The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2021-2022

ELECTROMECHANICAL DEVICES

TIME ALLOWED 2 HOURS

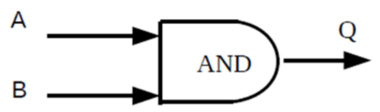
TOTAL MARKS 180 (80% OF TOTAL MODULE CREDITS)

QUESTION PAPERS TO BE COLLECTED AT THE END OF EXAM BY INVIGILATOR

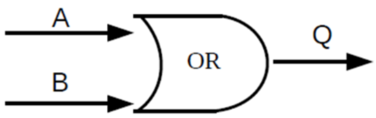
QUESTION 1 (50 MARKS)

1a) [6]

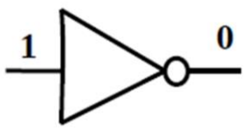
2 marks each for each gate. Minor mistake (like a silly mistake), take away 1 mark.



A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1



A	B	Q
0	0	0
0	1	1
1	0	1
1	1	1



A	Q
1	0
0	1

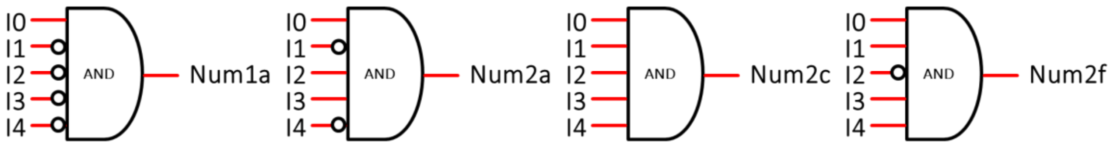
1b) **[10]**

2 marks for each row correctly answered

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

1c) **[16]**

Different circuits could be correct, give 4 marks as long as the truth table follows. Example answers below:



Please note, an alternate symbol for NOT gate is to simply show a circle (instead of the full "triangle + circle" symbol). In the example drawing below, both symbols are acceptable for NOT gate, give full marks if separate not gate symbols are used.

1d) **[4]**

Total of 5 floors can be represented by a binary number with just 3 bits, i.e., 000, 001, 010, 011, 100. It is inefficient to use 5 bits (in current system) to convey the same information that can be conveyed with just 3 bits. Give 1 mark for saying "convert parallel to serial, reduces 5 wires to 1 wire".

1e) **[10]**

You need 3 bits in total. 2 marks. Rest 8 marks for correct truth table.

INPUT					OUTPUT		
I0	**I1**	**I2**	**I3**	**I4**	**O2**	**O1**	**O0**
1	*0*	*0*	*0*	*0*	0	0	0
0	*1*	*0*	*0*	*0*	0	0	1
0	*0*	*1*	*0*	*0*	0	1	0
0	*0*	*0*	*1*	*0*	0	1	1
0	*0*	*0*	*0*	*1*	1	0	0

1f) **[4]**

A 3-bit binary number can count 8 unique states, so a new building with up to 8 levels will be fine.

QUESTION 2 (30 MARKS)

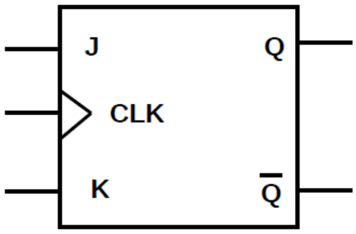
2a) **[4]**

Flip flop is the basic electronic component in any computing system that offers memory capability. Any digital system like a computer requires some form of information retention capability.

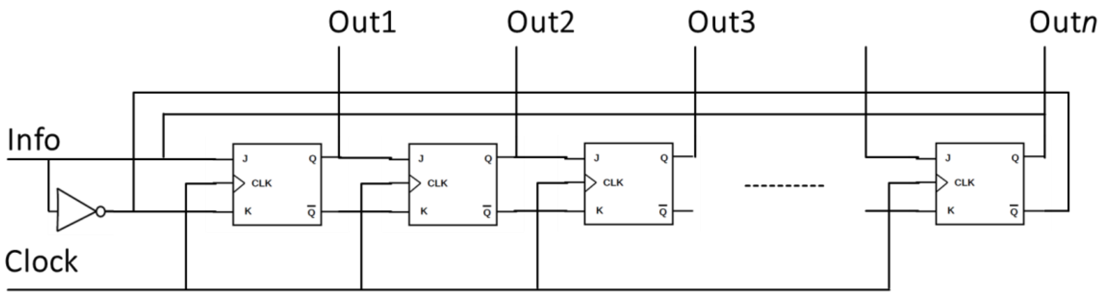
2b) **[8]**

All marks for getting the truth table correctly.

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



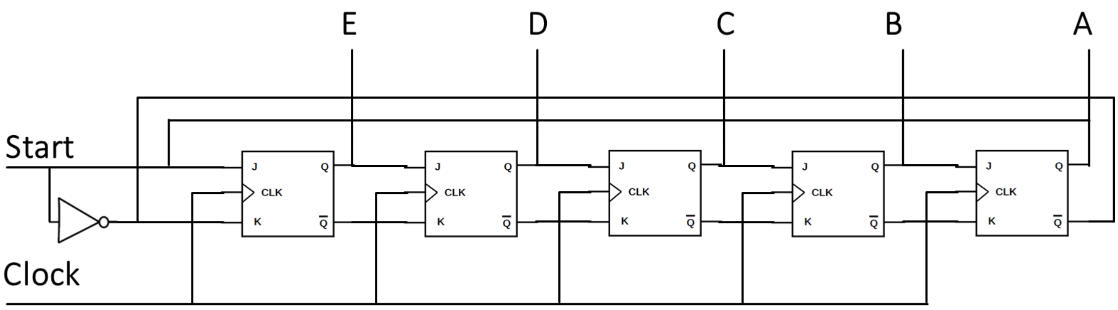
2c) **[4]**



A diagram or simple description in words would be sufficient. A clock is necessary as the pulses trigger "shifting" action in the shift register.

Please note: "Info" is simply a serial string of data; this has no bearing to the Stepper motor control.

2d) **[10]**



4 marks for getting the order correct, does not necessarily have to be E to A, as long as the sequence is correct.

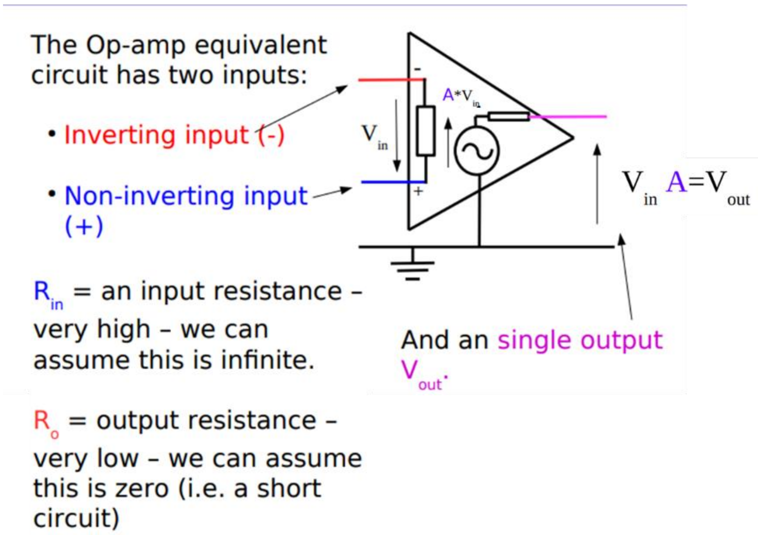
2e) **[4]**

The clock frequency changes the speed, direction is changed by re-routing the phase sequence.

QUESTION 3 (30 MARKS)

Please note: there are several slides in the lectures with incorrect grammar (as has been inherited from previous year's module convenor). Please ignore/excuse these errors. They do not have any bearing on accuracy of technical content or understanding of the concepts.

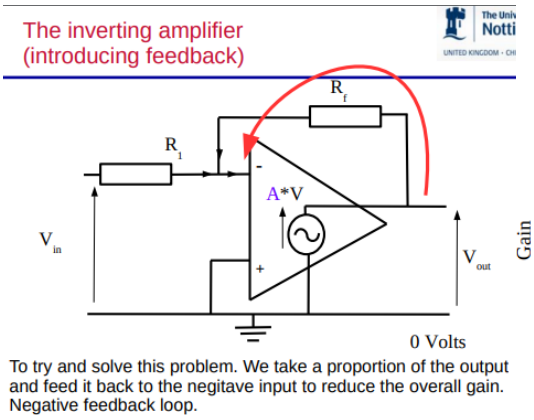
3a) **[4] Only diagram with input, output res and controlled-voltage source with gain value.**

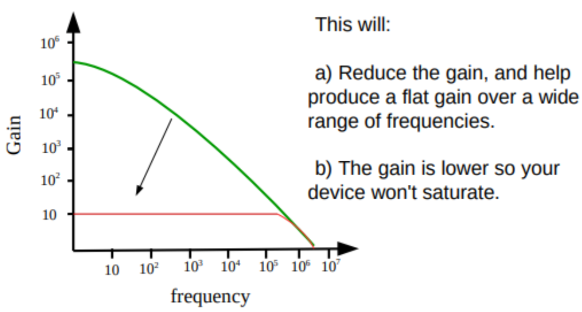


3b) **[4] Near infinite input res, near zero output res, near infinite open-loop gain.**

3c) **[4]**

The voltage gain is very high (so everything other than very small signals would get clipped), and highly non-linear and a function of input frequency. Applying feedback to the inverting input with some feedback resistance solves the problem.

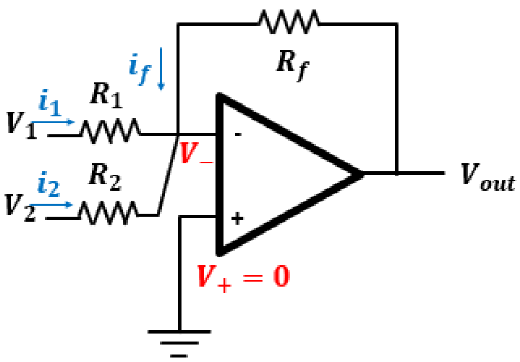




3d) **[8] Take away 2 marks for not showing the derivation**

Summing Amplifier

- $V_1 - V_- = i_1 R_1$
- $V_2 - V_- = i_2 R_2$
- $V_{out} - V_- = i_f R_f$
- $-A_{OL} V_- = V_{out}$



- $i_1 + i_2 = -i_f$
- $\frac{V_1 - V_-}{R_1} + \frac{V_2 - V_-}{R_2} = \frac{V_- - V_{out}}{R_f}$
- $\frac{V_1 + \frac{V_{out}}{A_{OL}}}{R_1} + \frac{V_2 + \frac{V_{out}}{A_{OL}}}{R_2} = \frac{-\frac{V_{out}}{A_{OL}} - V_{out}}{R_f}$
- $\frac{V_1 + 0}{R_1} + \frac{V_2 + 0}{R_2} = \frac{0 - V_{out}}{R_f}$

$$V_{out} = \frac{-R_f}{R_1} V_1 + \frac{-R_f}{R_2} V_2$$

3e) **[4]**

$R_f = R_1 = R_2$ gives $V_{out} = -(V_1 + V_2)$

3f) **[6]**

We need $V_{out} = -(3V_1 + V_2)$, this can be attained by $R_f = 3R_1 = R_2$

QUESTION 4 (30 MARKS)

4a) **[10] 4 marks for finding R_{eqv} 6 marks for voltage**

R_3 and R_4 are in series, $R_{34} = 20000\Omega$

R_2 and R_{34}in parallel, $R_{234} = \frac{R_2 R_{34}}{R_2+R_{34}} = \frac{200.20000}{200+20000} = \frac{4e6}{20200} = 198.0198\Omega$

R_1 and R_{234} in series, $R_{eqv} = R_1 + R_{234} = 50 + 198 = \mathbf{248.0198\Omega}$

Let us apply total of V_{in} volts. This gets divided into R_1 and R_{234} as standard potential divider rule,

$$V_{234} = V_{in}\frac{R_{234}}{R_1 + R_{234}} = V_{in}\frac{198}{248} = 0.798V_{in}$$

Now, we want 2.5A to flow in R_3, which is in series with R_4, so the same current flows. Applying Ohm's Law, $V_{34} = I_{34}R_{34} = 2.5 \times 20000 = 50kV$

Also, $50kV = 0.798V_{in}$

$$\Rightarrow \mathbf{62656V} = V_{in}$$

4b) **[6]**

Converting the earlier resistor network to complex impedance, $Z_R = 248 + j0$

At 50 Hz, $Z_L = R_L + X_L = (1 + j0) + (0 + j\omega L) = 1 + j(2\pi 50)250 \times 10^{-3} = 1 + j78.5$

Therefore, total impedance is, $Z_{eqv} = \mathbf{249.0198 + j78.5398}$

$$|Z_{eqv}| = \sqrt{249^2 + 78.5^2} = \sqrt{62001 + 6162.25} = \mathbf{261.112\Omega}$$

$$angle(Z_{eqv}) = \tan^{-1}\frac{78.5}{249} = \mathbf{17.505°}$$

4c) **[4]**

$$Z_L = R_L + X_L = (1 + j0) + (0 + j\omega L) = 1 + j(2\pi 50)250 \times 10^{-3} = 1 + j78.5398$$

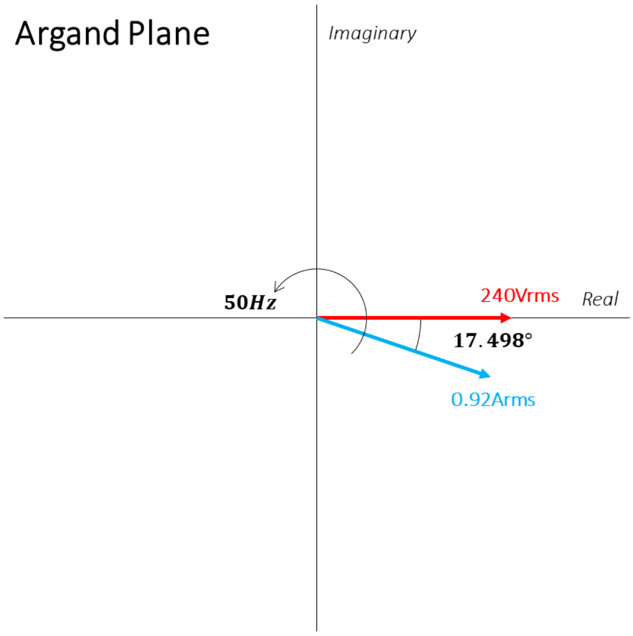
$$|Z_L| = \sqrt{1^2 + 78.5^2} = \sqrt{1 + 6162.25} = \mathbf{78.5462\Omega}$$

$$angle(Z_L) = \tan^{-1}\frac{78.5}{1} = \mathbf{89.27°}$$

4d) **[6]**

We know voltage input, and we know overall impedance. Applying generalised Ohm's law,

$I = \frac{V_{in}}{Z_{eqv}} = \frac{240\angle 0°}{261\angle 17.498°} = \mathbf{0.92\angle - 17.498°}$ **Current of 0.92A lagging the voltage by 17.5 degrees.**



4e) **[4]**

The only effect frequency has is on the reactive component, i.e., the inductor reactance value. As the frequency doubles, the inductor reactance also double. That would have an effect of increasing the total reactive component on the overall impedance, i.e., increase the magnitude slightly and more importantly, the current lags the voltage more as a result.

QUESTION 5 (40 MARKS)

5a) **[4]**

$$Syncrhonous\ speed = n_s = \frac{60 \times 50}{4} = 750\ RPM$$

5b) **[4]**

$$Slip = s = \frac{n_s - n}{n_s} \times 100\% = \frac{750 - 650}{750} \times 100\% = 13.33\%$$

5c) **[4]**

In star-connected neutral connection, $V_{ph} = \frac{V_{l2l}}{\sqrt{3}} = \frac{415}{1.732} = 240V$

5d) **[12]**

Give 3 marks for attempting and getting the equations correctly, 9 more for correct answers

We have been told that winding-resistance-to-reactance-ratio, or $\frac{R_L}{X_L} = a = 0.2$

Using the equation for Torque, $T = \frac{3p}{2\pi f}\frac{V^2 as}{X_L(a^2+s^2)}$,

$$150 = \frac{3 \times 4}{2\pi \times 50}\frac{240^2(0.1333)(0.2)}{X_L(0.1333^2 + 0.2^2)}$$

$$\Rightarrow 150 = \frac{12}{314}\frac{1535.616}{X_L(0.017768 + 0.04)}$$

$$\Rightarrow 150 = \frac{12}{314}\frac{1535.616}{X_L(0.057768)}$$

$$\Rightarrow 150 = \frac{1015.874}{X_L}$$

$$\Rightarrow X_L = \frac{1015.874}{150}$$

$$\Rightarrow \boldsymbol{X_L = 6.7725\Omega}$$

5e) **[12] Give 3 marks for attempting and getting the equations correctly, 9 more for correct answers**

$T = \frac{3p}{2\pi f}\frac{V^2 as}{X_L(a^2+s^2)}$, using this equation and knowing that the value of torque is maximum when s=a,

$$T_{max} = \frac{3p}{2\pi f}\frac{V^2 as}{X_L(a^2+s^2)} = \frac{3(4)}{2\pi(50)}\frac{(240)^2(0.2)(0.2)}{6.7725((0.2)^2+(0.2)^2)} = \boldsymbol{162.432Nm}$$

This is at slip of 20%, so 600 RPM.

5f) **[4]**

We know that $X_L = \omega L$, so reactance is directly proportional to the frequency. If the frequency doubles to 100Hz, reactance also doubles, therefore **halving** the ratio.