

# X036/13/01

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NATIONAL  
QUALIFICATIONS  
2014

THURSDAY, 15 MAY  
1.00 PM – 4.00 PM

TECHNOLOGICAL  
STUDIES  
ADVANCED HIGHER

200 marks are allocated to this paper.

Answer **all** questions in Section A (120 marks).

Answer **two** questions from Section B (40 marks each).

Where appropriate, you may use sketches to illustrate your answer.

You should plan assembler code programs using a flowchart or other suitable method.

Reference should be made to the Advanced Higher Data Booklet (2008 edition) which is provided.



SECTION A

Attempt ALL the questions in this Section. (Total 120 marks)

1. An oscillator provides clock pulses for the velodrome timer display shown in Figure Q1(a).

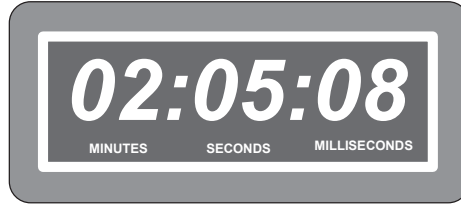


Figure Q1(a)

The oscillator pulses at a frequency of 1000 Hz, providing accuracy to one millisecond. The circuit shown in Figure Q1(b) produces an output signal having the required frequency.

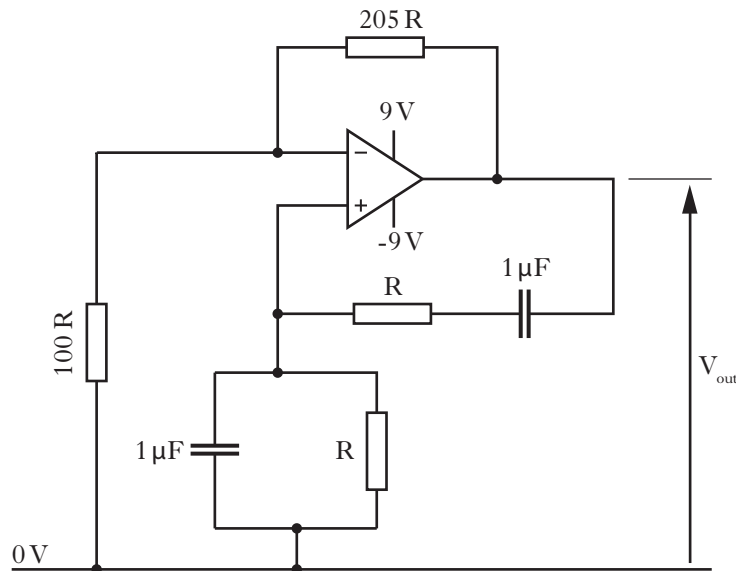


Figure Q1(b)

- (a) (i) State the name of the circuit shown in Figure Q1(b). 1
- (ii) State the name of the output waveform produced by this circuit. 1
- (b) Calculate the required value of resistor R. 4

The output waveform produced by the circuit in Figure Q1(b) is to be further processed in order to clock an edge-triggered frequency-divider circuit at 1000 Hz.

- (c) State the name of an appropriate device and sketch the waveform it produces. 2
- (8)**

2. The automatic hot-water dispenser shown in Figure Q2 is controlled by a microcontroller. It provides boiling water for making coffee or tea.

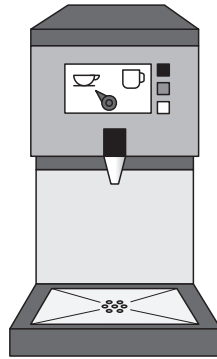


Figure Q2

The dispenser operates as follows:

A rotary dial is set to select the quantity of boiled water required to fill a cup or mug placed in the dispenser. The user then pushes a start button.

A simplified diagram of the control system for the dispenser is shown in **Information Sheet Q2**.

The microcontroller program *main* works as follows:

The start button is monitored in a loop to detect if it has been pressed (1=start).

The float switch is checked to confirm the water level in the reservoir (1=sufficient water).

If there is insufficient water, a bleeper and a lamp are actuated for 1s, then the program loops back to the beginning.

If there is sufficient water, the multiplexer control pin is set high to connect the multiplexer to the quantity dial.

A prewritten sub-procedure *adcread* is called, which reads a value via the multiplexer and Analogue-to-Digital Converter (ADC) and holds it in the Working Register, W.

The ADC value held in W is transferred to the register file QUANTITY.

The water heater is activated.

The multiplexer control pin is set low to check the water-temperature sensor via the multiplexer.

Sub-procedure *adcread* is called.

The ADC value held in W is transferred to the register file TEMPERATURE.

If the value in TEMPERATURE has not reached 180, the water heater remains on and the temperature is checked again. When the value in TEMPERATURE reaches 180, the heater is switched off.

The value held in QUANTITY is divided by two and saved in W to be used for the “on-time” variable for the water valve.

Boiled water is dispensed via the water valve (1=dispense). When the water has been dispensed, the valve closes and the program returns to the beginning.

Write, in assembler code, the program *main*.

**Note:**

A prewritten sub-procedure *wait* causes a delay of 0.1 s multiplied by the value held in the Working Register W when the sub-procedure is called.

TRISB has been initialised, and register files QUANTITY and TEMPERATURE have been defined.

26  
(26)

[Turn over

3. Figure Q3 shows a beam which supports a water tank and two other applied loads as shown.

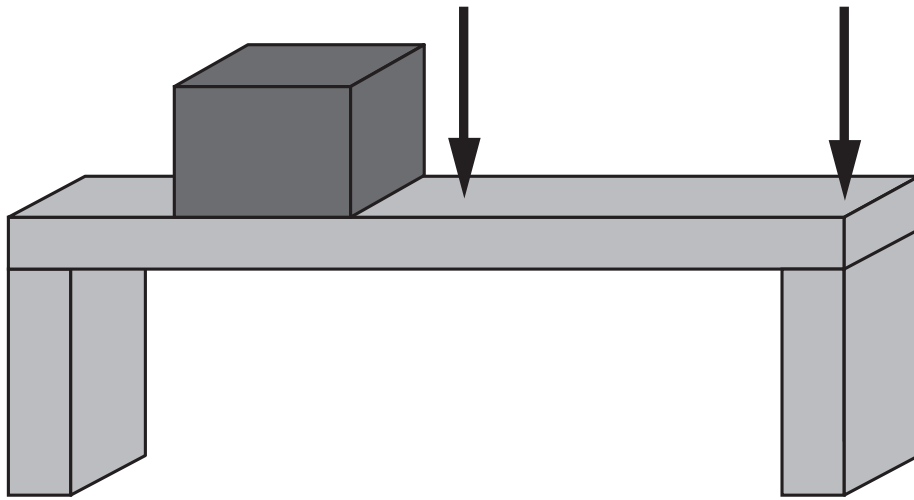


Figure Q3

The forces acting on the beam are shown in the simplified free-body diagram on **Worksheet Q3**.

- |     |   |             |
|-----|---|-------------|
| (a) | Calculate the reaction forces $R_A$ and $R_B$ .   | 4           |
| (b) | Draw, on <b>Worksheet Q3</b> , the Shear-Force Diagram. Show significant values.  | 6           |
| (c) | Draw, on <b>Worksheet Q3</b> , the Bending-Moment Diagram. Plot points at 0 m, 2 m, 3 m, 4 m, 6 m and 12 m from the left-hand end. Show all calculations. | 10          |
|     |   | <b>(20)</b> |

4. The drilling jig shown in Figure Q4(a) is controlled by a sequential control system which sets the position for drilling 5 holes in a bracket. A conveyor brings the bracket to a clamp, which holds the bracket in position whilst drilling takes place.

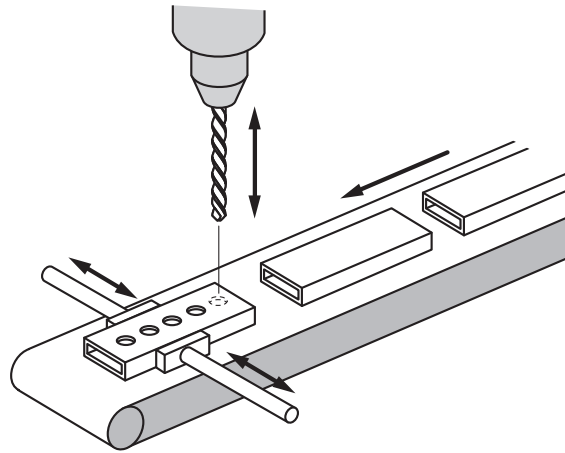


Figure Q4(a)

The sequence of operations for the drilling jig is shown in Figure Q4(b).

| Clock output DCBA | Conveyor | Clamp | Drill |
|-------------------|----------|-------|-------|
| 0000              | 0        | 1     | 1     |
| 0001              | 1        | 1     | 0     |
| 0010              | 0        | 1     | 1     |
| 0011              | 1        | 1     | 0     |
| 0100              | 0        | 1     | 1     |
| 0101              | 1        | 1     | 0     |
| 0110              | 0        | 1     | 1     |
| 0111              | 1        | 1     | 0     |
| 1000              | 0        | 1     | 1     |

Figure Q4(b)

- (a) Sketch a block diagram of a sequential control system for the conveyor, clamp and drill. 5

The clock-count for the sequence is provided by a 4-bit up-counter.

- (b) Draw, on **Worksheet Q4(b)**, a suitable up-counter, based on J-K bistables. 6

The drill is controlled by a second counter which is initially set to 5. This counter counts down to zero, when it resets the up-counter to zero and sends a signal to the conveyor to bring forward a fresh bar for drilling.

- (c) Draw, on **Worksheet Q4(c)**, a suitable JK-based counter circuit to fulfil the required specification. 7

(18)

5. The cross-sectional dimensions (in mm) of a beam are shown in Figure Q5.

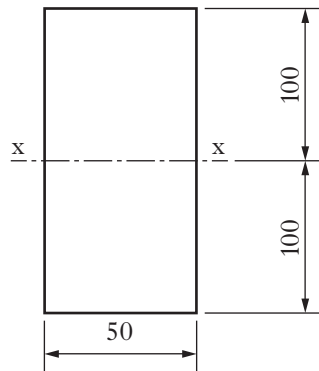


Figure Q5

- (a) State the name of the feature represented by the line x-x. 1
- (b) Calculate the Second Moment of Area about the line x-x. 2

The beam is subjected to a maximum Bending Moment of 40 kNm.

- (c) Calculate the magnitude of the maximum stress due to bending. 4
- (7)**

6. An Engineer is investigating the circuit shown in Figure Q6 to determine its suitability for use as part of a counter/display control system.

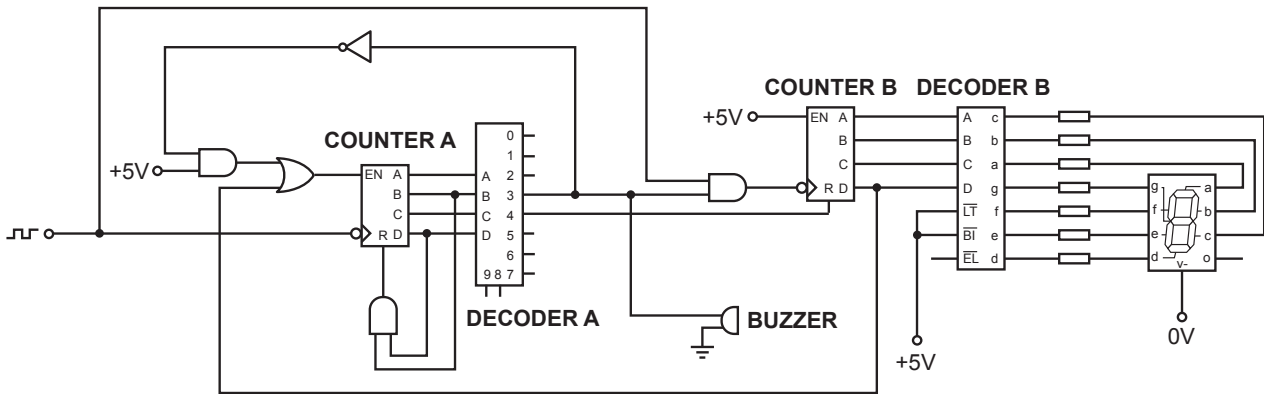


Figure Q6

- (a) State the name, and explain the purpose of, each of the two **decoders** in this circuit. 4
- (b) Explain in detail how the circuit functions, giving particular attention to the values on the outputs of the counters, decoders and on the seven-segment display. 11

(15)

[Turn over

7. The jet aircraft shown in Figure Q7(a) contains a radar dish inside the nose-cone, as shown in Figure Q7(b). The radar dish is operated by a closed-loop proportional-control system to scan forwards and backwards through a horizontal arc.

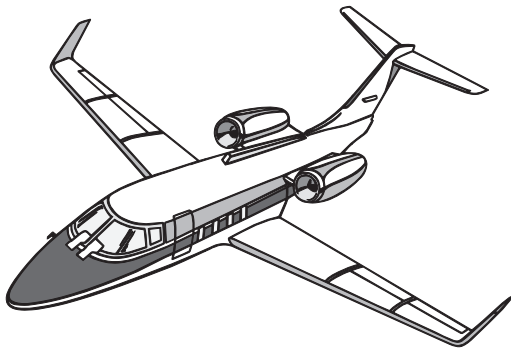


Figure Q7(a)

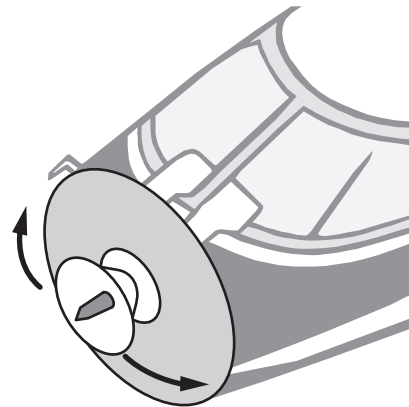


Figure Q7(b)

The gain factor ( $k$ ), of a closed-loop proportional-control system, determines the actual response of the output to a step-change of the desired output.

- (a) On **Worksheet Q7**, complete response graphs for a step-change of desired output for:
- (i) a **proportional-only** control system with gain factor ( $k$ ) set too **low**; 2
  - (ii) a **proportional-only** control system with gain factor ( $k$ ) set too **high**. 2

The response of a proportional-only control system is improved by adding **Integral** and **Derivative** elements.

- (b) (i) State the effect of adding an **Integral** control element to a proportional-only control system. 1
- (ii) State the effect of adding a **Derivative** control element to a proportional-only control system. 1

A **Proportional-Integral-Derivative** (PID) control system includes all three control elements.

- (c) On **Worksheet Q7**, complete the response graph for a step-change of output in a full **PID** control system. 2



## 7. (continued)

A device called a servo-motor, controlled by a microcontroller, rotates the radar dish. See **Information Sheet Q7**.

The radar dish scans to  $30^\circ$  on either side of the  $90^\circ$  position, as shown in Figure Q7(c). Mark times and Space times are all in milliseconds.

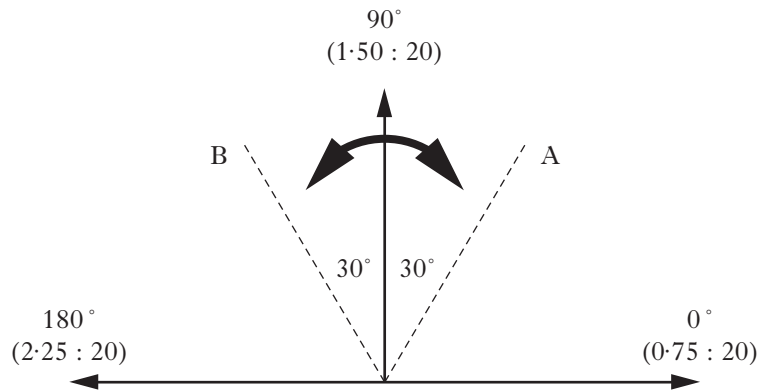


Figure Q7(c)

(d) Determine the *Mark* value (in milliseconds) corresponding to positions A and B. 3

In order to rotate the radar dish at a constant speed as it moves from A to B, the MARK time is incremented by  $10\mu\text{s}$  between each pulse sent to the servo-motor.

(e) Calculate the number of discrete steps required to scan the radar dish between positions A and B. 2

A sub-procedure *drive* controls the radar dish as follows:

- A register file MARK is set up with the **initial** starting position corresponding to position A.
- A register file COUNTER is set up for the number of discrete steps required to drive the servo to position B.
- The servo-motor connected to pin 4 operates continuously in a loop to provide the required scanning motion between positions A and B.

(f) Write, in assembler code, the sub-procedure *drive* which drives the servo-motor from position A to position B and back to position A. 13

(26)

**Note:**

Register files COUNTER and MARK have been set up. The prewritten sub-procedure *short* produces a time delay of  $10\mu\text{s}$  multiplied by the value held in the Working Register W when the sub-procedure is called. The prewritten sub-procedure *pause* produces a time delay of 1 ms multiplied by the value held in the Working Register W when the sub-procedure is called.

[END OF SECTION A]

[Turn over

## SECTION B

Attempt any TWO questions in this Section.

Each question is worth 40 marks

8. The robotic vacuum cleaner shown in Figure Q8(a) finds its way around an area using a laser-guidance navigation system controlled by a microcontroller. The guidance system allows it to map out the area so that it can manoeuvre around furniture and other obstacles as it cleans.



Figure Q8(a)

A sub-procedure *adcread* obtains the digital value from a proximity sensor and saves it in a register file DATA.

A sub-procedure *obstruction* monitors the proximity sensor in a loop by calling the sub-procedure *adcread*; if the value in DATA is less than 8 the drive-motor reverse (connected to PortB pin 6) is switched on for 2.6 seconds.

- (a) Write, in assembler code, the sub-procedure *obstruction*.

7

**Note:** The sub-procedure *wait* creates a delay of 100 ms multiplied by the value in the Working Register W before the procedure is called. The sub-procedure *adcread* and register file DATA have been set up.

The robotic vacuum cleaner is manoeuvred around by the use of a Drive Motor and a Steering Motor, each of which can run forwards or backwards.

A sub-procedure *navdata* uses data obtained by the navigation system and saves values in the register files FORWARDTIME and TURNSTOP.

The main program operates as follows:

The sub-procedure *navdata* is called. Then the Drive Motor Forward and Suction pump pins are switched on in a loop which repeats every 10 ms. On each cycle of the loop the sub-procedure *obstruction* is called and the variable FORWARDTIME is decremented.

When the value in FORWARDTIME is equal to zero the variable TURN is checked. If TURN is equal to 1 the steering motor is switched on, if TURN is equal to 0 the program repeats from the beginning.

The steering motor is pulse-width-modulated in a loop with a mark of 8 ms and a space of 19 ms. At the beginning of the loop a variable TURNTIME is cleared to zero and then each time around the loop it is incremented. If TURNTIME equals the value in the variable TURNSTOP the drive motor stops and the program repeats.

8. (continued)

Marks

The table below shows the relevant input and output connections for the robotic vacuum cleaner.

| Input connections | PORTB pins | Output connections  |
|-------------------|------------|---------------------|
|                   | 7          | Drive Motor Forward |
|                   | 6          | Drive Motor Reverse |
|                   | 4          | Steering Motor      |
|                   | 3          | Suction pump        |
| Proximity sensor  | 2          |                     |

- (b) Write, using assembler code, the main program. Show the pulse-width-modulation code for one of the turns only.

20

**Note:** The sub-procedure *pause* creates a delay of 1 ms multiplied by the value in the Working Register W when the procedure is called. The sub-procedures *navdata* and *obstruction* and register files FORWARDTIME, TURNTIME, TURNSTOP and TURN have been set up.

The main chassis of the vacuum cleaner uses an aluminium-alloy shaped bracket with a cross-section as shown in Figure Q8(b). The bracket has a uniform wall thickness of 2mm, the semicircle has a radius, R, of 36mm and the bracket is symmetrical about axis x-x.

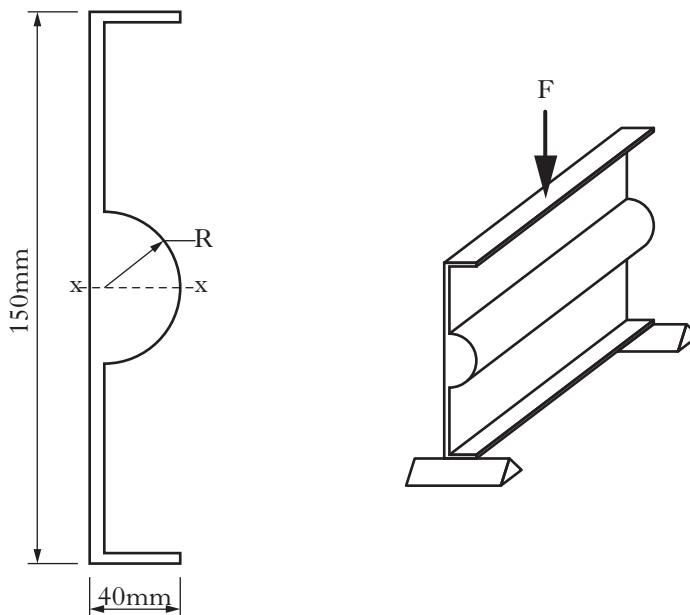


Figure Q8(b)

- (c) Calculate the Second Moment of Area of the bracket about x-x.

6

During development the bracket is subjected to a strength test. The bracket is 850mm long, can be considered to be simply supported at each end, and has a central point-load, F, applied vertically. The maximum allowable stress is 30 N/mm<sup>2</sup>.

- (d) Calculate the maximum point-load, F, that can be applied at the centre of the span of the bracket.

7  
(40)

9. Figure Q9(a) shows an electric “bilge” pump, which can be placed in the bottom of a small boat to pump out any water which may accumulate.

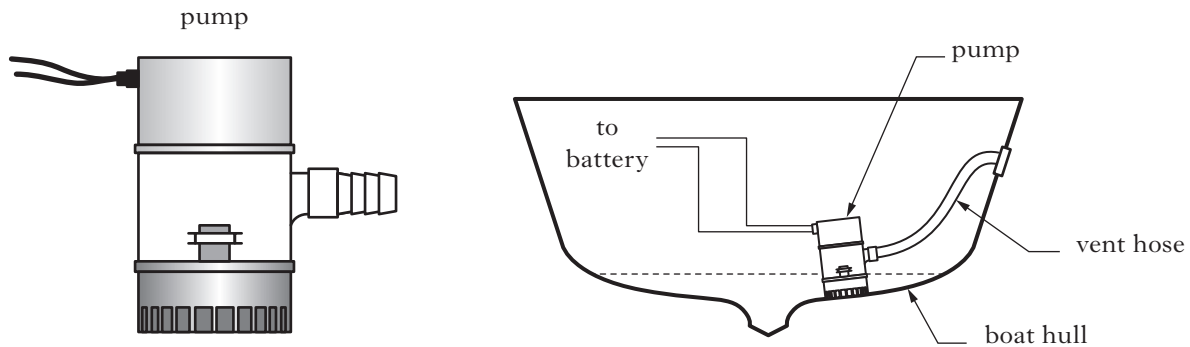


Figure Q9(a)

A microcontroller-based control system switches the pump on briefly at regular intervals, and automatically detects the presence of water in the bottom of the boat.

The system works as follows:

When the pump is **dry**, the electric motor draws only a small current.

When the pump is **wet**, the electric motor draws a much larger current.

The current flow is measured by the voltage drop ( $V_{in}$ ) across a resistor.  $V_{in}$  is processed by an ADC and the microcontroller switches the pump on and off as required.

A simplified diagram of the electrical arrangement is shown in Figure Q9(b).

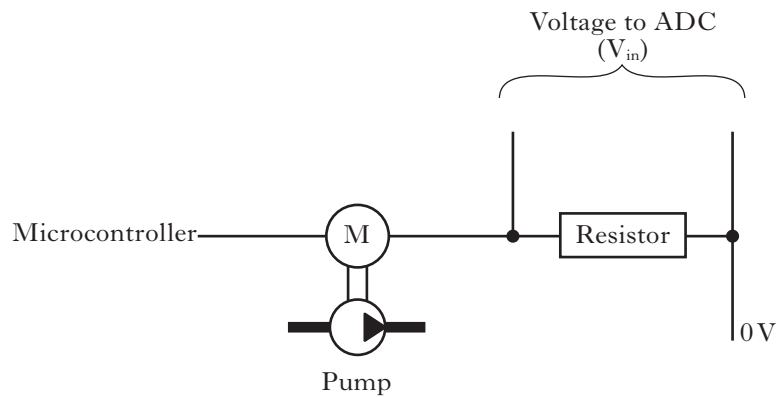


Figure Q9(b)

The 8-bit ADC has a feedback resistor  $R_f = 10.192 \text{ k}\Omega$  and outputs a binary number equivalent to decimal 235 when  $V_{in} = +4.606 \text{ V}$ .

The internal D-A converter uses logic voltages of 0 V and 5 V.

- (a) On **Worksheet Q9**, complete the circuit for the ADC. Show all value calculations.

9. (continued)

The voltage to the ADC, ( $V_{in}$ ) is also processed by the circuit shown in Figure Q9(c).

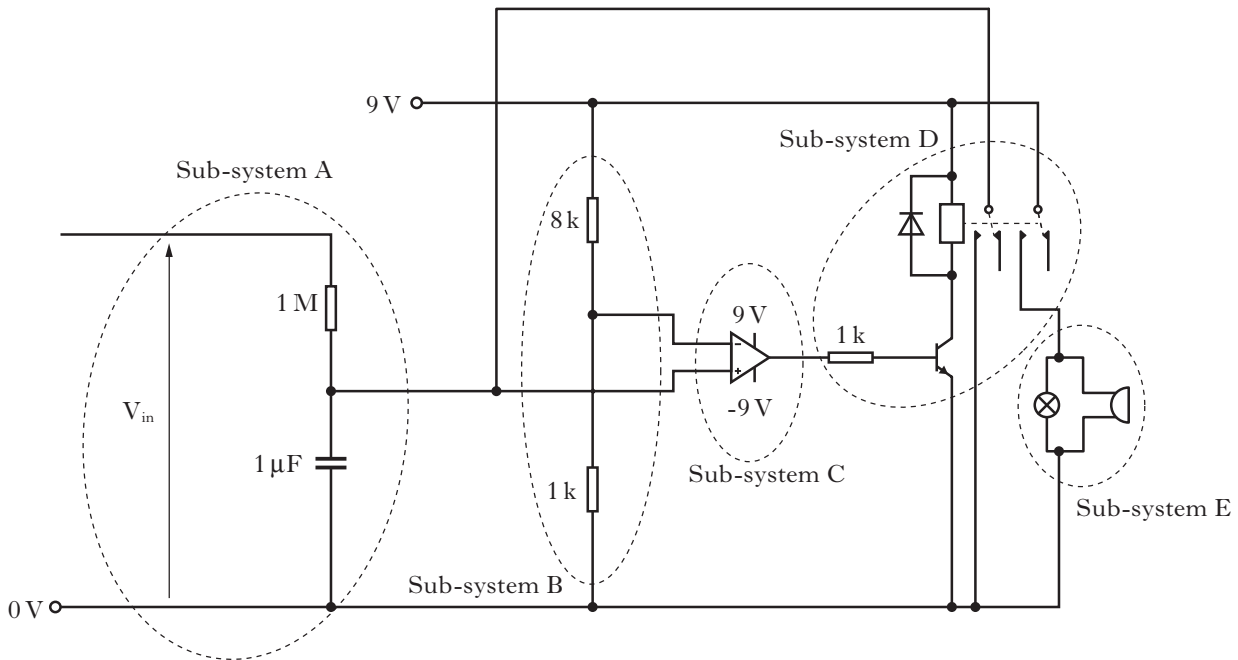


Figure Q9(c)

(b) For the circuit shown in Figure Q9(c):

- (i) state the full name of the circuit; 2
- (ii) describe in detail the operation of the circuit, making reference to sub-systems A to E; 10
- (iii) describe **one** disadvantage associated with the use of this type of circuit. 2

During normal operation, the microcontroller switches the pump on briefly for 0.5 seconds.

When a small current is detected (dry), ( $ADC < 140$ ), the pump then switches off and stays off for 5 minutes.

This is repeated in a loop as long as the boat is dry.

If the larger current is detected (wet), ( $ADC \geq 140$ ) the pump switches on and remains on continuously until the current reduces to the smaller value (indicating that the boat is pumped dry).

The process repeats continuously.

The 8-bit ADC threshold-value for a switching decision is decimal 140.

The 5-minute delay is achieved by calling a prewritten sub-procedure called *delay*.

The pump is connected to pin 4 of the microcontroller.

(c) Write, in assembler code, the program *main* described above.

16  
(40)

**Note:**

The prewritten sub-procedure *adcread* reads a value from the ADC and stores the value in the Working Register W. The prewritten sub-procedure *wait* produces a time delay of 0.1s multiplied by the value held in the Working Register W when the sub-procedure is called.

10. A symmetrical bridge structure is shown in Figure Q10(a).

Marks

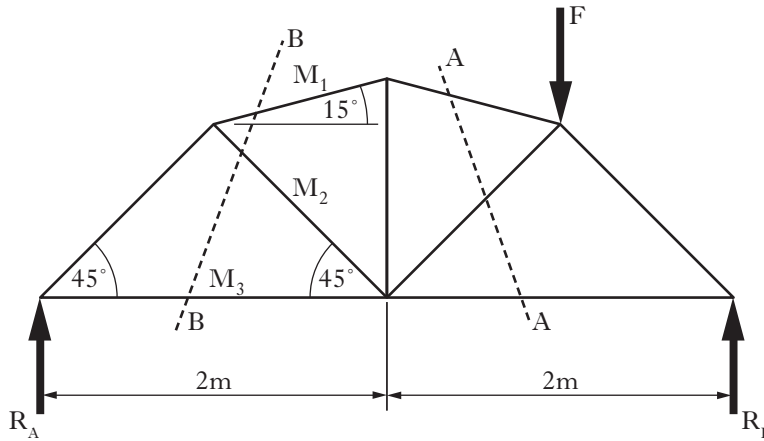


Figure Q10(a)

In order to determine various loadings on the bridge, strain gauges are installed on some of the bridge members. The gauges indicate the tensile or compressive forces acting on these members. A simplified force diagram for the portion of the structure to the right of section AA is shown in Figure Q10(b).

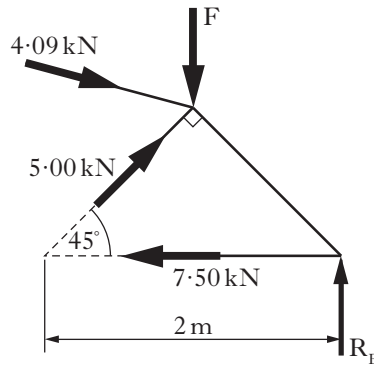


Figure Q10(b)

(a) Determine:

- (i) the reaction force  $R_B$ ;
- (ii) the load  $F$ .

3  
6

For the part of the structure to the left of section BB, shown in Figure Q10(c), the reaction force at  $R_A$  is 2.5 kN.

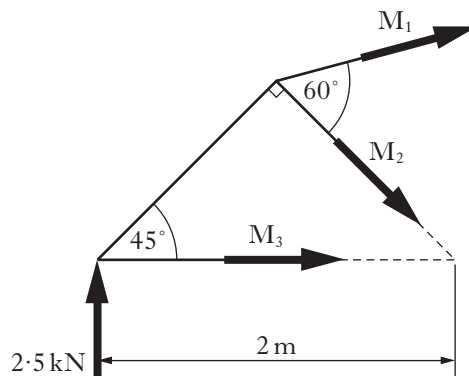


Figure Q10(c)

(b) Determine, using the *Method of Sections*, the magnitude and nature of the forces acting in members  $M_1$ ,  $M_2$ , and  $M_3$ .

13

10. (continued)

Marks

The analogue voltage signal produced by one of the strain-gauge circuits is processed by the integrator circuit shown in Figure Q10(d).

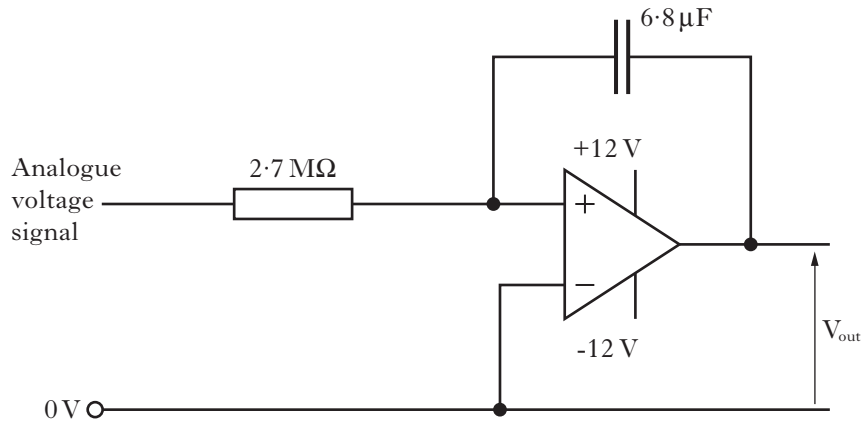


Figure Q10(d)

A graph of  $V_{out}$  against time for this integrator is shown in Figure Q10(e).

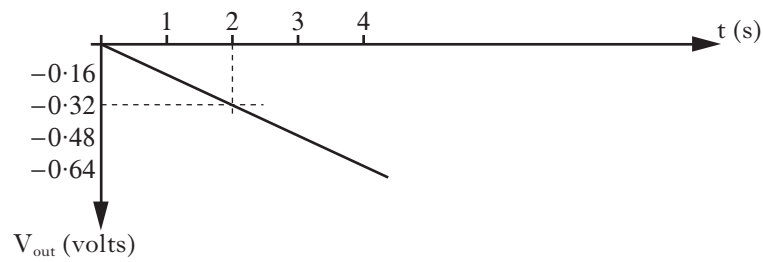


Figure Q10(e)

- (c) State, in its simplest form, the equation for  $V_{out}$  in terms of time ( $t$ ). 2
- (d) Calculate the input voltage,  $V_{in}$ . 4
- (e) Calculate the time taken to reach saturation. 2

[Turn over

10. (continued)

The analogue voltage signal from the integrator is processed using the Schmitt trigger shown in Figure Q10(f).

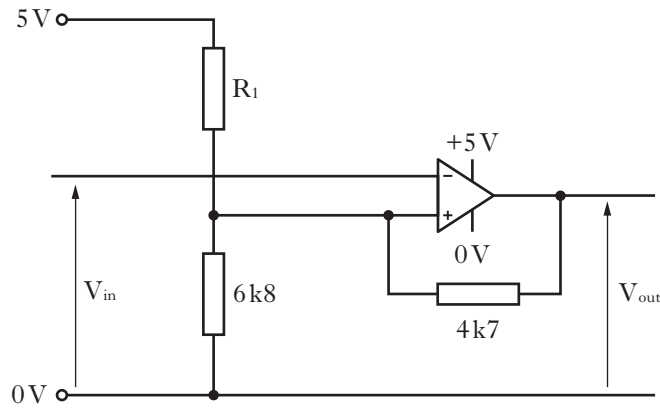


Figure Q10(f)

The graph in Figure Q10(g) shows the response of  $V_{out}$  compared with  $V_{in}$ .

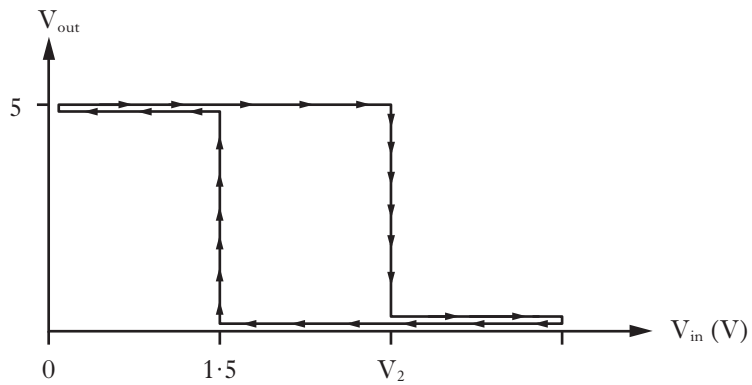


Figure Q10(g)

- (f) Determine the value of  $R_1$ . 6
  - (g) Calculate the switch-off voltage,  $V_2$ . 4
- (40)**

[END OF QUESTION PAPER]



ACKNOWLEDGEMENT

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## X036/13/11

NATIONAL  
QUALIFICATIONS  
2014

THURSDAY, 15 MAY  
1.00 PM – 4.00 PM

TECHNOLOGICAL  
STUDIES  
ADVANCED HIGHER  
Worksheets for Questions 3,  
4(b), 4(c), 7 and 9  
Information Sheets for  
Questions 2 and 7

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

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Scottish candidate number

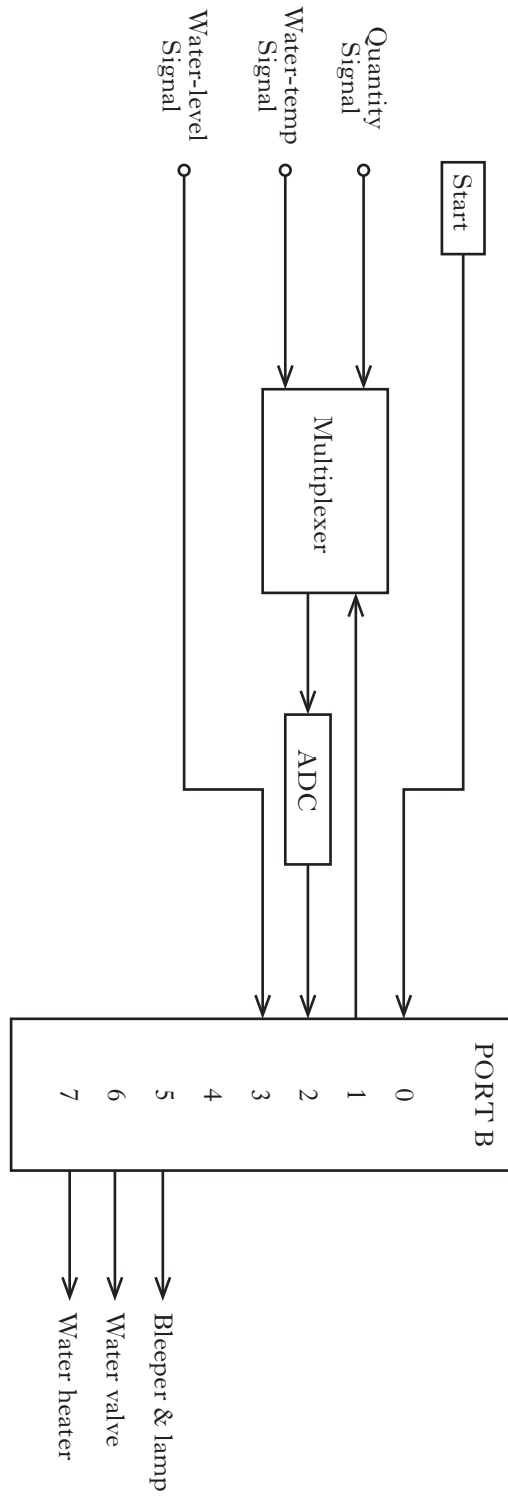
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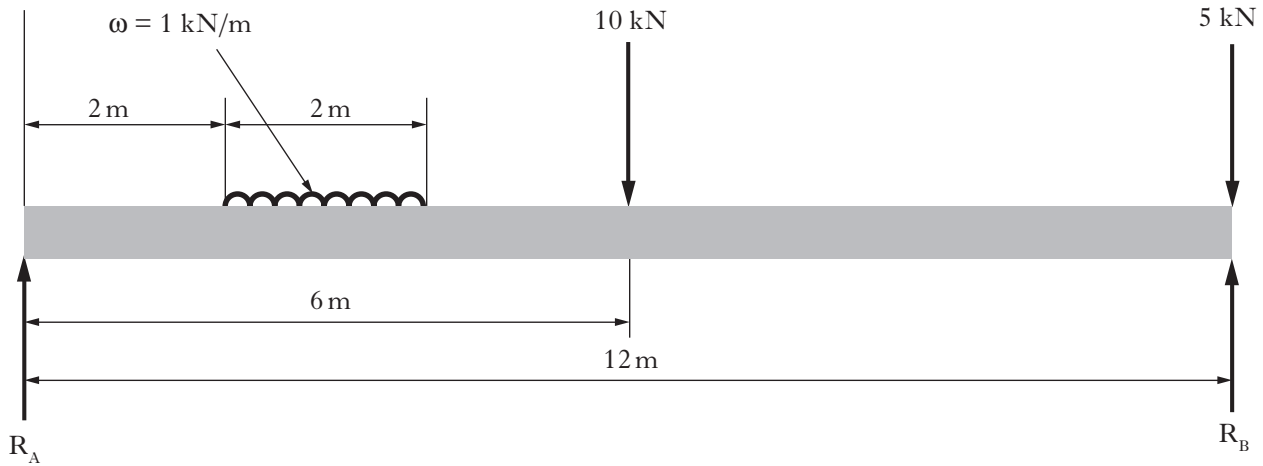
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INFORMATION SHEET Q2

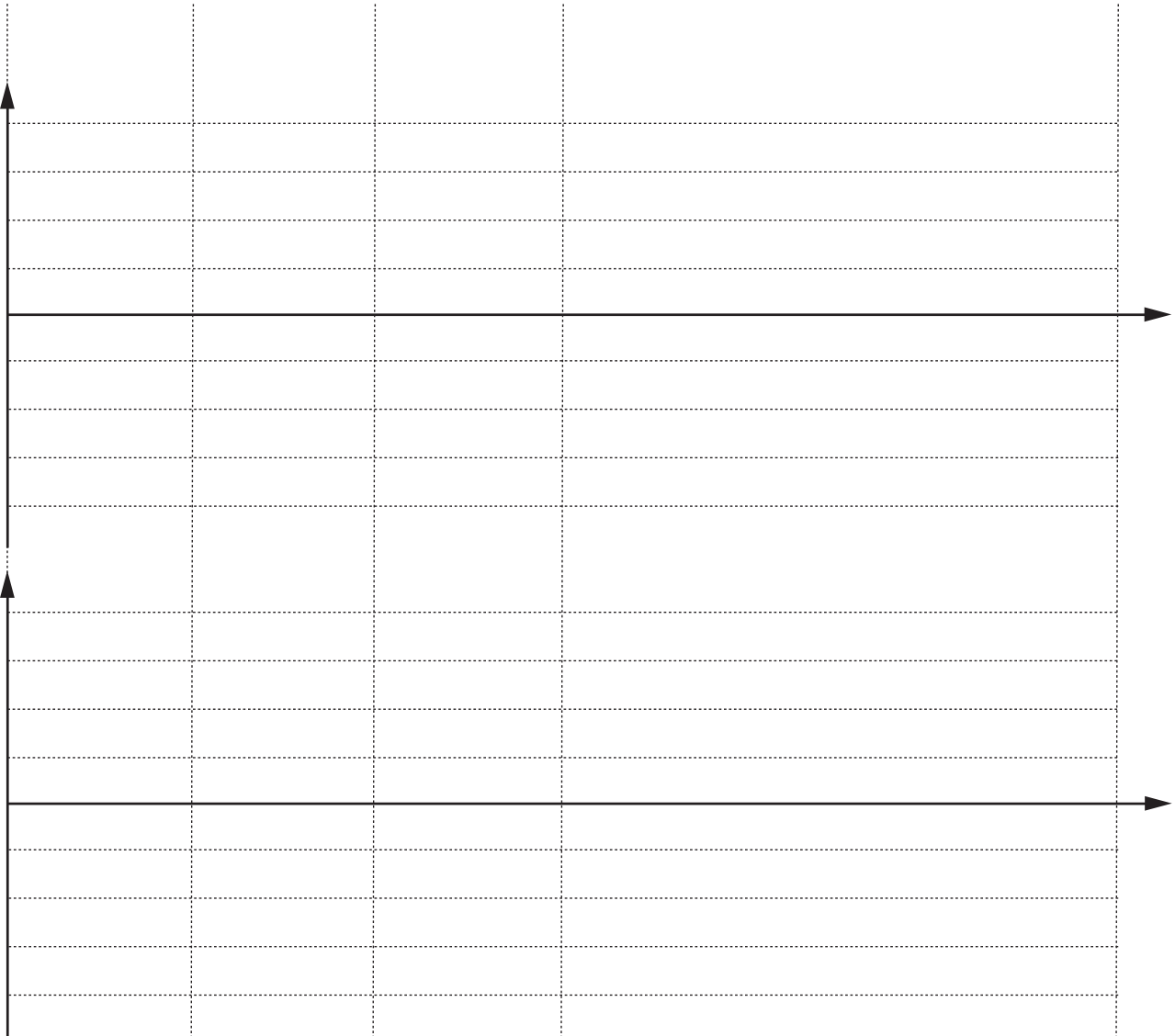


**WORKSHEET Q3**

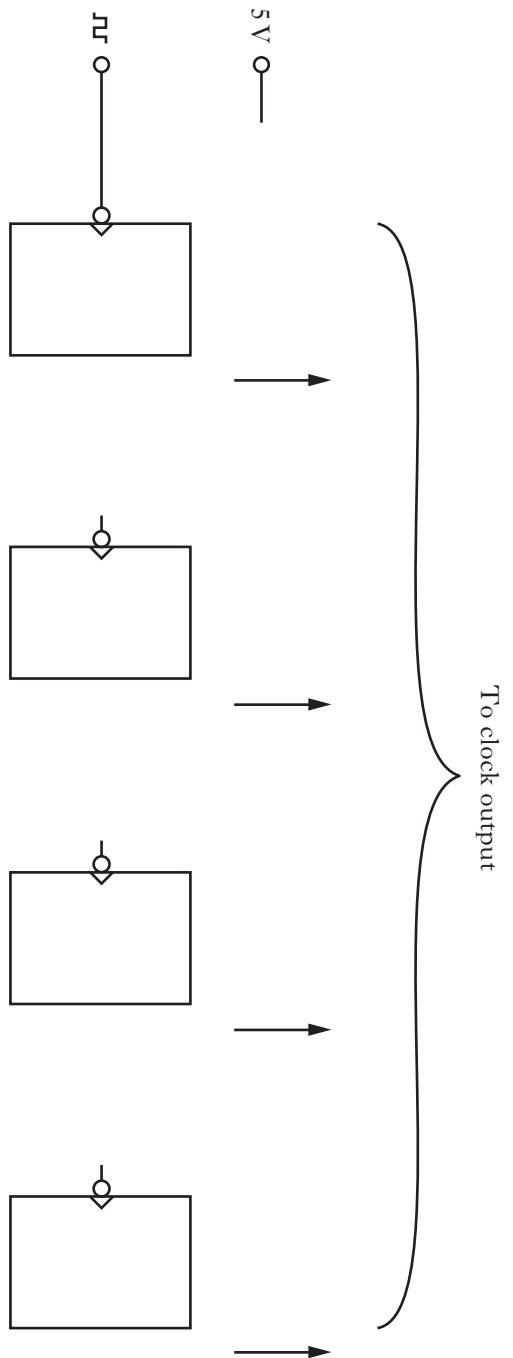


Shear Force Diagram (kN)

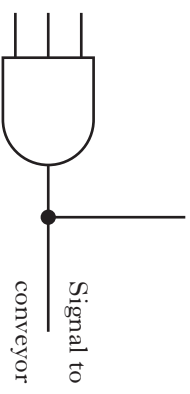
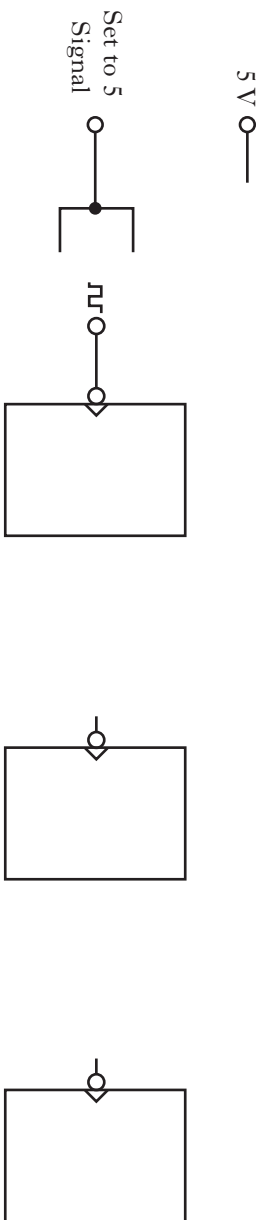
Bending Moment Diagram (kNm)



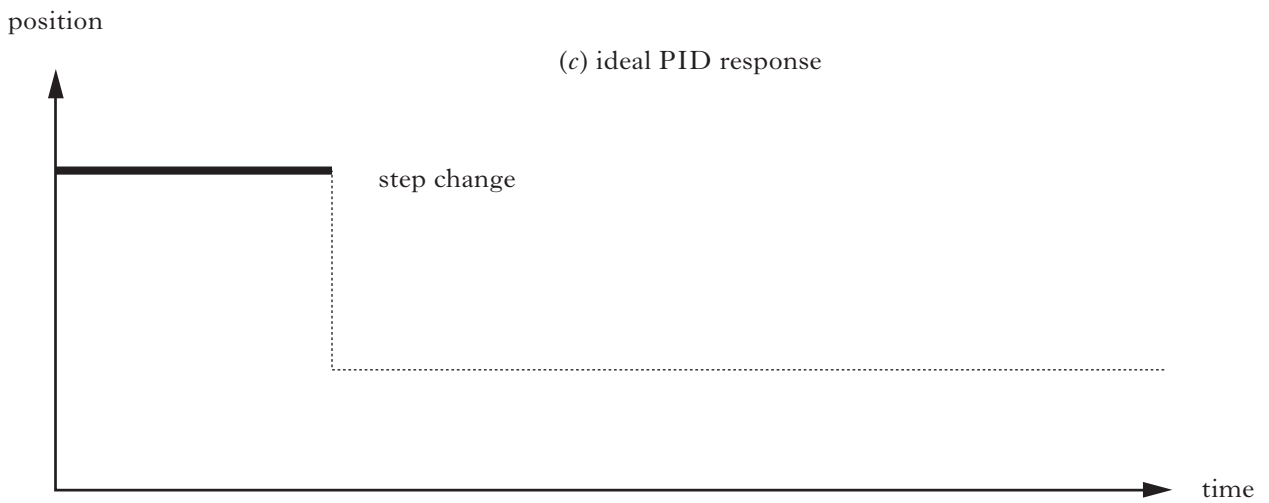
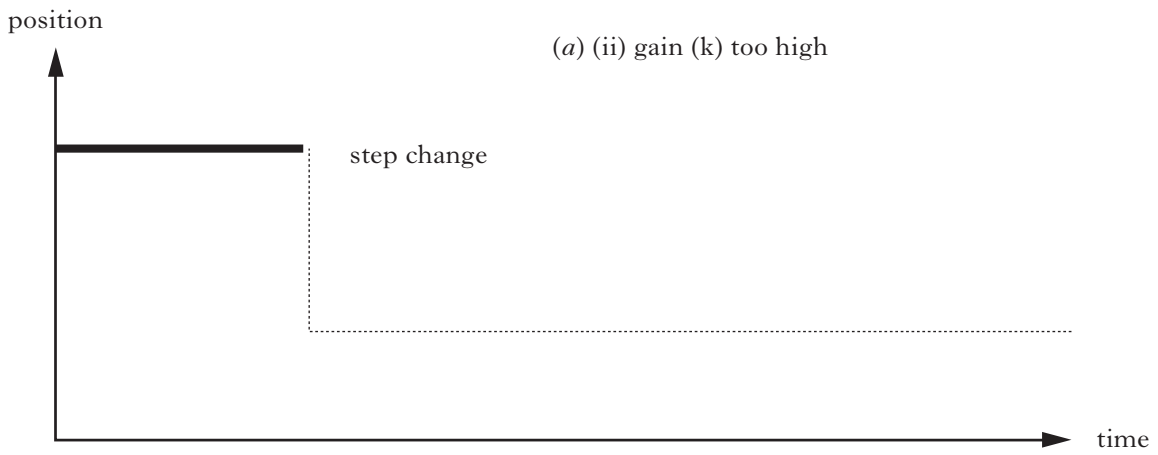
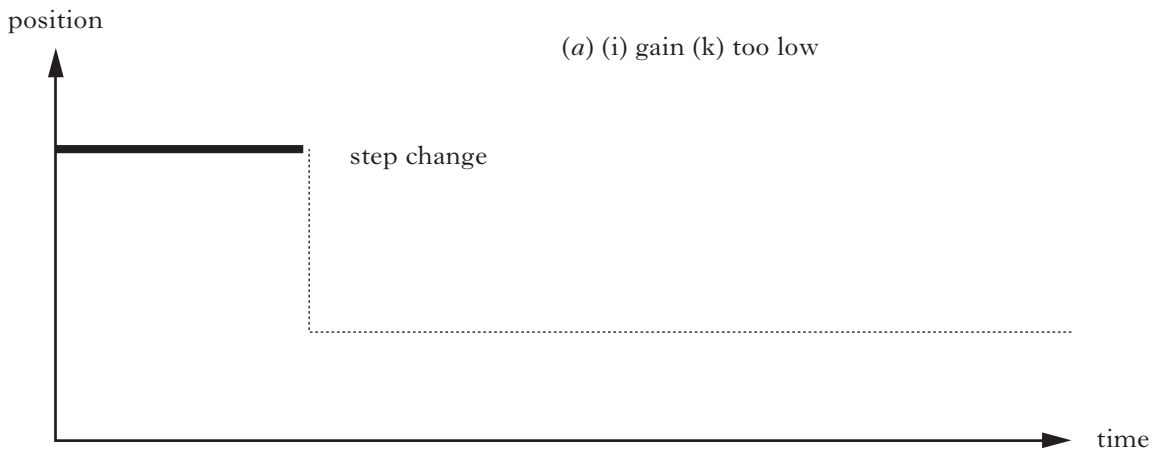
WORKSHEET Q4(b)



WORKSHEET Q4(c)



**WORKSHEET Q7**

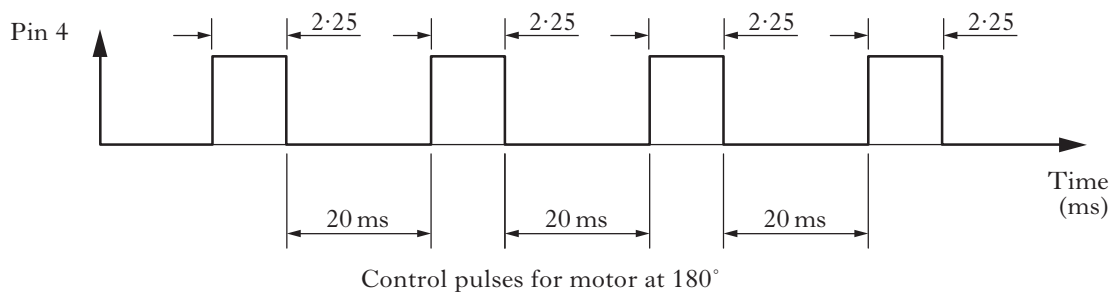
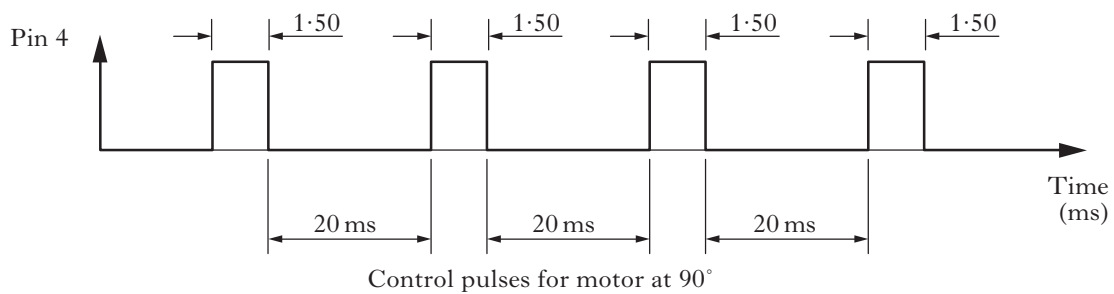
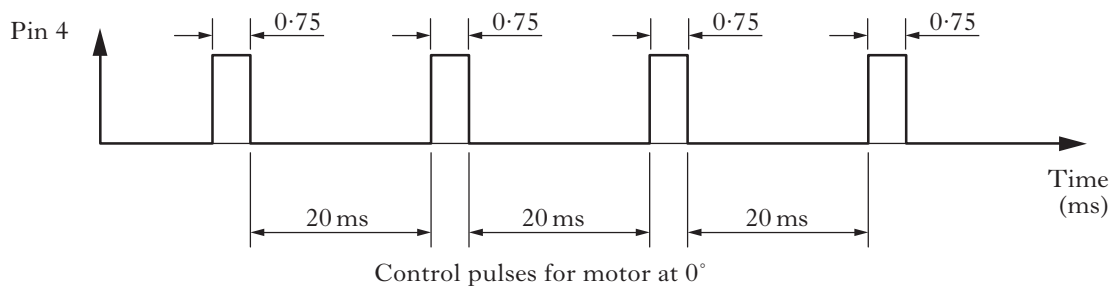


## INFORMATION SHEET Q7

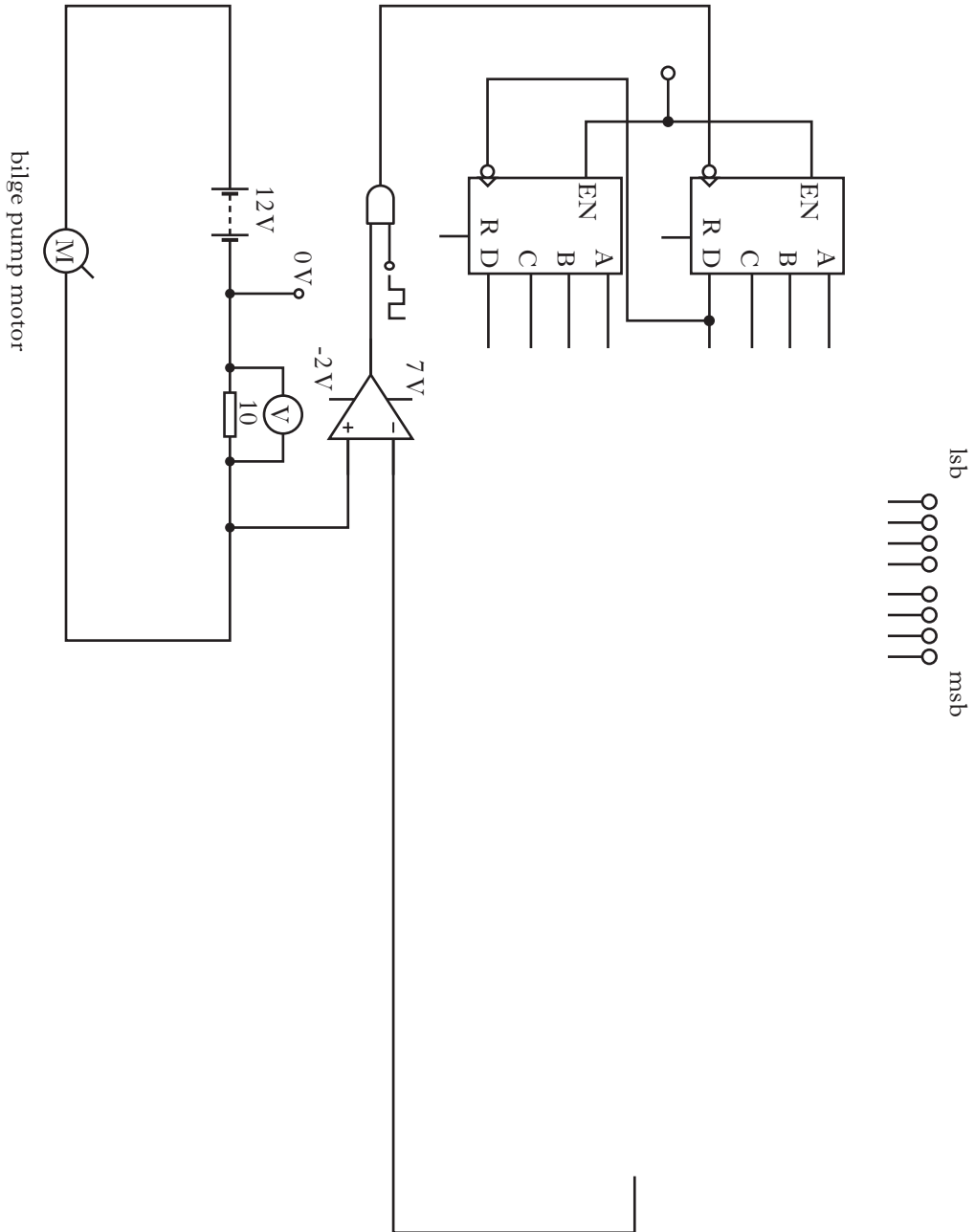
The “desired position” signal for the servo-motor is applied as a short pulse, applied every 20 ms to the signal wire. The length of the pulse determines the position to which the servo moves:

- a 0.75 ms pulse moves the servo to one end ( $0^\circ$ )
- a 1.50 ms pulse moves the servo to the central position ( $90^\circ$ )
- a 2.25 ms pulse moves the servo to the other end ( $180^\circ$ )
- any other pulse (between 0.75 and 2.25 ms) moves the servo to a corresponding intermediate position.

The graphs of the Mark times and Space times required to drive the dish to angular positions of  $0^\circ$ ,  $90^\circ$  and  $180^\circ$  are shown in the diagrams below.



WORKSHEET Q9



[END OF WORKSHEETS]



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