Unit 34: Electronic Circuit Design and Manufacture

Unit code: F/600/0299

QCF Level 3: BTEC Nationals

Credit value: 10

Guided learning hours: 60

Aim and purpose

This unit gives learners an understanding of the techniques used in the design and manufacture of electronic circuits including circuit simulation, thermal analysis and printed circuit board design and production.

Unit introduction

A diverse range of techniques is used in the manufacture of electronic circuits. The techniques used for manufacturing prototype electronic circuits are often significantly different from those used in high volume production. This unit provides an introduction to prototype manufacture, as well as the techniques used for the mass production of electronic circuits.

Large-scale electronic manufacture generally involves fully automated assembly techniques using equipment that can produce complex circuits quickly, accurately, at low cost and with minimal human intervention. Alternatively, if only one circuit is to be built (perhaps for evaluation or testing purposes) then a hand-built prototype is much more appropriate.

Computer aided design (CAD) and computer aided manufacture (CAM) are widely used in the production of electronic circuits. This unit will introduce learners to the use of modern production methods including printed circuit board (PCB) layout and computer numerical control (CNC) drilling and mask production.

When an electronic circuit is developed for a commercial application it is usually tested and proved using computer simulation prior to manufacture. This unit will give learners an opportunity to develop and test circuits using SPICE (simulation program with integrated circuit emphasis) software.

The unit will also enable learners to experience the full cycle of design, manufacture and testing of an electronic circuit assembled on a simple single-layer printed circuit board.

Learning outcomes

On completion of this unit a learner should:

1 Know the design processes and production methods used in the manufacture of a printed circuit board

2 Understand the use of software and thermal analysis techniques in the design, simulation and manufacture of an electronic circuit

3 Understand the use and application of surface mount technology in the manufacture of an electronic circuit

4 Be able to design, manufacture, assemble and test a prototype printed circuit board for a given electronic circuit.

Unit content

1 Know the design processes and production methods used in the manufacture of a printed circuit board

Design processes: design strategy eg methodology and techniques used in its realisation (build type, number of layers, net rules, track and gap, via size); design tools eg PCB design software, schematic design and capture, creating and modifying component geometries; creating and modifying schematic diagrams; design verification and design rule checking for both tracking and component layout; auto-routing tools; related documents eg parts lists, bills of materials, machine files, component geometries

Production methods: artwork generation; board production eg etching, masking, drilling, silk screening, cutting; automated production techniques eg robotics and automated assembly, CNC drilling and mask production; soldering methods eg wave soldering, automated wave soldering; fabrication and assembly requirements eg placement on one side, placement on both sides, combination of surface mount technology (SMT) and through-hole technology (THC); test strategy eg electromagnetic compatibility (EMC), signal integrity, high frequency requirements; manufacturability analysis

Types of PCB: laminates eg single and double sided, plated through-hole, fibreglass-resin laminate; solder mask over bare copper (SMOBC); tinned; conventional component and surface mount; single, double and multi-layer boards; gold plated contacts, flexible and membrane PCB, chip-on-board (COB)

2 Understand the use of software techniques and thermal analysis techniques in the design, simulation and manufacture of an electronic circuit

Computer aided design (CAD) software: simulation program with integrated circuit emphasis (SPICE) software; direct current (DC) analysis, alternating current (AC) small-signal analysis; more complex analysis methods eg mixed-mode analysis, transient analysis, pole-zero analysis, distortion analysis, sensitivity analysis, noise analysis, thermal analysis; software integration methods eg export and import data, links with companion software for circuit layout and PCB manufacture

Thermal analysis: heat dissipation methods; thermal ratings of semiconductor devices; thermal calculations eg total power dissipation, thermal resistance, $\theta_T = \theta_{JC} + \theta_{CS} + \theta_{SA}$, junction temperature, $T_J = (P_T \times \theta_T) + T_A$, temperature rise above ambient, $\Delta_T = P_T \times \theta_T = T_J - T_A$, de-rating, correct rating for thermal dissipator/heatsink

3 Understand the use and application of surface mount technology in the manufacture of an electronic circuit

Surface mount technology (SMT): types of SMT device eg passive components (resistors, capacitors, inductors and transformers), active components (transistors, diodes and integrated circuits), connectors and sockets; surface mount device (SMD) outlines, packaging and storage; manufacturers' markings and supporting data; hybrid circuits and multi-chip modules (MCM)

SMT circuit manufacturing: manufacturing methods eg use of solder pastes, flow and wave soldering equipment; SMT quality assurance methods eg batch testing, statistical methods; SMT component reliability and testing of finished SMT assemblies; assembly-level packaging and interconnection

4 Be able to design and manufacture a prototype printed circuit board and use it to assemble and test an electronic circuit

PCB design: single-sided printed circuit board for a given electronic circuit design that includes no more than four active devices eg transistors, diodes and conventional dual in-line (DIL) packaged integrated circuits; associated passive components eg PCB mounted resistors, capacitors, inductors, transformers; means of connection eg external controls, connectors, power sources; layout techniques based on the use of electronic CAD to generate PCB master artwork

PCB manufacture: developing, etching, drilling

Electronic circuit assembly: component mounting, soldering

PCB and circuit testing: functional testing using a supplied test specification to determine circuit design inputs and outputs eg test-point voltages, output signals

Assessment and grading criteria

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

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the processes used in the design of both a single and multi-layer PCB for electronic circuits of different complexity	**M1** explain the benefits of using automated techniques for the manufacture of an electronic circuit	**D1** apply thermal analysis techniques in order to determine the heat dissipation requirements for the electronic circuit
P2 describe typical production methods used in the manufacture of both a single and a multi-layer PCB for electronic circuits of different complexity	**M2** use SPICE software to carry out DC and small-signal AC analysis of a simple electronic circuit	**D2** evaluate the design and manufacture of the prototype PCB and circuit and make appropriate recommendations for mass production.
P3 describe how computer aided design software is used to analyse an electronic circuit prior to manufacture	**M3** explain the use of typical quality assurance methods in the manufacture of electronic circuits using SMT.	
P4 explain the need for thermal analysis and effective heat dissipation for an electronic circuit		
P5 explain the use of SMT in the manufacture of an electronic circuit and give two examples of the outlines and packages used for surface mounted devices		
P6 describe methods used for the manufacture of an electronic circuit using SMT		
P7 design, manufacture and test a prototype printed circuit board for a given electronic circuit. [IE1, IE2, IE4, CT1, SM2, SM3]		

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

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

Essential guidance for tutors

Delivery

A major feature of this unit is that it concentrates on the design and manufacture of electronic circuits. In this context, 'design' should be taken as referring to the realisation of an electronic circuit from a given circuit diagram, rather than the more theoretical aspects of designing an electronic circuit to achieve desired circuit parameters eg the design of an active filter.

For learning outcomes 2 and 4, learners should be introduced to the use of appropriate software packages for PCB layout and manufacture and simulation of electronic circuits prior to manufacture using SPICE software.

In relation to learning outcomes 1 and 3, learners should be given the opportunity to experience production methods used in large-scale manufacturing of electronic circuits (including extensive use of integrated CAD/CAM and the use of wave and flow soldering techniques). Emphasis should be placed on the processes most relevant to local industrial requirements. Where possible, centres should arrange visits to industrial sites so that learners can see current manufacturing techniques such as wave soldering.

All CAD activities and SPICE tests carried out by learners should be recorded in an appropriate logbook (with the capacity to include relevant printed output and screen-dumps).

Due to the hazardous nature of some of the processes, materials and chemicals used, appropriate attention must be given to health, safety and welfare arrangements.

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.

Outline learning plan

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

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

Topic and suggested assignments/activities and/assessment
Whole-class teaching: • introduction to unit content, scheme of work and assessment • introduction to different types of electronic circuit and the techniques for manufacturing them (whole-class teaching). *Group work:* • activity based on examples of different electronic circuit construction techniques.
Whole-class teaching: • manufacturing processes and production methods. Automated production methods. *Industry visit:* • view automated circuit manufacturing processes.
Preparation for and carrying out **Assignment 1: PCB Design and Manufacturing Techniques** (P1, P2 and M1).
Whole-class demonstration followed by individual and group work: • computer aided design software and simulation packages. Learners feed back results of individual and group work.

Topic and suggested assignments/activities and/assessment
Preparation for and carrying out **Assignment 2: Circuit Simulation and Analysis Using SPICE** (P3 and M2).
Whole-class demonstration followed by individual and group work: • thermal design considerations. Learners feed back results of individual and group work.
Preparation for and carrying out **Assignment 3: Thermal Analysis and the Design of Heat Dissipaters** (covering P4 and D1).
Whole-class demonstration followed by individual and group work: • surface mounting technology. Learners feed back results of individual and group work.
Preparation for and carrying out **Assignment 4: Surface Mounting Technology** (covering P5, P6 and M3).
Whole-class teaching and demonstration: • design and manufacture of prototype PCB. Health and safety issues.
Preparation for and carrying out **Assignment 5: Design, Manufacture, Assembly and Testing of a Prototype PCB** (covering P7 and D2).
Unit review and final feedback.

Assessment

P1 and P2 are closely related and evidence could be gathered from either an extended case study or from research and investigation. Case studies and investigations should ideally be based on production techniques and manufacturing processes that are used locally. Learners would benefit from visits to local industry to view the processes in action. An alternative to an extended case study or investigation might be the use of one or more written essay-type questions. However, this approach is likely to be less effective in bringing the topic to life.

To achieve P1, evidence should focus on design strategy, design tools (for example, schematic capture and auto-routing PCB CAD), creating and modifying schematic diagrams (for example, exchanging logic functions), design verification and design rule checking for both tracking and component layout.

It is important that learners demonstrate that they understand the additional processes required to produce multi-layer boards and that they appreciate the need for this type of board in conjunction with more complex electronic circuits. For example, circuits where microprocessor bus systems are realised on different layers or where power and ground connections are separated from signal tracks.

For P2, learners should be able to describe typical production methods used in the manufacture of both single and multi-layer types of printed circuit board for electronic circuits of different complexity.

The explanation of the use of computer aided design software required for P3 should normally be based on the use of a SPICE package to verify a circuit design before it is manufactured.

For P4, learners should explain the need for thermal analysis and effective heat dissipation in terms of the total power dissipated and the maximum junction temperature ratings for the semiconductor device(s) present. They should explain that the requirements are satisfied by means of appropriately designed heat dissipaters on which the semiconductor devices are mounted.

To satisfy P5, learners should provide a written or verbal presentation of the use of surface mount technology (SMT) in the manufacture of electronic circuits. Learners should be able to state the advantages and disadvantages of SMT and surface mounted devices (SMD) and should be able to describe the typical outlines and packages used for SMD.

For P6, learners should describe the typical methods used for the manufacture of electronic circuits using SMDs. Note that learners are not expected to know how SMDs themselves are manufactured.

For P7, learners should design, manufacture and test a prototype printed circuit board for a given electronic circuit. The electronic circuit should be supplied, complete with a full component list and component supplier's references. Learners will be able to use these to determine physical constraints such as lead diameter, pin spacing and package outlines as well as any specialised mounting requirements such as the fitting of a heat dissipater. The circuits chosen should use no more than four active devices (for example transistors, diodes and conventional dual in-line (DIL) packaged integrated circuits) and associated passive components (for example PCB mounted resistors, capacitors, inductors, and transformers). The circuit should have an identifiable function and should be capable of functional testing without specialised equipment.

In order to carry out this task, learners should be supplied with a simple test specification based on test-point voltages, output signal levels etc. Centres are encouraged to provide learners with a standard test-jig in order to carry out these functional checks.

Typical examples of circuits that learners might develop include:

- a variable pulse generator (based on two 555 timers)
- a function generator (based on a single integrated circuit waveform generator)
- an audio amplifier (based on a complementary symmetrical output stage with driver and pre-amplifier stage)
- a regulated power supply (based on a bridge rectifier and a three-terminal fixed voltage regulator).

Note that these last two examples could require learners to undertake some thermal analysis and incorporate appropriate arrangements for heat dissipation (extending the work required for P4 and providing a basis for developing evidence for D1).

Evidence for M1 could be gathered through a written assignment or formal written test. M2 could be assessed through appropriately designed practical activities and M3 by means of an assignment in which learners investigate modern industrial processes used for the high-volume manufacture of electronic circuits.

Learners can achieve D1 by means of an extended assignment involving thermal analysis and the design of a heat dissipator (for example, a heatsink for fitting to a three-terminal integrated circuit voltage regulator).

For D2, the exercise carried out to satisfy P7 could be developed further as learners evaluate their designs and make appropriate recommendations for mass production (based on the understanding that they have evidenced in relation to P1 and P2).

These recommendations will typically include size reduction (including the use of miniaturised or equivalent surface mounted components), the use of multi-layer boards and the use of appropriate interconnecting technologies (for example the use of multi-pole insulation displacement connectors (IDCs) fitted with PCB headers).

Programme of suggested assignments

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

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	PCB Design and Manufacturing Techniques	Learners investigate the techniques and processes used in the design and manufacture of PCB (including manufacture of both single and multilayer PCB as well as both manual and automated component assembly).	A report containing written responses including, where appropriate, sketches that describe and explain the techniques and processes used in the design and manufacture of PCB.
P3, M2	Circuit Simulation and Analysis Using SPICE	Learners investigate and use simulation programs with integrated circuit emphasis (SPICE) to carry out a DC and small-signal AC anaylsis of a simple electronic circuit (eg a single stage amplifier with given circuit data, component values and SPICE models).	A report containing written responses including, where appropriate, sketches that describe and explain the use of computer aided design software in the analysis of a simple electronic circuit prior to manufacture. Learners should include evidence of their use of a SPICE package to carry out a DC and small-signal AC analysis in the form or screen grabs and/or hard copies of the results obtained.
P4, D1	Thermal Analysis and the Design of Heat Dissipaters	Learners investigate thermal analysis techniques and use them to design an effective heat dissipater for an electronic device (eg a TO3 or TAB encapsulated transistor, voltage regulator or other integrated circuit for which electrical and thermal data is supplied).	A report containing written responses including, where appropriate, sketches that describe and explain the use of heat dissipaters. Learners should include evidence of their thermal analysis including the use of appropriate formulae and relevant calculations of thermal resistance, junction and surface temperature.
P5, P6, M3	Surface Mounting Technology	Learners investigate the use of surface mounting technology (SMT) and surface mounted devices (SMD).	A report containing written responses including, where appropriate, sketches of SMT packages and mounting arrangements.

Criteria covered	Assignment title	Scenario	Assessment method
P7, D2	Design, Manufacture, Assembly and Testing of a Prototype PCB	Learners will design, manufacture and test a prototype electronic circuit. In order to complete this task they will need to design and produce a printed circuit board (PCB). The PCB layout should be produced using computer aided design techniques.	A process portfolio containing a circuit diagram, detailed component list, sketches, notes, screen dumps, component and PCB track layout diagrams, test voltages and currents, waveform sketches (as appropriate) together with the learner's final prototype electronic circuit. The portfolio should include an evaluation of the design and manufacture of the electronic circuit together with an appropriate set of recommendations for its mass production.

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

This unit forms part of the BTEC Engineering sector suite. This unit has particular links with the following unit titles in the Engineering suite:

Level 1	Level 2	Level 3
	Engineering Assembly Techniques	Electrical and Electronic Principles
	Electronic Devices and Communication Applications	Principles and Applications of Electronic Devices and Circuits
	Electronic Circuit Construction and Testing	

The unit supports aspects of the SEMTA Level 3 National Occupational Standards in Electrical and Electronic Engineering, particularly:

- Unit 4: Designing Electronic Circuit Board Layouts Using CAD Tools
- Unit 10: Selecting and Preparing Materials and Components for Manufacturing
- Unit 11: Preparing Manufacturing Systems Equipment for Operations
- Unit 12: Monitoring and Analysing Data from Electronic Circuit Manufacturing Processes
- Unit 13: Adjusting and Sustaining Electronic Circuit Manufacturing Processes.

Essential resources

Learners will need access to an electronics workshop with a range of electronic manufacturing equipment sufficient to meet the needs of the grading criteria (eg developing tanks, heated etching baths, PCB drilling equipment, soldering and wiring equipment). Centres will need to provide sufficient electronic test equipment to confirm the functionality of printed circuit boards and provide access to PCs equipped with PCB CAD and SPICE simulation packages. Learners will also need to be provided with relevant personal protective equipment (eg goggles, gloves, protective clothing) when manufacturing circuit boards, handling chemicals, soldering etc.

Employer engagement and vocational contexts

Industry visits would be highly effective in support of this unit, especially when delivering learning outcomes 1 and 3. Not only will they help learners put the work that they do in the classroom into context, but they will also provide an opportunity to view modern production techniques at first hand. A well planned industry visit would include CNC tooling used for PCB production, automated parts assembly, flow-soldering and the use of automatic test equipment (ATE). Ideally they would also include an opportunity to investigate the use of modern electronic computer aided design (CAD) software. In addition, learners could benefit greatly from an opportunity to contrast the use of modern surface mounted devices (SMD) with the much simpler conventional components that they will be using in the construction of their own electronic prototypes.

There are a range of organisations that may be able help centres engage and involve local employers in the delivery of this unit, for example:

- Work Experience/Workplace learning frameworks – Centre for Education and Industry (CEI, University of Warwick) – www.warwick.ac.uk/wie/cei
- Learning and Skills Network – www.vocationallearning.org.uk
- Network for Science, Technology, Engineering and Maths Network Ambassadors Scheme – www.stemnet.org.uk
- National Education and Business Partnership Network – www.nebpn.org
- Local, regional Business links – www.businesslink.gov.uk
- Work-based learning guidance – www.aimhighersw.ac.uk/wbl.htm

Indicative reading for learners

Textbooks

Sinclair I – *Practical Electronics Handbook* (Newnes, 2000) ISBN 0750645857

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Newnes, 2006) ISBN 0750669233

Williams T – *Circuit Designer's Companion* (Newnes, 2004) ISBN 0750663700

Electronic component suppliers and parts catalogues

Farnell Electronic Components – www.farnell.co.uk

Greenweld – www.greenweld.co.uk

Jaycar Electronics – www.jaycarelectronics.co.uk

Magenta – www.magenta2000.co.uk

Maplin Electronics – www.maplin.co.uk

Quasar Electronics – www.quasarelectronics.com

Electronic CAD, PCB design and SPICE resources

5Spice Analysis – www.5spice.com

B2 SPICE software – www.spice-software.com

CadSoft Online Eagle PCB Design – www.numberonesystems.com

Electronics Workbench Multisim – www.electronicsworkbench.com

Labcenter Electronics – www.labcenter.co.uk

Matrix Multimedia – www.matrixmultimedia.co.uk

WebEE Electronic Engineering Homepage – www.web-ee.com

WinSpice – www.winspice.com

Delivery of personal, learning and thinking skills

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

Skill	When learners are ...
Independent enquirers	designing, manufacturing, assembling and testing a prototype printed circuit board for a given electronic circuit
Creative thinkers	designing, manufacturing, assembling and testing a prototype printed circuit board for a given electronic circuit
Self-managers	designing, manufacturing, assembling and testing a prototype printed circuit board for a given electronic circuit.

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

Skill	When learners are ...
Reflective learners	designing, manufacturing, assembling and testing a prototype printed circuit board for a given electronic circuit.

Functional Skills – Level 2

Skill	When learners are ...
ICT – Use ICT systems	
Select, interact with and use ICT systems independently for a complex task to meet a variety of needs	using SPICE software to carry out DC and small-signal AC analysis of a simple electronic circuit applying thermal analysis techniques in order to determine the heat dissipation requirements for the electronic circuit designing, manufacturing, assembling and testing a prototype printed circuit board for a given electronic circuit
ICT – Find and select information	
Select and use a variety of sources of information independently for a complex task	designing, manufacturing, assembling and testing a prototype printed circuit board for a given electronic circuit
Access, search for, select and use ICT-based information and evaluate its fitness for purpose	designing, manufacturing, assembling and testing a prototype printed circuit board for a given electronic circuit
Mathematics	
Understand routine and non-routine problems in a wide range of familiar and unfamiliar contexts and situations	applying thermal analysis techniques in order to determine the heat dissipation requirements for the electronic circuit
Identify the situation or problem and the mathematical methods needed to tackle it	applying thermal analysis techniques in order to determine the heat dissipation requirements for the electronic circuit
English	
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	researching and investigating electronic circuit manufacture
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	describing typical processes used in the design of both a single and multi-layer PCB for electronic circuits of different complexity describing typical production methods used in the manufacture of both a single and a multi-layer PCB for electronic circuits of different complexity explaining how computer aided design software can be used in the analysis of en electronic circuit prior to manufacture explaining the need for thermal analysis and the need for effective heat dissipation of an electronic circuit explaining the use of SMT in the manufacture of an electronic circuit and give two examples of the outlines and packages used for surface mounted devices describing methods used for the manufacture of an electronic circuit using SMT.