Department
for Education

Electronics

GCE AS and A level subject content

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Contents

The content for AS and A level electronics

Introduction

1. The AS and A level subject content sets out the knowledge, understanding and skills for AS and A level specifications in electronics, to ensure progression from GCSE science and mathematics requirements and provide a basis for moving to further study. They provide the framework within which awarding organisations create the detail of the subject specifications.

Subject aims and outcomes

2. Specifications in AS and A level electronics will ensure that students have the electronic and mathematical knowledge and electronic engineering skills to solve problems. They should enable students to appreciate how many problems in society can be tackled by the application of the scientific ideas in the field of electronics using engineering processes.

3. AS and A level specifications in electronics should enable students to:

- develop essential scientific knowledge and conceptual understanding of the behaviour of electrical/electronic circuits
- develop and demonstrate a deep understanding of the nature, processes and methods of electronics as an engineering discipline
- develop competence and confidence in a variety of practical, mathematical and problem-solving skills
- develop and learn how to apply observational, practical and problem-solving skills in the identification of needs in the world around them and the testing of proposed electronic solutions
- develop and learn how to apply creative and evaluative skills in the development and assessment of electronic systems to solve problems
- develop their interest in electronics, including developing an interest in further study and careers associated with electronics

Subject content

4. AS and A level electronics specifications must build upon the skills, knowledge and understanding set out in the GCSE subject content for the relevant areas of GCSE science. The skills, knowledge and understanding set out in the GCSE subject content for GCSE electronics are not assumed.

5. AS and A level specifications in electronics should reflect the aims and learning outcomes outlined above, and should include the skills, knowledge and understanding

listed below, giving due consideration to the assessment objectives. The essential subject content outlined here provides the framework for developing a coherent study at AS and A level.

6. The skills, knowledge and understanding set out in this document comprise the totality of AS and A level specifications in electronics. The content detailed in this document sets out the full range of content for AS and A level specifications in electronics. Awarding organisations may, however, use any flexibility to increase depth, breadth or context within the specified topics, as long as the rigour and challenge of the specification is maintained.

7. The knowledge, understanding and skills in appendices 1 and 2 also form part of the mandatory content requirement.

Knowledge and understanding

8. The knowledge and understanding for AS and A level electronics is shown below in normal (non-bold) text. The bold text is for A level electronics only.

9. AS and A level specifications in electronics should require students to demonstrate and apply knowledge and understanding of:

- Use of apparatus
  - the construction of digital and analogue electrical circuits
  - making measurements on electrical circuits using multimeters (on voltage, current and resistance ranges), timing equipment, logic probes and oscilloscopes (or computers configured as oscilloscopes)
- System synthesis
  - the structure of electronic systems in terms of inputs, processes and outputs and possibly feedback
  - the representation of complex systems in terms of sub-systems
  - the analysis and design of systems using system diagrams
- Logic systems
  - the identification and use of NOT, Schmitt inverter and 2 and 3 input AND, NAND, OR, NOR, XNOR and XOR logic gates, singly and in combination
  - the use of truth tables for these gates and simple combinations of them
  - the use of combinations of one or more types of gate to perform other logic functions including NAND-gate simplification
  - logic-system simplification using Boolean algebra, Karnaugh maps and multiplexers

    - the design and construction of electronic circuits containing logic gates, with consideration to sourcing, sinking, pull-up and pull-down resistors

- DC electrical circuits

    - standard circuit symbols to interpret and draw circuit diagrams
    - the definition of resistance and the effect of resistors in circuits
    - the effective resistance of series and parallel combinations of resistors
    - the analysis of circuits using Kirchhoff's laws and Thevenin's theorem for a single power supply
    - appropriate values of resistor, selecting from the E24 series
    - **[the conditions for the balance of a bridge circuit]**

- Energy *(E)* and Power *(P)*

    - the relationship between energy, power and time: $P = \frac{E}{t}$
    - the power relationships: $P = VI = I^2 R = \frac{V^2}{R}$
    - rms voltage and current and their use in power calculations in a sinusoidal AC circuit

- Input and output sub-systems

    - the design and construction of analogue sensing systems using photosensitive devices, negative temperature coefficient (NTC) thermistors and switches
    - the interpretation and use of characteristic curves for the above devices, and their experimental determination
    - the use of a Schmitt inverter to provide signal conditioning
    - the use of a variety of output devices including a buzzer, a loudspeaker, a motor, a solenoid, a relay, a mechanical actuator (servo) and a seven-segment display in a system
    - **[the use of the slotted discs (for sensing rotational speed) and encoded discs (for sensing angular position)**
    - **the comparison of the Gray coding of encoded discs with binary coding**
    - **the use of bridge circuits with thermistors and with strain gauges]**

- Semiconductor components

    - the uses of light-emitting diodes, silicon diodes and Zener diodes in electronic systems, including carrying out relevant calculations on circuits containing these components
    - the use of bipolar and field-effect transistors as switches, using data to design suitable circuits

- Op-amps

  - the definition of the voltage gain of an amplifier
  - the characteristics of an ideal op-amp and their comparison with those of typical op-amps
  - the dependence of the output state of an op-amp on the relative values of the two input states
  - the concept of a virtual earth
  - the characteristics of the following op-amp circuits, including recognising, drawing and performing calculations: inverting amplifier, non-inverting amplifier, summing amplifier, comparator and voltage follower circuits
  - the design of single stage amplifiers based on inverting and non-inverting voltage amplifiers
  - the relationship between the gain and bandwidth of an amplifier
  - clipping distortion and the slew-rate limit
  - **[the op-amp difference amplifier circuit, including recognising, drawing and performing calculations**
  - **the analysis and design of instrumentation amplifiers based upon the op-amp difference amplifier circuit]**

- Timing circuits

  - the definition of the capacitance of a capacitor and the effective capacitance of series and parallel combinations of capacitors
  - charging and discharging graphs for capacitors, including the use of log graphs
  - the use of capacitors as the basis of timing circuits and in debouncing switches, including the time constant (T) for an RC circuit (T = RC)
  - the use of the exponential charging and discharging equations for a capacitor and the use of suitable approximations for effective charge and discharge times
  - the properties of monostable circuits and their use in time-delay circuits
  - the properties of an astable circuit and its use as a pulse generator
  - the design of an astable circuit based upon a Schmitt trigger
  - the analysis of monostable and astable circuits based upon a 555 timer IC, the drawing of these circuits and calculations of their characteristics including pulse duration, frequency and mark-space ratio

- Sequential logic sub-systems

  - a Set-Reset (SR) latch based on NAND gates, including the design and description of the action
  - the significance of propagation delays in sequential systems

- the construction and use of timing diagrams to explain the operation of sequential logic circuits
- the characteristics and uses of the inputs and outputs of D-type flip-flops in the context of transition gates, frequency divider circuits, asynchronous counters, **[parallel-in, series out (PISO) and series in, parallel out (SIPO) registers and synchronous counters]**
- the design of systems that use a dedicated 4-bit counter and combinational logic to produce a sequence of events
- converting between binary, decimal, hexadecimal and binary-coded decimal (BCD) number systems

- Microcontrollers

    - the analysis and design of flowchart programs for microcontrollers
    - programming microcontrollers using a flowchart program
    - **[the nature of microcontrollers as programmable assemblies of memory, input ports, output ports, CPU and clock**
    - **the use of interrupts to allow an external device to be serviced on request**
    - **the applications of a microcontroller**
    - **the design and analysis of systems with a microcontroller sub-system**
    - **programming microcontrollers using assembler language**

- **Signal conversion**

    - **the need for signal conversion between analogue and digital form in communications and microprocessors**
    - **the use of a digital-to-analogue (DAC) converter for converting digital into analogue signals; the analysis and design of a DAC based upon an op-amp summing amplifier to meet a given specification**
    - **the use of an analogue-to-digital (ADC) converter for converting analogue into digital signals and the analysis and design of a flash converter ADC based on comparators to meet a specification**
    - **the analysis and design of a priority encoder to meet a specification**
    - **the difference between digital ramp and flash ADC**

- **AC circuits and passive filters**

    - **the use of V-t, I-t and P-t graphs for resistive loads and the relationship between rms and peak values**
    - **the relationship between current and potential difference for capacitors and inductors, reactance and the impedance of RC and RL series circuits**
    - **the analysis and design of high-pass and low-pass RC passive filters and LC passive band-pass filters**

  - **displaying the outputs of filters using linear-log and log-log graphs**
  - **the advantage of buffering passive filters**

- **Communications systems**

  - **the relationships between bandwidth, data rate and information-carrying capacity**
  - **the necessity for multiplexing a number of signals and the principles of frequency and time-division multiplexing**
  - **the distinction between noise and distortion**
  - **the significance of attenuation for the signal-to-noise ratio and its expression in dB**

- **Digital communications**

  - **the analysis and design of Schmitt trigger circuits to regenerate a digital signal**
  - **the production and analysis of graphs to illustrate pulse modulation techniques: pulse width modulation (PWM), pulse amplitude modulation (PAM), pulse code modulation (PCM)**
  - **the operation of a PCM communication system including block diagram**
  - **the relationship between the required sampling frequency and the highest frequency in the signal**
  - **the use of time-division multiplexing (TDM) to improve the capacity of a PCM communications link**
  - **the limitation on the number of channels that can be incorporated into a PCM communications link, using TDM**

- **Wireless transmission**

  - **the use of the different regions of the radio spectrum for data transmission, including in terms of bandwidth requirements and available frequency channels**
  - **the principles of amplitude and frequency modulation**

- **Optical communication**

  - **the long distance transmission of signals in optical fibres related to the refractive properties of glass**
  - **the effects of dispersion, attenuation and radiation losses in optical fibre communication**
  - **the principles of the operation of circuits for converting between electrical and optical signals**

- **Principles of semiconductors**
    - **the conduction processes in n- and p-type semiconductors in terms of mobile electrons and holes**
    - **conduction processes at a p-n junction and the operation of a LED and a photodiode**
    - **the properties of an n-channel MOSFET in terms of the pinching of the conducting channel**

- **Audio systems**
    - **the structure of a simple audio system**
    - **the analysis and design of a multi-stage voltage preamplifier to meet bandwidth and gain requirements**
    - **the analysis and design of a mixer circuit based upon a summing amplifier**
    - **the operation of first order active filters (bass boost, treble boost, bass cut, treble cut) including calculation of the break frequency**
    - **the maximum power transfer theorem**
    - **the properties of emitter and source follower power amplifiers and push-pull power amplifiers consisting of either emitter or source followers**
    - **cross-over distortion and its removal using negative feedback**
    - **the gain of a power amplifier expressed in dB**
    - **the process of digitizing audio signals and the effects of sampling rate and resolution]**

- Mains power supply systems
    - the use of diodes for half-wave and full-wave rectification
    - the effect of capacitors and loads on the rectified output of a simple power supply
    - Zener-regulated power supplies, including their design, and graphs to show the effect of loading
    - **[the distinction between load regulation and line regulation**
    - **the analysis and design of a voltage regulator based upon a Zener diode, an emitter follower and a non-inverting amplifier**

- **High power switching systems**
    - **the design of a DC thyristor switching circuit and an explanation of the process of capacitor commutation**
    - **the circuit diagram and graphs for an AC phase control circuit, using an RC network, a triac and a diac and calculations of the phase shift between the supply voltage and capacitor voltage]**

Electronics skills

10. The knowledge, understanding and skills of each specification in AS and A level electronics should require students, in the context of the knowledge and understanding above, to demonstrate the ability to:

a) analyse a problem[1] to enable solutions to be developed
b) develop a design brief to solve a problem
c) propose an electronic system, composed of sub-systems, to satisfy a design brief
d) make predictions about the way that electronic systems behave
e) design and build an electronic system, modelling its performance against the design brief, modifying as appropriate
f) plan tests to make measurements, to explore a problem, selecting appropriate techniques and instruments
g) evaluate practical risks in system development and application
h) carry out tests having due regard to the correct manipulation of apparatus, accuracy of measurement and Health and Safety considerations
i) make and record measurements on electrical circuits
j) report results using standard scientific conventions
k) evaluate the performance of the electronic system against the design brief
l) suggest improvements to the electronic system following evaluation
m) design a microcontroller system; programming the microcontroller using a flowchart program; **[programming the microcontroller using assembly language]**

Assessment of electronics skills

11. Specifications in AS and A level electronics should assess these electronics skills by requiring students to undertake development and testing tasks. Solutions will require a synthesis of different aspects of the knowledge and understanding specified above. The weighting of the tasks must be proportionate to the range and nature of the skills to be assessed at each level.

12. At AS level, specifications should require students to undertake tasks that assess all of the above skills and include working with both digital and analogue circuits.

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[1] In the context of GCE AS and A level electronics skills, 'problem' is interpreted broadly, to embrace:

- problem – difficulties in a situation e.g. people with partial hearing cannot hear the doorbell
- context – looking at situations for possible design openings e.g. people crossing the road
- opportunity – possibilities arising e.g. from a new improved component

13. At A level, specifications should require students to undertake tasks that assess all of the above skills working with both digital and analogue sub-systems. This must include a System Development Task of sufficient complexity and must offer an appropriate degree of uncertainty in outcome to allow students to demonstrate the full range of skills outlined and include concepts from the bold knowledge and understanding statements.

Appendix 1

Equations for AS and A level electronics

In solving quantitative problems, AS and A level students should be able correctly to use the following relationships, using standard SI units, without them being provided:

$V = IR$	definition of resistance
$P = VI = I^2R = \dfrac{V^2}{R}$	power relationships
$R = R_1 + R_2 + \dots$	resistors in series
$\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dots$	resistors in parallel
$R = \dfrac{R_1 R_2}{R_1 + R_2}$	two resistors in parallel
$V_{\mathrm{OUT}} = \dfrac{R_2}{R_1 + R_2} V_{\mathrm{IN}}$	potential divider
$E = Pt$	energy transfer
$\overline{A + B} = \overline{A} . \overline{B}$ $\overline{A . B} = \overline{A} + \overline{B}$	de Morgan's theorem

In addition, AS and A level students should be able correctly to select from a list and apply the following relationships:

$A + \overline{A} . B = A + B$ $A . B + A = A . (B + 1) = A$	Boolean identities
$G = \dfrac{V_{\mathrm{OUT}}}{V_{\mathrm{IN}}}$	amplifier voltage gain
$G = 1 + \dfrac{R_{\mathrm{F}}}{R_1}$	non-inverting op-amp circuit voltage gain
$G = -\dfrac{R_{\mathrm{F}}}{R_{\mathrm{IN}}}$	inverting op-amp circuit voltage gain
$\text{Slew rate} = \dfrac{\Delta V_{\mathrm{OUT}}}{\Delta t}$	definition of slew rate
$V_{\mathrm{OUT}} = -R_{\mathrm{F}} \left(\dfrac{V_1}{R_1} + \dfrac{V_2}{R_2} + \dots . \right)$	summing amplifier output voltage

$V_C = V_0\left(1 - e^{-\frac{t}{RC}}\right)$	charging capacitor
$t = -RC\ln\left(1 - \frac{V_C}{V_0}\right)$	charging capacitor
$V_C = V_0 e^{-\frac{t}{RC}}$	discharging capacitor
$t = -RC\ln\left(\frac{V_C}{V_0}\right)$	discharging capacitor
$V_{rms} = \frac{V_0}{\sqrt{2}}$; $I_{rms} = \frac{I_0}{\sqrt{2}}$	rms values
$I_C = h_{FE} I_B$	bipolar transistor
$I_D = g_M(V_{GS} - 3)$	MOSFET
$f = \frac{1}{T}$	frequency, period relationship
$T = 1.1RC$	555 monostable
$t_H = 0.7(R_A + R_B)C$	mark time of a 555 astable circuit
$t_L = 0.7R_B C$	space time of a 555 astable circuit
$f = \frac{1.44}{(R_1 + 2R_2)C}$	frequency of a 555 astable circuit
$f \approx \frac{1}{RC}$	Schmitt astable circuit

In addition, A level students should be able correctly to select from a list and apply the following relationships:

$X_C = \frac{1}{2\pi fC}$; $X_L = 2\pi fL$	capacitive and inductive reactances
$Z = \sqrt{R^2 + X^2}$	impedance of a series circuit
$f_b = \frac{1}{2\pi RC}$	break frequencies for *RC* filters
$V_{OUT} = V_{DIFF}\left(\frac{R_F}{R_1}\right)$	difference amplifier
$f_0 = \frac{1}{2\pi\sqrt{LC}}$	resonant frequency for *LC* filters
$R_D = \frac{L}{r_L C}$	dynamic resistance
$Q = \frac{f_0}{\text{bandwidth}} = \frac{2\pi f_0 L}{r_L}$	*Q*-factor

$$m = \frac{\left(V_{\mathrm{max}} - V_{\mathrm{min}}\right)}{\left(V_{\mathrm{max}} + V_{\mathrm{min}}\right)} \times 100\%$$ depth of modulation

$$\beta = \frac{\Delta f_{\mathrm{c}}}{f_{\mathrm{i}}}$$ modulation index

$$\text{Bandwidth} = 2\left(\Delta f_0 + f_{\mathrm{i}}\right) = 2\left(1 + \beta\right) f_{\mathrm{i}}$$ transmitted FM bandwidth

$$V_{\mathrm{L}} \approx V_{\mathrm{Z}}\left(1 + \frac{R_{\mathrm{F}}}{R_1}\right)$$ stabilised power supply

$$\phi = \tan^{-1}\left(\frac{R}{X_{\mathrm{C}}}\right)$$ triac phase control

$$\text{resolution} = \frac{\text{i/p voltage range}}{2^n}$$ ADC/PCM resolution

$$P_{\mathrm{MAX}} = \frac{V_{\mathrm{S}}^{\;2}}{8R_{\mathrm{L}}}$$ power amplifier

Appendix 2

Mathematical requirements and exemplification

In order to be able to develop their skills, knowledge and understanding in electronics, students need to have been taught, and to have acquired competence in the following areas of mathematics indicated in the table below.

All mathematical content must be assessed within the lifetime of the specification.

The table illustrates where these mathematical skills may be developed and could be assessed. The normal (non-bold) text applies to AS and A level and the bold text applies to A level only.

The list of examples is not exhaustive. These skills could be developed in other areas of the specification content.

	Mathematical skill	**Exemplification of mathematical skill (assessment is not limited to the examples given below)**
E.0 – arithmetic and numerical computation		
E.0.1	Recognise and make use of appropriate units in calculations	Convert between units with different prefixes, e.g. A to mA Identify the correct units for physical properties such as Hz, the unit for frequency
E.0.2	Recognise and use expressions in decimal and standard form	Use frequencies expressed in standard form such as 2.5 × 107 Hz
E.0.3	Use fractions, ratios and percentages	Calculate the fraction of the charge lost from a capacitor in a given time
E.0.4	Estimate results	Estimate the resistor values needed in a potential divider so that the output voltage does not drop significantly
E.0.5	Use calculators to handle power functions, exponential and logarithm functions	Calculate the power rating required for a resistor Calculate the time constant from a decay curve
E.0.6	**[Use calculators to handle tan and $\tan^{-1}$ functions**	**Calculate the phase angle for a triac phase-control circuit]**

E.1 – handling data		
E.1.1	Use an appropriate number of significant figures	Report calculations to an appropriate number of significant figures Understand that calculated results can only be reported to the limits of the least accurate measurement
E.1.2	Find arithmetic means	Calculate a mean value for repeated experimental findings
E.1.3	Make order of magnitude calculations	Evaluate equations with variables expressed in different orders of magnitude, e.g. 150 kΩ and 2.6 mA
E.1.4	Use Karnaugh maps	Simplify a logic system
E.2 – algebra		
E.2.1	Understand and use the symbols: =, <, <<, >, >>, $\propto$, $\approx$, Δ	Recognise the significance of the symbols in the expression: $\text{Slew rate} = \frac{\Delta V_{\text{OUT}}}{\Delta t}$
E.2.2	Change the subject of an equation, including non-linear equations	Rearrange $P = \frac{V^2}{R}$ to make *R* the subject
E.2.3	Substitute numerical values into algebraic equations using appropriate units for physical quantities	Calculate the frequency of a 555 astable by substituting the values for R_1, R_2 and *C* into the equation: $f = \frac{1.44}{(R_1 + 2R_2)C}$
E.2.4	Solve algebraic equations	Find a capacitor value for a given time delay and resistance in a 555 monostable
E.2.5	Use Boolean algebra	Simplify a logic system
E.3 – graphs		
E.3.1	Translate information between graphical, numerical and algebraic forms	Measure the ripple voltage from output graphs for rectified power supplies
E.3.2	Plot two variables from experimental or other data	Plot *V-I* characteristics of a diode
E.3.3	Determine the slope of a graph	Calculate a resistance value from a *V-I* graph
E.3.4	Calculate the rate of change from a graph showing a linear relationship	Calculate the slew rate from a *V-t* graph
E.3.5	Draw and use the slope of a tangent to a curve as a measure of rate of change	Calculate the gain of an amplifier from the transfer characteristic

E.3.6	Sketch relationships which are modelled by $y = \sin x$ and $y = \sin^2 x$	Sketch a graph of power against time for an alternating current in a resistor
E.3.7	**[Use log-log and semi-log graph grids**	**Sketch and interpret gain curves for filters]**

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