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**FINAL**
Examination Paper

(COVER PAGE)

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| Session | : | January 2017 |
| Programme | : | Diploma In Electrical And Electronic Engineering (DEEI) |
| Course | : | **EEE2108: Modern Control Systems Engineering** |
| Date of Examination | : | 7 March 2017 (Tuesday) |
| Time | : | 8:00am – 10:00am |
| Duration | : | 2 Hours    Reading Time : Nil |
| Special Instructions | : | |

This paper consists of **SIX (6)** questions. Answer any **FOUR (4)** questions in the answer booklet provided. All questions carry equal marks.

**IMPORTANT NOTE : THIS PAPER SHOULD NOT BE TAKEN OUT OF THE EXAMINATION HALL BY THE STUDENTS.**

Materials Permitted :
Scientific Calculator (Model fx570 Series)

Materials Provided :
Laplace Transform Table
Formula Sheet

Examiner(s) : **Chan Tse Wei**

Moderator : Dr. Ooi Beng Lee

*This paper consists of 6 printed pages, including the cover page.*

INTI INTERNATIONAL COLLEGE PENANG

DIPLOMA IN ELECTRICAL AND ELECTRONIC ENGINEERING PROGRAMME (DEEI)
EEE2108: MODERN CONTROL SYSTEMS ENGINEERING
FINAL EXAMINATION: JANUARY 2017 SESSION

Instructions: This paper consists of SIX (6) questions. Answer any FOUR (4) questions in the answer booklet provided. All questions carry equal marks. Marks for each sub-question are shown in square brackets. Present your answers neatly and clearly. The assessor reserves the rights to ignore your answers if they are ambiguous.

## Question 1

a. Find the negative unity feedback system that is equivalent to the system shown in Figure-Q1(a). [13]

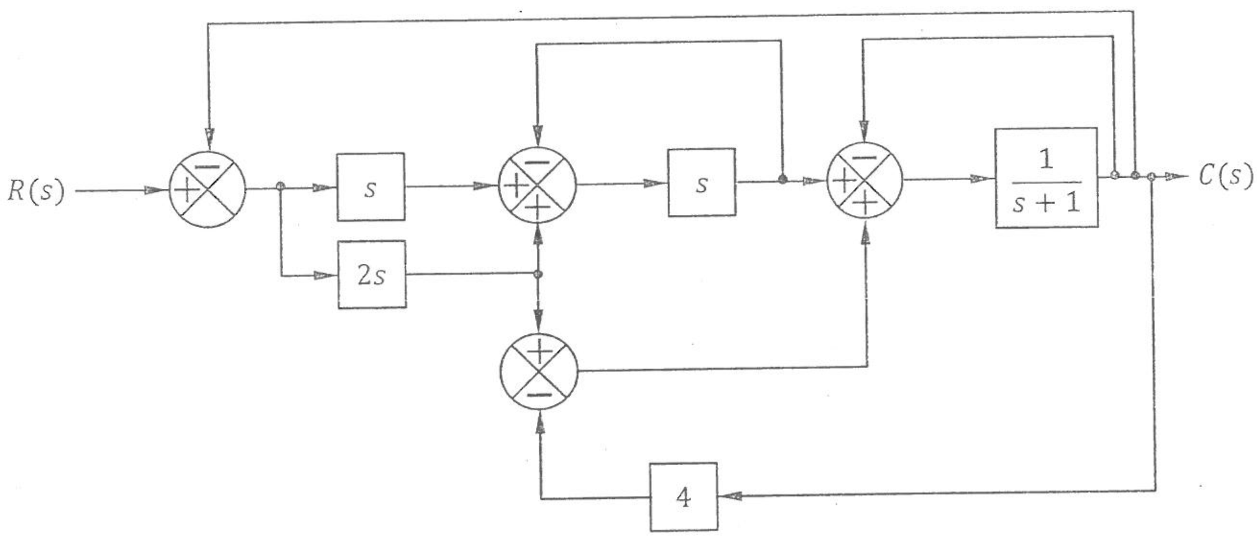


Figure-Q1(a)

b. Find the transfer function, $T(s) = C(s)/R(s)$, of the system represented in the signal flow graph shown in Figure-Q1(b). [12]

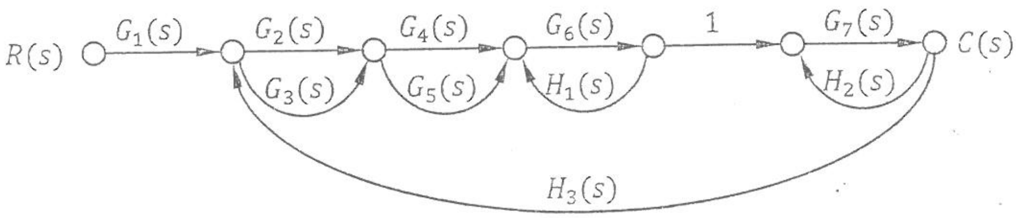


Figure-Q1(b)

## Question 2

a. The behavior of a control system is described by the following differential equation,

$$\frac{d^2c(t)}{dt^2} + 12\frac{dc(t)}{dt} + 32c(t) = 32r(t)$$

Where, $c(t)$ = controlled variable and $r(t)$ = reference variable.

All initial conditions of the system is assumed zero.

i. Solve for $c(t)$ if $r(t)$ is a unit step function. [8]

ii. From the solution obtained in part (a)(i), determine the steady-state value of the controlled variable. [3]

iii. From the solution obtained in part (a)(ii), determine the steady-state error of the system. [2]

b. i. State one advantage of analyzing the behavior of a system in frequency domain. [2]

ii. Define "poles" of a system. [3]

iii. Explain how poles help to identify the stability of a given system. [3]

iv. The transfer function of a system is given by,

$$T(s) = \frac{50(s+2)}{s^3 + 2s^2 + 3s + 4}$$

Calculate the system's poles and identify if the system is stable. [4]

## Question 3

a. i. Explain how Routh-Hurwitz stability criterion helps to immediately identify a system with the following transfer function is unstable.

$$T(s) = \frac{5s}{s^3 - 3s^2 + 4s + 7}$$ [3]

ii. When the Routh-Hurwitz array table has an entire row containing all zero value elements, explain how this condition helps to identify all the pole locations of a forth order system using manual calculation. [3]

iii. Explain how Routh-Hurwitz array table can be used to identify the parameter limits of a system to ensure system stability. [3]

b. A second order system has poles located at $s = -2.1 \pm j5.62$ and a DC gain of 10.

i. State if the system is stable or unstable and briefly explain. [2]

ii. State the damped natural frequency of the system. [2]

iii. Calculate the time constant of the system's transient response. [3]

iv. Calculate the undamped natural frequency of the system. [3]

v. Calculate the damping factor of the system. [3]

vi. Derive the system's transfer function. [3]

## Question 4

a. A negative unity feedback system has an open-loop transfer function given as,

$$G(s) = \frac{60(s+3)(s+4)(s+8)}{s^2(s+6)(s+17)}$$

Calculate the steady-state error of the system if the input is $80t^2u(t)$. [8]

b. The closed-loop transfer function of a system is given by,

$$T(s) = \frac{2500}{s^3 + 52s^2 + 150s + 2500}$$

Approximate the damping factor and undamped natural frequency of the system. [8]

c. Determine appropriate values for the components in Figure-Q4(c) so that the output voltage, $V_{out}$ exhibits the following performance criteria when responding to a unit step input :

Overshoot $= 16.3\%$

Settling time $= 80\ \mu s$ at 2% accuracy

Peak time $= 36\ \mu s$ [9]

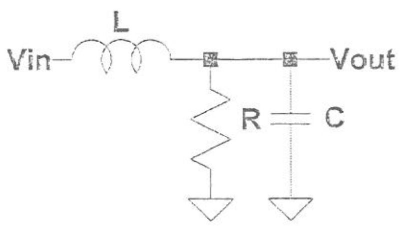


Figure-Q4(c)

Question 5

a. Figure-Q5(a) shows the root locus of a control system.

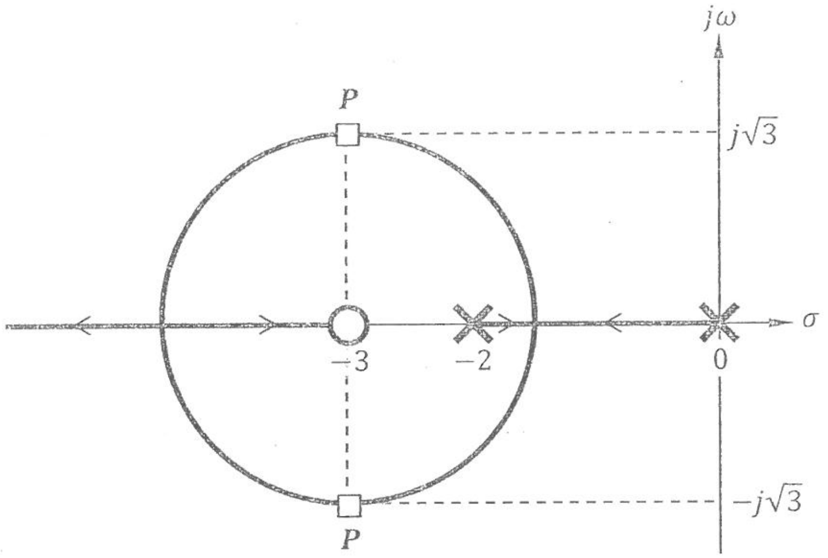


Figure-Q5(a)

i. Determine the system open-loop transfer function, $G(s)H(s)$. [4]

ii. By calculation, find the value of the system open-loop gain, $K$ which locates a closed-loop pole on the locus at $P$. [6]

b. A system has an open-loop transfer function given by,

$$G(s)H(s) = \frac{K}{s(s+3)(s^2+6s+64)}$$

i. Determine by calculation, the maximum value of the gain constant $K$ for which the system is stable in closed-loop. [4]

ii. Sketch the complete root loci for the system. [11]

Question 6

a. A type-0 negative unity feedback system has an open-loop transfer function given by,

$$G(s) = \frac{K}{1 + sT_1}$$

i. Calculate the static position error constant $(K_p)$ of the system. [2]

ii. Sketch the Bode magnitude diagram of $G(s)$. [3]

iii. From the sketch obtained in part (a)(ii), identify the point that indicate the static position error constant of the system. [1]

b. A type-1 negative unity feedback system has an open-loop transfer function given by,

$$G(s) = \frac{K}{s(1 + sT_1)}$$

Assume $K > 1$ and $\frac{1}{T_1} > 1$.

i. Calculate the static velocity error constant $(K_v)$ of the system. [2]

ii. Sketch the Bode magnitude diagram of $G(s)$. [4]

iii. From the sketch obtained in part (b)(ii), identify the points that indicate the static velocity error constant of the system. [2]

c. A type-2 negative unity feedback system has an open-loop transfer function given by,

$$G(s) = \frac{K}{s^2(1 + sT_1)}$$

Assume $K > 1$ and $\frac{1}{T_1} > 1$.

i. Calculate the static acceleration error constant $(K_a)$ of the system. [2]

ii. Sketch the Bode magnitude diagram of $G(s)$. [5]

iii. From the sketch obtained in part (c)(ii), identify the points that indicate the static acceleration error constant of the system. [4]

~ The End ~

# THE LAPLACE TRANSFORM TABLE

| | Definition | $f(t)$ from $t > 0$ | $F(s) = \mathcal{L}[f(t)] = \int_0^\infty f(t)e^{-st}dt$ |
|---|---|---|---|
| 1. | Sum | $af_1(t) + bf_2(t)$ | $aF_1(s) + bF_2(s)$ |
| 2. | First Derivative | $\frac{d}{dt}[f(t)]$ | $sF(s) - f(0)$ |
| 3. | $n^{th}$ Derivative | $\frac{d^n}{dt^n}[f(t)]$ | $s^n F(s) - s^{n-1}f(0) - s^{n-2}f'(0) \cdots f^{(n-1)}(0)$ |
| 4. | Definite Integral | $\int_0^t f(u)du$ | $\frac{F(s)}{s}$ |
| 5. | Shift in $t$ | $f(t - kT)$ | $e^{-skT}F(s)$ |
| 6. | Exponential multiplier | $e^{-\alpha t}f(t)$ | $F(s + \alpha)$ |
| 7. | Periodic function (period T) | $f(t)$ | $\frac{1}{1 - e^{-sT}} \int_0^T e^{-st} f(t)dt$ |
| 8. | Initial Value | $\lim_{t \to 0} f(t)$ | $\lim_{s \to \infty} sF(s)$ |
| 9. | Final Value | $\lim_{t \to \infty} f(t)$ | $\lim_{s \to 0} sF(s)$ |
| 10. | Unit impulse at $t=0$ | $\delta(t)$ | 1 |
| 11. | Unit impulse at $t=$ kT | $\delta(t - kT)$ | $e^{-skT}$ |
| 12. | Unit step | $u(t)$ | $\frac{1}{s}$ |
| 13. | Delayed step | $u(t - kT)$ | $\frac{e^{-skT}}{s}$ |
| 14. | Rectangular pulse (duration kT) | $u(t) - u(t - kT)$ | $\frac{1 - e^{-skT}}{s}$ |
| 15. | Unit ramp | $r(t) = t$ | $\frac{1}{s^2}$ |
| 16. | Delayed ramp | $r(t - kT)$ | $\frac{e^{-skT}}{s^2}$ |

| | Definition | $f(t)$ from $t > 0$ | $F(s) = \mathcal{L}[f(t)] = \int_0^\infty f(t)e^{-st}dt$ |
|---|---|---|---|
| 17. | $n^{th}$ order ramp | $t^n$ | $\frac{n!}{s^{n+1}}$ |
| 18. | Exponential decay | $e^{-at}$ | $\frac{1}{s+a}$ |
| 19. | Exponential growth | $1-e^{-at}$ | $\frac{a}{s(s+a)}$ |
| 20. | Exponential × $t$ | $te^{-at}$ | $\frac{1}{(s+a)^2}$ |
| 21. | Exponential × $t^n$ | $t^n e^{-at}$ | $\frac{n!}{(s+a)^{n+1}}$ |
| 22. | Difference of exponentials | $e^{-at} - e^{-bt}$ | $\frac{b-a}{(s+a)(s+b)}$ |
| 23. | Difference of exponentials | $\frac{1}{b-a}\left(be^{-bt} - ae^{-at}\right)$ | $\frac{s}{(s+a)(s+b)}$ |
| 24. | Sine | $\sin \omega t$ | $\frac{\omega}{s^2+\omega^2}$ |
| 25. | Phase-advanced sine | $\sin(\omega t + \phi)$ | $\frac{\omega \cos\phi + s\sin\phi}{s^2+\omega^2}$ |
| 26. | Sine × $t$ | $t\sin \omega t$ | $\frac{2\omega s}{\left(s^2+\omega^2\right)^2}$ |
| 27. | Exponentially decaying sine | $e^{-at}\sin\omega t$ | $\frac{\omega}{(s+a)^2+\omega^2}$ |
| 28. | Cosine | $\cos\omega t$ | $\frac{s}{s^2+\omega^2}$ |
| 29. | Phase-advanced cosine | $\cos(\omega t + \phi)$ | $\frac{s\cos\phi - \omega\sin\phi}{s^2+\omega^2}$ |
| 30. | Cosine × $t$ | $t\cos\omega t$ | $\frac{s^2-\omega^2}{\left(s^2+\omega^2\right)^2}$ |
| 31. | Exponentially decaying cosine | $e^{-at}\cos\omega t$ | $\frac{s+a}{(s+a)^2+\omega^2}$ |

## Step Response Performance Criteria of 2nd Order System

$$Overshoot, OS = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$$

$$Peak\ Time, t_p = \frac{\pi}{\omega_d}$$

$$Rise\ Time, t_r = \frac{\pi - \cos^{-1}(\zeta)}{\omega_d}$$

$$Settling\ Time, t_s = -\frac{1}{\zeta\omega_n}\ln\left(\frac{P}{100}\right)$$

## Formulas for Root Locus Construction

$$Asymptote\ Centroid, \sigma_A = \frac{\Sigma(poles) - \Sigma(zeros)}{n-m}$$

$$Asymptote\ Angle, \phi_A = \frac{2q+1}{n-m} \times 180°, \qquad q = \{0,1,2,\dots,(n-m-1)\}$$

$$Angle\ of\ Departure, \phi = -\Sigma(other\ GH\ pole\ angles) + \Sigma(GH\ zero\ angle) + 180°$$

$$Angle\ of\ Arrival, \phi' = \Sigma(GH\ pole\ angles) - \Sigma(other\ GH\ zero\ angle) - 180°$$