The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2021-2022

ELECTROMECHANICAL DEVICES

Time allowed TWO Hours

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced

Answer ALL questions
(Maximum Marks 180)

Only a calculator from approved list B may be used in this examination.

Basic Models	***Scientific Calculators***	***Graphical Calculators***
Aurora HC133 Casio HS-5D Deli – DL1654 Sharp EL-233	Aurora AX-582 Casio FX83 family Casio FX85 family Casio FX570 family Casio FX 991 family Sharp EL-531 family	Casio FX9750 family

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn examination paper over until instructed to do so

ADDITIONAL MATERIAL: Formula sheet (3 pages)

INFORMATION FOR INVIGILATORS:

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

Turn Over

1. You have been asked to design the "floor indicator LCD display" for a lift in a building that has total 5 floors/levels including the ground floor (treat ground floor as floor 0, so total of 5 stops with floor **0** to **4**). The "display" looks as below in Figure Q1A: there are two "digits" in the display, Num1 and Num2, each digit composed of 7 individual lights a-g. All floor display is shown in Figure Q1B. The input signal is an individual ON/OFF signal for each floor, i.e., there are 5 individual inputs I0, I1, I2, I3, I4 which individually go high (1) if the lift is on that respective floor, e.g., I3=1 and rest (I0-I2 and I4) =0 when the lift is on the 3rd floor:

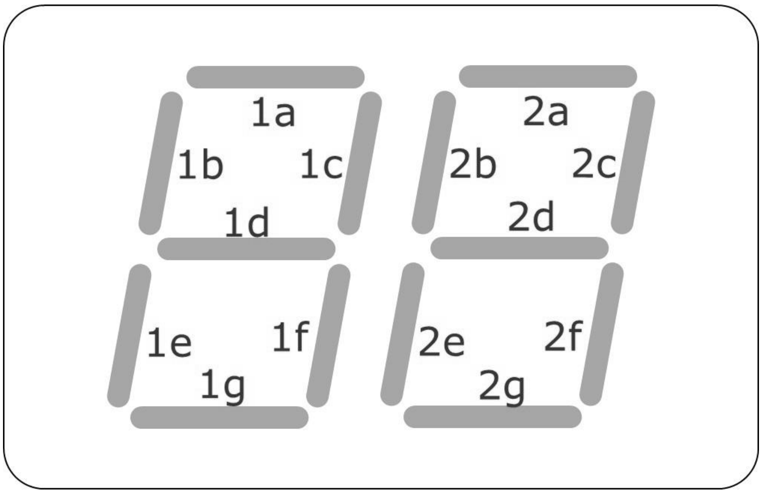

Figure Q1A – Lift floor display

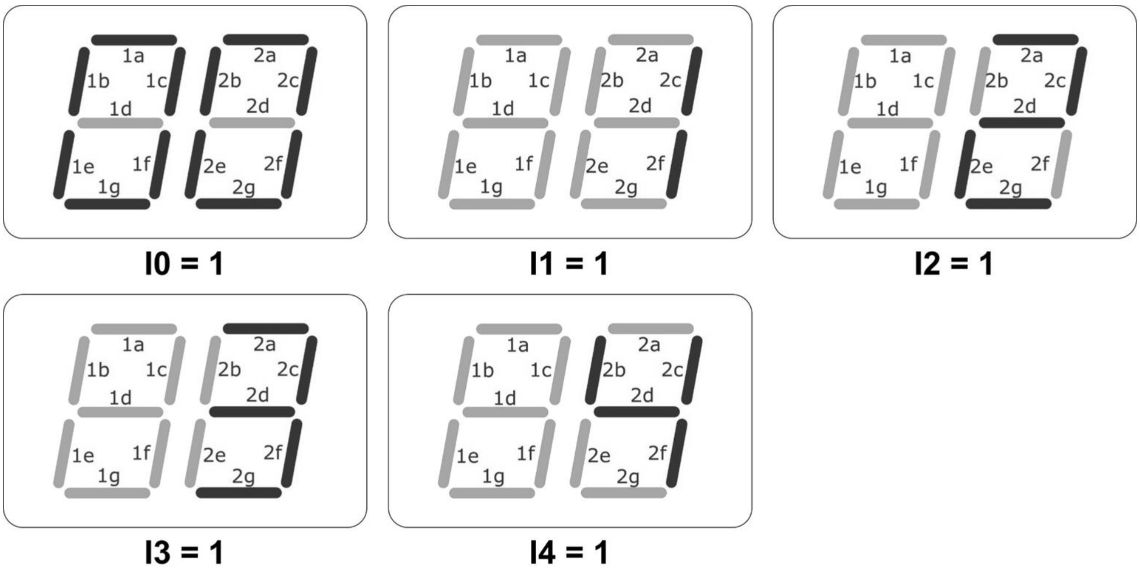

Figure Q1B – All lift floors shown in display form

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(a) Produce the truth table of AND, OR, NOT gates, and sketch their respective symbols? [6]

(b) Produce the truth table for all floors shown in Figure Q1B? Copy the template in Figure Q1C and fill in the blanks. [10]

I0	I1	I2	I3	I4	1a	1b	1c	1d	1e	1f	1g	2a	2b	2c	2d	2e	2f	2g
1	*0*	*0*	*0*	*0*														
0	*1*	*0*	*0*	*0*														
0	*0*	*1*	*0*	*0*														
0	*0*	*0*	*1*	*0*														
0	*0*	*0*	*0*	*1*														

Figure Q1C – Truth table template

(c) Sketch the digital circuit design (a set of logic gates connected) of the following outputs? Hand-draw the sketch of the gates and the Boolean expression. [16]

i) 1-a
ii) 2-a
iii) 2-c
iv) 2-f

(d) The "floor number" information needs to be processed in the building central control system. Currently, this information is conveyed using five bits. Why is this inefficient? What is a better way forward, if the number of bits (or parallel wires) is what you want to minimise? Timing information and clock is not to be used. [4]

(e) You are asked to design a "binary encoder" to convert the 5-bit "floor number" information to a binary number indicating the floor number. How many bits do you need to represent the floor number? Produce the truth table of this encoder with each bit as an output (so as many outputs as many bits you think are needed to represent this information)? [10]

(f) If you were to simply replicate this encoder on a different building (with a different number of floors) with the exact same display system, what is the maximum number of floors could this building have? [4]

Turn Over

2. Figure Q2A presents simplified diagram of a 10-pole reluctance motor. Each phase comprises a pair of poles (e.g., A-A′ etc.). These phases need to be powered consecutively (A→E) in the order to rotate the shaft in **clockwise direction**. A circuit using Flip-Flops must be designed to drive this motor:

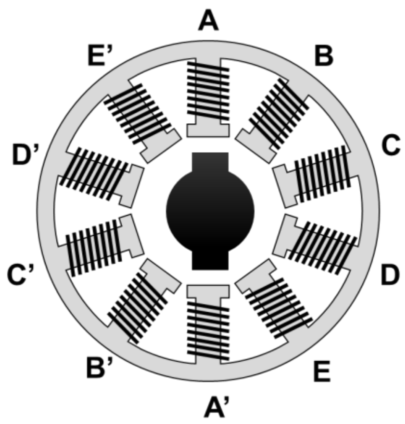

Figure Q2A – 10-pole reluctance motor

(a) What is a Flip Flop and why is it so critical in any digital system? [4]

(b) Draw the circuit of the JK Flip Flop and its truth table? Copy the template in Figure Q2B and fill in the blanks ($\bar{Q}$ can also be written as Q′). [8]

J	K	Q	Q'
0	*0*		
0	*1*		
0	*0*		
1	*1*		

Figure Q2B – Truth table template

(c) What is a Shift Register? Why is a clock signal necessary for its correct application? [4]

(d) Design a shift register to turn the 10-pole motor in the counter-clockwise direction? Support your design with step-by-step explanation of its working. [10]

(e) How do you change the speed of this motor? How do you change the direction of this motor? [4]

3. Op-Amp (Operational Amplifier):

(a) Explain what an Op-Amp is, with the help of a diagram depicting the mathematical operation of a simple (open-loop) op-amp and its input and output resistances? [4]

(b) What are typical values of input, output resistances and open-loop gain of an op-amp? [4]

(c) Why is an op-amp seldom used in its open-loop configuration? What is the alternative (sketch a diagram)? [4]

(d) Draw a "summing amplifier" circuit for two input voltage signals? Support this with the mathematical relation between V_1, V_2 and V_{out}? Use R_1 and R_2 as the input resistors for the two voltage inputs V_1 and V_2 (mark any other resistors required in the circuit appropriately). Assume that the open-loop gain is close to infinity. [8]

(e) What is the condition required on the resistors (R_1, R_2, R_f) to produce equal-weighted sum of the inputs? [4]

(f) Modify the above design to give 3x weightage to V_1 compared with V_2 and redraw the circuit? [6]

4. Circuit Analysis:

(a) Calculate the equivalent resistance between P and Q in the circuit shown in Figure Q5A below. How much DC voltage must be applied across the total circuit (nodes P and Q) so that the current in R_3 is at least 2.5A? [10]

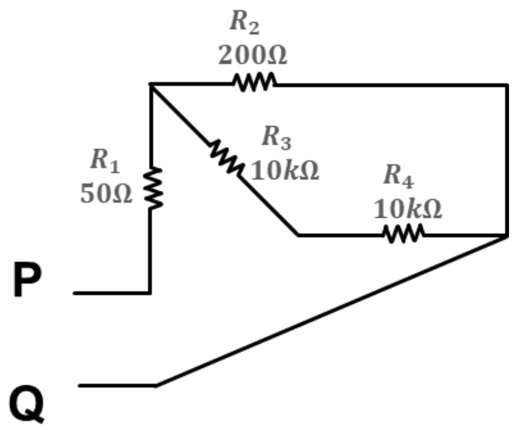

Figure Q5A – Resistor network

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Turn Over

(b) A single-phase motor winding has now been put in series with the resistance network (see Figure Q5B below). The motor winding is a real inductor which can be approximated as an ideal inductance in series with a small resistance. An AC voltage of 240Vrms 50Hz has been applied between P and R. What is the impedance of the motor winding (mention magnitude and phase), i.e., between Q and R? [6]

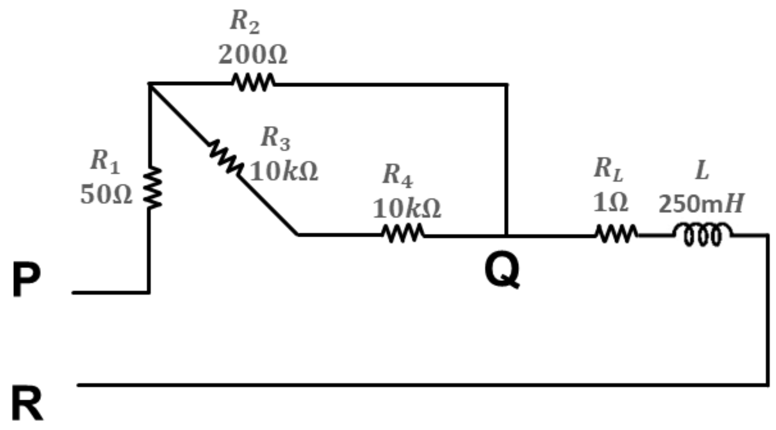

Figure Q5B – Final impedance network

(c) What is the overall impedance of the circuit between P and R (mention magnitude and phase)? [4]

(d) Sketch the phasor diagram of the input voltage and the overall circuit current? Use voltage phasor as the reference (i.e., on the positive x axis). Ensure to add all the important information in the diagram, i.e., magnitude, phase angle, rotation direction and frequency. [6]

(e) Using fewer than 100 words, explain the effect on supply current if the voltage frequency were to suddenly increase to 100Hz? Use the phasor diagram from part 5(d) to mark what changes would occur. [4]

5. You have been asked to design a three-phase 8-pole (4 pole pairs) star-connected induction motor for an application that requires a steady speed of 650 RPM (revolutions per minute) at the peak load torque of 150Nm. You have a 415Vrms (line-to-line) 50 Hz standard supply. You can change the reactance (X_L) of the stator winding (by increasing or decreasing the number of turns in the winding coil) but this also results in the coil resistance (R_L) changing, such that the magnitude of the reactance is exactly five times the resistance in the given conditions.

(a) What is the synchronous speed of the motor? [4]

(b) What is the slip at the desired operation speed, i.e., 650 RPM? [4]

(c) What is the voltage measured between any line and neutral? [4]

(d) What value of winding reactance is needed for the motor to deliver the required rating, i.e., 150Nm torque at 650 RPM? [12]

(e) An induction machine produces an output torque that is dependent on slip. Figure Q6 below shows an example of induction machine torque-speed characteristic – slip increases as the speed drops, reaches a peak when slip is equal to the winding resistance-to-reactance ratio. Calculate the maximum torque that can be produced by this induction machine and the speed at which this torque occurs? [12]

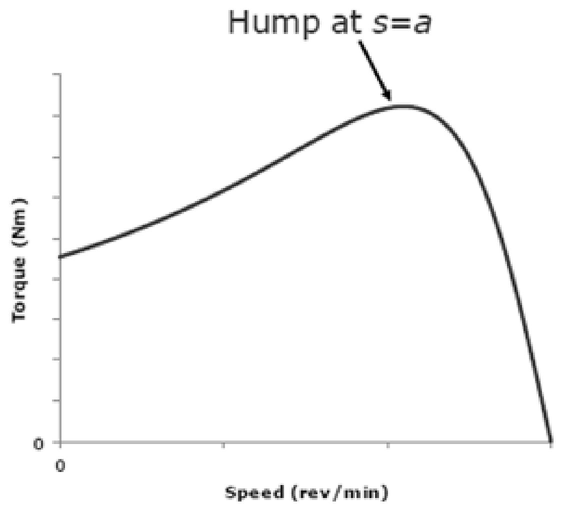

Figure Q6 – Ideal torque-speed characteristics of an induction machine

(f) What happens to the stator winding resistance-to-reactance ratio if the input frequency doubles to 100 Hz? [4]

END