

1. The inductor network shown in Fig. Q.1 is connected to a 60 Hz 20 V supply. Calculate the equivalent inductance of the network, the inductive reactance, and the magnitude and phase angle of the current. Assume there is no mutual inductance. [5]

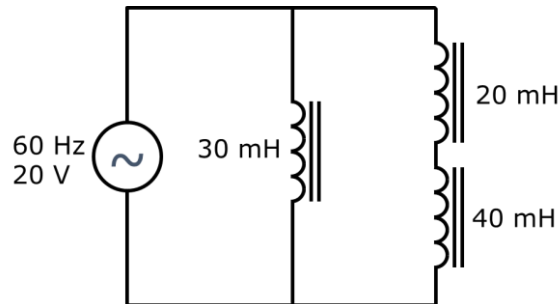


Fig. Q.1

Eq inductance is 20 mH [2]. Impedance is $j 7.54$ ohms [1], current is $-j2.65$ A or 2.65 A at a phase angle of -90 deg [2].

2. A permanent magnet DC motor is stated to provide its rated torque of 0.12 Nm when it is drawing a current of 5 A. At what no-load speed (in rev min^{-1}) will it run if it is connected to a 12 V supply, neglecting friction? If it rotates at 4000 rev min^{-1} when it is supplying its rated torque while being driven from a 12 V supply and drawing 5 A, what is its armature resistance? [5]

$$\mathbf{K = T/I = 0.12/5 = 0.024 \text{ V s/rad [1]}}$$

$$\mathbf{\Omega = E/K = 12/0.024 = 500 \text{ rad/s [1] so } n = 500 \times 60/2\pi = 4774 \text{ rev min}^{-1} \text{ [1]}}$$

$$\mathbf{V = E + IR \text{ so } R = (V - E)/I = (12 - (4000 \times 2\pi/60) \times 0.024)/5.28 = 0.384 \Omega \text{ [2]}}$$

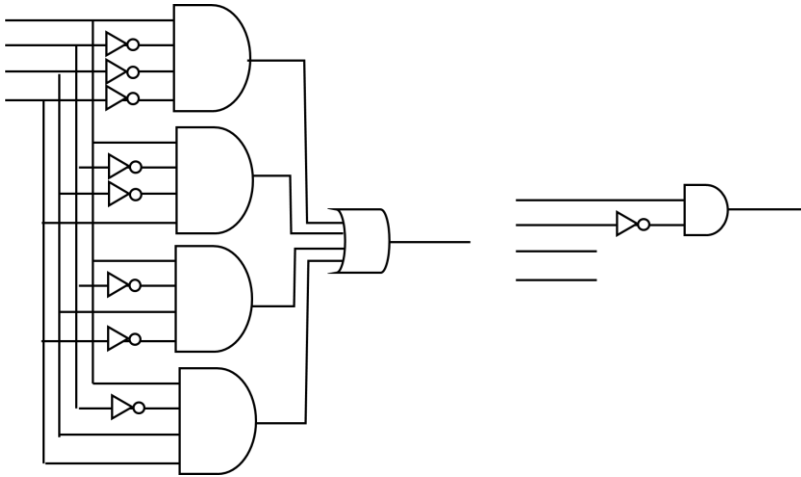
3. An electromagnetic actuator has 3000 turns of wire and has pole pieces of area $1.1 \times 10^{-4} \text{ m}^2$. When the pole pieces are 0.01 m apart, what force does the actuator provide when a current of 1.5 A is flowing in the actuator? Assume that the flux density is uniform within the airgap and neglect the reluctance of any other parts of the magnetic circuit. [5]

$$\mathbf{H = NI/l = 3000 \times 1.5/0.01 = 45000 \text{ A/m [1]}}$$

$$\mathbf{B = \mu H = \mu_0 \mu_r H = 4\pi \times 10^{-7} \times 1 \times 450000 = 0.565 \text{ T [2]}}$$

$$\mathbf{F = B^2 A / (2\mu) = 0.565^2 \times 1.1 \times 10^{-4} / (2 \times 4\pi \times 10^{-7} \times 1) = 13.9 \text{ N [2]}}$$

4. A digital device needs to be activated when the numerical value carried on a set of four digital lines takes one of the four following values: 1000, 1001, 1010 or 1011. Design a digital logic circuit that will output a "high" (1) digital signal when the four lines carry one of these numbers and will output a "low" (0) signal otherwise. [4]



5. Derive an expression for the output voltage V_{out} of the circuit shown in Fig. Q.5 in terms of the input voltage V_{in} , the op-amp gain A and the values of the resistors R_1 and R_f . You may make the usual assumptions of infinite input impedance, zero output impedance and $V_{out}=Av$. Hence simplify your expression for the case where A is very large. [6]

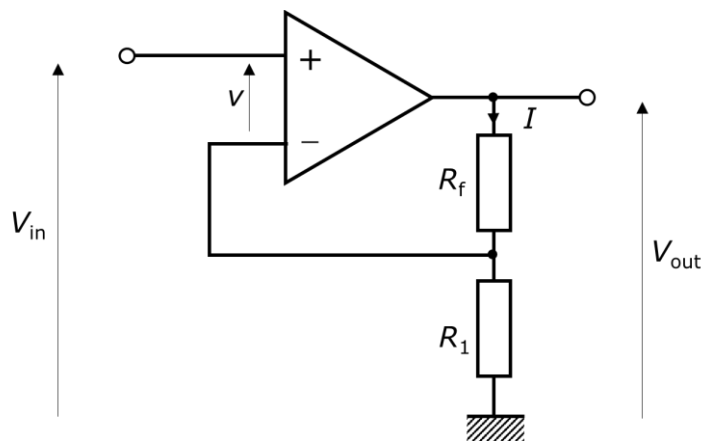
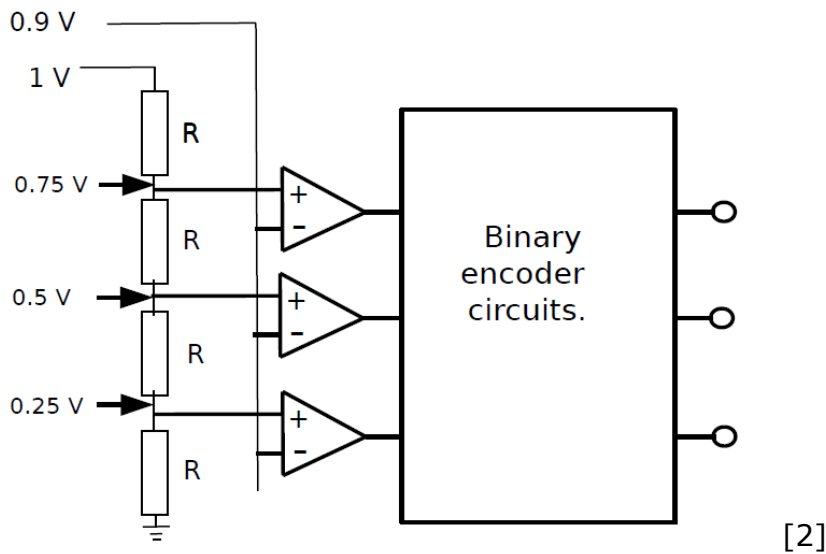


Fig. Q.5.

$$\begin{aligned}
 I &= V_{out}/(R_1+R_f) \\
 V_{fb} &= R_1 \times I = V_{out} R_1/(R_1+R_f) \quad [1] \\
 V_{out} &= Av = A (V_{in} - V_{out} \times R_1/(R_1+R_f)) \quad [1] \\
 V_{out} (1 + A \times R_1/(R_1+R_f)) &= AV_{in} \quad [1] \\
 V_{out} &= AV_{in}/(1 + A \times R_1/(R_1+R_f)) \\
 &= AV_{in}/((R_1+R_f + A \times R_1)/(R_1+R_f)) \\
 &= AV_{in}(R_1+R_f)/(R_1+R_f + A \times R_1) \quad [2] \\
 \text{If } A \text{ is very large, this becomes} \\
 V_{out} &= V_{in}(R_1+R_f)/R_1 = V_{in}(1+R_f/R_1) \quad [2]
 \end{aligned}$$

6. Explain the operation of a flash ADC, illustrating your answer with a circuit diagram. [5]



[2]

Resistors act as potential divider to create set of reference voltages [1]
 Some of these exceed input voltage, count the ones which input voltage exceeds [1]
 Convert this to binary code to give digitised version of input voltage [1]

7. (a) A 400 V (line-to-line voltage) 50 Hz three phase power supply is star-connected to an induction motor which draws a current of 78 A at a phase angle of 50° lagging. Calculate the total active power drawn by the motor. [5]

$$\text{Active power} = \sqrt{3} V_L I_L \cos \phi = \sqrt{3} \times 400 \times 78 \times \cos 50 = 34736 \text{ W [5]}$$

- (b) The star-connected induction motor described above has a rotor resistance of 15Ω and a rotor standstill reactance of 75Ω referred to the stator windings. There are three pairs of poles per phase. Calculate the phase voltage, the slip and the torque when the motor is driving a load at 955 rev min^{-1} . Hence calculate the power supplied by the motor and its efficiency. [12]

$$V_p = 400/\sqrt{3} = 230.94 \text{ V [1]}$$

$$n_s = 60 \times 50 / 3 = 1000 \text{ [1]}$$

$$a = 15/75 = 0.2 \text{ [2]}$$

$$s = (1000 - 955) / 1000 = 0.045 \text{ [2]}$$

$$T = \frac{(3p/2\pi f)(V^2 a s)}{(a^2 + s^2)} = \frac{(3 \times 3 / (2 \times \pi \times 50))(230.94^2 \times 0.2 \times 0.045)}{(75 \times (0.2^2 + 0.045^2))}$$

$$= 327.2 \text{ Nm [3]}$$

$$\omega = 955 \times 2 \times \pi / 60 = 100 \text{ rad s}^{-1} \text{ [1]}$$

$$\text{Power} = T\omega = 327.2 \times 4.36 \times 100 = 32779.436 \text{ W} \quad [1]$$

$$\text{Efficiency} = 100 \times 32779.436 / 34736 = 94.5 \text{ \%} \quad [1]$$

(Note: as is seen above, question as set in paper gives unrealistically low power and efficiency. However, these were marked as correct. See feedback sheet for details of how marking was handled).

- (c) Each phase of the above power supply (relative to neutral) is provided from a separate transformer which steps an 11 kV (11 000 V) supply down to the phase voltage (as calculated by you in b). Noting once again that the transformer supplies 78 A at a phase angle of 50° lagging to each phase of the motor, what current will be drawn by the 11 kV winding of the transformer, and hence what will the apparent power (VA) rating of this transformer need to be? (Note: only consider a single transformer here, and do not consider how the connections of the primary winding of this transformer relate to those of the other two transformers in the system). [9]

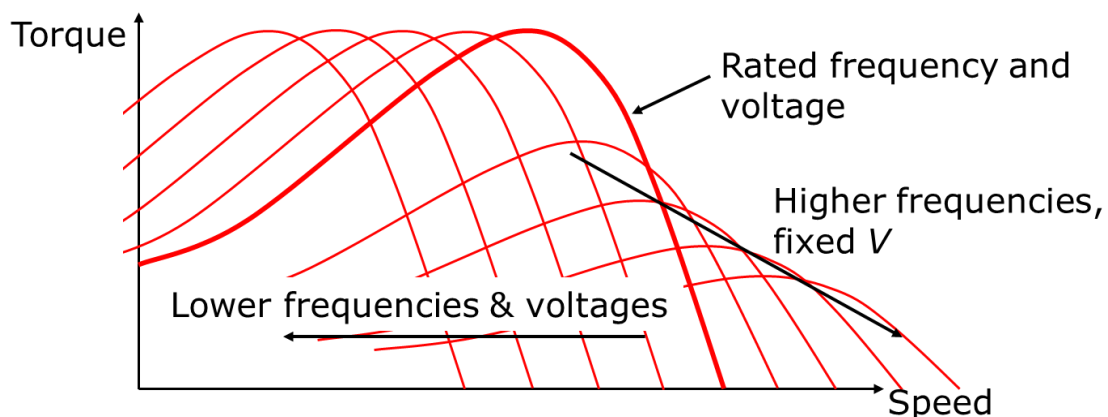
$$V_1 = 11000 \text{ V}, V_2 = 230.94 \text{ V} \quad [2]$$

$$I_1 V_1 = I_2 V_2 \quad [2] \text{ so } I_1 = I_2 V_2 / V_1 = 78 \times 230.94 / 11000 = 1.64 \text{ A} \quad [2]$$

$$\text{Apparent power} = VI = 11000 \times 1.64 = 18013 \text{ VA} = \text{VA rating of transformer.} \quad [3]$$

- (d) It is now desired to be able to vary the speed of the motor so that it runs faster or slower than the 955 rev min^{-1} stated earlier. Explain what determines the approximate speed of an induction motor when run directly from the mains supply, and hence explain what additional electronic hardware would be required to vary the speed of the motor over a wide range. Sketch the torque-speed characteristics that describe its behaviour when driven from this additional electronic hardware. [9]

Motor speed is normally a few percent below synchronous speed [2] which is directly related to frequency [1]. To be able to vary motor speed we need to be able to vary frequency so need variable-frequency inverter [2]



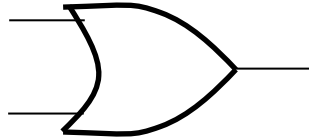
[4]

8. (a) You are an engineer designing a computer for a flight control system, key components of this system are OR gates, AND gates, XOR gates, NOT gates and a JK flip-flops.

- (i) Write down the truth table for these components and the circuit symbol of each component. [5]

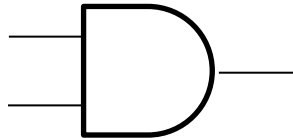
OR

A	B	O
0	0	0
0	1	1
1	0	1
1	1	1



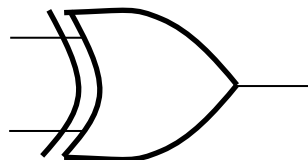
AND

A	B	O
0	0	0
0	1	0
1	0	0
1	1	1



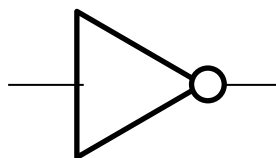
XOR

A	B	O
0	0	0
0	1	1
1	0	1
1	1	0



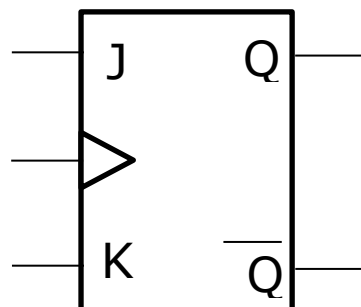
NOT

A	O
0	1
1	0



JK

J	K	Q	Comment
0	0	Q	No change
1	0	1	Set Q to 1
0	1	0	Set Q to 0
1	1	flip	Flip



- (ii) Part of the computer uses 8 bit numbers to perform mathematics. Write down the 8-bit binary codes for the decimal numbers 64, 100 and 120. [3]

64=1000000, 100=1100100, 120=1111000

- (iii) The computer must be connected to a shaft-encoder measuring relative shaft position with a resolution of $<1^\circ$. How many optical sensors would need to be used to achieve this level of accuracy? . [2]

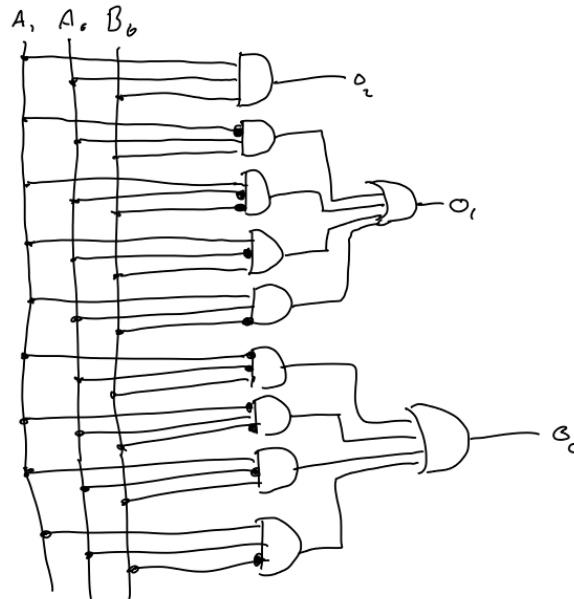
$360/(2^9) < 1$ so the answer is 9 sensors giving a resolution of 0.70312 deg

- (b) (i) As part of the design for the computer you have to design a chip to add a two digit binary number to a one digit binary number. The chip has two input wires (A1,A0) representing the two bit binary number and one input wire representing the one bit binary number (B0). The chip has three output wires representing the answer (O2,O1,O0). Write down the truth table for this chip. For the output the most significant bit must be stored in O2 while the least significant bit stored in O0, for the input the most significant bit must be stored in A1 and the least significant bit stored in A0. [4]

A1	A0	B0	O2	O1	O0
0	0	0	0	0	0
0	0	1	0	0	1
0	1	0	0	0	1
0	1	1	0	1	0
1	0	0	0	1	0
1	0	1	0	1	1
1	1	0	0	1	1
1	1	1	1	0	0

- (ii) Draw the complete circuit diagram for this adding unit. You should allow a complete page of your exam booklet for the answer to this question part as it will take up a lot of space.

[5]



[This is hard to break down into separate parts so marking of this subsection is "all or nothing" i.e. 5 for correct answer, 0 for wrong answer.]

- (iii) After having designed the chip, you are doing some boolean algebra to check your design is fully minimized. For example, fully minimize the following expression using boolean algebra:

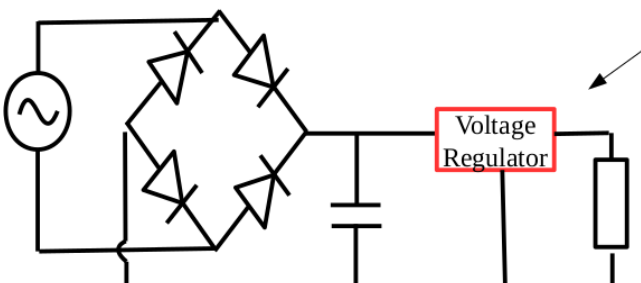
$$(x+z)(x+y)(\bar{z}+y)$$

[4]

$$\mathbf{zx+zy+xy}$$

- 9 (a) You need to design a power supply. It must include a voltage regulator, smoothing capacitors, a load and the bridge rectifier. Draw the circuit diagram for the power supply incorporating these features

[5]

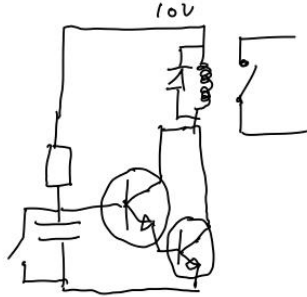


[Minor errors e.g. omitting capacitor: lose 2 each. Incorrect drawing of bridge lose 3, incorrect wiring of voltage regulator lose 2].

- (b) Part of the specification for the computer is that it only turns on a few seconds after the user presses its power button; this is so not too much

load is placed on the power supply. To achieve this you decide to use a Darlington pair based timer, you connect the Darlington pair to a relay, which will in turn be used to power on the computers main circuits.

- (i) Draw a circuit diagram of a Darlington pair based timer circuit which could be used for this. The circuit diagram must include a switch and a relay. [5]



[0 marks for omitting the capacitor as that is crucial. 3 marks for circuit which is otherwise correct but mis-draws Darlington pair. 3 marks for circuit which is otherwise correct but mis-draws relay.]

- (ii) The transistors in the circuit have a beta of 10 and 8 respectively. What is the overall gain of the Darlington pair? [2]

80

END