Ref. No.: Ex/IEE/PC/B/T/224/2022

B.I.E.E. 2nd Yr. 2nd Semester Examination, 2022

SUBJECT: Linear Control Systems

Time: Three hours Full Marks 100

All Modules are Compulsory. Stepwise marking will be done.

| Q.No. | | Marks |
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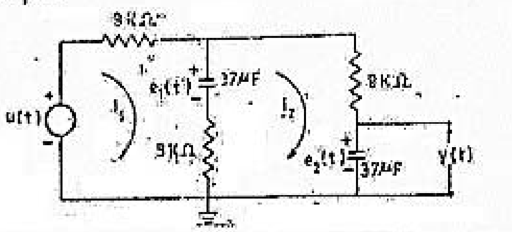
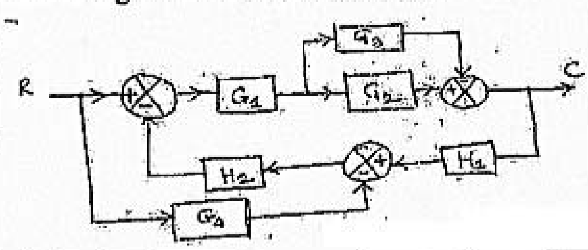
| | **Module I (CO1)** | |
| 1. | a) Provide the following for Figure 1. (i) Laplace domain circuit diagram representation, (ii) KVL using Laplace domain variables, (iii) State variable (SV) representation of system considering states as $e_1(t)$ and $e_2(t)$, input u(t) and output y(t). (iv) T(s)=Y(s)/U(s) using a)KVL in (ii) and b)A, B, C matrices in (iii). Consider all R= 9kΩ and C= 37μF.<br><br>Fig. 1 | 4 |
| | b) Draw the schematic of an automobile assuming two wheels with frictional forces $f_1(t)/2$ each, a brake suspension system ($D_1$, $K_1$) underneath the chassis of mass $M_1$ and top loaded with a seat of mass $M_2$ connected through a seat suspension system ($D_2$, $K_2$). Assume a force of $f_2(t)$ acting on the seat due to passenger weight. Derive the system equations and formulate and draw the force-voltage analog circuit. | 2+2+2 |
| | OR | |
| | Draw a two tank liquid level system with an inlet flow rate of Q+q and outlet flowrate of $Q+q_2$. Consider the tank capacities as $C_1$ and $C_2$ and the intermediate and end point restrictions as $R_1$ and $R_2$ respectively. The flow rate through $R_1$ may be considered as $Q+q_1$. Derive the system equations and derive and draw the electrical analog circuit. | 2+2+2 |
| 2. | (i) State with diagrammatic support the rule for a) moving summing point ahead of a pick-off point and b) moving a pick-off point ahead of a summing point. Use block-diagram reduction in Figure 2a to obtain C/R. Draw the equivalent signal flow graph of the system. Use Mason's gain formula to obtain C/R.<br><br>Fig.2a | 2+3+2+3 |

| Q.No. | | Marks |
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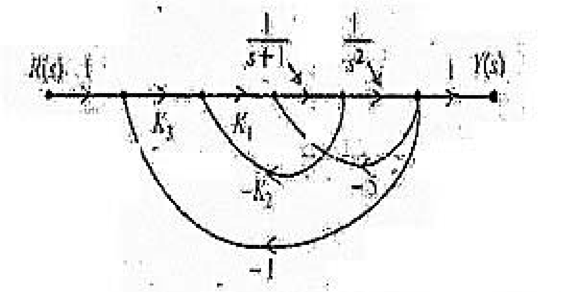
| 2. contd. | OR | |
| | a) Find TF for $K_1=1$, $K_2=5$ and $K_3=5$ as in Fig.2b using Mason's gain formula. Forward gains are 1, 1, 1, $1/(s+1)$, $1/s^2$ and 1 resp. Draw equivalent block diagram and use block diagram algebra to obtain the TF. Find sensitivity of TF to change in $K_1$ and $K_3$ at dc operating conditions. | 3+2+3+2 |
| |   Fig. 2b | |
| | **Module 2 (CO2)** | |
| 3. | Derive a) the unit step response for a 2[nd] order underdamped system from first principles, b) the initial value, c) the transient response, d) the envelopes and d) their start values, $t_p$, $M_p$, and $t_s$. Draw the response illustrating all items listed in a)-d). | 6+4 |
| | OR | |
| | a) Identify type of system for a closed loop unity feedback control system with $G_1(s) = (s+2)/(s+4)$ and $G_2(s) = 4/s(s+1)$. Compute the error constants and steady state errors for unit step, ramp and parabolic inputs. | 6 |
| | b) A unity feedback system having closed-loop transfer function $\omega_n^2/(s^2 + 2\zeta\omega_n s + \omega_n^2)$ should have a maximum overshoot of 20% and settling time ≤ 2s. Determine required $\omega_n$ and $\zeta$. | 4 |
| 4. | Show the pole locations of 2 systems with a) same $\sigma$, b) same $\zeta$, c) same $\omega_d$, while the other parameters are different. Show the comparative time domain responses of the systems and justify in terms of $M_p$, $t_s$ etc. | 3x3 +1 |
| | OR | |
| | Consider a unity feedback position servomechanism with forward gains $G_1=6.88 \times 10^4$ and $G_2(s) = 1/s\ (200s + 5 \times 10^3)$. Determine close loop TF, $\zeta$, $\omega_n$, $\omega_d$, $M_p$, $t_p$, $t_s$, $e_{ss}$ for step input of 1 rad, $e_{ss}$ for constant angular velocity of 1 rpm. | 10 |

| Q.No. | | Marks |
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| | **Module 3 (CO3)** | |
| 5. | a) For a simple pole $1/(1+j\omega T)$, draw the asymptotic Bode (i) magnitude plot and (ii) phase plot, (iii) identify the critical frequency, (iv) derive the expression for the asymptotic segments and (v) derive the values of errors at twice and ten times the critical frequency. | 2+2+1+3+2 |
| | b) For a unity feedback system with $GH(s)=K/s(s+4)(s+5)$, determine (i)the breakaway point, (ii)the critical gain and the critical frequencies and (iii) the gain margin at K=180 in dB. | 6 |
| | c) For a system $GH(s)=Ke^{(-sT)}/s(s+2)$, draw the root locus. Mention the change in angle condition and its implication in the root locus. | 4 |
| | OR | |
| | For the system having open loop TF $GH(s) = 160(s+1)/s^2(s^2+4s+16)$,<br>a) Identify Bode components and state magnitude and phase characteristics of the components, identify critical frequencies.<br>b) Draw the Bode magnitude and phase plots using asymptotes,<br>c) Provide table for calculated and graphically obtained gain and phase values at critical frequencies.<br>d) Identify gain margin, phase margin in the plots and compare graphical gain and phase margins with theoretical values.<br>e) Comment on system stability. | 4+8+4+3+1 |
| 6. | a) Draw the root contours of the system with $GH(s) = K/s(s+1)(s+\alpha)$.<br>OR<br>Draw the root locus of $GH(s) = Ks/(s^2+4)(s^2+16)$. | 10 |
| | b) Draw Nyquist contour and Nyquist plot of $G(s)=1/s(sT+1)$. What is the real intercept at $\omega = 0$?<br>OR<br>Draw Nyquist contour and Nyquist plot of $G(s) = 10(s+3)/s(s-1)$. Determine $\omega$ for real axis crossing and the gain thereof. | 6 |
| | c) State the expressions for GM and PM. Illustrate $\omega_p$, $\omega_g$, GM and PM in notional Bode magnitude and phase plots. Show how GM and PM are identified in a log magnitude vs. phase plot. | 6 |
| | d) How to determine the $\omega$ at which PM is $+90°$ using N circles?<br>OR<br>Derive from first principles the relation for M circles in terms of the real and imaginary parts of $G(j\omega)$. | 3 |

| Q.No. | | Marks |
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| | **Module 4 (CO4)** | |
| 7. | For a system with $GH(s) = K(s+2) / (s^2+2s+3)$, determine K for a) repetitive roots, b) $\zeta = 0.7$ and c) range of K for underdamped closed loop system. | 6 |
| | OR | |
| | a) Determine the value of controller gains $K_p$ and $K_I$ for a forward path PI controller $(K_p + K_I/s)$ for a unity feedback system with $G(s) = 2/(s+4)$ so that its damping ratio and natural frequency of oscillation become 1 and 4 Hz resp. | 3 |
| | b) Determine the range of values of K of a unity feedback system with $G(s) = K/s(s+1)$ so that $e_{ss} < 0.004$ when $r(t) = 0.2t$. | 3 |
| 8. | For a unity feedback system with $G(s)=4/s(s+2)$, determine $\xi$, $\omega_n$, $\omega_d$, $\omega_g$ and PM theoretically.<br>a) How much is the lead/lag compensation required to achieve $PM \geq 50°$?<br>b) (i) Determine the amount of lead/lag compensation required if the system is desired to have $\omega_n = 4$ rad/s for the same $\xi$.<br>(ii) Draw a passive RC circuit to provide the suitable angle compensation and state values of elements. | 5+1+1+2 |
| | OR | |
| | Design a lead compensator for a type 1 unity feedback system with $G(s)=K/s(s+1)$. For this, a) determine system gain needed, b) sketch the Bode plot and determine $\omega_g$ and PM, c) determine amount of phase compensation needed, d) determine corresponding $\alpha$ and new $\omega_g$, and $\tau$ and e) lead compensator TF and overall compensated system TF. | 1+3+1+2+2 |