HIGHER ENGINEERING SCIENCE

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ENGINEERING SCIENCE

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INTRODUCING HIGHER ENGINEERING SCIENCE

COURSE CONTENT AND ASSESSMENT

SYLLABUS

The main purpose of this book is to help you improve your chances of success within the Higher Engineering Science course, and to act as a supplement to your learning in school. Regular studying of this book, and using it to strengthen your learning and understanding of what you are taught in class, will go a long way towards your success in the course.

The course consists of three main units, and each chapter within this book covers the content you will need to know and understand. These units are:

- Engineering Contexts and Challenges
- Electronics and Control
- Mechanisms and Structures.

Engineering Contexts and Challenges

This part of the course gives a broad context of engineering. As you complete this, you will develop a deep understanding of engineering concepts by exploring and analysing a range of complex engineered objects, engineering problems and their solutions. You will investigate existing and emerging technologies and engineering challenges, and consider any implications that will arise from the solutions.

Electronics and Control

Within this part of the course, you will study several key concepts and devices used within electronic control systems. These will include analogue, digital and programmable electronics. Your skills in problem-solving and evaluating will be developed further, through simulation and/or practical projects, and you will explore several different engineering problems and solutions in a range of different contexts.

Mechanisms and Structures

This unit is designed to help develop a deep understanding of mechanisms and structures. Areas of this section may also be done through simulation and/or practical projects. Your problem-solving and evaluation skills will be strengthened through several different practical, simulated and investigative tasks.

ONLINE

Head to www.brightredbooks.net for a link to SQA documentation on the course.

DON'T FORGET

Make sure you read through the task and marking instructions beforehand to ensure you fully understand what is being asked of you, and you know how to succeed.

COURSE ASSESSMENT

To achieve success in this course, you must be able to show that you can apply the knowledge and skills developed through the course, in both practical and theoretical contexts. To do this, your assessment will be broken into two separate parts:

Part 1: assignment (50 marks, 31% of the overall award)

Part 2: question paper (110 marks, 69% of the overall award).

The marks of these two components will be combined, and your award will be based on your total score. This means your total course assessment will be based on 160 marks.

Assignment

The assignment is designed so that you can demonstrate aspects of challenge and application in a practical context. You will apply knowledge and skills you have gained

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from completing this course to solve a challenging practical engineering problem. This has 50 marks, and is 31% of your overall grade, so it is worthwhile putting in the effort to ensure it is completed to the best of your ability. Like the National 5 assignment, this will be completed under closed-book conditions and should take 8 hours to complete.

The assessment of this project will be similar to what you experienced in National 5. There will be one overarching project, but it will be broken into different tasks. Within this assignment, you may be asked to complete tasks focusing around five key areas:

Analysing the problem
This could be writing or reading a specification, drawing system diagrams and/or sub-system diagrams, or writing a description of a system.

Designing a possible solution
This may include reading or creating a flowchart or design mechanisms and structures, with calculations to prove that the solution works to given criteria.

Constructing/simulating a solution
This may include producing code and modelling/simulating solutions to problems in any electronic, mechanical or structural systems.

Testing the solution
This will include creating or completing test plans and then testing the potential solutions you have created.

Reporting and evaluation of the solution
This will include reporting on what you have done, and a reflection of your development process. It will also include an evaluation of any solution against a set specification.

DON'T FORGET

Remember: during the question paper, you will be given a data booklet. This contains all the calculations and data you will need. Don't forget to use this to help you!

ONLINE

If your teacher hasn't already given you a copy of the data booklet, it is worthwhile printing it out to help you answer your coursework. You can find a link to the data booklet on the BrightRED Digital Zone.

Question Paper

The purpose of the exam is to assess your breadth and application of knowledge from across all the units. Here you will display your depth of understanding, and it will give you the opportunity to apply this knowledge and understanding to answer a selection of challenging questions.

The question paper will have 110 marks, which is 69% of the total mark, and is designed to give you the opportunity to demonstrate your skills, knowledge and understanding in the areas in this table:

Area	Marks
Engineering roles and disciplines, the impacts of engineering, the systems approach, energy and efficiency	10–17
Analogue electronic control systems	20–35
Digital electronic control systems	15–25
Drive systems and pneumatics	10–20
Structures and forces	15–25
Materials	8–14

The question paper will have two different sections.

Section 1 will be out of 20 marks, and will consist of short-answer questions.

Section 2 will be out of 90 marks, and will be made up from longer, more challenging questions that may combine several areas of the course.

If you are unsure of an answer during the question paper, then miss it out and come back to it at the end instead of wasting time thinking of a possible solution – but **always** come back to it. If you are still not sure, then use the data booklet to help, and at least have a sensible guess. If you guess, you may pick up some marks. If you leave it blank, you are guaranteed to lose all marks on this question.

ONLINE

Head to www.brightredbooks.net for a link to the official SQA past papers and answer schemes. It is highly recommended that throughout this course you visit these and try to answer the questions for the topic you are studying. One of the best ways to prepare for an exam is to answer exam questions!

THINGS TO DO AND THINK ABOUT

When answering calculations in this course, make sure you are using **significant figures** within your final answers. In a number, all figures are significant, except zeros at the front (to show decimal points) or at the end. For example, in the number 1,234 there are 4 significant figures. In 0·0001234, there are also 4 significant figures.

The number of significant figures you use in your final answers should be equivalent to those used within the question. Information about this is also given at the front of your question paper.

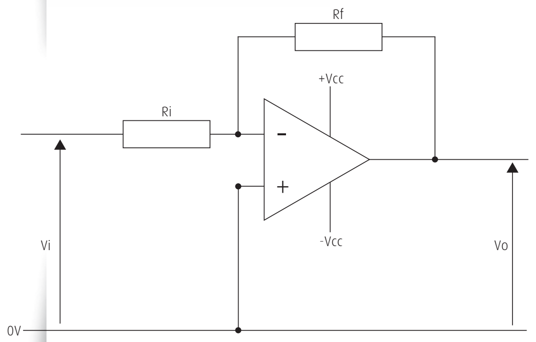
ANALOGUE ELECTRONICS: OPERATIONAL AMPLIFIERS 2

ONLINE

Head to www.brightredbooks.net for additional activities, videos and tests on this topic!

THE INVERTING AMPLIFIER

The **inverting amplifier** is a special type of Op Amp configuration that allows the signal to be inverted. This means that if the signal comes into the Op Amp as a positive, it will leave as an amplified negative signal, and vice versa.



As previously stated, an Op Amp's gain is extremely high, but in a practical sense this has the potential to make it both unstable and hard to control, as the smallest of input signals (just a few microvolts (µV)) could be enough to cause the output voltage to saturate and lose complete control of the output. This can be fixed by the addition of a feedback resistor. This changes the system from being open-loop to closed-loop by the addition of **negative feedback**.

The negative feedback in this configuration is because the inverting input terminal has a different signal from the actual input voltage. It now becomes the sum of the input voltage plus the negative feedback voltage. For this to work, it must therefore have the inverting input separated from the real input signal – and this is done by using an **input resistor**, R_i.

As this configuration does not use the non-inverting input, it is connected to the 0 V rail.

An inverting Op Amp is used to multiply the input voltage by the gain, while inverting the signal. In most cases, a circuit that includes an inverting Op Amp has two of them – one directly following the other. This is not only to amplify the signal twice, but also to allow the inverted signal to be inverted back again into a positive value.

To calculate the output voltage of an inverting Op Amp circuit, we can use the following equation:

$V_o = (R_f / R_i) \times V_i$

To calculate the gain (Av) of the Op Amp, there are two calculations you can use for an inverting amplifier:

$Av = V_o / V_i$ **or** $Av = -R_f/R_i$

DON'T FORGET

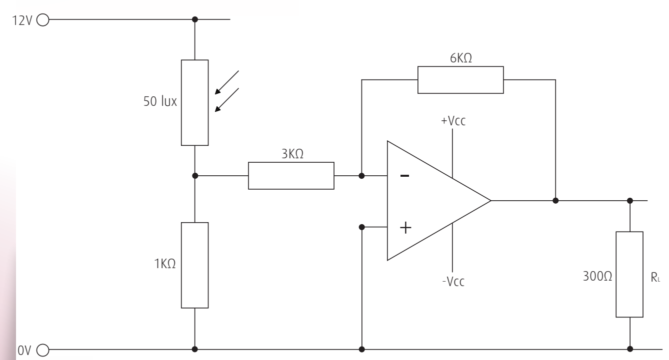
If asked to draw an Op Amp configuration in any form of assessment, it must be **exactly** the same as it is in the data booklet. This means drawing **all** labels and information shown there.

DON'T FORGET

Don't be scared off by a complex-looking circuit. Break it down into small chunks, use the data booklet to find out the calculation you need for the end goal, then continue to use your data booklet and knowledge to work out how to obtain the different aspects of that calculation.

Example:

This example shows a circuit that utilises an inverting Op Amp. By applying your acquired knowledge, several different aspects of this circuit can be calculated. This is probably similar to what would be asked in an assessment, but it won't be as easy as working out a simple calculation. Instead, it is to be expected that you will have to work out several different aspects of the circuit before you can reach your end goal.



For example, the resistance of the LDR can be calculated using the LDR graph, as you know the light level (lux):

50 lux = 2 kΩ

Knowing this, V_{out} from the voltage-divider can easily be calculated:

$V_{out} = (R_2 / R_1 + R_2) \times V_{cc} = (1 / (2 + 1)) \times 12$
$= \underline{\mathbf{4\ V}}$

The gain of the Op Amp can also be calculated:

$A_v = -R_f / R_i = -6 / 3$
$= \underline{\mathbf{-2}}$

With this information, the output of the Op Amp can now also be calculated:

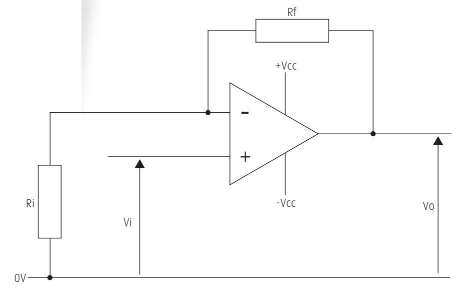
contd

$A_v = V_o / V_i$
$\Rightarrow V_o = A_v \times V_i = -2 \times 4$
$= \underline{\mathbf{-8\ V}}$

And, now that this has been found out, the current going through the load resistor can be calculated:

$V = IR$
$\Rightarrow I = V / R = -8 / 300$
$= \underline{\mathbf{-26{\cdot}7\ mA}}$

THE NON-INVERTING AMPLIFIER



In this configuration of an Op Amp, the input voltage signal (V_i) is applied directly to the non-inverting (+) input terminal. This means that the output gain of the amplifier becomes positive, which is in contrast to the inverting-amplifier circuit in the previous pages. Like the inverting amplifier, it is used to multiply the input voltage by the gain, but in this case it **does not** invert the signal.

To calculate the output voltage of the circuit, we can use the following equation:

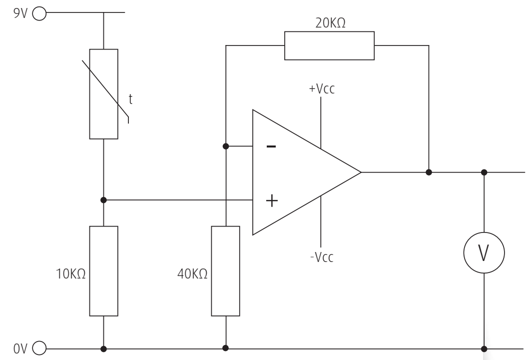
$V_o = (1 + (R_f / R_i)) \times V_i$

To calculate the gain (Av) of the Op Amp, there are two calculations you can use for a non-inverting amplifier:

$Av = V_o / V_i$ **or** $Av = 1 + (R_f/R_i)$

Example:

This example shows a circuit that utilises a non-inverting Op Amp. Like before, several different aspects of this circuit can be calculated by applying the knowledge you have gained.
This circuit uses a type 1 thermistor in a voltage-divider circuit to create a temperature sensor. It has been set so that when it is warm it shows a temperature of 30°C, and in the cold it shows 10°C.



Firstly, we can calculate the gain of the Op Amp:

$Av = 1 + R_f / R_i = 1 + (20 / 40)$
$= \underline{1{\cdot}5}$

We can also determine the voltages that would appear on the voltmeter in both light conditions:

Case 1: Thermistor = 10°C

Using the thermistor graph, we can find out that 10°C = 2 KΩ.

$V_{out} = (R_2 / R_1 + R_2) \times V_{cc}$
$= (10 / (2 + 10)) \times 9$
$= 7{\cdot}5$ V (Vi)

V_{out} (from Op Amp) $= Av \times Vi$
$= 1{\cdot}5 \times 7{\cdot}5$
$= \underline{11{\cdot}25\ \text{V}}$

Case 2: Thermistor = 30°C

Using the thermistor graph, we can find out that 30°C = 1 KΩ.

$V_{out} = (R_2 / R_1 + R_2) \times V_{cc}$
$= (10 / (1 + 10)) \times 9$
$= 8{\cdot}2$ V (Vi)

V_{out} (from Op Amp) $= Av \times Vi$
$= 1{\cdot}5 \times 8{\cdot}2$
$= \underline{12{\cdot}3\ \text{V}}$

DON'T FORGET

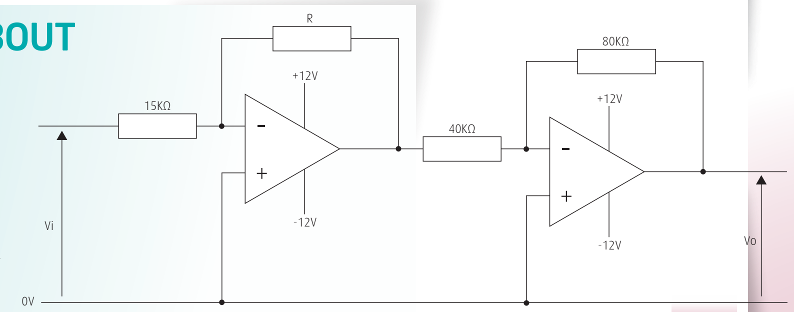
It is easy to mix up the non-inverting and the inverting Op Amp, so make sure you are looking properly at its connections!

DON'T FORGET

Gain does not have a unit.

THINGS TO DO AND THINK ABOUT

This circuit is used to amplify the signal produced by a flow sensor in part of a water-treatment plant.



a) Explain the reasons for the inclusion of the second Op Amp in this circuit.

b) Calculate the required value of resistor R, so that V_{out} reaches its maximum value when V_{in} is 0·9 V.

MECHANISMS AND STRUCTURES

MATERIALS: MATERIAL PROPERTIES

PROPERTIES AND BEHAVIOURS OF MATERIAL

A structural engineer's expertise lies not only in the design of a structure but also in the understanding of the properties and behaviour of the material from which it is made when put under different conditions. It is not only the shape of a structure, or how the members are joined, that influences a structure's overall performance, but also the material that it is made from. If any single member in a frame structure was to fail, it would create a domino effect on the other members, and ultimately the structure would collapse. So, what it is made from has to be fit for purpose. In order to select the correct material, the structural engineer must research and consider a range of different types of materials, or modify materials in specific ways to improve the performance, durability and cost-effectiveness of the structure.

When doing this, the properties that the engineer would consider are:

Strength

The strength of a material is its ability to resist a force. All materials have some degree of strength, but the greater the force that the material can resist, the stronger it is.

Some materials, like mild steel, can be strong in tension but weak in compression. The opposite is also true for some materials, like concrete, which are strong in compression but weak in tension. This is the reason some materials are mixed to create a material that holds multiple properties. An example of this would be reinforced concrete, which is concrete reinforced with mild steel. This allows it to have the compressive strength of concrete as well as the tensile strength of steel.

Elasticity

The elasticity of a material is its ability to return to its original shape or length once a load or force acting on it has been removed. A material such as rubber is described as having high elasticity, as it can be stretched but will return to its original condition once the force acting on it stops.

Plasticity

A material with plasticity is one that will change its shape or length under a load, but will stay this deformed shape once the load is removed. Clay has high plasticity.

Ductility

A ductile material is one that can bend and stretch without breaking, allowing it to be formed into thin sheets or very thin wire, for example. Copper is seen as a ductile material.

Brittleness

A brittle material is one that is easily cracked, snapped or broken when a force is applied. It is the opposite of a ductile material, which also means it has very little plasticity. A brittle material, such as glass, will fail under loading without stretching.

Malleability

If a material is malleable, it means it can be shaped, worked or formed without fracturing. It is a property that is very closely related to plasticity. An example of a malleable material is gold, where it can be changed into multiple objects – from jewellery to being flattened into a metal leaf without breaking.

It is very likely that a material will have multiple properties, and in the modern world they are frequently coated or mixed with another material to ensure that particular material properties are achieved. For example, steel is strong, but it corrodes easily due to its iron content. This can be changed, though, by covering it in particular paints.

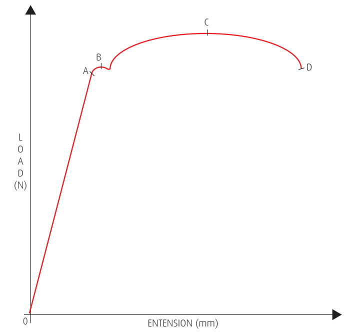
MATERIALS TESTING

In order to discover the properties of a material, a sample must undergo some form of material testing. There are many different types of test available, but the most commonly used one is the tensile test by using a tensometer. As the name suggests, the material is subjected to a tensile force by stretching it and pulling it apart. The results from a tensile test allow the following properties to be determined:

1. the elasticity of a material
2. the plasticity or ductility of the material
3. the ultimate tensile strength of the material.

The results of a typical tensile test for a sample of mild steel are shown in the graph.

The shape of the graph is very important and is used to help engineers predict how materials will behave or react under different forces or loading conditions.



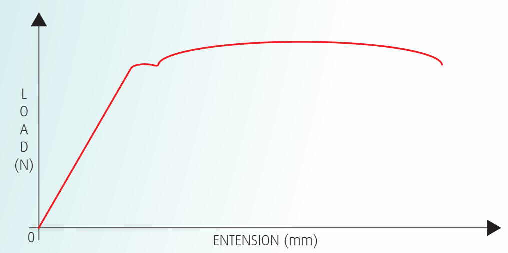
- **Between points 0 and A**, the material will behave elastically and is known as the **elastic region**. This means that the material will stretch under the load in this area, but it will return to its original length when this load is removed.
- **Point A** is known as the **limit of elasticity**. Any loading beyond this point results in a plastic deformation of the sample.
- **Point B** is called the **yield point**, and a permanent change in length will result when this is reached, even when the load is removed. Loading beyond this point will result in a rapidly increasing extension.
- The area **between points B and D** is known as the **plastic range**. This is so called because between these two points on the graph the material will behave in a plastic manner.
- **Point C** is known as the **ultimate load**. This is the point where the maximum load or force that the material can withstand is reached.
- **Between points C and D**, the amount of force the material can now withstand deteriorates rapidly, and the sample will start to 'neck'. This means the cross-sectional area of the specimen is starting to become thinner as it is pulled further apart.
- The sample eventually reaches **point D**, where it breaks or fractures. This is known as the **breaking point**.

THINGS TO DO AND THINK ABOUT

The graph shown was produced using data from a tensile test on a specimen of material.

Redraw this on paper, and identify the following points on the graph.

- Yield point
- Elastic range
- Ultimate load
- Breaking point
- Plastic range.



VIDEO LINK

Go to www.brightredbooks.net to see a specimen material being tensile tested.

VIDEO LINK

Go to www.brightredbooks.net to see how a tensometer works.

ONLINE TEST

Test your knowledge of this topic at www.brightredbooks.net

BrightRED Study Guides

CfE HIGHER

ENGINEERING SCIENCE

Paul MacBeath

This BrightRED Study Guide is the ultimate companion to your CfE Higher Engineering Science studies! Written by our trusted author and experienced teacher Paul MacBeath, this book is full-colour and packed with clear and accessible information, excellent examples, activities and advice. Inside, you will find:

- **All the essential course information, fully up-to-date with SQA course changes,** arranged in easily digestible double-page topic spreads.
- **Detailed examples, diagrams and illustrations** to make sure all that study sticks!
- ***Don't forget*** pointers offering advice on the key facts to remember, and on how to avoid common mistakes.
- ***Things to do and think about*** sections encouraging the regular review of key points covered.
- ***Digital Zone*** **activities and tests** to supercharge your learning efforts online!
- **A glossary of key terms** to help you reference and check important course information.
- **A full index** to help when revising.

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ISBN 978-1-84948-316-2

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