Next Generation Higher National Unit Specification

Instrumentation and Control: Transducers, Transmitting Signals and Functional Safety (SCQF level 8)

Unit code: J7BW 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 knowledge and skills that are specific to instrumentation and control.

They learn about a variety of topics, including:

- strain, position and vibration measurement
- pneumatic transmission systems
- instrument electrical transmission systems
- modulation techniques
- digital transmission systems
- safety-instrumented systems (SISs)
- risk-reduction techniques and logic solvers
- safety integrity levels (SIL)
- field instruments used in safety systems

The target learner group for the unit is learners who want to develop their instrumentation and control skills to support a career in instrumentation and control or engineering systems.

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

- a broad understanding of instrumentation and control principles, for example, passes at SCQF level 7 in Instrumentation and Control, or Engineering Systems units
- relevant, equivalent workplace experience

The unit provides learners with suitable knowledge and skills to progress to further study or employment in a wide range of engineering industries such as oil and gas, process, utilities, renewables, chemical, pharmaceutical, and food and drink.

Unit outcomes

Learners who complete this unit can:

1 design systems to measure strain, position and vibration in industrial applications
2 analyse elements of pneumatic transmission systems
3 analyse elements of instrument electrical transmission systems
4 analyse modulation system components
5 explain elements of digital transmission systems
6 apply safety-instrumented systems (SISs), risk reduction and logic solvers
7 analyse safety integrity levels (SIL) and safety in field instruments

Evidence requirements

You should assess the unit holistically, using a portfolio of evidence generated by learners. They must produce a reflective report for each outcome, evaluating the knowledge and skills they have gained.

All outcomes can be assessed holistically using product, written and/or oral recorded evidence. 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

- Explain the principle of operation of strain-measuring systems.
- Design a system to measure strain in an industrial application.
- Explain the principle of operation of position-measuring systems.
- Design a system to measure position in an industrial application.
- Explain the principle of operation of vibration-measuring systems.
- Design a system to measure vibration in an industrial application.

Outcome 2

- Explain the principle of operation of a pneumatic relay.
- Explain the principle of operation of a volume booster.
- Explain the principle of operation of a pneumatic force balance transmitter.
- Calculate the output pressure and then plot a graph that shows the relationship between input force and output pressure for a pneumatic force balance transmitter.
- Analyse the closed-loop gain of a pneumatic force balance transmitter.

Outcome 3

- Explain the principle of operation of a variable capacitive-sensing element.
- Explain the principle of operation of a current-to-pneumatic (I/P) converter.
- Explain the principle of operation of an operational amplifier.
- Perform calculations on the circulating currents and voltages in a differential amplifier circuit.
- Analyse the relationship between the applied differential pressure and the two capacitance values in a differential pressure transmitter.
- Graphically demonstrate the relationship between effective common mode rejection (CMR), true CMR and average CMR.

Outcome 4

- Explain the principle of operation of amplitude modulation.
- Explain the principle of operation of frequency modulation.
- Explain the principle of operation of time-division multiplexing (TDM).
- Explain the principle of operation of frequency-division multiplexing (FDM).
- Explain the advantages and disadvantages of TDM and FDM.
- Analyse the response of a high- or low-pass filter (that is, perform tests on the filter and produce an asymptotic graph of gain against frequency for the filter).
- Perform calculations on an amplitude-modulated system.
- Perform calculations on a frequency-modulated system.

Outcome 5

- Explain the sampling theorem and the effects of aliasing on a signal that is not sampled sufficiently.
- Explain the process of pulse-code modulation.
- Explain the principle of operation of a digital shaft encoder.
- Explain the principle of operation of an analogue-to-digital (A/D) converter.
- Demonstrate knowledge and understanding of the principle of optical transmission.
- Calculate the output voltage generated by a 4-bit ladder-type digital-to-analogue (D/A) converter.
- Generate an error-detection code using the double parity method and detect errors in the received code.
- Generate a chain code for a 4-bit number.

Outcome 6

- Explain the concept of an SIS.
- Explain the differences between process control and safety control when applied to hazardous areas in a process plant.
- Explain the six layers of protection related to the operation of a hazardous plant.
- Explain the basic SIS configurations, and those SIS configurations that use shared functions.
- Explain the design of a safety programmable logic controller (PLC) and process safety time.
- Explain redundancy systems and redundant channel safety PLC architecture.
- Explain communications used in safety controllers.
- Apply an SIS to a basic process control system (BPCS).
- Apply the concepts of hazard, risk, risk reduction and ‘as low as reasonably practicable’ (ALARP).
- Apply reliability analysis to determine risk-reduction factor (RRF), probability of failure on demand (PFD) and safety availability (SA).
- Design the logic for a logic solver used in process control applications.
- Plan a shutdown sequence for a process control application.

Outcome 7

- Explain the concept of SIL according to International Electrotechnical Commission (IEC) regulations.
- Explain the requirements of a safety requirements specification (SRS).
- Explain reliability and failure causes in field devices.
- Explain techniques used to minimise the failure of actuators.
- Explain methods used to separate SISs from process control systems.
- Use SIL graphs to determine the SIL.
- Use the layers of protection analysis (LOPA) method to determine the SIL.
- Use an event matrix to determine the SIL.
- Apply the concepts of redundancy and fault tolerance to SISs.

Knowledge and skills

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

Knowledge	Skills
Outcome 1 Learners should understand: ♦ the principle of operation of strain-measuring systems ♦ the principle of operation of position-measuring systems ♦ the principle of operation of vibration-measuring systems	**Outcome 1** Learners can: ♦ design a system to measure strain in an industrial application ♦ design a system to measure position in an industrial application ♦ design a system to measure vibration in an industrial application
Outcome 2 Learners should understand: ♦ the principle of operation of a pneumatic relay ♦ the principle of operation of a volume booster ♦ the principle of operation of a pneumatic force balance transmitter	**Outcome 2** Learners can: ♦ calculate the output pressure and then plot a graph that shows the relationship between input force and output pressure for a pneumatic force balance transmitter ♦ analyse the closed-loop gain of a pneumatic force balance transmitter
Outcome 3 Learners should understand: ♦ the principle of operation of a variable capacitance-sensing element ♦ the principle of operation of an I/P converter ♦ the principle of operation of an operational amplifier	**Outcome 3** Learners can: ♦ perform calculations on the circulating currents and voltages in a differential amplifier circuit ♦ analyse the relationship between the applied differential pressure and the two capacitance values in a differential pressure transmitter ♦ graphically demonstrate the relationship between effective CMR, true CMR and average CMR

Knowledge	Skills
Outcome 4 Learners should understand: ♦ the principle of operation of amplitude modulation ♦ the principle of operation of frequency modulation ♦ the principle of operation of TDM ♦ the principle of operation of FDM ♦ the advantages and disadvantages of TDM and FDM	**Outcome 4** Learners can: ♦ analyse the response of a high- or low-pass filter ♦ perform calculations on an amplitude-modulated system ♦ perform calculations on a frequency modulated system
Outcome 5 Learners should understand: ♦ the sampling theorem and the effects of aliasing on a signal that is not sampled sufficiently ♦ the process of pulse-code modulation ♦ the principle of operation of a digital shaft encoder ♦ the principle of operation of an A/D converter ♦ the principle of optical transmission	**Outcome 5** Learners can: ♦ calculate the output voltage generated by a 4-bit ladder-type D/A converter ♦ generate an error-detection code using the double parity method and detect errors in the received code ♦ generate a chain code for a 4-bit number
Outcome 6 Learners should understand: ♦ the concept of an SIS ♦ the differences between process control and safety control when applied to hazardous areas in a process plant ♦ the six layers of protection related to the operation of a hazardous plant ♦ basic SIS configurations and SIS configurations that use shared functions ♦ the design of a safety PLC and process safety time ♦ redundancy systems and redundant channel safety PLC architecture ♦ communications used in safety controllers	**Outcome 6** Learners can: ♦ apply an SIS to a BPCS ♦ apply the concepts of hazard, risk, risk reduction and ALARP ♦ apply reliability analysis to determine RRF, PFD and SA ♦ design the logic for a logic solver used in process control applications ♦ plan a shutdown sequence for a process control application

Knowledge	Skills
Outcome 7 Learners should understand: ♦ the concept of SIL according to IEC regulations ♦ the requirements of an SRS ♦ reliability and failure causes in field devices ♦ techniques used to minimise the failure of actuators ♦ methods used to separate SISs from process control systems	**Outcome 7** Learners can: ♦ use SIL graphs to determine the SIL ♦ use the LOPA method to determine the SIL ♦ use an event matrix to determine the SIL ♦ apply the concepts of redundancy and fault tolerance to SISs

Meta-skills

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

Self-management

Learners develop the meta-skills of integrity (self-awareness, ethics and self-control) and adapting (critical reflection and self-learning) when producing their portfolio or investigation reports. They also develop initiative (decision making, self-motivation and responsibility) during learning activities and projects.

Social intelligence

Learners develop skills in communicating (receiving information, listening, giving information) by accessing unit material through a virtual learning environment (VLE), keeping an e-portfolio and writing technical reports. They also demonstrate their collaborating skills (team working and collaboration) when engaging with lecturers and other learners throughout the unit.

Innovation

Learners develop the meta-skills of curiosity (information sourcing, questioning and observation); sense-making (holistic thinking and analysis); and critical thinking (deconstruction, logical thinking and judgement) during learning activities and projects, working either individually or in groups.

Literacies

Learners develop core skills in the following literacies:

Numeracy

Learners develop numeracy skills by performing calculations related to transmission systems and SISs.

Communication

Learners develop communication skills by studying the course material, completing unit assessments and engaging with lecturers and other learners.

Digital

Learners develop digital skills and computer literacy by accessing the course material through a VLE and using information and communication technology (ICT) to elaborate reports and display information and data.

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.

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

The amount of time you allocate to each outcome is at your discretion, however, we suggest the following time distribution for each outcome, including assessment:

Outcome 1 — design systems to measure strain, position and vibration in industrial applications
(30 hours)

Outcome 2 — analyse elements of pneumatic transmission systems
(10 hours)

Outcome 3 — analyse elements of instrument electrical transmission systems
(10 hours)

Outcome 4 — analyse modulation system components
(15 hours)

Outcome 5 — explain elements of digital transmission systems
(15 hours)

Outcome 6 — apply safety-instrumented systems (SISs), risk reduction and logic solvers
(20 hours)

Outcome 7 — analyse safety integrity levels (SIL) and safety in field instruments
(20 hours)

Additional guidance

The guidance in this section is not mandatory.

Content and context for this unit

This unit gives learners some of the knowledge and skills they need to support a career in instrumentation and control engineering.

Design systems to measure strain, position and vibration in industrial applications (outcome 1)

This outcome introduces learners to strain-, position- and vibration-measurement systems, providing them with the key principles that relate to measuring these in industrial situations. They learn how to investigate commercially available instruments, and select strain-, position- and vibration-measuring systems for given industrial applications:

- strain measurement:
  - types of strain (such as tensile, compressive and bending)
  - definition and industrial applications of strain gauges
  - causes of strain — pressure, forces, heat and structural changes in the material
  - Young's modulus of elasticity
  - gauge factor
  - operating principle of a strain gauge
  - optimum position to install a strain gauge
  - effects of ambient temperature changes on a strain gauge
  - dummy gauges used for ambient temperature compensation
  - Wheatstone bridge measuring circuit for a strain gauge
  - calibration methods for a strain gauge measurement system
  - definition and industrial applications for load cells
  - Wheatstone bridge measuring circuit for a load cell
  - calibration methods for a load cell measurement system

- position measurement:
  - types of position measurement (linear displacement, angular displacement and proximity)
  - industrial applications for linear displacement, angular displacement and proximity measurement
  - methods of measuring linear displacement (for example, linear variable differential transformer (LVDT), linear potentiometer and variable area capacitance transducer)
  - methods of measuring angular displacement (for example, tachometer and optical shaft encoder)
  - methods of measuring proximity (for example, micro-switch, variable reluctance proximity switch, Hall effect proximity switch and optical sensor)
  - calibration methods for a position measurement system

- vibration measurement:
  - — definition and industrial applications for vibration measurement
  - — principles and laws of vibration — simple harmonic motion (sine waves), Newton's law of motion (second law), free vibration and forced vibration
  - — operation of seismic accelerometers
  - — calibration methods for a vibration-measurement system

Analyse elements of pneumatic transmission systems (outcome 2)

This outcome introduces learners to different methods and techniques for transmitting pneumatic signals:

- flapper and nozzle assembly
- operating actions of pneumatic instrument relays — direct-acting and reverse-acting
- versions of pneumatic instrument relays — continuous bleed and non-bleed
- types of instrument relays — high-pass, low-pass and computer
- volume booster
- pneumatic force balance transmitter — single beam and double beam
- relationship between the input force and the resultant output pressure in a pneumatic transmitter — shown mathematically and graphically
- closed-loop gain of a pneumatic force balance transmitter that includes parameters:
  - — area of feedback bellows
  - — flapper and nozzle sensitivity
  - — amplifier gain
  - — input force
  - — output pressure
  - — pivot position relative to position of input force, feedback bellows and zero spring

Analyse elements of instrument electrical transmission systems (outcome 3)

This outcome introduces learners to different methods and techniques for transmitting instrument electrical signals:

- variable capacitance-sensing element — operation, calculations of capacitance values at the high- and low-pressure sides, and the relationship between differential pressure and capacitance values
- I/P converter — operation and industrial applications
- operational amplifier — ideal characteristics and applications
- screened amplifier circuit
- CMR — definition and graphical representation of effective CMR, true CMR and average CMR
- Differential amplifier circuit used to remove common mode signals

Analyse modulation system components (outcome 4)

This outcome introduces learners to modulation systems components:

- standard symbols for high-pass, low-pass, band-pass and band-stop filters
- characteristics of high-pass, low-pass, band-pass and band-stop filters
- electronic circuits for high-pass and low-pass filters
- software packages used to demonstrate operating characteristics of high- and low-pass filters
- use of signal generators and oscilloscopes to demonstrate the operating characteristics of high- and low-pass filters
- asymptotic gain and frequency response graphs for high- and low-pass filters
- amplitude modulation — principle of amplitude modulation, depth of modulation, modulating index and bandwidth
- frequency modulation — principle of frequency modulation, sensitivity of voltage-controlled oscillator (VCO), and modulating index and bandwidth
- TDM and FDM, and their advantages

Explain elements of digital transmission systems (outcome 5)

This outcome introduces learners to digital transmission systems:

- sampling and the sample theorem
- aliasing — causes and effects
- digital shaft encoder — binary and Gray code versions
- A/D converters — comparator type, counter-ramp type and successive approximation type
- ladder-type D/A converter — operation and calculation to determine output voltage
- single parity error detection — generating the code and checking the received code is correct
- double parity error detection — generating the code and detecting errors in the received code
- chain-code error detection — generating the code and detecting errors in the received code
- fibre-optic transmission — transmission of light (optical transmitter, optical fibre, optical receiver), causes of attenuation and splicing fibre-optic cables

Apply safety-instrumented systems (SISs), risk reduction and logic solvers (outcome 6)

This outcome introduces learners to the concepts of SIS risk reduction and logic solvers, which are used extensively in industry to improve the safety of process plants:

- BPCS
- SISs — concept, diagrams and component parts
- safety instrumented functions (SIF)
- safety life cycle model

- hazard, risk and risk reduction
- ALARP
- safety-related systems for equipment under control (EUC)
- fatal accident rate (FAR)
- difference between process control and safety control
- layers of protection
- application of safe instrumented systems to process control
- reliability analysis applied to safety systems — mean time to failure (MTTF), mean time between failures (MTBF) and failure rate
- RRF — unprotected risk frequency, tolerable risk frequency and protected risk frequency
- PFD
- SA
- proof-of-test intervals
- technologies for logic solvers — basic SIS configurations and shared functions
- types of SIS — pneumatics, relays, trip amplifiers, safety relays, solid-state systems and safety PLCs
- safety PLC — design and reliability
- PLC architecture — single channel, dual redundant and triple modular redundant (TMR)
- communication factors for safety controllers
- networks for PLC interfaces
- process safety time
- examples of simple and complex shut down sequences
- generation of the logic for the logic solver in a safety critical application

Analyse safety integrity levels (SIL) and safety in field instruments (outcome 7)

This outcome introduces learners to SIL and safety that is incorporated into field instruments:

- concept of SIL — high demand and low demand
- current IEC safety standards
- quantitative methods of determining SIL — fault tree and event tree
- LOPA to determine SIL classification
- SRS — functional requirement specification and integrity requirement specification
- risk graph method — determining SIL classification and risk graph calibration
- hazardous event matrix to determine SIL classification
- sensors and transmitters — reliability, potential causes of failure and failure modes
- failure modes — dangerous detected failure, dangerous undetected failure and safe failure
- actuators — solenoid valves, control valves and failure modes
- techniques to minimise failures in solenoid valves and control valves
- fail-safe design of sensors and actuators — redundancy, separation, diagnostics and testing
- separating the SIS from the BPCS

- redundancy in sensors, transmitters and actuators
- hardware fault tolerance
- architecture — simplex (1oo1), duplex (1oo2 or 2oo2) and triplex (2oo3)
- safe failure fraction (SFF)

Approaches to delivery

We recommend that you deliver outcome 6 before outcome 7. Apart from that, the outcomes can be delivered in any order.

You should deliver the unit in a learning space or through a VLE. You should teach primarily using problem-based-learning (PBL) techniques such as case studies and mini projects, supported by other methods. The holistic teaching format of PBL encourages learners to consider the deeper context of the theory.

Approaches to assessment

We recommend that you assess the unit holistically by reviewing case study reports and mini projects. Learners should collate all evidence in their individual portfolio. They should generate evidence under controlled or supervised, open-book conditions.

Learners should demonstrate evidence of all knowledge and skills in the context of one or more overarching instrumentation and control engineering scenarios.

For case studies and mini projects, you can assess knowledge and skills through coursework exercises. Learners should produce product evidence (for example, in the form of a coursework report) under controlled or supervised, open-book conditions,

Learners can keep a reflective account to measure their meta-skills, digital literacies, professional skills and wider employer-desired skills. They should record this in their personal portfolio. You should provide learners with support, guidance and feedback on areas of development, and signpost developmental opportunities.

As the assessment is open book, you must take care to ensure authenticity. You can do this by using variable values in the coursework, making use of oral questioning and using originality-checking software.

Required resources

You do not require any specific resources for this unit other than ICT. However, learners' understanding of the subject material would be greatly enhanced by demonstration on a range of instrumentation and control systems.

Opportunities for e-assessment

Assessment that is supported by information and communication technology (ICT), such as e-testing or the use of e-portfolios or social software, may be appropriate for some assessments in this unit.

If you want to use e-assessment, you must ensure that you apply the national standard to all evidence and that conditions of assessment (as specified in the evidence requirements) are met, regardless of the mode of gathering evidence.

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

Instrumentation and Control: Transducers, Transmitting Signals and Functional Safety (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 instrumentation and control engineering. It forms part of the Higher National Diploma (HND) in Engineering, and is aimed at those who want to become engineering technicians or, after further study, engineers.

Before starting the unit, we recommend that you have a broad knowledge and understanding of engineering and mathematical concepts and principles. In particular, you should have a broad understanding of instrumentation and control principles. For example, you may have achieved passes at SCQF level 7 in an engineering discipline such as instrumentation and control, electrical, electronics, or mechanical or engineering systems.

In the unit, you learn about measuring strain, position and vibration. You also cover transmission of pneumatic, analogue electronic and digital signals, as well as modulation techniques. Finally, you learn about safety-instrumented systems (SISs).

There is a holistic approach to assessment, where you demonstrate evidence of all knowledge and skills in the context of one or more overarching instrumentation and control engineering scenarios. You are assessed using a variety of ways, including by reviewing case study reports and mini projects. You should collate all evidence in your individual portfolio.

The unit provides you with suitable knowledge and skills to progress to further study or employment in a wide range of engineering industries, such as oil and gas, process, utilities, renewables, and food and drink.

Unit outcomes

On completion of this unit, you can:

1 design systems to measure strain, position and vibration in industrial applications
2 analyse elements of pneumatic transmission systems
3 analyse elements of instrument electrical transmission systems
4 analyse modulation system components
5 explain elements of digital transmission systems
6 apply safety-instrumented systems (SISs), risk reduction and logic solvers
7 analyse safety integrity levels (SIL) and safety in field instruments

Outcome 1 introduces you to strain, position and vibration measurement. This provides you with a good understanding of the operating principles of instruments used to measure strain, position and vibration in a range of industrial applications. This includes investigating commercially available instruments and selecting suitable ones for given industrial applications.

Outcome 2 introduces you to methods to transmit pneumatic signals. This provides you with a good understanding of pneumatic instrument relays, volume boosters and force balance transmitters.

Outcome 3 introduces you to methods to transmit instrument electrical signals. This provides you with a good understanding of capacitance-sensing elements, current-to-pneumatic (I/P) converters, operational amplifiers and circuits used to remove common mode signals.

Outcome 4 introduces you to modulation techniques. This provides you with a good understanding of high- and low-pass filters, amplitude, frequency modulation and multiplexing techniques.

Outcome 5 introduces you to digital transmission systems. This provides you with a good understanding of sampling techniques, analogue-to-digital (A/D) converters, digital-to-analogue (D/A) converters, shaft encoder discs and error-detection methods.

Outcome 6 introduces you to SISs, risk-reduction techniques and logic solvers that are used to add additional safety to control systems that are potentially hazardous. This provides you with a good understanding of the concept of SISs, risk-reduction techniques and the operation of logic solvers.

Outcome 7 introduces you to safe integrity levels (SIL) and methods of adding safety into the field instruments. This provides you with a good understanding of layers of protection analysis (LOPA), risk graphs and event matrixes that can be used to determine the SIL. You also learn about techniques that can be used to minimise failures and improve the performance of safety-rated sensors and transmitters.

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 skills of focusing, adapting and initiative as you study the course material.

Social intelligence

You develop communication skills as you receive information from your lecturer.

Innovation

You develop curiosity, sense-making and critical thinking skills as you study the operation of instrumentation and control systems.

Administrative information

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Superclass: VE

History of changes

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

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