

X036/12/01

NATIONAL TUESDAY, 21 MAY
QUALIFICATIONS 1.00 PM – 4.00 PM
2013

TECHNOLOGICAL
STUDIES
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.

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



SECTION A

Marks

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

1. The operation of an industrial stamping machine is controlled by a logic system with inputs and output as shown in the following table.

INPUTS	OUTPUT
L (= 1 when left-hand button is pressed)	S (= 1 to operate stamping machine)
R (= 1 when right-hand button is pressed)	
G (= 1 when guard is in position)	

The logic system shown in Figure Q1(a) ensures that the machine only operates when the guard is in place and either button is pressed.

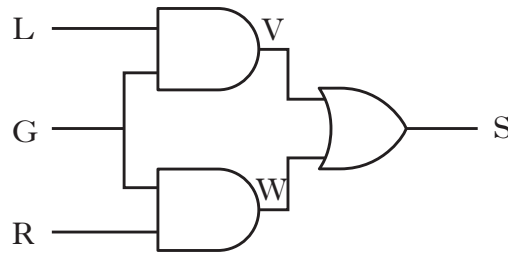


Figure Q1(a)

- (a) Write a Boolean expression for the output S in terms of the inputs L, G and R. **3**
- (b) Using only two-input NAND gates, draw a logic system equivalent to the logic system shown in Figure Q1(a). Delete any redundant gates. **4**

The logic system shown in Figure Q1(b) was designed to provide the same logic function as the logic system shown in Figure Q1(a).

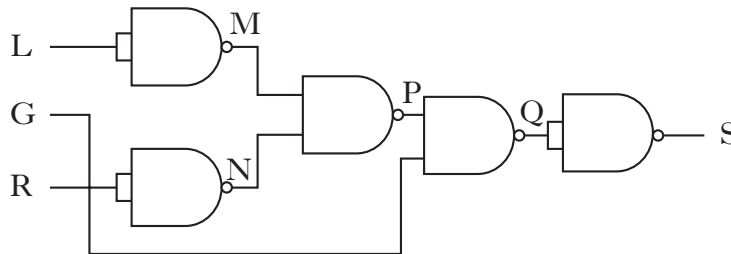


Figure Q1(b)

- (c) Draw and complete a truth table for the logic system shown in Figure Q1(b). Include the intermediate logic values M, N, P & Q. **5**
- (d) Draw a logic system equivalent to that shown in Figure Q1(b) using only two-input AND and OR gates. **3**

2. The circuit shown in Figure Q2 is used in a light-sensing system for a camera.

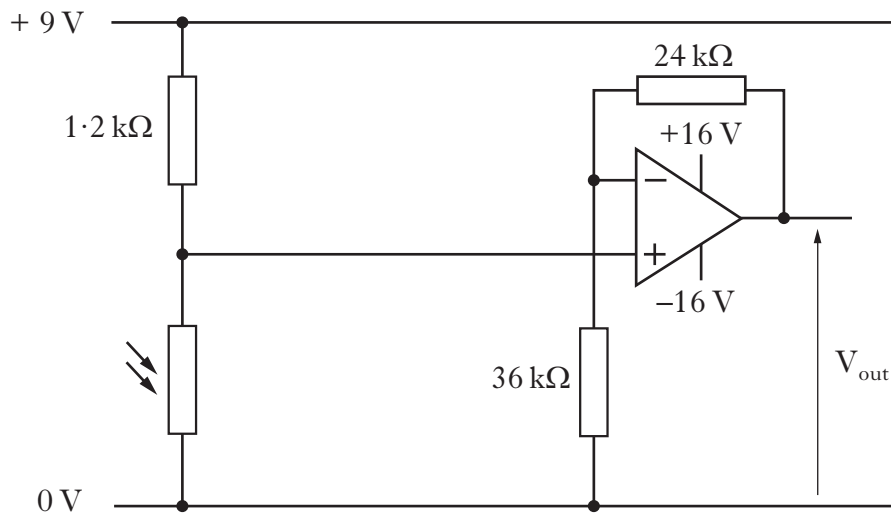


Figure Q2

- (a) Calculate the output voltage, V_{out} , when the light level is 80 lux. 5
- (b) Determine the minimum light level that this system can respond to before the operational amplifier (op-amp) saturates. 6

MOSFET transistors are used in the camera.

- (c) State **two** advantages of a MOSFET transistor, when compared with a bipolar transistor. 2
- (13)**

[Turn over

3. The windscreen-wiper arm shown in Figure Q3(a) is used to hold a windscreen wiper against a car windscreen.



Figure Q3(a)

The forces exerted on the windscreen-wiper arm by a retaining spring and by the windscreen wiper are shown in Figure Q3(b). P is the pivot-point.

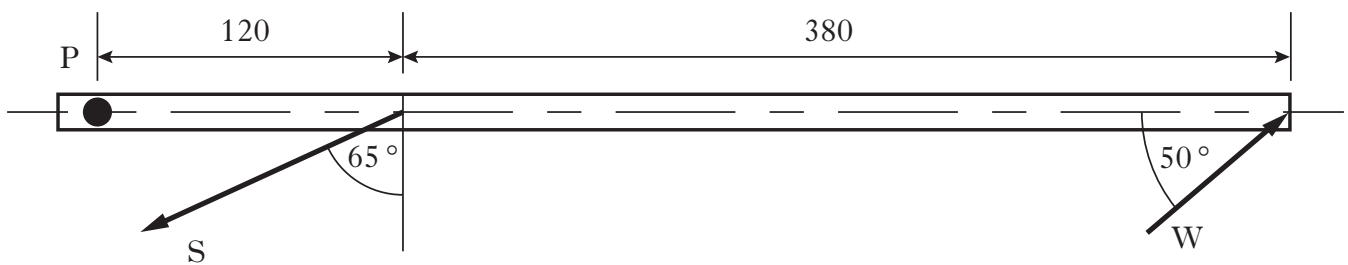


Figure Q3(b)

All dimensions in mm

Calculate, for a force, W, of 6.25 N:

- (a) the force S exerted by the spring (take moments about P); 5
- (b) the magnitude and direction of the reaction force at the pivot P. 11
- (16)**

4. The circuit shown in Figure Q4 is designed to switch on a greenhouse heater when the temperature in the greenhouse falls to 15 °C.

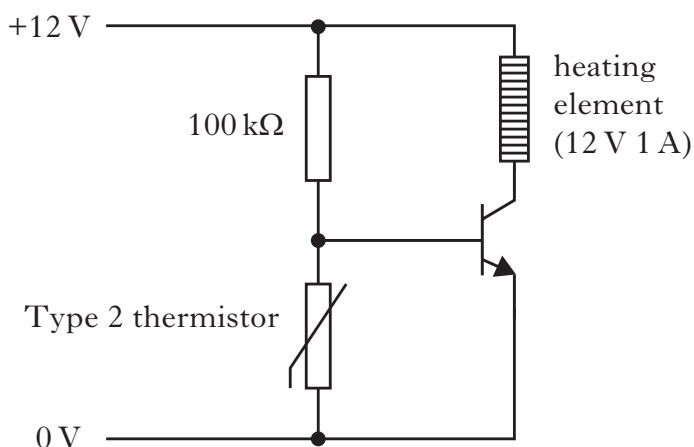


Figure Q4

- (a) Calculate, for a temperature of 15 °C with the transistor switched on and saturated:
- the current flowing through the 100 kΩ resistor; 2
 - the current flowing through the thermistor; 3
 - the current flowing into the base of the transistor. 1

The heating element is rated at 12 V, 1 A.

- (b) Calculate the minimum current gain, h_{FE} , required for the heating element to fully switch on at 15 °C. 2

As the required gain could not be achieved with a single transistor, the circuit was modified by substituting a Darlington pair with an overall h_{FE} of at least 40,000. The following transistors were available.

TRANSISTOR	h_{FE}	$I_{c(max)}$ (A)
A	450	0.1
B	300	0.5
C	100	1
D	50	2

- (c) Draw a suitable Darlington pair. Label each transistor in the Darlington pair with the appropriate letter from the table above. 4

(12)

5. The windscreen-wipers of a car have three modes of operation controlled by a switch which sends signals to a microcontroller. The switch is mounted on a stalk beside the steering wheel, as shown in Figure Q5(a).



Figure Q5(a)

The control sequence is represented by the flowchart shown in Figure Q5(b).

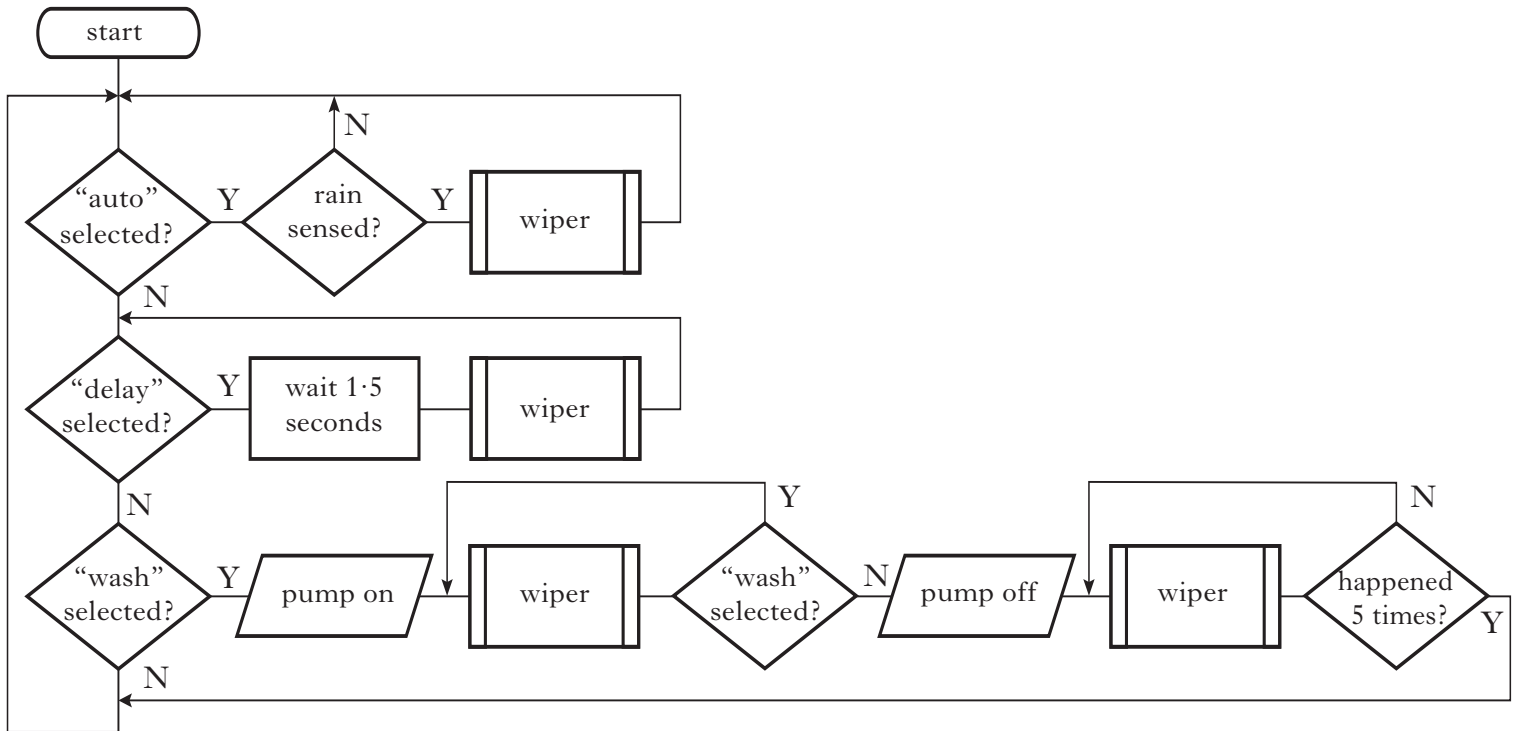


Figure Q5(b)

5. (continued)

The relevant connections to the microcontroller are shown in Figure Q5(c).

INPUTS	PIN	OUTPUTS
“auto” switch (= 1 when auto selected)	0	
“delay” switch (= 1 when delay selected)	1	
“wash” switch (= 1 when wash selected)	2	
	3	
	4	
rain sensor (= 1 when rain sensed)	5	
	6	pump
	7	

Figure Q5(c)

Write, in PBASIC, the control program represented by the flowchart in Figure Q5(b).

17
(17)

6. A support wire for an outdoor suspended sign is in tension. While still in its elastic range, it extends by 0.15 mm when under a load of 717 N.

The support wire has a diameter of 12 mm and a length of 2600 mm.

- (a) (i) Calculate Young’s Modulus for the support wire. 7
(ii) State the name of the material used in the support wire. 1

A Factor of Safety of 7 is applied to the support wire.

- (b) Calculate the maximum safe working load for the support wire. 4
(c) State **two** reasons for the choice of a high Factor of Safety in this application. 2
(14)

[Turn over

7. A room heating system uses the control circuit shown in Figure Q7. A thermistor monitors the room temperature.

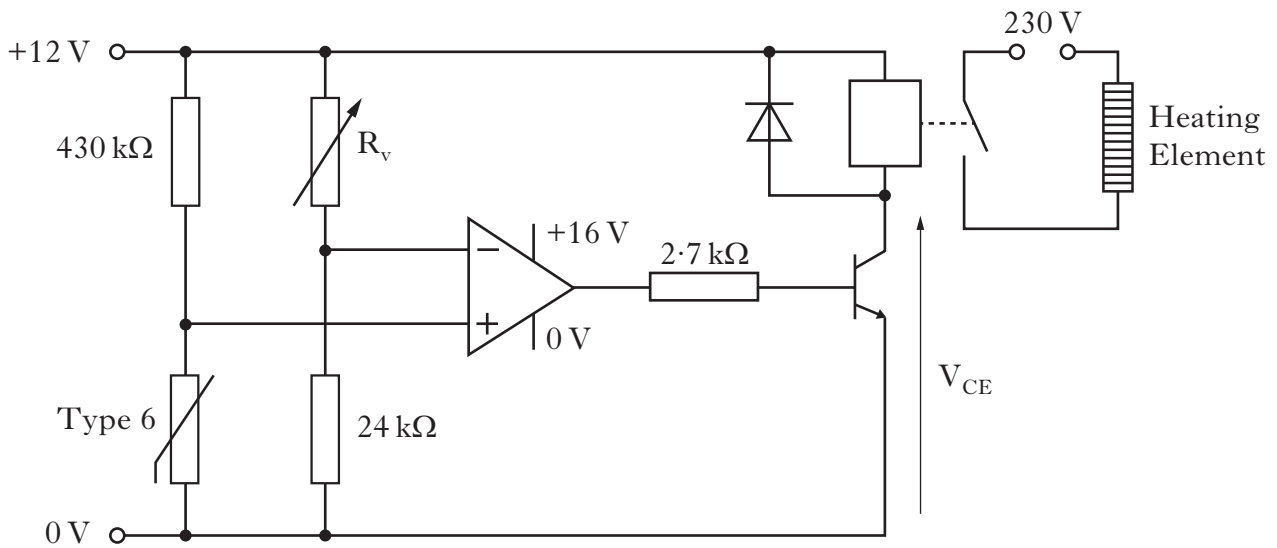


Figure Q7

(a) State the full name of the type of control used. 2

(b) State the function of the diode in this circuit. 1

(c) Explain clearly the operation of the circuit as the temperature falls. 6

The heating element should switch on at 16 °C.

(d) Calculate the required value of resistor R_v . 5

The relay has a coil resistance of $60\ \Omega$. When the transistor is fully saturated, $V_{CE} = 0.2\ \text{V}$.

(e) Calculate the minimum required current gain, h_{FE} , of the transistor. 7

(21)

8. A car is fitted with a two-speed heater fan. The power to the heater-fan motor is controlled by a single pin from a microcontroller. Assuming no losses in the output driver, the heater-fan motor receives either 100% or 60% of the full power available.

- (a) State the full name of the technique used to vary the power to an output device using a single pin of a microcontroller. 1
- (b) Draw a clearly labelled graph, showing how this technique could be used to control the heater-fan motor so that it runs at 60% of its full power. 3

A MOSFET output-driver circuit provides current to the heater-fan motor.

- (c) Draw the output-driver circuit showing connections to the motor, the power-supply rails, and to the output pin of the microcontroller. 4

Figure Q8 shows the operational characteristics of the output-driver circuit. Lines A, B, C, D, and E show the characteristics of the MOSFET for five different gate-source voltages (V_{GS}). Line F shows the characteristics of the motor.

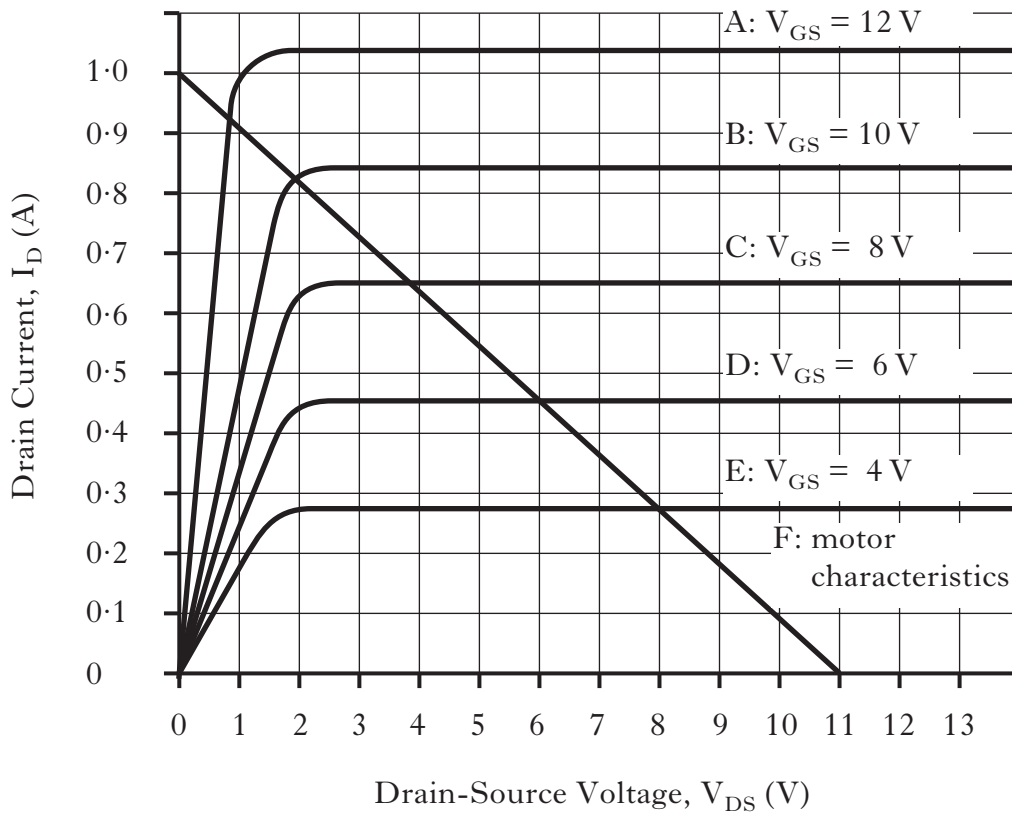


Figure Q8

- (d) For a signal of 4 V on the microcontroller output pin:
 - (i) determine the Drain-Source Voltage; 1
 - (ii) determine the Drain Current; 1
 - (iii) calculate the power dissipated in the MOSFET. 2

(12)

[END OF SECTION A]

SECTION B

Marks

Attempt any TWO questions in this Section.

Each question is worth 40 marks.

9. The coolant in a power plant flows through large pipes. A motorised flow-control valve (FCV) in one pipe is shown in Figure Q9(a).

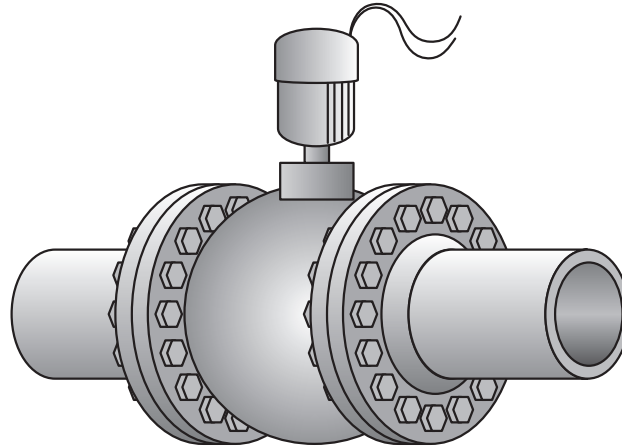


Figure Q9(a)

The coolant exerts a force of 820 kN on the pipe flange, which is secured by 28 Mild Steel bolts. A Factor of Safety of 4.5 is applied, and each bolt is pre-stressed by 10 N/mm² due to initial tightening.

- (a) Calculate the minimum required diameter of the bolts. 7

The initial effective length of the bolts is 60 mm.

- (b) Calculate the extension of the bolts. 5

The coolant flow rate is controlled by the electronic circuit shown in Figure Q9(b).

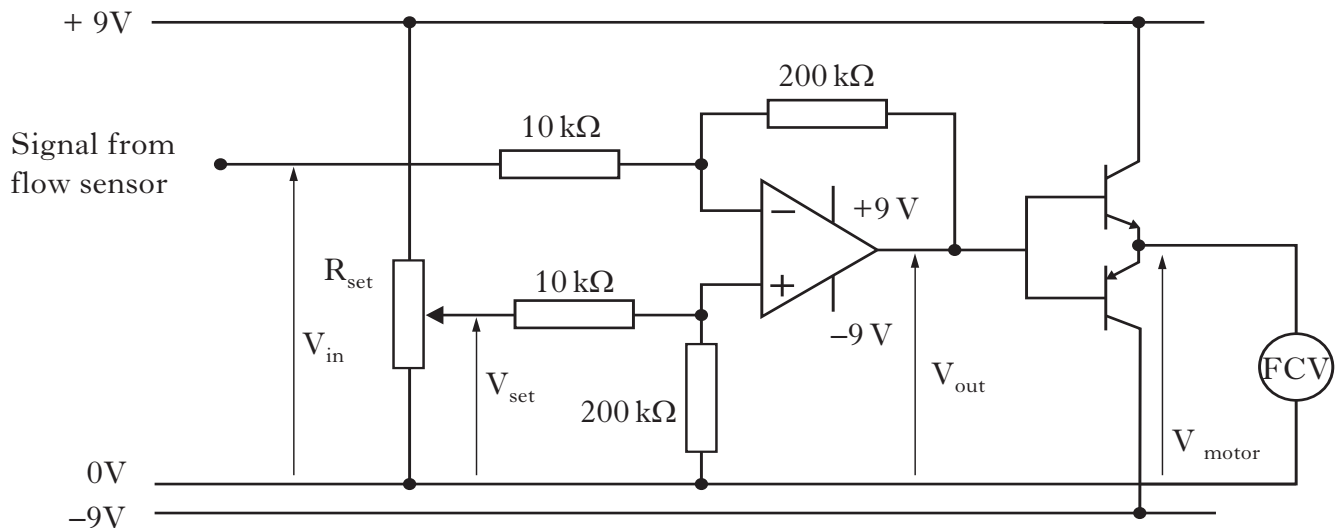


Figure Q9(b)

9. (continued)

When the flow rate is zero, the FCV is fully open.

- (c) Explain the operation of this circuit as the flow rate increases from zero. **6**

The FCV closes when the PNP transistor saturates, and when $V_{\text{motor}} = -4 \text{ V}$.

- (d) Calculate the minimum required signal (V_{in}) from the flow sensor to close the FCV when V_{set} is 1.47 V . **7**

The coolant flow rate is monitored and recorded by a data-logging system. An 8-bit A-D converter has a reference voltage of 2.8 V and the maximum signal from the flow sensor is 4 V .

- (e) Draw a circuit diagram based on op-amps to condition the signal from the flow sensor. Show all resistor values. **5**

A sub-procedure *recorddata* reads and stores 480 readings of coolant flow-rate over a 40 minute period, in memory addresses on page 0 and page 1 of an EEPROM.

Two pre-written sub-procedures are used: *adcread* reads the current value from the ADC and stores it in the variable *DATA*; *eewrite* stores the variable *DATA* in the EEPROM.

- (f) Write, in PBASIC, the sub-procedure *recorddata*. **10**
(40)

[Turn over

10. A small-scale community-based hydroelectric scheme uses the water in a river to turn a turbine and generator. The turbine should turn at a constant speed.

A tachogenerator on the turbine shaft generates a voltage proportional to the shaft speed. A control system processes this signal to control the turbine inlet valve, operated by a motor which turns one way to open the valve and the opposite way to close the valve.

(a) Draw a control diagram for this control system. Label all sub-systems.

6

The tachogenerator provides an output voltage with a linear response of 1 V per 1000 r/min of the turbine shaft. The control system voltage, V_{out} , sent to the motor driver is given by the formula:

$$V_{out} = \frac{R_f \times (3 - V_{tach})}{1000} \quad \text{where } V_{tach} \text{ is the tachogenerator output voltage}$$

(b) Show that the desired turbine speed is 3000 r/min. Include all calculations.

3

When the turbine speed is 1% below the desired speed of 3000 r/min, V_{out} should be 12 V.

(c) Calculate the required value of R_f using the equation for V_{out} shown above.

4

The circuit shown in Figure Q10(a) gives a warning if the turbine speed is either too fast or too slow.

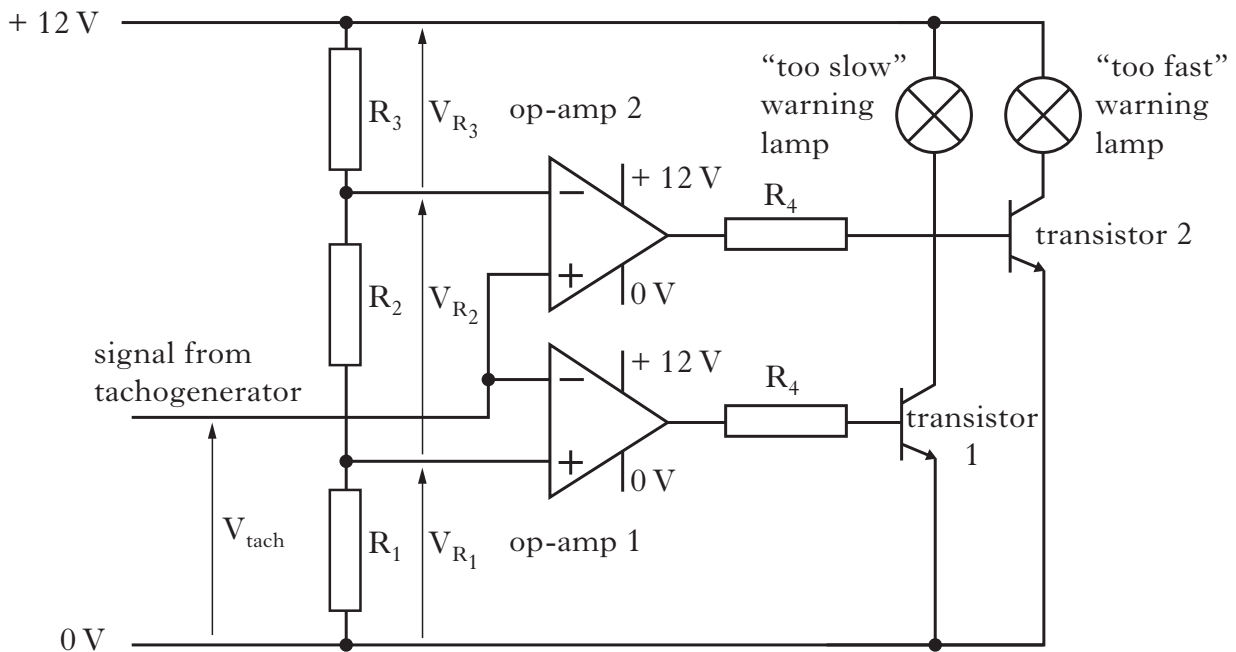


Figure Q10(a)

(d) Explain in detail the operation of the circuit shown in Figure Q10(a).

6

10. (continued)

A warning light shows when the turbine speed varies by more than 5% from the desired speed of 3000 r/min. The total resistance of the resistor ladder in Figure Q10(a) is 12 kΩ.

- (e) Calculate appropriate values for resistors R_1 , R_2 , and R_3 . (The tachogenerator gives a linear output voltage of 1 V per 1000 r/min.)

9

The power supply cable from the generator is supported on pylons. Figure Q10(b) shows the force on a pylon arm due to the weight of the cable.

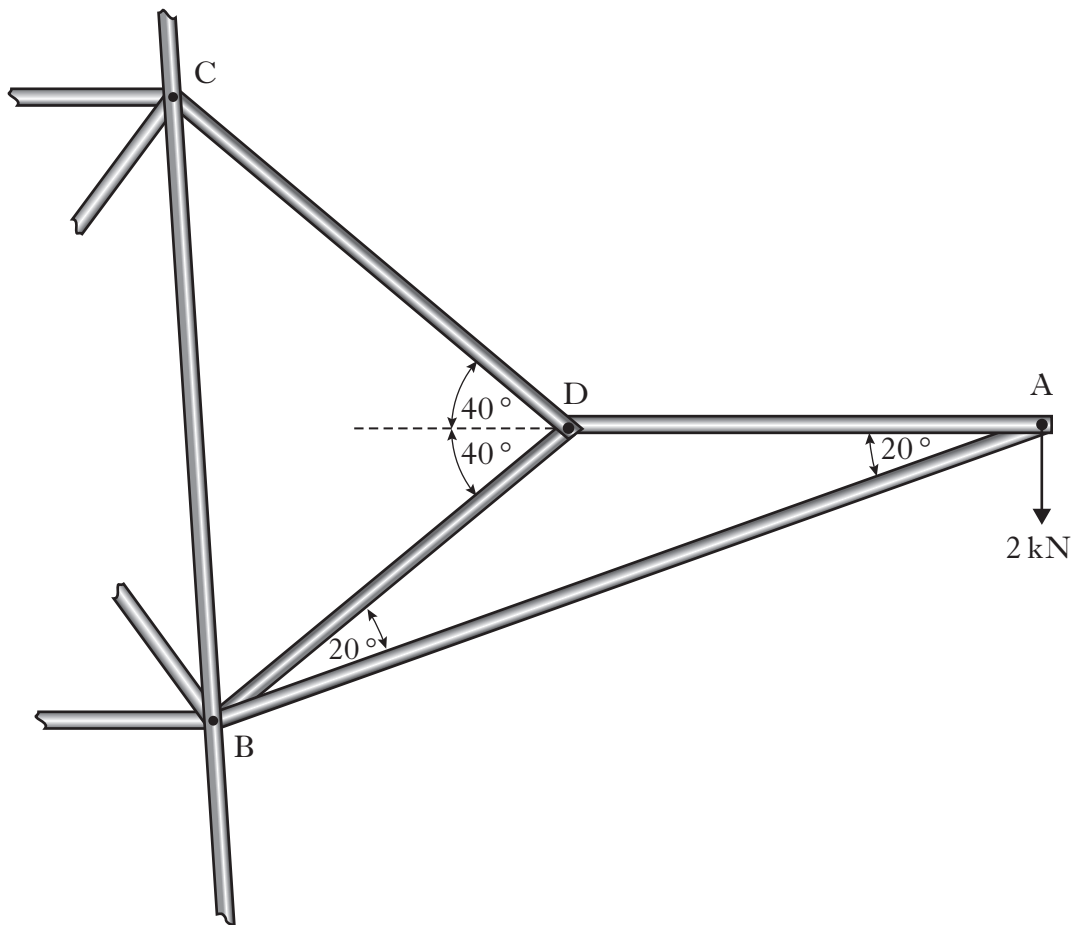


Figure Q10(b)

- (f) Calculate the magnitude and nature of the forces in members AB, AD, BD and CD.

12
(40)

[Turn over

11. The computer-controlled milling machine shown in Figure Q11(a) uses a rotating cutter head to produce 3-D models. Three stepper motors move the cutter head horizontally in the x-axis and y-axis, and vertically in the z-axis.

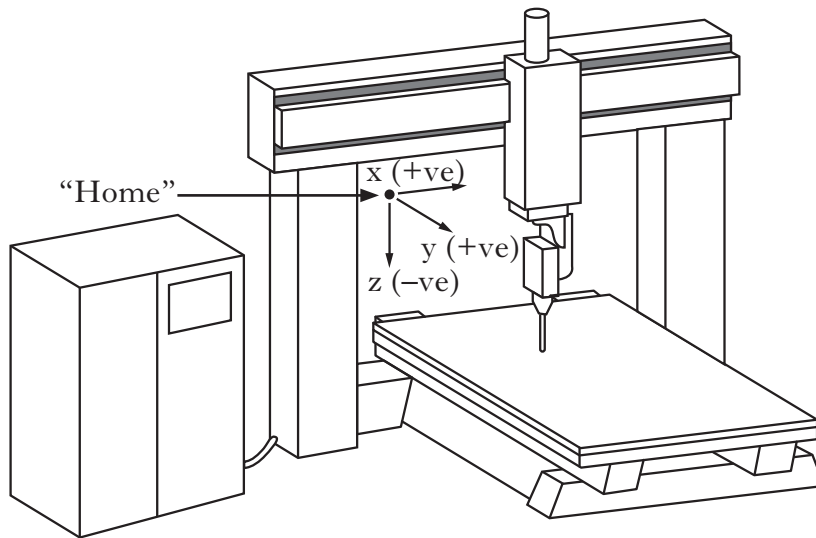


Figure Q11(a)

Each of the three axes has a limit switch which registers the cutter head “home” position at the origin of that axis. Before starting any new sequence the cutter head always moves to its “home” position, ($x=0$, $y=0$, $z=0$). The stepper motors are controlled by a stepper-motor-driver integrated circuit (IC).

A sub-procedure *startpos_x* moves the cutter head to the x-axis home position. The step-angle of the stepper motor is 7.5° and each full revolution of the stepper motor moves the cutter head 4.8 mm.

- (a) (i) Calculate the required time interval between stepper-driver pulses to move the cutter head at 25 mm/s. 4
- (ii) Draw a flowchart to represent the sub-procedure *startpos_x*. 6

A combinational logic system provides a safety feature which switches off the rotating cutter head if the cut being taken is too deep.

The drive motor for the cutter head is controlled by a relay (R). When $R=0$ the drive motor is off.

The safety feature operates according to the Boolean statement:

$$\overline{R} = S \cdot \overline{P} \cdot \overline{D} + S \cdot P \cdot \overline{D}$$

S is a pressure sensor
P is a z-axis pulse
D is step direction

- (b) (i) Draw the Truth Table for R in terms of S, P and D. 3
- (ii) Explain which of the signals S, P and D does not affect the state of R. 2

11. (continued)

A digital-analogue converter (DAC) enables the microcontroller to run the cutter motor at different speeds. The inputs to the DAC are from pins 4, 5 and 6 of the microcontroller, and are either 0 V or 5 V. The output voltages from the DAC, for different microcontroller pin states, are shown in the table in Figure Q11(b).

Pin6	Pin5	Pin4	$V_{\text{out}}(\text{V})$
0	0	0	0
0	0	1	1.2
0	1	0	2.4
0	1	1	3.6
1	0	0	4.8
1	0	1	6.0
1	1	0	7.2
1	1	1	8.4

Figure Q11(b)

A summing amplifier provides the D-A conversion.

- (c) Draw an appropriate op-amp-based circuit that produces the output voltage V_{out} as shown in Figure Q11(b). Show all resistor values. **7**
- (d) Calculate the minimum supply voltage required for the op-amp circuit. **2**

[Turn over

11. (continued)

The sub-procedure *speed* shown in Figure Q11(d) uses the value stored in variable *b7* to control the three output pins. A warning buzzer is connected to pin 7.

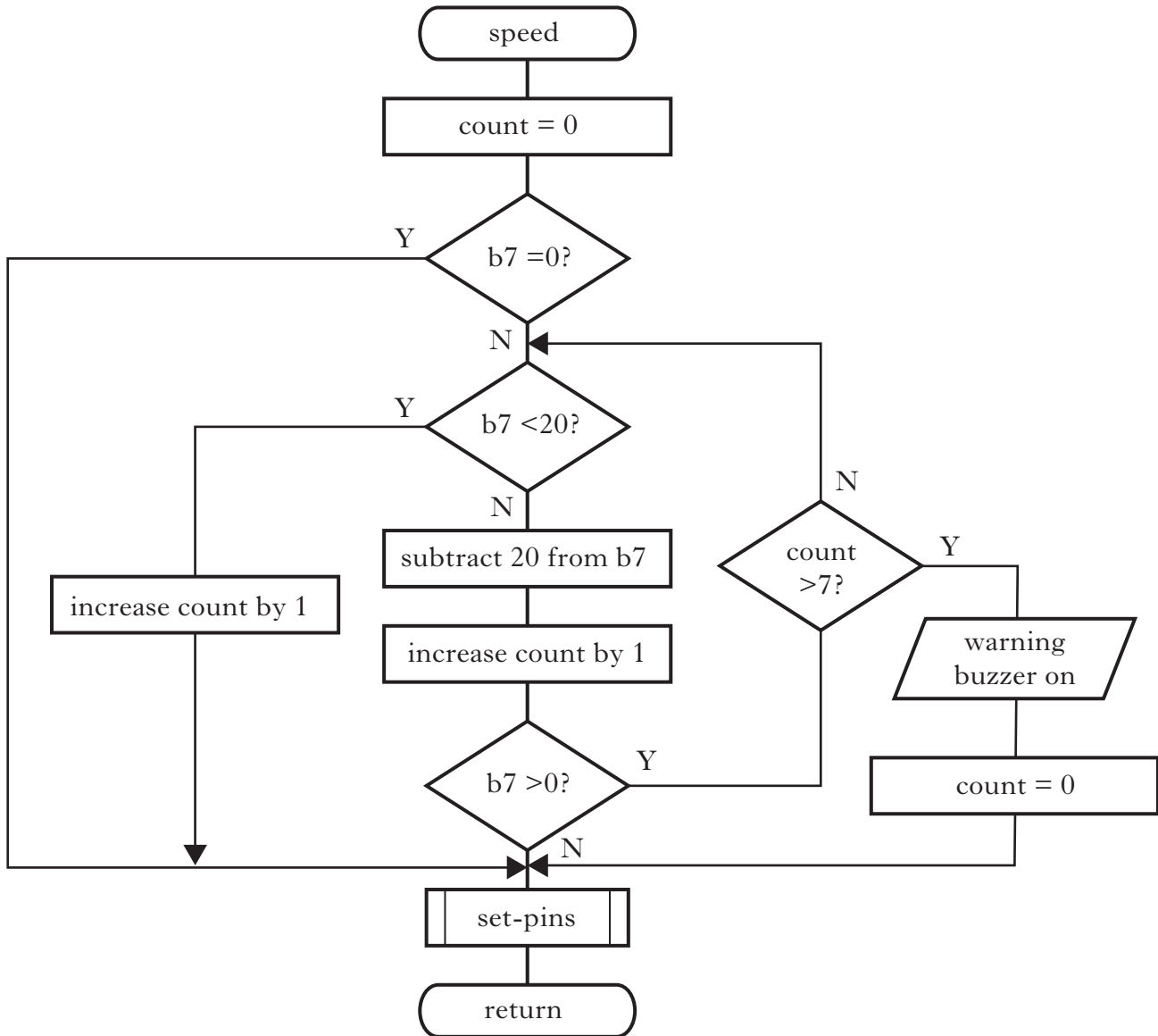


Figure Q11(d)

(e) Write, in PBASIC, the sub-procedure *speed*.

16

(40)

[END OF QUESTION PAPER]