2601/201
2602/201
2603/201
CONTROL SYSTEMS AND PROGRAMMABLE
LOGIC CONTROLLERS
Oct./ Nov. 2022
Time: 3 Hours

THE KENYA NATIONAL EXAMINATIONS COUNCIL

# DIPLOMA IN ELECTRICAL AND ELECTRONIC ENGINEERING
# (POWER OPTION)
# (TELECOMMUNICATION OPTION)
# (INSTRUMENTATION OPTION)

## MODULE II

CONTROL SYSTEMS AND PROGRAMMABLE LOGIC CONTROLLERS

3 hours



### INSTRUCTIONS TO CANDIDATES

*You should have the following for this examination:*
*answer booklet;*
*drawing instruments;*
*non programmable scientific calculator.;*
*Nichols chart.*
*This paper consists of **EIGHT** questions in **TWO** sections; A and **B**.*
*Answer any **THREE** questions from section A and any **TWO** questions from section **B** in the answer booklet provided.*
*Maximum marks for each part of a question are as indicated.*
***Candidates should answer the questions in English.***

**This paper consists of 9 printed pages and one insert.**

**Candidates should check the question paper to ascertain that all the pages are printed as indicated and that no question is missing.**

## SECTION A: CONTROL SYSTEMS

*Answer any **THREE** questions from this section.*

1. (a) State two effects of negative feedback on a control system. (2 marks)

(b) Describe the following elements of a closed loop control system:

(i) controller;
(ii) measurement element. (4 marks)

(c) **Figure 1** shows a signal flow graph for a control system. Determine the:

(i) gain for the forward paths;
(ii) gain for the single loops;
(iii) overall transfer function for the system. (7 marks)

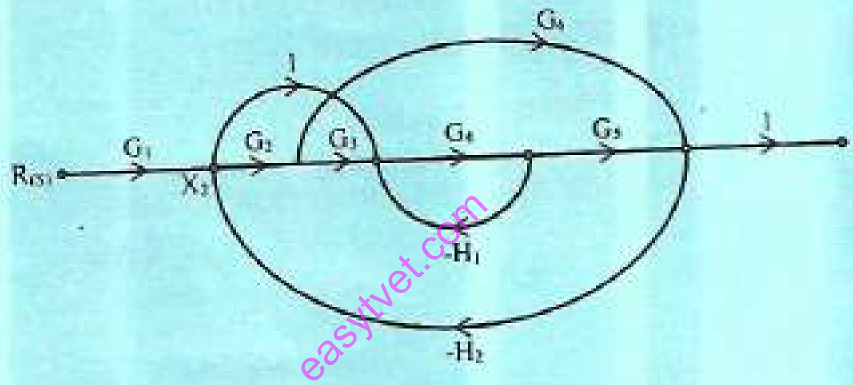




Fig. 1

(d) **Figure 2** shows an Op-AMP based circuit. Derive its transfer function, $\frac{E_{0(s)}}{E_{i(s)}}$. (7 marks)

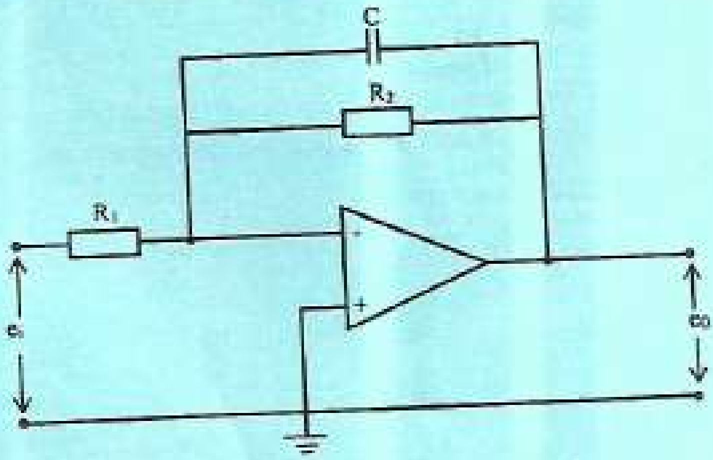



Fig. 2

2. (a) Figure 3 shows a block diagram of a control system. Using block diagram reduction method, derive the transfer function. (10 marks)

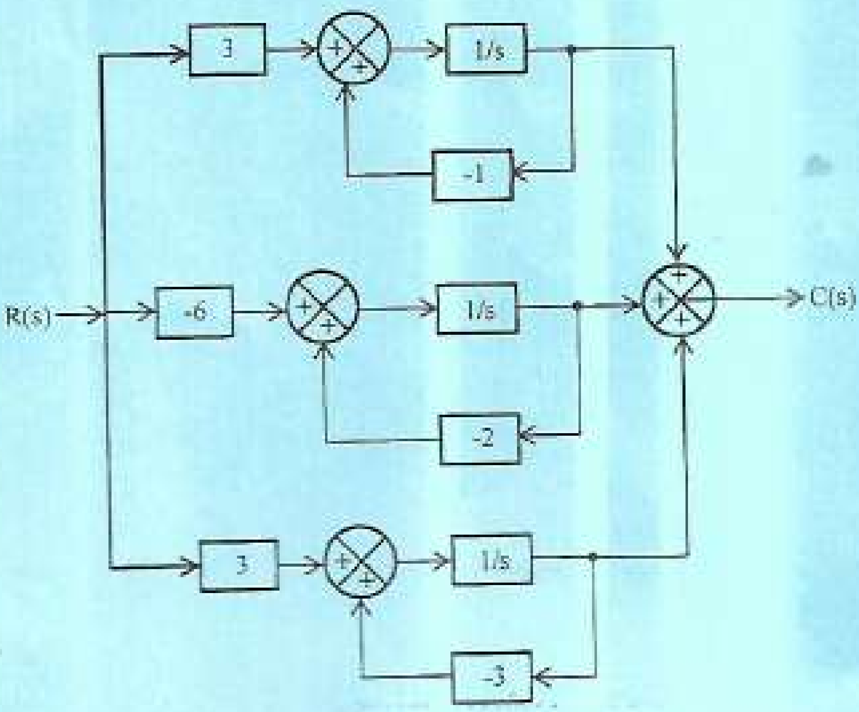



Fig. 3

(b) Table 1 shows the results obtained from an open loop frequency response test on a unity feedback position control system.



**Table 1**

| Frequency (rad/s) | 4.4 | 5.7 | 6.9 | 8.2 | 10.0 | 12.6 | 18.8 |
|---|---|---|---|---|---|---|---|
| Magnitude (dB) | 8 | 5 | 3 | 0.25 | −2.5 | −5.5 | −13 |
| Phase shift ($\theta°$) | −118 | −127 | −133 | −139 | −147 | −150 | −160 |

(i) Draw the Nichols chart for the system.

(ii) Determine:

(I) phase margin;
(II) closed loop $M_{max}$;
(III) gain cross over frequency;
(II) bandwidth.

(10 marks)

3. (a) Draw a graphical representation of each of the following input test signals indicating an expression describing the nature of the curve:

(i) acceleration;
(ii) ramp.

(6 marks)

(b) A servomechanism control system is described by the expression.

$$C_{(t)} = 1 + 0.2e^{-60t} - 1.2e^{-10t}$$

If it's subjected to a unit input, determine the:

(i) expression for closed loop transfer function;
(ii) undamped natural frequency;
(iii) damping ratio.

(10 marks)

(c) On the same axis, draw the response curves of each of the following stating the damping ratio:

(i) overdamped system;
(ii) critically damped system.

(4 marks)



4. (a) (i) State **three** factors that affect the accuracy of an analogue computer.

(ii) A control system is represented by the following second order simultaneous equations:

$$\ddot{y} - 4y - x = 0$$
$$\ddot{x} + 3\dot{x} + 2x = 5$$

Obtain an analogue computer flow diagram to solve the equations.
Assume a ±10 V supply is available. (13 marks)

(b) With the aid of a labelled diagram, explain the operation of a four-phase variable reluctance stepper motor. (7 marks)

5. (a) (i) Define an actuator as applied in automatic control systems.

(ii) List **three** categories of actuators used in control systems.

(5 marks)

(b) **Figure 4** shows asymptotic approximation of log-magnitude versus frequency plot. Derive the transfer function. (10 marks)

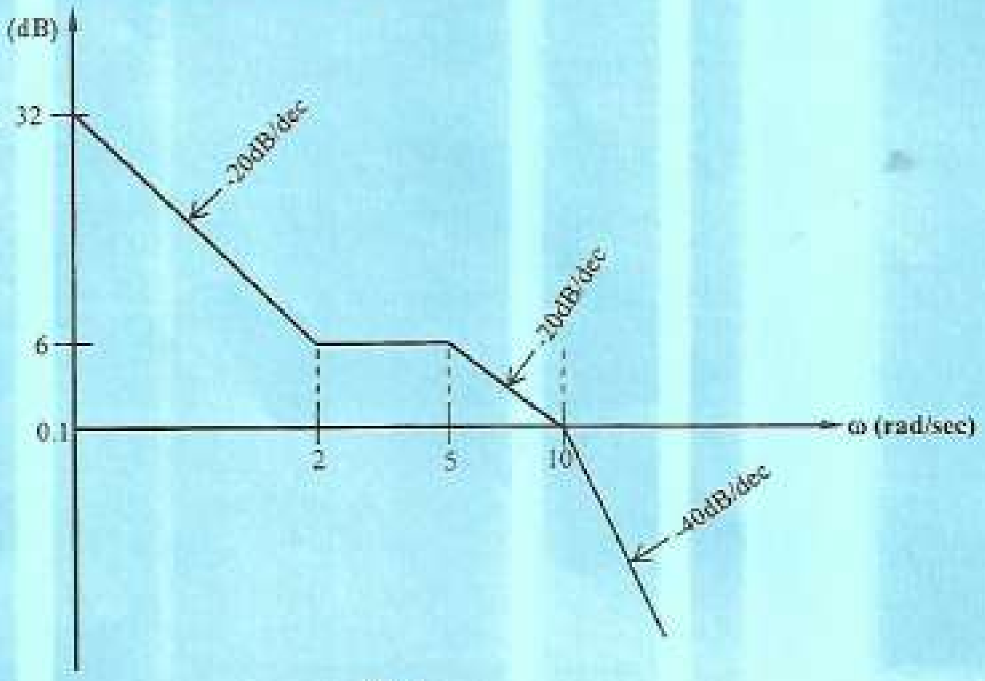



**Fig. 4**

(c) For a system whose open loop gain is given by,

$$G_{H(s)} = \frac{60}{(s+2)(s+10)}$$



a step input of 5% is applied. Determine the:

(i) steady state error;

(ii) error coefficient.

(5 marks)

## SECTION B: PROGRAMMABLE LOGIC CONTROLLERS

*Answer any **TWO** questions from this section.*

6. (a) State any **two**:

(i) types of calibration systems;

(ii) programming devices used in PLCs.

(4 marks)

(b) Table 2 shows a program listing for a PLC. Draw its equivalent ladder diagram program. (6 marks)

**Table 2**

| Steps | Instruction |
|---|---|
| 1 | LD × 400 |
| 2 | OR × 402 |
| 3 | LD × 401 |
| 4 | ORI × 403 |
| 5 | ANB |
| 6 | OUT Y430 |

(c) **Figure 5** shows a roller door for a garage entrance. The door is controlled by a PLC with the sensors and actuator listed in Table 3. Strategic locations have been identified for the installation of the sensors and actuators shown by letters A - E in the **Figure 5**.

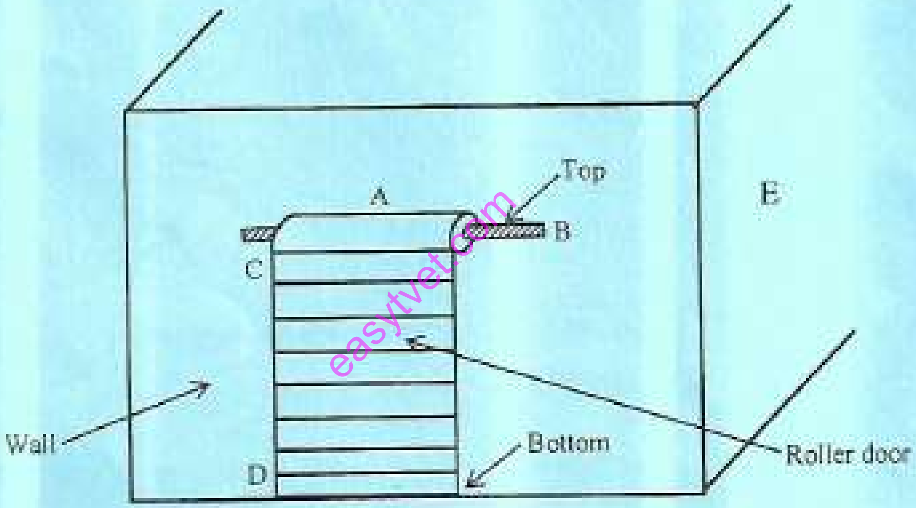




**Fig. 5**

**Table 3**

| **Device** | **Description** |
|---|---|
| - Limit switch | - Normally closed |
| - Infrared transmitter/ receiver | - Provides logic/ when beam is broken |
| - Ultrasound sensor | - Provide logic/ when movement is detected |
| - D.C motor | - Has two connections. Forward (F) to raise the door and reverse (R) to lower the door. |

The operations is as follows.

When an incoming vehicle is detected, the roller door should roll all the way to the top where it will be stopped. When the vehicle is inside, the door should be lowered all the way to the bottom where it will be stopped. Device E is located inside the garage.

(i) Identify from Table 3 the appropriate device to be installed in locations A, B, C, D and E.

(ii) Draw a ladder diagram program to control the opening and closing of the door. (10 marks)

7. (a) State any **three** main elements of a SCADA system. (3 marks)

(b) Describe each of the following terms as used in a SCADA system:

(i) logging;
(ii) archiving.

(4 marks)

(c) With the aid of labelled diagrams, explain the operation of:

(i) distributed SCADA systems;

(ii) point to point communication in a HART communication network.

(10 marks)

(d) State **three** benefits of industrial networks. (3 marks)



8. (a) Describe the following networking devices:

(i) hub;
(ii) bridge;
(iii) switch.

(6 marks)

(b) Outline the **seven** layers of OSI model of industrial networks for outgoing data (7 marks)

(c) State any **two** features for each of the following network layouts:

(i) Local Area Network;
(ii) Wide Area Network.

(4 marks)

(d) Differentiate between Modbus and Profibus protocols used in industrial networking. (3 marks)

## TABLE OF LAPLACE TRANSFORM FORMULAS

$\mathcal{L}[t^n] = \dfrac{n!}{s^{n+1}}$ $\qquad$ $\mathcal{L}^{-1}\left[\dfrac{1}{s^n}\right] = \dfrac{1}{(n-1)!}t^{n-1}$

$\mathcal{L}[e^{at}] = \dfrac{1}{s-a}$ $\qquad$ $\mathcal{L}^{-1}\left[\dfrac{1}{s-a}\right] = e^{at}$

$\mathcal{L}[\sin at] = \dfrac{a}{s^2+a^2}$ $\qquad$ $\mathcal{L}^{-1}\left[\dfrac{1}{s^2+a^2}\right] = \dfrac{1}{a}\sin at$

$\mathcal{L}[\cos at] = \dfrac{s}{s^2+a^2}$ $\qquad$ $\mathcal{L}^{-1}\left[\dfrac{s}{s^2+a^2}\right] = \cos at$

**First Differentiation Formula**

$$\mathcal{L}[f^{(n)}(t)] = s^n\mathcal{L}[f(t)] - s^{n-1}f(0) - s^{n-2}f'(0) - \dots - f^{(n-1)}(0)$$

$\mathcal{L}\left[\int_0^t f(u)\,du\right] = \dfrac{1}{s}\mathcal{L}[f(t)]$ $\qquad$ $\mathcal{L}^{-1}\left[\dfrac{1}{s}F(s)\right] = \int_0^t \mathcal{L}^{-1}[F(s)]\,du$



In the following formulas, $F(s) = \mathcal{L}[f(t)]$ so $f(t) = \mathcal{L}^{-1}[F(s)]$

**First Shift Formula**

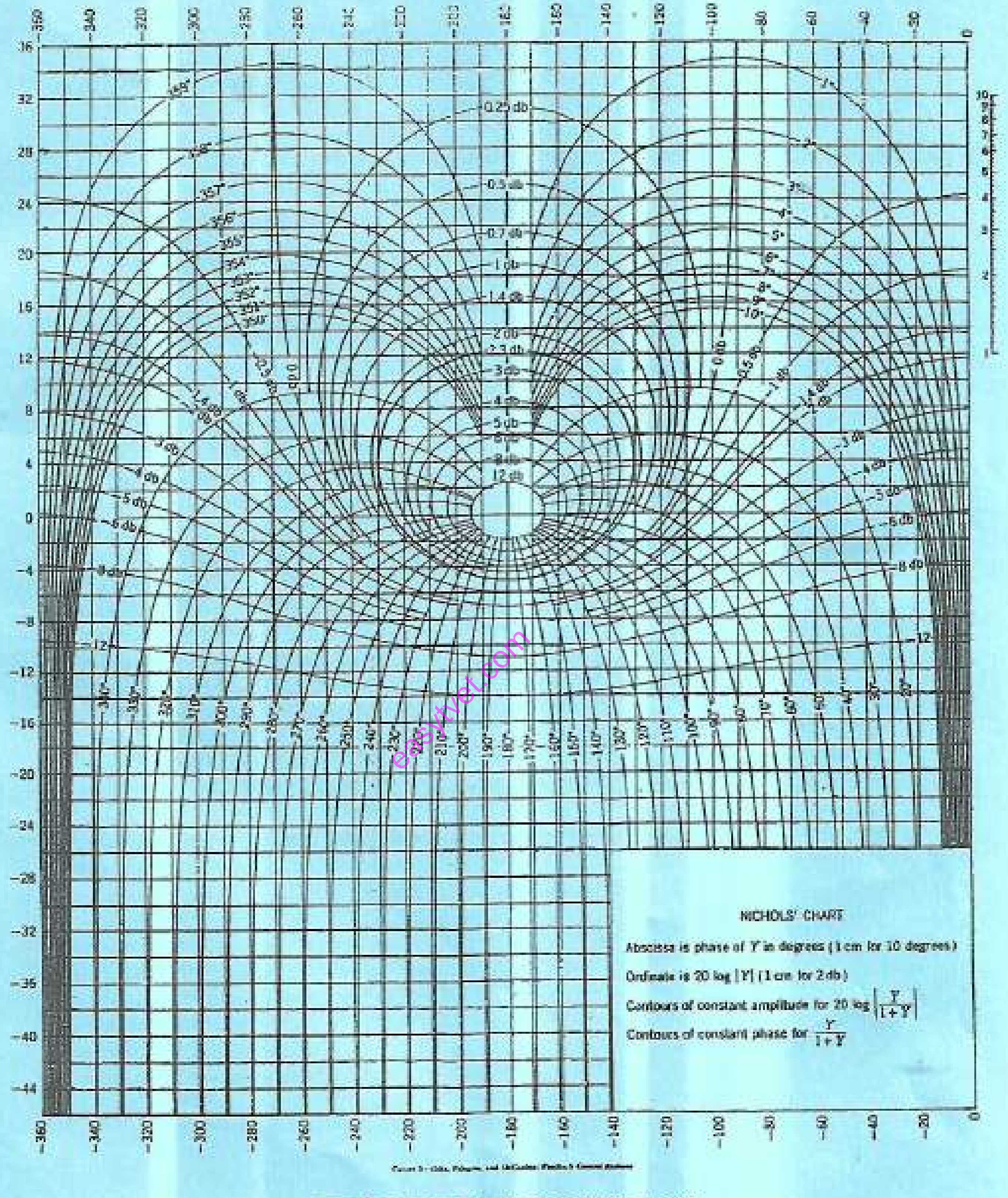
$\mathcal{L}[e^{at}f(t)] = F(s-a)$ $\qquad$ $\mathcal{L}^{-1}[F(s)] = e^{at}\mathcal{L}^{-1}[F(s+a)]$

**Second Differentiation Formula**

$\mathcal{L}[t^n f(t)] = (-1)^n\dfrac{d^n}{ds^n}\mathcal{L}[f(t)]$ $\qquad$ $\mathcal{L}^{-1}\left[\dfrac{d^nF(s)}{ds^n}\right] = (-1)^n t^n f(t)$

**Second Shift Formula**

$\mathcal{L}[u_a(t)g(t)] = e^{-as}\mathcal{L}[g(t+a)]$ $\qquad$ $\mathcal{L}^{-1}[e^{-as}F(s)] = u_a(t)f(t-a)$

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