop the practical, personal and professional skills required for a successful career as an engineering technician.

Entry to the unit is at your centre’s discretion. However, we recommend that learners have one or more of the following:

- broad knowledge and understanding of analogue electronics at SCQF Level 7, for example Advanced Higher Physics or Engineering Science, or a Higher National Certificate (HNC) in a related engineering subject
- relevant, equivalent work experience

Unit outcomes

Learners who complete this unit can:

1 analyse, using Laplace and transient analysis, passive circuits containing voltage and current sources, resistors, capacitors, and inductors
2 analyse non-ideal characteristics of circuits containing bipolar (BJT) and field-effect (FET) transistors, and operational amplifiers
3 design, simulate, build, test and evaluate active filter and oscillator circuits
4 design PCB layouts with consideration for electromagnetic compatibility (EMC)

Evidence requirements

You assess the unit holistically, using a portfolio of evidence generated by learners. Learners must produce a reflective report for each outcome, evaluating the knowledge and skills they have gained. They should produce reports to a professional standard, using word-processing software.

Learners should provide evidence in an appropriate format. This could be written, oral, video, electronic (for example, a blog), artefact (for example, photos) or another format. Learners generate evidence under controlled or supervised, open-book conditions, and it must be authenticated as being all their own work. The evidence must contain a mix of knowledge and skills items to match the evidence requirements of the unit, and include various forms of evidence, such as:

- assignments
- case studies
- reports
- essays
- simulations
- structured controlled tests
- practical evidence
- other relevant sources of evidence

To successfully achieve the unit, learners must provide evidence for the following outcomes:

Outcome 1

1a Using DC and alternating current (AC) transient analysis, analyse a first-order passive circuit containing a voltage or current source, resistor, and capacitor or inductor, using:

- differential equations
- initial and final conditions
- forced and natural responses
- Laplace and inverse Laplace transforms
- transient and steady state calculations

Learners should analyse a different circuit each time the outcome is assessed.

1b Using DC and AC transient analysis, analyse a second-order passive circuit containing voltage and current sources, resistors, capacitors, and inductors, using:

- differential equations
- initial and final conditions
- forced and natural responses
- Laplace and inverse Laplace transforms
- transient and steady state calculations

Learners should analyse a different circuit each time the outcome is assessed.

1c Use mathematical software to analyse a second-order passive circuit containing voltage and current sources, resistors, capacitors, and inductors. Calculate the damping and resonance parameters of the circuit with varying component values.

Outcome 2

2a Using two-port theory, identify voltage series feedback, voltage shunt feedback, current series feedback, and current shunt feedback circuits, and explain the differences between them.

2b Contrast and compare ideal with non-ideal BJT amplifier AC and DC characteristics.

2c Contrast and compare ideal with non-ideal FET amplifier AC and DC characteristics.

2d Contrast and compare ideal with non-ideal operational amplifier AC and DC characteristics.

2e Using data sheets, create a small signal model for a specific BJT amplifier circuit, and derive the admittance, impedance or hybrid-pi matrix for this circuit.

Learners should use a different circuit each time the outcome is assessed.

2f Using data sheets, create a small signal model for a specific FET amplifier circuit, and derive the admittance, impedance or hybrid-pi matrix for this circuit.

Learners should use a different circuit each time the outcome is assessed.

2g For the circuit in 2e, calculate the transistor power dissipation under pre-specified conditions.

2h For the circuit in 2f, calculate the transistor power dissipation under pre-specified conditions.

2i Using data sheets, optimise a specific operational amplifier circuit to achieve a pre-defined specification, and simulate the circuit to prove optimised operation.

2j Design a comparator circuit, with hysteresis, for a pre-defined specification, and simulate this circuit to prove its functionality.

Outcome 3

3a Contrast and compare the effects of negative and positive feedback in operational amplifier circuits, with consideration of:

- gain
- non-linear operation
- input and output impedance
- stability using Bode plots
- frequency response
- distortion
- noise

3b Design two oscillator circuits from the following list, and, using simulation software, critically compare their operation and characteristics:

- Wien bridge oscillator
- Colpitts oscillator
- Hartley oscillator
- Clapp oscillator

Learners should design and compare different circuits each time the outcome is assessed.

3c Build the circuits designed in 3b on breadboard, stripboard, PCB or equivalent.

3d Using standard test equipment, test the circuits built in 3c and critically evaluate the test results against pre-defined specifications. Critically compare the results.

3e Explain the operation and equivalent circuit of a crystal oscillator circuit, and, using examples, critically compare the operation and characteristics of two oscillators from the following list:

- fixed-frequency (XO)
- voltage-controlled (VCXO)
- temperature-compensated (TCXO)
- oven-controlled (OCXO)

Learners should compare different oscillators each time the outcome is assessed.

3f Critically compare passive and active filters, with reference to first- and second-order types.

3g Using tables, design two second-order filter circuits from the following list, and, using simulation software, critically compare their operation and characteristics:

- Butterworth
- Chebyshev
- Bessel

Learners should compare a different filter each time the outcome is assessed.

3h Build the circuits designed in 3g on breadboard, stripboard, PCB or equivalent.

3i Using standard test equipment, test the circuits built in 3h and critically evaluate the test results against pre-defined specifications. Critically compare the results.

Outcome 4

4a Clearly defining strategy and using PCB layout software, design and track a PCB for best EMC, considering:

- emission and susceptibility
- electrical noise and its sources
- current coupled interference
- magnetically induced interference
- screening
- filtering
- segregation and separation
- grounding and ground planes
- power planes
- tracking considerations

4b Critically appraise two interfacing considerations from this list:

- coaxial cable
- twisted pair
- differential signals
- impedance optimisation

Learners should appraise a different two each time the outcome is assessed.

Knowledge and skills

The following table shows the knowledge and skills covered by the unit outcomes:

Knowledge	Skills
Outcome 1 Learners should understand: ♦ differential equation representation of passive circuits ♦ passive circuit initial and final values ♦ passive circuit forced and natural responses ♦ Laplace and inverse Laplace transforms for passive circuit analysis ♦ passive circuit transient and steady state calculations ♦ second-order circuit damping factors ♦ second-order circuit resonance factors	**Outcome 1** Learners can: ♦ analyse first- and second-order passive circuits using: — differential equations — initial and final conditions — forced and natural responses — Laplace and inverse Laplace transforms — transient and steady state calculations ♦ use mathematical software to analyse second-order passive circuits ♦ calculate damping and resonance factors for second-order passive circuits
Outcome 2 Learners should understand: ♦ two-port theory and its use in identifying and comparing voltage series feedback, voltage shunt feedback, current series feedback and current shunt feedback circuits ♦ AC and DC differences between ideal and non-ideal BJTs ♦ AC and DC differences between ideal and non-ideal FETs ♦ AC and DC differences between ideal and non-ideal operational amplifiers ♦ admittance, impedance and hybrid-pi matrices ♦ hysteresis in comparator circuits	**Outcome 2** Learners can: ♦ create BJT small signal circuit models ♦ create FET small signal circuit models ♦ derive admittance, impedance and hybrid-pi matrices ♦ calculate BJT and FET power dissipation ♦ optimise an operational amplifier circuit to mitigate the effects of non-ideal parameters ♦ design a comparator circuit with hysteresis

Knowledge	Skills
Outcome 3 Learners should understand: ♦ the effects of negative and positive feedback in operational amplifier circuits, in terms of: — gain — non-linear operation — input and output impedance — stability using Bode plots — frequency response — distortion — noise ♦ the operation and characteristics (including the equivalent circuit) of fixed-frequency, voltage-controlled, temperature-compensated and oven-controlled crystal oscillators, including the equivalent circuit ♦ the differences between first- and second-order passive and active filters	**Outcome 3** Learners can: ♦ design Wien bridge, Colpitts, Hartley and Clapp oscillators ♦ simulate oscillator circuits and critically evaluate their operation ♦ build hardware oscillator circuits and critically evaluate their operation ♦ design Butterworth, Chebyshev and Bessel filters, using tables ♦ simulate filter circuits and critically evaluate their operation ♦ build hardware filter circuits and critically evaluate their operation
Outcome 4 Learners should understand: ♦ factors affecting PCB EMC, including: — emission and susceptibility — electrical noise and its sources — current coupled interference — magnetically induced interference — screening — filtering — segregation and separation — grounding and ground planes — power planes — tracking considerations ♦ interfacing for best EMC including coaxial cables, twisted pairs, differential signals and impedance optimisation	**Outcome 4** Learners can: ♦ define strategies for PCB best EMC layout ♦ using software, design and track a PCB for best EMC

Meta-skills

Throughout the unit, learners develop meta-skills to enhance their employability in the engineering sector.

Self-management

Learners develop the meta-skill of adapting through evaluating and modifying designs to account for non-ideal characteristics.

Social intelligence

Learners develop the meta-skills of communicating and collaborating as they work with others on formative activities.

Innovation

Learners develop the meta-skill of sense-making as they identify and minimise potential EMC problems in PCB layouts.

Literacies

Numeracy

Learners develop numeracy skills by performing engineering calculations when evaluating devices and circuits.

Communication

Learners develop communication skills by studying the course materials and engaging with you and their peers.

Digital

Learners develop digital skills and computer literacy by using engineering simulation and PCB layout software.

Delivery of unit

This unit is part of the Higher National Diploma (HND) in Engineering. The framework includes mandatory and optional units, and you can tailor the selected combination of units to specific engineering pathway needs.

This unit complements, and can be delivered alongside, Digital Electronics: Digital System Design.

While the exact time allocated to the unit is at your centre's discretion, the notional design length is 120 hours.

The amount of time you allocate to each outcome is also at your discretion. We suggest the following distribution of time, including assessment:

Outcome 1 — Analyse, using Laplace and transient analysis, passive circuits containing voltage and current sources, resistors, capacitors, and inductors
(25 hours)

Outcome 2 — Analyse non-ideal characteristics of circuits containing bipolar (BJT) and field-effect (FET) transistors, and operational amplifiers
(25 hours)

Outcome 3 — Design, simulate, build, test and evaluate active filter and oscillator circuits
(40 hours)

Outcome 4 — Design PCB layouts with consideration for electromagnetic compatibility (EMC)
(30 hours)

Additional guidance

The guidance in this section is not mandatory.

Content and context for this unit

This unit provides learners with sufficient knowledge of analogue electronic circuits and components to allow them to design and analyse low frequency circuits, typical of those found in electronic, and control and instrumentation engineering.

Analyse, using Laplace and transient analysis, passive circuits containing voltage and current sources, resistors, capacitors, and inductors (outcome 1)

In outcome 1, learners analyse first- and second-order passive circuits by writing differential equations, then they use Laplace transforms, and initial and final values to obtain forced and natural responses. Learners also calculate the responses of first- and second-order passive circuits using DC transient analysis, to obtain transient and steady state responses. They use mathematical software to corroborate their answers, and to obtain damping and resonance factors for these circuits.

Analyse non-ideal characteristics of circuits containing bipolar (BJT) and field-effect (FET) transistors, and operational amplifiers (outcome 2)

In outcome 2, learners study two-port network theory and apply this theory to networks with voltage series and shunt, and current series and shunt feedback. Learners then study small signal models of BJTs and FETs, using two-port network theory to obtain admittance, impedance and hybrid-pi matrices for circuits containing BJTs and FETs. Learners go on to compare and contrast real operational amplifiers and transistors with ideal ones. Finally, learners study comparator circuits with hysteresis so that they can design a simple comparator circuit including the required hysteresis.

You could use operational amplifier circuits and their equivalent block diagrams as examples. Learners should use data sheets to obtain real transistor parameters. They should analyse a variety of circuits, each containing a single transistor, for example:

- common base
- common emitter
- common collector
- common source
- common gate
- common drain

Learners should calculate transistor power dissipation in specific circuits and environments.

When comparing and contrasting real transistors with ideal ones, learners should consider AC and DC characteristics such as:

- gain variation
- the Early effect
- leakage currents
- input and output impedances
- internal capacitances
- temperature coefficients
- large signal behaviour

When comparing and contrasting real operational amplifiers with ideal ones, learners should consider AC and DC parameters such as:

- gain bandwidth product
- bias and offset currents
- bias and offset voltages
- large signal operation
- distortion and saturation
- input and output impedance
- noise
- temperature coefficients
- transient response and slew rate
- power dissipation
- common mode rejection ratio (CMRR) and power supply rejection ratio (PSRR)

For outcome 2, you should give learners operational amplifier circuits. They should calculate the errors caused by non-ideal parameters, then optimise these circuits to reduce the errors. Circuits could include high gain amplifiers, high frequency amplifiers, audio amplifiers, logarithmic amplifiers, instrumentation amplifiers, integrators and differentiators. Use real-world applications and case studies to contextualise this outcome.

Design, simulate, build, test and evaluate active filter and oscillator circuits (outcome 3)

In outcome 3, learners first study the effects of positive and negative feedback, before moving on to study and design active filters and oscillators. Learners also study crystal oscillators to learn how they function, including parallel and series resonance, and equivalent models.

In outcome 3, learners should critically compare, design for and test filters' characteristics such as:

- critical frequency
- flatness of passband response
- roll off and transition steepness

- phase shift and distortion in passband
- how operational amplifiers improve performance
- quality factor
- tuning

Learners should critically compare, design for and test oscillators' characteristics such as:

- output frequency
- frequency stability
- output amplitude and waveform
- phase noise and jitter

Learners should learn the differences between the listed types of oscillators.

Design PCB layouts with consideration for electromagnetic compatibility (EMC) (outcome 4)

In outcome 4, learners study EMC, in terms of emissions and susceptibility. Learners then go on to use proprietary software to lay out a PCB for best EMC, implementing the mitigating measures they have learnt, such as segregation, ground and power planes, filters, shields and screens, and tracking considerations.

Approaches to delivery

We recommend that you teach outcome 1 first, but this is not essential. Learners should analyse a variety of multi-loop series and parallel circuits containing current sources, voltage sources, resistors, capacitors and inductors. To contextualise the subject, you could relate circuits to real industrial systems; for example, switching electrical loads. You should emphasise to learners the requirement for accurate manual calculations and the benefits of using software for manual calculation corroboration and easy re-calculation of changes.

We recommend that you teach outcome 2 after outcome 1. There is no requirement to build hardware circuits in outcome 2, but learners should simulate circuits using proprietary software. You should make them aware of the shortcomings of simulation in identifying non-ideal operation.

Outcome 3 allows evidence sampling. Where there are evidence sampling options, you should teach learners the theory of all the options.

You should use real-world applications of filters and oscillators to contextualise this outcome. Encourage learners to use manufacturers' data sheets for the oscillators.

In outcome 4, you should introduce relevant standards, such as IEC EN61000, to emphasise the importance of design for EMC. Learners study the causes and effects of electrical current and magnetically coupled interference. Use case studies to highlight good and poor PCB layouts, and to contextualise the problems caused by poor EMC performance. PCB tracking will be new to most learners, so you should devote time to teaching them how to use the software. It would be helpful to show students how PCBs are manufactured; for example, through videos or site visits. Learners should also be aware of how implementing EMC improvements adds cost and complexity to a PCB.

Approaches to assessment

Analyse, using Laplace and transient analysis, passive circuits containing voltage and current sources, resistors, capacitors, and inductors (outcome 1)

To minimise plagiarism in summative assessment, you could present each learner with a different circuit for analysis, using different component values. For 1b and 1c, learners can use the same circuit to evidence all the analysis methods.

A single report covering all the outcome's knowledge and skills requirements, and including critical self-reflection, can be used as evidence. Each learner should generate a distinct report.

Analyse non-ideal characteristics of circuits containing bipolar (BJT) and field-effect (FET) transistors, and operational amplifiers (outcome 2)

You should encourage learners to work together for formative assessment, for example to critically discuss non-ideal parameters and their effects.

Summative assessment is open-book, and you should encourage learners to use manufacturers' data sheets and manuals. To minimise plagiarism, you could present different learners with different circuits, devices and/or parameters for analysis, using different component values.

Each learner should generate a distinct report. A single report covering all the outcome's knowledge and skills requirements, and including critical self-reflection, can be used as evidence. This should include design and simulation evidence, with research sources correctly cited and referenced. Alternatively, you may prefer separate reports — for example, one covering transistors and one covering operational amplifiers — to reduce the assessment burden.

Design, simulate, build, test and evaluate active filter and oscillator circuits (outcome 3)

For formative assessment, you should encourage learners to work together, for example to compare feedback and characteristics of oscillators and comparators.

You can use the same filter and oscillator circuits for both summative simulation and summative hardware build and test. Simulation should prove functional performance, and learners' circuits must be fully functional at both simulation and hardware test to pass the outcome. Partially pre-built circuits can be used for hardware to save time. Learners should use contemporary test equipment, including signal analysers such as Bode plotters, spectrum analysers and fast Fourier transform (FFT) analysers. It is not necessary to test against all the listed parameters, and you should write specifications in accordance with the test equipment available.

Learners should complete the summative practical exercises individually, generating distinct reports. A single report covering all the outcome's knowledge and skills requirements, and including critical self-reflection, can be used as evidence. This should include design, simulation and test evidence, with research sources correctly cited and referenced. Alternatively, you may prefer separate reports — for example, one covering filters and one covering oscillators — to reduce the assessment burden. This should be accompanied by demonstrations (these could be videos, screenshots or live) of working simulations and hardware.

Design PCB layouts with consideration for electromagnetic compatibility (EMC) (outcome 4)

Although learners should complete the practical exercise individually, it is acceptable for all learners to use the same circuit. The circuit should present sufficient challenge to ensure most EMC mitigating measures are required, but not so complex as to require PCB layout expertise. Learners should individually decide and explain their EMC strategies, and carry out at least three different ones.

Each learner should generate a distinct PCB layout and report. A single report covering all the outcome's knowledge and skills requirements, and including critical self-reflection, can be used as evidence. This should be accompanied by demonstrations (these could be videos, screenshots or live) of final PCB designs.

Equality and inclusion

This unit is designed to be as fair and as accessible as possible with no unnecessary barriers to learning or assessment.

You should take into account the needs of individual learners when planning learning experiences, selecting assessment methods or considering alternative evidence.

Guidance on assessment arrangements for disabled learners and/or those with additional support needs is available on the assessment arrangements web page: www.sqa.org.uk/assessmentarrangements.

Information for learners

Analogue Electronics: Design and Analysis (SCQF level 8)

This information explains:

- what the unit is about
- what you should know or be able to do before you start
- what you need to do during the unit
- opportunities for further learning and employment

Unit information

This unit provides you with knowledge and skills specific to electronics engineering. It is part of the Higher National Diploma (HND) in Engineering, which is aimed at learners who want to become engineering technicians in electronics, or control and instrumentation. The unit also provides you with knowledge and skills to go on to further study.

Before starting the unit, we recommend that you have some knowledge and understanding of analogue electronics. For example, you may have passed an SCQF level 7 (HNC level) qualification in a subject related to electronics principles.

Unit outcomes

On completion of the unit, you can:

1 analyse, using Laplace and transient analysis, passive circuits containing voltage and current sources, resistors, capacitors, and inductors
2 analyse non-ideal characteristics of circuits containing bipolar (BJT) and field-effect (FET) transistors, and operational amplifiers
3 design, simulate, build, test and evaluate active filter and oscillator circuits
4 design PCB layouts with consideration for electromagnetic compatibility (EMC)

In outcome 1, you learn about mathematical analysis of passive circuits. Passive circuits contain voltage and current sources, resistors, capacitors, and inductors. You learn how to use transient and Laplace analysis to determine how these circuits respond to input changes. You also learn to use mathematical software to determine passive circuit responses.

In outcome 2, you learn how two-port network theory can simplify circuit analysis. You also learn about non-ideal characteristics of circuits containing BJTs and FETs, and operational amplifiers. By deriving small signal transistor models, you learn how admittance, impedance and hybrid-pi matrices can represent transistor circuits. Finally, you learn how to design comparator circuits with hysteresis.

In outcome 3, you learn about active filters and oscillator circuits. You compare different types of active filters and then go on to compare different types of oscillators. You learn how to design and build these circuits, and test them using simulation and hardware test equipment.

In outcome 4, you learn about printed circuit board (PCB) layout, and the importance of electromagnetic compatibility (EMC). You use PCB tracking software to design a PCB layout for best EMC performance.

You are assessed by completing mini projects, technical reports and critical self-evaluation. You collate your evidence in a portfolio.

Meta-skills

Throughout the unit, you can develop meta-skills to enhance your employability in the engineering sector.

Meta-skills include self-management, social intelligence and innovation.

Self-management

You develop the meta-skill of adapting through evaluating and modifying designs to account for non-ideal characteristics.

Social intelligence

You develop the meta-skills of communicating and collaborating as you work with other learners.

Innovation

You develop the meta-skill of sense-making through your ability to identify and minimise potential EMC problems in PCB layouts.

Administrative information

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Superclass: XL

History of changes

Version	Description of change	Date
2.0	♦ Evidence requirements updated to clarify conditions of assessment.	Dec 2024

Note: please check SQA's website to ensure you are using the most up-to-date version of this document.