COURSE PLAN

A. COURSE OVERVIEW

Degree:	BE	Programme:	EC
Academic Year:	2024-25	Semester:	IV
Course Title:	Control Systems	Course Code:	BEC403
L-T-P-S:	3-0-2-0	Duration of SEE	3 Hrs
Total Contact Hours:	40 hours Theory+ 12 Lab slots	SEE Marks:	50*
CIE Marks:	50	IA Test	30
Credits:	04	Components	20
Lesson Plan Author:	Mrs Sowmya Anil	Sign	Date 29/01/25
Checked By:	Mr ShivaPrasad	Sign	Date 29/01/25

*The SEE will be conducted for 100 marks and proportionally reduced to 50 marks.

B. PREREQUISITES

- Mathematics-III for EC Engineering (BMATEC301)
- Network Analysis(BEC304)
- Introduction to Electrical Engineering (BESCK104B-204B)

C. COURSE DESCRIPTION

i) Course Outcomes

At the end of the course, the student will be able to;

- Develop the mathematical model of mechanical and electrical systems from differential equations representation.
- Deduce Transfer function from Block diagram representation and signal flow representation.
- Calculate the time response specifications
- Draw and analyse the effect of gain on system behaviour using root loci.
- Perform frequency response analysis and find the stability of the system.

ii) Relevance of the Course

- Signal processing
- Micro Electro Mechanical System

iii) Applications areas

- Industrial control systems are used in industrial production for controlling an equipment or machine
- Air flight control system.
- Engine control system.
- Robotics.
- Intelligent flight control system.

Mrs Sowmya Anil Prepared by:	Mr Shivaprasad Checked by:	HOD

D1. ARTICULATION MATRIX, CO v/s PO

Mapping of CO to PO

	POs											
COs	1	2	3	4	5	6	7	8	9	10	11	12

1.Develop the mathematical model of mechanical and electrical systems from differential equations representation.	3	3	2	1	-	-	-	-	-	-	-	1
2.Deduce Transfer function from Block diagram representation and signal flow representation.	3	3	1	2	2	-	-	-	-	-	-	1
3.Calculate the time response specifications and analyze the stability of the system	3	3	2	2	1	-	-	-	-	-	-	1
4.Draw and analyse the effect of gain on system behaviour using root loci.	3	3	3	3	2	-	-	-	-	-	-	1
5.Perform frequency response Analysis and find the stability of the system.	3	3	2	2	2	-	-	-	-	-	-	1

D2. ARTICULATION MATRIX, CO v/s PSO

Mapping of CO to PSO		
	PSOs	
COs	1	2
1.Develop the mathematical model of mechanical and electrical systems from differential equations representation.	-	-
2.Deduce Transfer function from Block diagram representation and signal flow representation.	-	1
3.Calculate the time response specifications and analyze the stability of the system	-	2
4.Draw and analyse the effect of gain on system behaviour using root loci.	-	2
5.Perform frequency response Analysis and find the stability of the system.	-	2

E. MODULE PLANS
MODULE – I

Title: Introduction to control systems	Appr. Time:	8– Hrs
MO:		RBT
At the end of the Module, the student will be able to:		
1.Differentiate between open loop and closed loop system.		L1
2.Define transfer function of closed loop control system.		L2
3. Understand the physical and mathematical modeling of systems.		L3
4. Convert mechanical system into electrical system.		L3

Lesson Schedule:

Lecture No.	Portion to be covered	CO
1	Introduction to Control Systems.	CO1
2	Types of Control Systems, Effect of Feedback Systems	CO1
3	Differential equation of Mechanical Systems(translational),	CO1
4	Differential equation of Mechanical Systems(rotational),	CO1
5	Differential equation of Electrical Systems,	CO1
6	Differential equation of Electrical Systems(problems)	CO1
7	Differential equation of Electrical Systems(problems)	CO1
8	Analogous Systems.(F-V,F-I) problems	CO1

9	Analogous Systems.(T-V,T-I)problems	CO1
10	Analogous Systems problems	CO1

Application Areas:

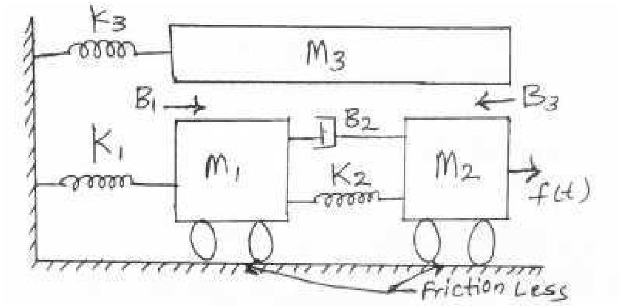
- Automotive fields
- To develop transfer functions for the systems.

Review Questions / Questions Appeared in the Previous Years (CO):

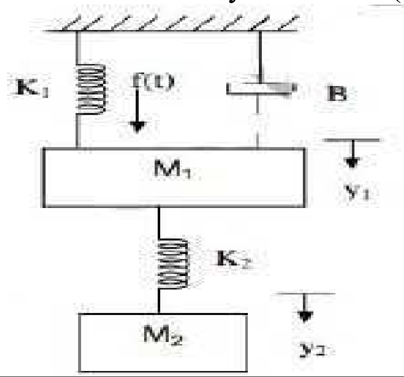
1	What are the merits and demerits of closed loop control system(CO1)
2	Define control system and explain the same with an example(CO1)
3	Compare closed loop and open loop control systems. Give one example for each (CO1)

4 For the mechanical system shown in fig.

1. Draw the mechanical network
2. Obtain equations of motion
3. Draw an electrical network based on force current analogy(CO1)

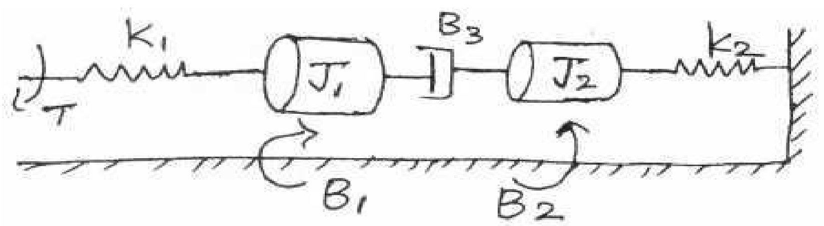


5 Determine the transfer function of system below(CO1)

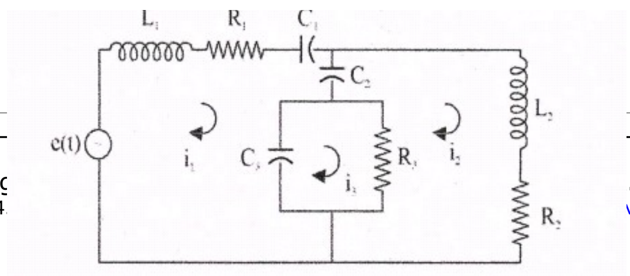


6 For the mechanical system shown in fig (CO1)

1. Draw equivalent mechanical network
2. Write performance equations
3. Draw torque-voltage analogy(CO1)



7 Find the translational mechanical system for the force voltage electrical circuit? (CO1)



8	What are the effects of negative feedback in control systems?(CO1)

MODULE – II

Title:	Block Diagram and Signal Flow Graph	Appr. Time:	8– Hrs
MO:			RBT
At the end of the Module, the student will be able to:			
1. Represent a system using block diagram			L2
2. Derive the transfer function of the black diagram using the reduction techniques			L3
3.Represent a system using signal flow graph			L3
4. Derive the transfer function from the signal flow graph using Mason's formula			L3

Lesson Schedule:

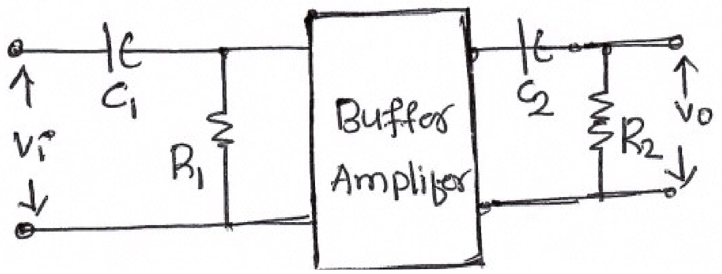
Lecture No.	Portion to be covered	CO
1	Block diagrams introduction and rules for block diagram reduction	CO2
2	Problems to reduce the block and find transfer functions.	CO2
3	Problems to reduce the block and find transfer functions.	CO2
4	Problems to reduce the block and find transfer functions	CO2
5	Signal flow graphs introduction, Mason gain formula	CO2
6	To draw signal flow graph for a given block and circuit	CO2
7	Transfer functions from signal flow graph	CO2
8	Transfer functions from signal flow graph	CO2
9	Transfer functions from signal flow graph	CO2
10	Transfer functions from signal flow graph	CO2

Application Areas:

- Signal Processing
- Modeling techniques

Review Questions / Questions Appeared in the Previous Years (CO):

1. Obtain the transfer function Vo(s)/Vi(s) for the system shown with unity gain buffer amplifier(CO2)



2. The system block diagram is given below in fig.3(c).Find C(s)/R(s) if N(s)=0(CO2)

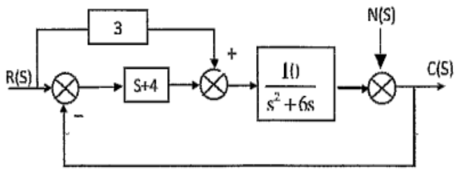
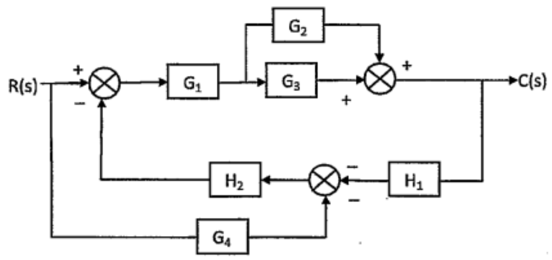
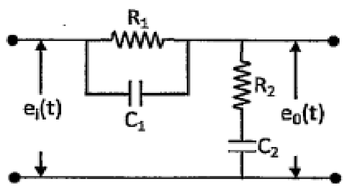
<table>
<tr><td></td><td>


FIG 3 (c)
</td></tr>
<tr><td>3</td><td>
Reduce the following block diagram of the system shown in Figure below into a single equivalent block diagram by block reduction rules (CO2)



</td></tr>
<tr><td>4</td><td>
Derive the transfer function for the lead lag network shown in the fig below, when R1=R2=1MΩ , C1=C2=1μF (CO2)



</td></tr>
<tr><td>5</td><td>
Find the transfer function for the below shown signal flow graph using Mason's Gain formula. (CO2)

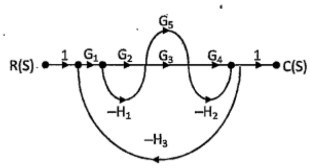


FIG 4 (b)
</td></tr>
<tr><td>6</td><td>Find the transfer function for the signal flow graph shown in fig. 4(b)above using block diagram reduction technique(CO2)</td></tr>
<tr><td>7</td><td>
Illustrate how to perform the following in connection with block diagram reduction techniques:(CO2)
a) moving a summing point ahead of a block and behind a block
b) moving a take off point ahead of a block and behind a block
</td></tr>
<tr><td>8</td><td>
Find the transfer function by constructing the block diagram and reducing the same for the circuit shown below in fig 4(b)(CO2)

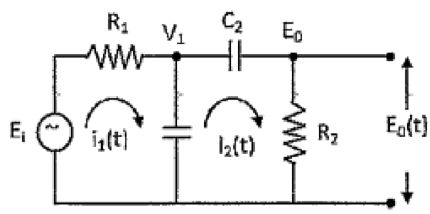


Fig 4(b)
</td></tr>
<tr><td>9</td><td>Find the transfer function by constructing the SFG and Mason's gain formula for the circuit in fig. 4.(b) above.(CO2)</td></tr>
</table>

COURSE PLAN

MODULE – III

Title:	Time Response of feedback control systems	Appr. Time:	8 – Hrs
MO:			RBT
At the end of the Module, the student will be able to:			
1 Understand different test signals			L2
2 Understand and derive response of first and second order systems			L3
3 Determine type of the system, steady state error and error constants			L3
4 Analyze the time response of a given system			L3
5 Understand PI, PD and PID Controllers			L2

Lesson Schedule:

Lecture No.	Portion to be covered	CO
1	Standard test signals	CO3
2	Unit step response of First and Second order Systems.	CO3
3	Unit step response of First and Second order Systems.	CO3
4	Unit step response of First and Second order Systems.	CO3
5	Time response specifications	CO3
6	Time response specifications	CO3
7	Time response specifications of second order systems	CO3
8	Time response specifications of second order systems	CO3
9	Steady state errors and error constants.	CO3
10	Introduction to PI, PD and PID Controllers	CO3

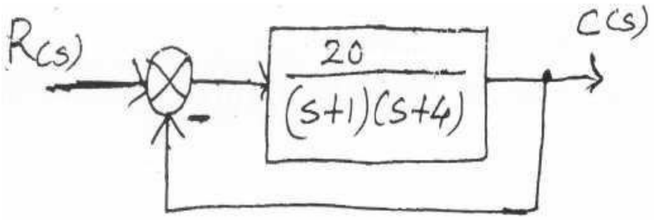
Application Areas:

- Used in radar tracking systems
- Used to study the transient behavior of the systems

Review Questions / Questions Appeared in the Previous Years (CO):

1 List the standard test inputs used in control system and write their Laplace transform.(CO3)

2 For the system shown in fig obtain closed loop transfer function, damping ratio, natural frequency and expression for the output response if subjected to unit step input .(CO3)



3 Find Kp, Kv, Ka and steady state error for a system with open loop transfer function as

$$G(s)H(s)=\frac{10(s+2)(s+3)}{s(s+1)(s+5)}$$ where the input is $r(t)=3+t+t^2$.(CO3)

4 What are static error coefficients? Derive expression for the same .(CO3)

5 For a unity feedback control system with G(s)=64/s(s+9.6). Write the output response to unit step input. Determine i)the response at t=0.1sec ii) settling time for 2% of steady state. .(CO3)

6 For a given system $G(s)H(s)=\frac{K}{s^2(s+3)(S+2)}$. Find the value of K to limit the steady

	state error to 10 when the input is $1+10t+20t^2$. .(CO3)
7	An unity feedback system has $G(s)=20(1+s)/S^2(2+s)(4+S)$. Calculate its steady state error co-efficient when the applied input r(t) : $40 + 2t+ 5t^2$. (CO3)
8	Write the general block diagrams for PD, PI, PID type controllers. .(CO3)
9	A unity feedback control system has an open loop transfer function G(S)= 10/S(S+2).Find the rise time, percentage over shoot, peak time and settling time. .(CO3)
10	For a unity feedback control system the open loop transfer function G(S) = 10(S+2)/ S2(S+1).Find (a) position, velocity and acceleration error constants. (b)the steady state error when the input is R(S) where $R(S) =3/S –2/S^2+1/3S^3$ (.(CO3)
11	The open loop transfer function of a servo system with unity feed back system is G(S) = 10/ S(0.1S+1).Evaluate the static error constants of the system. Obtain the steady state error of the system when subjected to an input given Polynomial $r(t) = a_0 +a_1t +(a_2 /2)t^2$ (CO3)
12	The unity feedback system is characterized by an open loop transfer function is G(S)= K / S(S+10).Determine the gain K ,so that the system will have a damping ratio of 0.5.For this value of K, determine settling time, Peak overshoot and time to Peak overshoot for unit step function.(CO3)

MODULE – IV

Title:	Stability analysis and Introduction to Root-Locus Techniques,	Appr. Time:	8 – Hrs
MO:			RBT
At the end of the Module, the student will be able to:			
1.Understand the concept of stability			L2
2.Analyze the stability using Routh stability criterion			L2
3.Use root locus approach to determine the location of the roots in the s- plane, and analyze the system stability			L2
	Lecture No.		
1	Concepts of stability		CO3
2	Routh stability criterion		CO3
3	Relative stability analysis		CO3
4	Problems on the Routh stability criterion,		CO3
5	Introduction to Root-Locus Techniques,		CO4
6	Construction of root loci		CO4
7	Problems on Root-Locus Techniques		CO4
8	Problems on Root-Locus Techniques		CO4
9	Problems on Root-Locus Techniques		CO4
10	Problems on Root-Locus Techniques		CO4
Application Areas:			
•Stability of systems in automobile •Stability of machines.			
Review Questions / Questions Appeared in the Previous Years (CO):			
	1		
2	$s^6+ 4s^5+ 3s^4-16s^2-64s-48=0$. find the number of roots of this equation with positive real part, zero real part and negative real part using RH criterion.(CO3)		
3	Sketch the rough nature of the root locus of a certain control system whose characteristic		

	equation is given by $s^3 + 9s^2 + Ks + K = 0$, comment on the stability.(CO3)
4	For the system with characteristics equations $s^4 + s^3 + s^2 + s + 1 = 0$,determine the range of K for stability.(CO3)
5	Sketch the root locus plot for a negative feedback control system whose open loop transfer function is given by G(s) H (s)= K /s(s+ 3)(s ^{2} + 2s+ 2) for all values of K ranging from 0 to ∞ . Also find the value of K for a damping ratio of 0.5.(CO4)
6	The open loop transfer function of a unity feedback system is G(s)= K (s+ 2) / s(s+ 3)(s ^{2} + 2s+ 2) 1. find the value of K so that the steady state error for the input r(t)=tu(t) is less than or equal to 0.001 2. for the value of K found in part 1, verify whether the closed loop system is stable or not using RH criterion(CO4)
7	Feed back control system has a characteristic equation $s^6+2s^5+9s^4+16s^3+24s^2+32s+16=0$. How many poles are in the left half of the s-plane, on imaginary axis and on right half of the s-plane(CO3)
8	Feed back control system has a characteristic equation $s^5-s^4-2s^3+2s^2-8s+8=0=0$. How many poles are in the left half of the s-plane, on imaginary axis and on right half of the s-plane.(CO4)
9	The polynomial P(s) $=s^4+2s^3+3s^2+s+1$ has all roots in LHS of a plane. Use R-H criterion to determine the number of roots of P(s) lying between s=-1/2 and s=-1.(CO3)
10	A negative feedback control system has, $G(s)=K/s(s^2+s+1)$ and $H(s)=1/(s+4)$. Determine the range of K for the absolute stability of the system,also determine the frequency of sustained oscillations for the limiting value of K. Sketch the root locus (CO4)
11	For a closed loop control system $G(s)=100/s(s+8)$, H(s) = 1. Determine the resonant peak and resonant frequency. (CO4)

MODULE – V

Title:	Frequency domain analysis and stability	Appr. Time:	– Hrs
MO:			RBT
At the end of the Module, the student will be able to:			
1.Sketch the bode plot for the given transfer function and determine the relative stability from it.			L2
2.Evaluate or (determine) the transfer function of a given system from its bode plot and polar plot			L2
3. Determine the stability of closed loop system by investigating the properties of the frequency domain plot, the Nyquist plot.			L2
4. Grasp the foundational concepts of states, state variables, and their role in modeling dynamic systems.			L2
5. Express the state-space model in canonical forms.			L2
Lesson Schedule:			

Lecture No.	Portion to be covered	CO
1	Correlation between time and frequency response	CO5
2	Bode Plot and determination of transfer function	CO5
3	Bode Plot and determination of transfer function	CO5
4	Bode Plot and determination of transfer function	CO5
5	Bode Plot and determination of transfer function	CO5

6	Nyquist Stability criterion	CO5
7	Concept of State, State variables & State model,	CO3
8	State model for Linear Continuous systems and Discrete time systems	CO3
9	Diaganolisation.	CO3
10	Problems on state variable	CO3

Application Areas:

- To find controllability of electrical, mechanical and automobile system.
- Assessing relative stability of electrical systems using Nyquist criterion

Review Questions / Questions Appeared in the Previous Years (CO):

1 For a unity feedback system $G(s)=\frac{242(s+5)}{s(s+1)(s2+5s+121)¿}$ sketch the bode plot and find w_{gc}, w_{pc} ,gain margin and phase margin.(CO5)

2 Draw the bode plot for a system having

G(s)= $\frac{K(1+0.2s)(1+0.025s)}{s3(1+0.01s)(1+0.005s)}$

Comment on the stability of the system .Also find the range of K for stability (CO5)

3 State and explain Nyquist Stability Criterion.(CO5)

4 Sketch the bode plot for the transfer function

$G(s)=\frac{Ks^2}{(1+0.2s)(1+0.02s)}$ (CO5)

5 Define Gain margin, Phase margin Gain cross over frequency and phase cross over frequency (CO5)

6 Plot the bode diagram for the open loop transfer function of a unity feed back system given by $G(s)=\frac{100(0.1s=1)}{s(s+1)^2(0.01s+1)}$. Find gain margin and phase margin.Also comment on the closed loop stability of the system. (CO5)

7 A linear time invariant system is characterized by the homogeneous state equation:(CO5)

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

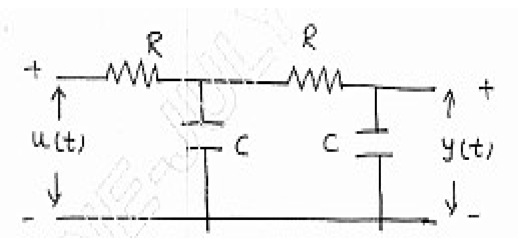
Compute the solution of homogeneous equation. Assume initial state vector

$X_0=\begin{pmatrix} 1 \\ 0 \end{pmatrix}$ (CO5)

8 Define the following terms i)state ii) state variables iii) state space iv) state vector (CO5)

9 List the advantages of state variable analysis (CO5)

10 Obtain an appropriate state model: (CO5)



11 The transfer function of a control system is given by

	$\frac{y(s)}{(u(s))} = \frac{s^2+3s+4}{s^3+2s^2+3s+2}$ obtain a state model .(CO5)
12	Explain controllabilty and observability. (CO5)

F. LABORATORY CONTENTS:

Expt No.	Title of the Experiments	RBT	CO
1	Implement Block diagram reduction technique to obtain transfer function a control system.	L4	CO1
2	Implement Signal Flow graph to obtain transfer function a control system	L4	CO2
3	Simulation of poles and zeros of a transfer function	L4	CO2
4	Implement time response specification of a second order Under damped System, for different damping factors	L4	CO3
5	Implement frequency response of a second order System	L4	CO3
6	Implement frequency response of a lead lag compensator	L4	CO3
7	Analyze the stability of the given system using Routh stability criterion	L4	CO4
8	Analyze the stability of the given system using Root locus	L4	CO4
9	Analyze the stability of the given system using Bode plots	L4	CO4
10	Analyze the stability of the given system using Nyquist plot .	L4	CO4
11	Obtain the time response from state model of a system	L4	CO5
12	Implement PI and PD Controllers	L4	CO3
13	Implement PID controllers	L4	CO3
14	Demonstrate the effect of PI, PD and PID controller on the system response	L4	CO3
15	Open ended experiment – 1		
16	Open ended experiment – 2		

1. EXPERIMENT NO:1

2. TITLE: Implement Block diagram reduction technique to obtain transfer function of a control systems

3. LEARNING OBJECTIVES:
- To learn various rules to be followed to solve the block diagram reduction problem
- To determine the overall transfer function from the set of systems with individual gains and transfer function

4. AIM: To find the transfer function of the systems which are connected in series and parallel using block diagram reduction method

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:
- **Block diagram** reduction is a method used in control system engineering to simplify complex systems by rearranging interconnected blocks representing various components or subsystems. The aim is to create an equivalent representation that is easier to analyze and understand
- **Block Diagram Algebra**: This involves using algebraic rules to manipulate blocks and

signals in the diagram, such as distributing common terms, factoring, and rearranging equations

- **Combining Blocks in Series**: When blocks are connected in series, you can combine them into a single block. For instance, if you have two blocks A and B in series, the combined transfer function would be the product of the individual transfer functions: AB.
- **Combining Blocks in Parallel:** Blocks in parallel can be combined using addition. If you have two blocks A and B in parallel, the combined transfer function would be the sum of the individual transfer functions: A + B.
- **Negative Feedback systems:** Negative feedback loops can be eliminated by replacing its transfer function: G/(1+GH)

7. FORMULA / CALCULATIONS:

- $G_s(s)=G_1(s)*G_2(s)$, where G_1(s) and G_2(s) are transfer function's of first and second sub system
- $G_p(s)=G_1(s)+G_2(s)$, where G_1(s) and G_2(s) are transfer function's of first and second sub system
- $G_f(s)=\frac{(G(s))}{(1+G(s)H(s))}$, where G(s) and H(s) are transfer function's of open loop gain and feedback gain

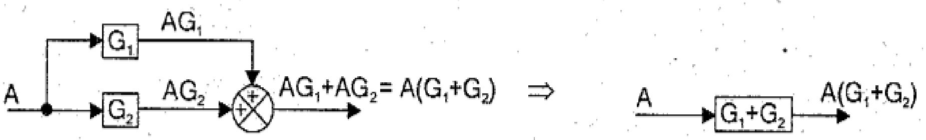
8. PROCEDURE / PROGRAMME / ACTIVITY:

```
clc;close all;
nr1=4;%nr coeff of first sub system
dr1=[1,2,1];%dr coeff of first sub system
tf1=tf(nr1,dr1);
display(tf1);
nr2=1;%nr coeff of second sub system
dr2=[1,2];%dr coeff of second sub system
tf2=tf(nr2,dr2);
display(tf2);
tfs=series(tf1,tf2); %TF of cascaded system
tfp=parallel(tf1,tf2);%TF of parallel system
tffb=feedback(tf1,tf2); %TF of feedback system
display(tfs);
display(tfp);
display(tffb);
```

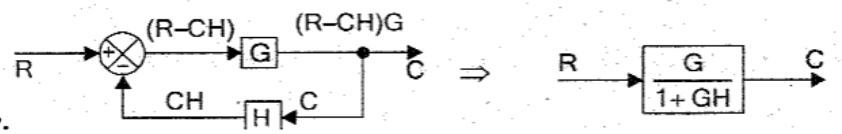
9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:

Rule-1 : ***Combining the blocks in cascade***

Rule-2 : ***Combining Parallel blocks (or combining feed forward paths)***



Rule-10 : Elimination of (negative) feedback loop



10. OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:

```
tf1 =

        4
  -------------
  s^2 + 2 s + 1

tf2 =

    1
  -----
  s + 2

tfs =

            4
  ---------------------
  s^3 + 4 s^2 + 5 s + 2

tfp =

      s^2 + 6 s + 9
  ---------------------
  s^3 + 4 s^2 + 5 s + 2

tffb =

          4 s + 8
  ---------------------
  s^3 + 4 s^2 + 5 s + 6
```

12. RESULTS & CONCLUSIONS:
- Transfer function of series, parallel and feedback subsystems are realized

13. LEARNING OUTCOMES:
- Understand how to determine the transfer function of a given system from the numerator and denominator polynomial function in S domain
- Analyze the transfer function of cascade, parallel and feedback sub systems

14. APPLICATION AREAS: Transfer function reduction methods enables engineers to simplify complex systems, derive transfer functions, and design effective control strategies for real-world applications.

15. REMARKS:

1. EXPERIMENT NO:2

2. TITLE: Implement Signal Flow graph to obtain transfer function of a control system

3. LEARNING OBJECTIVES:
- To determine the transfer function of a signal flow graph using Mason's Gain formula
- To analyze number of forward path's, loop's, non touching loop's in signal flow graph

4. AIM: To find the transfer function of the system using signal flow graph by applying Mason's Gain formula

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:

Mason's Gain Formula is a powerful tool in control system analysis, particularly for systems with multiple feedback loops. It allows you to calculate the overall transfer function of a system by considering all possible paths between the input and output nodes in a block diagram.

7. FORMULA / CALCULATIONS:

- Overall gain $T=(\frac{1}{\Delta})\sum_{k}(P_k\Delta_k)$
- T= Transfere function of the system
- Pk = Forward path gain of Kth forward path
- K = Numnber of forward paths in the signal flow graph
- Δ = 1- (sum of individual loop gains) + (sum of gain products of all possible combinations of two non touching loops) - (sum of gain products of all possible combinations of three non touching loops) + ...
- Δk= Δ for that part of the graph which is not touching Kth forward path

8. PROCEDURE / PROGRAMME / ACTIVITY:

```
clc;clear all;close all;
g12=input('enter the gain between node 1 and node 2');%1
g23=input('enter the gain between node 2 and node 3');%1
g34=input('enter the gain between node 3 and node 4');%1
g45=input('enter the gain between node 4 and node 5');%1
g56=input('enter the gain between node 5 and node 6');%1
g67=input('enter the gain between node 6 and node 7');%1
g78=input('enter the gain between node 7 and node 8');%1
g25=input('enter the gain between node 2 and node 5');%1
p1=g12*g23*g34*g45*g56*g67*g78; %first Fwd path gain
p2=g12*g25*g56*g67*g78;
%%%Individual Loop gains
g343=input('enter the loop gain b/w node 3->4->3');%-1
g343=g34*g343;
g3453=input('enter the loop gain b/w node 3->4->5->3');%-1
g3453=g34*g45*g3453;
g676=input('enter the loop gain b/w node 6->7->6');%-1
g676=g67*g676;
%Gain product of Non touching loops
p11=g343*g676;
p12=g3453*g676;
delta= 1- sum([g343,g3453,g676])+sum([p11,p12]);
%Part of graph not touching first forward path(None)
delta1=1;
%Part of graph not touching second forward path(g343)
delta2=1-g343;
T=(1/delta)*(p1*delta1 + p2*delta2);
display(T);
```

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:

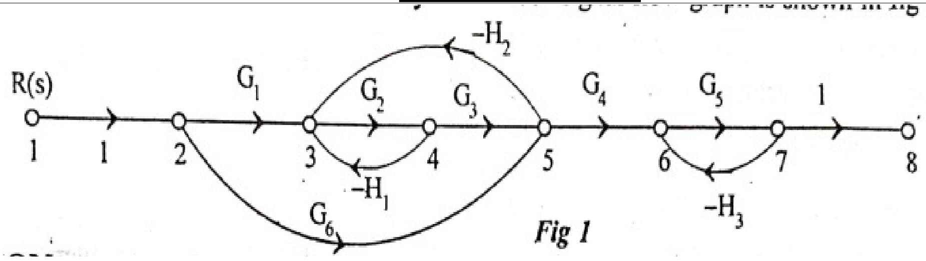


Fig 1

$$T = \frac{1}{\Delta}\sum_K P_K\Delta_K = \frac{1}{\Delta}(P_1\Delta_1 + P_2\Delta_2) \quad \text{(Number of forward paths is 2 and so K = 2)}$$

$$= \frac{G_1G_2G_3G_4G_5 + G_4G_5G_6(1+G_2H_1)}{1+G_2H_1+G_2G_3H_2+G_5H_3+G_2G_5H_1H_3+G_2G_3G_5H_2H_3}$$

$$= \frac{G_1G_2G_3G_4G_5 + G_4G_5G_6 + G_2G_4G_5G_6H_1}{1+G_2H_1+G_2G_3H_2+G_5H_3+G_2G_5H_1H_3+G_2G_3G_5H_2H_3}$$

$$= \frac{G_2G_4G_5\left[G_1G_3 + G_6/G_2 + G_6H_1\right]}{1+G_2H_1+G_2G_3H_2+G_5H_3+G_2G_5H_1H_3+G_2G_3G_5H_2H_3}$$

10. OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:
T = 0.5000

12. RESULTS & CONCLUSIONS:

- Transfer function of multiple feedback system is determined using Mason's gain formula

13. LEARNING OUTCOMES:

- Understand how to determine the transfer function of multiple feedback systems using signal flow graph
- Analyze number of forward path's, loop's, non touching loop's in signal flow graph

14. APPLICATION AREAS:The signal flow graph is widely used in control systems, robotics, communication, power systems, and biomedical engineering for deriving transfer functions and analyzing system dynamics.

15. REMARKS:

1. EXPERIMENT NO:3

2. Simulation of poles and zeros of a transfer function

3. LEARNING OBJECTIVES:

- To understand importance of pole's and zero's of a transfer function
- To check the stability of system from the given transfer function

4. AIM: To determine the pole's and zero's of the given transfer function

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:
In control system analysis, the zeros and poles of a transfer function are critical concepts. They provide valuable insights into the behavior and stability of a system.

Zeros: Zeros of a transfer function are the values of H(s) for which the transfer function becomes zero. Geometrically, zeros represent points in the complex plane where the transfer function intersects the x-axis (real axis). Zeros can influence the system's response by affecting the locations of peaks, dips, or cancellations in the frequency response.

Poles: Poles of a transfer function are the values of H(s) for which the transfer function becomes infinite or undefined. Geometrically, poles represent points in the complex plane where the transfer function diverges or approaches infinity. Poles are crucial in determining the stability and transient response of a system. The stability of a system is directly related to the location of its poles: if all the poles are in the left half of the complex plane, the system is stable.

7. FORMULA / CALCULATIONS:

- $H(s)=\dfrac{\prod_{k=1}^{N}(s-z_k)}{\prod_{k=1}^{M}(s-p_k)}$ where N is the number of zeros and M is the number of poles

8. PROCEDURE / PROGRAMME / ACTIVITY:

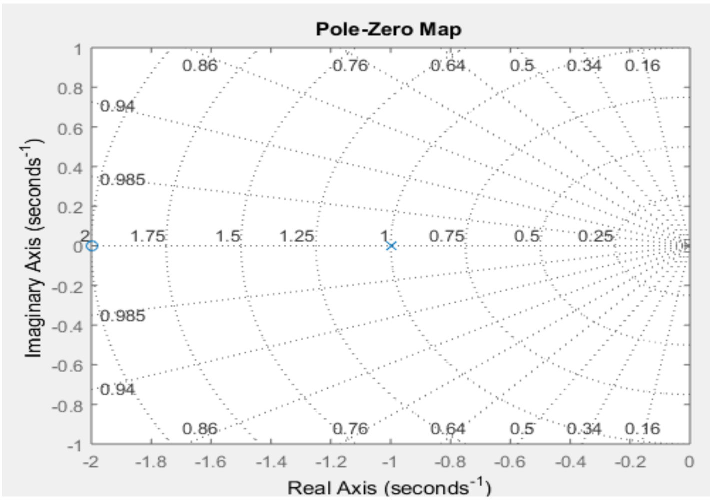
```
clc;clear all;close all;
nr1=[1,2]; %(s+2)/(s^2+2*s+1)
dr1=[1,2,1];
tf1=tf(nr1,dr1);
display(tf1);
pzmap(tf1);
grid on;
```

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:

10. OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:

```
tf1 =

      s + 2
  -------------
  s^2 + 2 s + 1
```



12. RESULTS & CONCLUSIONS:

- Identified the location of zero's and pole's in the pole/zero plot
- The system is stable system as all the poles are lying on the left half of the s-plane.

13. LEARNING OUTCOMES:

- Determine stability of the system using pole's

14. APPLICATION AREAS: Poles determine stability and response speed while Zeros affect frequency characteristics and response shaping. They are used in signal processing and biomedical engineering, making pole-zero analysis a critical tool across various engineering disciplines.

15. REMARKS:

1. EXPERIMENT NO:4

2. TITLE: Implement time response specification of a second order Under damped System, for

different damping factors

3. LEARNING OBJECTIVES:

- To understand oscillations, overshoots and settling time in second order under-damped system
- To apply various damping factors and analyze the response of the system

4. AIM: To determine the step response of second order under-damped system for various damping factors

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:

A second-order under-damped system is a common type of dynamic system in control theory. These systems have two complex conjugate poles, both of which have negative real parts and imaginary parts that give rise to oscillations.

A second-order under-damped system is characterized by oscillatory behavior, with the damping ratio determining the degree of oscillation and the natural frequency determining the frequency of oscillation. These systems are common in various engineering applications, including control systems, mechanical systems, and electrical circuits.

7. FORMULA / CALCULATIONS:

The general transfer function for a second-order underdamped system can be expressed as:

$$H(s) = \frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2}$$

Where:

- ω_n is the natural frequency of the system.
- ζ (zeta) is the damping ratio. For an underdamped system, $0 < \zeta < 1$.
- s is the complex variable.

$\therefore$ For closed loop under damped second order system,

$$\text{Unit step response} = 1 - \frac{e^{-\zeta\omega_n t}}{\sqrt{1-\zeta^2}} \sin(\omega_d t + \theta) \; ; \quad \theta = \tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$$

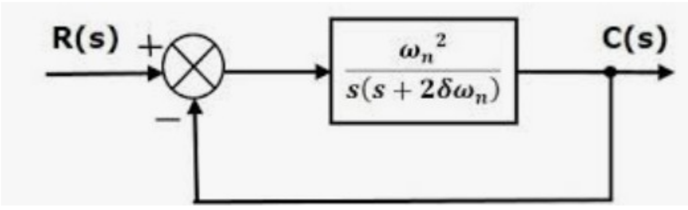
$$\text{Step response} = A\left[1 - \frac{e^{-\zeta\omega_n t}}{\sqrt{1-\zeta^2}} \sin(\omega_d t + \theta) \; ; \quad \theta = \tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}\right]$$

8. PROCEDURE / PROGRAMME / ACTIVITY:

```
clc;clear all;close all;
zeta1=0.1;
zeta2=0.4;
zeta3=0.6;
zeta4=0.8;
wn=1;
t=0:0.1:16;
phi1=atan((sqrt(1-zeta1.^2))/(zeta1));
phi2=atan((sqrt(1-zeta2.^2))/(zeta2));
phi3=atan((sqrt(1-zeta3.^2))/(zeta3));
phi4=atan((sqrt(1-zeta4.^2))/(zeta4));
c1= 1 - ((1/sqrt(1-zeta1.^2)).*(exp(-zeta1*wn*t)).*(sin(wn*t*sqrt(1-zeta1.^2)-phi1)));
```

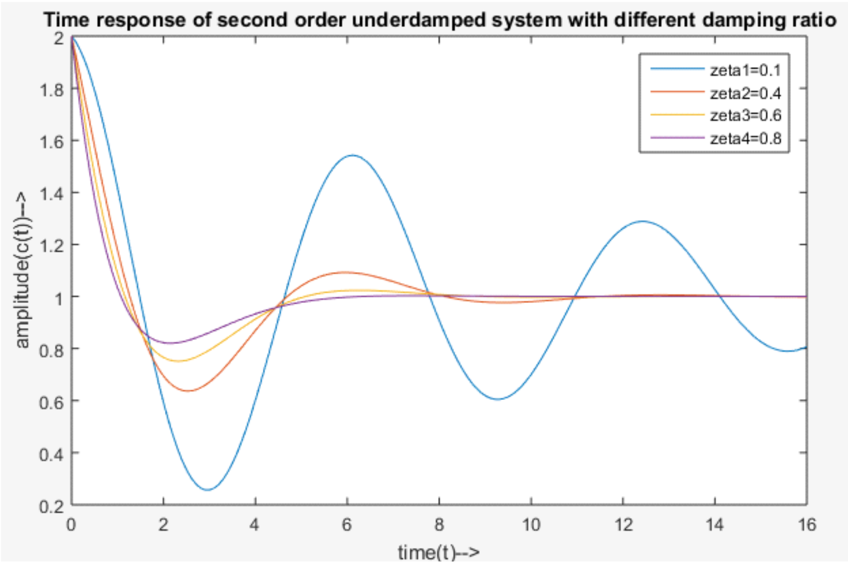
```
c2= 1 - ((1/sqrt(1-zeta2.^2)).*(exp(-zeta2*wn*t)).*(sin(wn*t*sqrt(1-zeta2.^2)-phi2)));
c3= 1 - ((1/sqrt(1-zeta3.^2)).*(exp(-zeta3*wn*t)).*(sin(wn*t*sqrt(1-zeta3.^2)-phi3)));
c4= 1 - ((1/sqrt(1-zeta4.^2)).*(exp(-zeta4*wn*t)).*(sin(wn*t*sqrt(1-zeta4.^2)-phi4)));
plot(t,c1,t,c2,t,c3,t,c4);
legend('zeta1=0.1','zeta2=0.4','zeta3=0.6','zeta4=0.8');
xlabel('time(t)-->');
ylabel('amplitude(c(t))-->');
title('Time response of second order under-damped system with different damping ratio')
```

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:



10. OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:



12. RESULTS & CONCLUSIONS:
- Verified the response of second order under-damped system for various damping factors

13. LEARNING OUTCOMES:
- Understand oscillations, overshoots and settling time in second order under-damped system

14. APPLICATION AREAS: Time response specifications of underdamped systems are used in robotics, aerospace, biomedical devices and industrial automation. By varying the damping factor, engineers can analyze the system's performance.

15. REMARKS:

1. EXPERIMENT NO:5

2. TITLE: Implement frequency response of a second order System

3. LEARNING OBJECTIVES:
- To determine frequency response of the second order systems

- To obtain magnitude and phase response of second order systems

4. AIM: To Implement frequency response of a second order system

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:

- The frequency response of a second-order system describes how the system responds to different frequencies of input signals. This response is characterized by the system's transfer function in the frequency domain. A typical second-order system can be represented by the transfer function:

$$H(s)=\frac{w_n^2}{(s^2+2\mathrm{w}_n\zeta s+w_n^2)}$$

- Take wn=1, ţ=1 we get

$$H(s)=\frac{1}{(s^2+2s+1)}$$

7. FORMULA / CALCULATIONS:

- Laplace transform of time domain signal h(t) is given by

$$H(s)=\int x(t)e^{(-st)}dt$$

- Fourier transform of time domain signal h(t) is given by

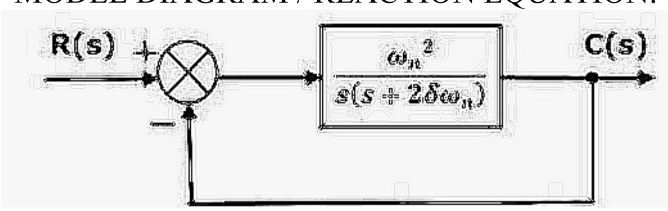
$$H(jw)=\int x(t)e^{(-jwt)}dt$$

- Comparing the above two relations, to obtain frequency response of time domain signal from the transfer function we replace **s by jw**.

8. PROCEDURE / PROGRAMME / ACTIVITY:

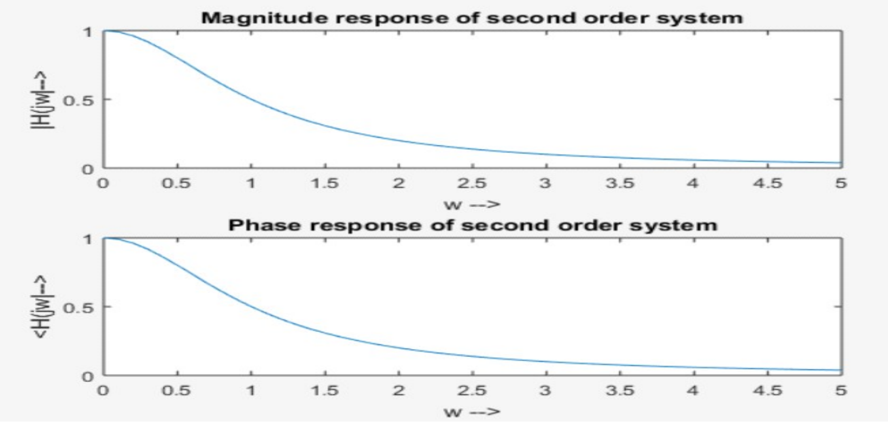
```
clc;clear all;close all;
W=0:0.1:5;
S=1i*W;
Wn=1;%natural freq Wn=1
zeta=1;%critically damped zeta=1
H= (Wn^2)./((S.^2)+(2*Wn*zeta*S)+(Wn.^2)); %TF of closed loop second order system
subplot(2,1,1);
plot(W,angle(H)) ;
xlabel('w -->');
ylabel('|H(jw|-->');
title('Magnitude response of second order system');
subplot(2,1,2);
plot(W,abs(H));
xlabel('w -->');
ylabel('<H(jw|-->');
title('Phase response of second order system');
```

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:



10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:



12. RESULTS & CONCLUSIONS:

- Verified the frequency response of second order system.

13. LEARNING OUTCOMES:

- Understand the frequency response of second order systems

14. APPLICATION AREAS:The frequency response of an underdamped second-order system finds applications in various fields, including mechanical engineering, electrical systems, communication, aerospace, and biomedical engineering.

15. REMARKS:

1. EXPERIMENT NO:6

2. TITLE: Implement frequency response of a lead lag compensator.

3. LEARNING OBJECTIVES:

- To determine frequency response of the lead compensator
- To determine frequency response of the lag compensator
- To determine frequency response of the lead lag compensator

4. AIM: To Implement frequency response of a second order system

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:

In control systems, a compensator is a component added to the system to improve its performance. The primary objectives of a compensator are to enhance the stability, speed of response, and accuracy of the system.

Compensators can be implemented using hardware (analog compensators) or software (digital compensators). There are several types of compensators, each designed to address specific performance criteria. The most common types are lead, lag, and lead-lag compensators.

The Lead lag compensator is the combination of a lag compensator and a lead compensator. The lag section has one real pole and one zero with the pole to the right of zero. The lead section also has one real pole and one real zero but the zero is to the right of the pole.

Advantages of Phase Lag Lead Compensation 1. Due to the presence of phase lag-lead network the speed of the system increases because it shifts gain crossover frequency to a higher value. 2. Due to the presence of phase lag-lead network accuracy is improved.

7. FORMULA / CALCULATIONS:

- LAG NETWORK

$$T(s)=\frac{(s+\frac{1}{T})}{(s+\frac{1}{T\beta})} \quad ;\beta>1$$

- LEAD NETWORK

$$T(s)=\frac{(s+\frac{1}{T})}{(s+\frac{1}{T\alpha})};\ for\ \alpha<1$$

- LEAD LAG NETWORK

$$T(s)=\frac{(s+\frac{1}{T_1})}{(s+\frac{1}{T_1\alpha})}\frac{(s+\frac{1}{T_2})}{(s+\frac{1}{T_2\beta})}$$

8. PROCEDURE / PROGRAMME / ACTIVITY:

```
%lag network
clc;clear all;close all;
T=input('enter the value of time constant');
beta=input('enter the value of the beta(should be >1)');
n=[1 1/T];
d=[1 1/(beta*T)];
figure,freqs(n,d);
title('Frequency response in s domain Lag compensator N/w')
grid on;
%lead network
clc;clear all;close all;
T=input('enter the value of time constant');
alpha=input('enter the value of the alpha(should be <1)');
n=[1 1/T];
d=[1 1/(alpha*T)];
figure,freqs(n,d);
grid on;
%lead-lag network
T1=input('enter the value of time constant');
T2=input('enter the value of time constant');
alpha=input('enter the value of alpha constant');
beta=input('enter the value of beta constant');
n1=[1 1/T1];
n2=[1 1/T2];
n=conv(n1,n2);
d1=[1 1/(alpha*T1)];
d2=[1 1/(beta*T2)];
d=conv(d1,d2);
figure,freqs(n,d);
grid on;
```

COURSE PLAN

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:

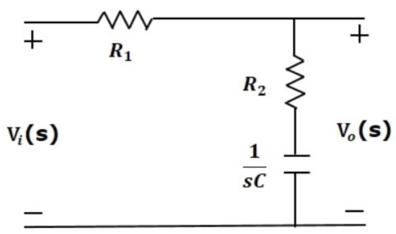


Fig.1. Lag compensator N/Ww

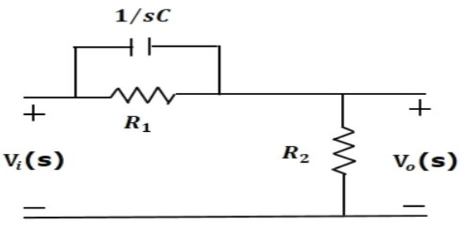


Fig.2. Lead compensator N/w

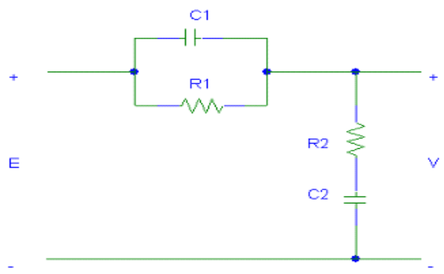
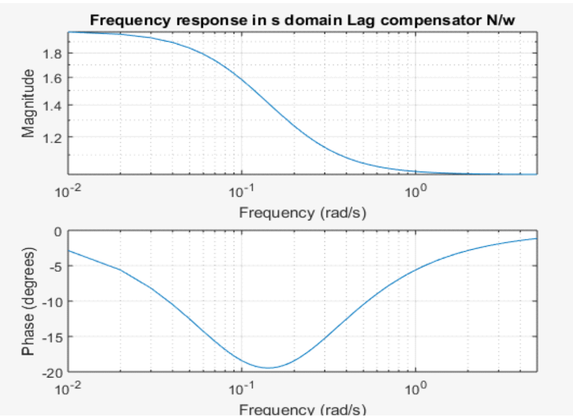
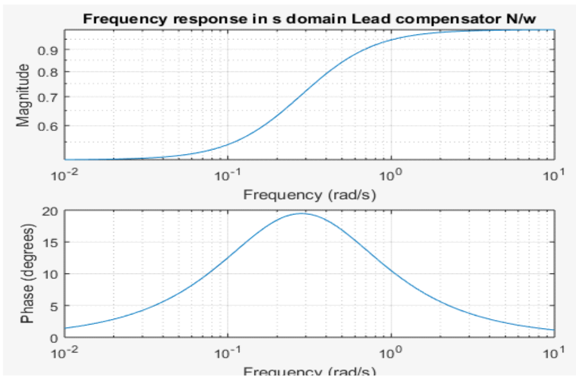


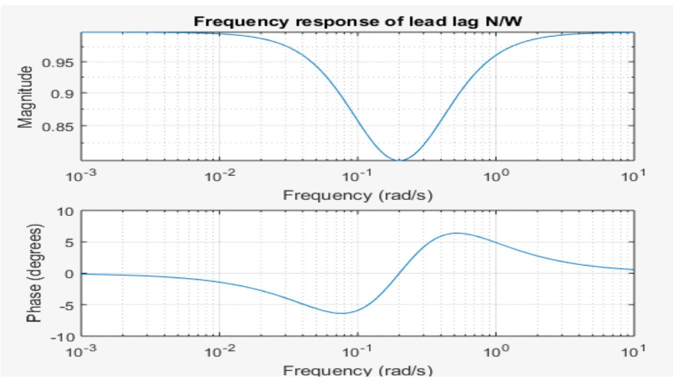
Fig.3. Lead-lag N/w

10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:







12. RESULTS & CONCLUSIONS:

- Verified the frequency response of lead, lag and lead-lag compensator

13. LEARNING OUTCOMES:
- Understand the frequency response of lead compensator
- Understand the frequency response of lag compensator
- Understand the frequency response of lead-lag compensator

14. APPLICATION AREAS:

15. REMARKS:

1. EXPERIMENT NO:7

2. TITLE: Analyze the stability of the given system using Routh stability criterion

3. LEARNING OBJECTIVES:
- To determine stability of LTI system using Routh hurwitz criterion

4. AIM: To analyze the stability of given system using Routh hurwitz criterion

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:
- The Routh-Hurwitz criterion is a mathematical test used in control systems and signal processing to determine the stability of a linear time-invariant (LTI) system. Specifically, it provides a way to determine whether all the roots of a given polynomial lie in the left half of the complex plane, which corresponds to a stable system.

Steps for Applying the Routh-Hurwitz Criterion

1. **Construct the Characteristic Polynomial:** The first step is to write down the characteristic polynomial of the system. For an LTI system, this polynomial is typically of the form $P(s)=a_n s^n + a_{(n-1)} s^{(n-1)} + a_{(n-2)} s^{(n-2)} + .. + a_1 s^1 + a_0$ **(1),** where a_n, a_{n-1}, ... a_0 are the coefficients of polynomial.
2. **Build Routh Array:** The Routh array is constructed using the coefficients of the characteristic polynomial. The array has n+1 if the polynomial is of degree n. The first two rows are filled with the coefficients of polynomials as shown
   First row: a_n, a_{n-2}, a_{n-4} …
   Second row: a_{n-1}, a_{n-3}, a_{n-5} …
   For the subsequent rows, the elements are computed using the determinants of 2x2 submatrices formed from the elements of the previous two rows. Specifically, for the i-th row and j-th column element rij (starting from the third row):

$$r_{ij} = -\frac{\begin{vmatrix} r_{i-2,1} & r_{i-2,j+1} \\ r_{i-1,1} & r_{i-1,j+1} \end{vmatrix}}{r_{i-1,1}} \qquad (2)$$

3. **Determine stability:** The system is stable if and only if all the elements in the first column of the Routh array have the same sign (either all positive or all negative). If there is any change in sign, the system has roots with positive real parts, indicating instability

7. FORMULA / CALCULATIONS:

8. PROCEDURE / PROGRAMME / ACTIVITY

```
%Stability check using Routh Stability criterion
clc;clear all;close all;%[1 1 3 1 6]
```

```
e=input('Enter the coeff of characteristic equation');
le=length(e);
m=mod(le,2);
a=[];
b=[];
if m==0
   for i=1:(le/2)
      a(i)=e((2*i)-1);
      b(i)=e(2*i);
   end
else
   e1=[e 0];
   for i=1:((le+1)/2)
      a(i)=e1((2*i)-1);
      b(i)=e1(2*i);
   end
end
%remaining rows
l1=length(a);
c=[];
c(1,:)=a;
c(2,:)=b;
for m=3:le
   for n=1:l1-1
      c(m,n)= -(1/c(m-1,1))*det([c((m-2),1) c((m-2),(n+1));c((m-1),1) c((m-1),(n+1))]);
   end
end
disp('The Routh matrix ');
disp(c)
if c(:,1)>0
   disp('System is stable')
else
   disp('System is unstable')
end
```

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:

10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:

I/P: Enter the coeff of characteristic equation[1 1 3 1 6]

O/P:

The Routh matrix

```
  1    3    6
  1    1    0
  2    6    0
 -2    0    0
  6    0    0
```

System is unstable

12. RESULTS & CONCLUSIONS:

The Routh-Hurwitz criterion is a powerful tool for determining the stability of LTI systems without explicitly computing the roots of the characteristic polynomial. By constructing the Routh array and checking the sign changes in the first column, one can infer the stability of the system

13. LEARNING OUTCOMES:
Understand how to develop Routh array from characteristic equation to determine the stability

14. APPLICATION AREAS:

15. REMARKS:

1. EXPERIMENT NO:8

2. TITLE: Analyze the stability of the system using Root-Locus

3. LEARNING OBJECTIVES:

- To understand whether the system is stable, marginally stable or unstable for various values of K(gain)
- To plot Root locus plot of given transfer function

4. AIM: To plot root locus and bode plot for the given transfer function

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

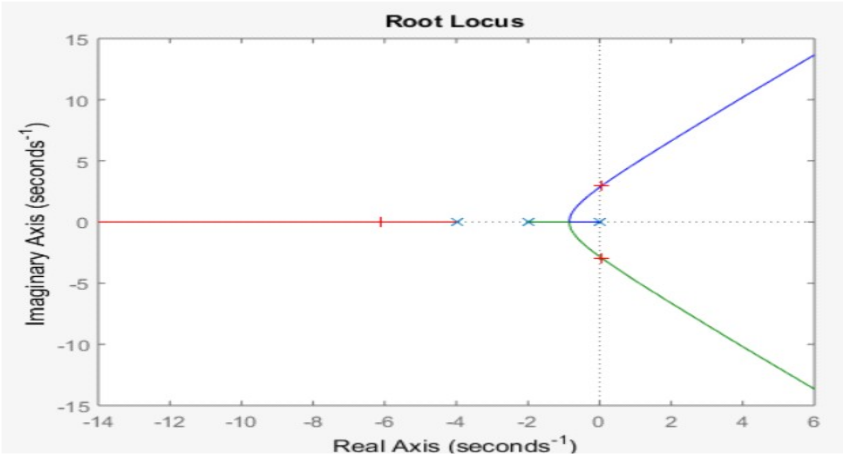
6. THEORY / HYPOTHESIS:
ROOT LOCUS A simple technique known as “Root Locus Technique” used for studying linear control systems in the investigation of the trajectories of the roots of the characteristic equation. This technique provides a graphical method of plotting the locus of the roots as gain k is varied be from zero to infinity. The roots corresponding to a particular value of the system parameter can then be located on the locus or the value of the parameter for a desired root location can be determined form the locus. The root locus is a powerful technique as it brings into focus the complete dynamic response of the system. The root locus also provides a measure of sensitivity of roots to the variation in the parameter being considered. This technique is applicable to both single as well as multiple-loop systems.

8. PROCEDURE / PROGRAMME / ACTIVITY:

```
%Root Locus
%open loop transfer function G(s) = K/s(s+2)(s+4)
num=input('enter the value of Numerator=');
den=input('enter the value of Denominator=');
sys=tf(num,den);
rlocus(sys);
rlocfind(sys);
```

10. OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:
From the root locus plot for a open loop TF =G(s)=K/s(s+2)(s + 4)
Break Away Point: -0.845
Intersection with imaginary axis:±2.8
K=48;
Range of K is 0<K<48 (Stable)
K=48(Marginally Stable)
K>48(Unstable)
The root locus has three branches. The first and second root locus starts at s=0 ans s=-2and travel through negative real axis and break away at s=-0.845 then crosses imaginary axis at $s=\pm j2.8$ and travel towards infinity following asymptotes path. The third locus starts at s=-4 and towards negative infinity to meet zero.

11. GRAPHS / OUTPUTS:
Enter the value of Numerator coeff=1
Enter the value of Denominator coeff=[1 6 8 0]



12. RESULTS & CONCLUSIONS:
- The root locus plot for a given open loop transfer function is plotted
- Observed the values of the gain for the system to be stable, marginally stable and unstable

13. LEARNING OUTCOMES:
- Understand to plot root-locus
- Determine the stability of the system form root-locus

14. APPLICATION AREAS:
- These plots are used to analyze the stability of control systems.
- These plots are useful for compensating fixed-gain amplifiers.

15. REMARKS:

1. EXPERIMENT NO:9

2. TITLE: Analyze the stability of the given system using Bode plots

3. LEARNING OBJECTIVES:
- To determine gain margin, gain cross over frequency
- To determine phase margin, phase cross over frequency
- To determine whether the system is stable, marginally stable and unstable

4. AIM: To obtain the bode diagram of unity feedback system with open loop transfer function

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:
- A Bode plot is a graphical representation used in control systems and signal processing to depict the frequency response of a system. It consists of two plots:
- **Magnitude Plot**: This shows how the amplitude of the output signal changes with frequency.
- **Phase Plot**: This shows how the phase of the output signal changes with frequency.
- Both plots are typically drawn on a logarithmic scale for the frequency axis, which allows for a wide range of frequencies to be represented compactly

Steps to draw bode plot

1. In the given open loop transfer function, replace s by jw. Let the open loop transfer function be G(s) = 10/(s)(1+0.4s)(1+0.1s), then G(jw)= 10/(jw)(1+0.4jw)(1+0.1jw)
2. Obtain the magnitude and phase response of the given frequency response G(jw)

$$|(G(jw))| = \frac{10}{(w*\sqrt{(1^2+(0.4w)^2)}\sqrt{(1^2+(0.1w)^2)})}$$

$\measuredangle(G(jw)) = -90 - \tan^{-1}(0.4w) - \tan^{-1}(0.1w)$

3. Find the corner frequencies, wc1= 1/0.4=2.5 rad/sec and wc2=1/0.1= rad/sec. Select these in increasing order
4. Obtain the magnitude table

Term	Corner frequency rad/sec	Slope db/dec	Change in slope db/dec
10/jw	-	-20	-
1/(1+0.4jw)	wc1=2.5	-20	-40
1/(1+0.1jw)	wc2=10	-20	-60

Choose lower frequency wl<wc1, wl=0.1 rad/sec, and higher frequency wh>wc2=50 rad/sec.
Calculate gain in dB at the points wl, wc1, wc2 and wh.
At wl, G= 20 log10 |10/0.5| = **40 dB**
At wc1, G= 20 log10 |10/2.5| = **12.04 dB**
At wc2, G= slope from wc1 to wc2 * log10|wc2/wc1| + Gain at wc1 = -40* log10(10/2.5)+12.04 dB = **-12.04 dB**
At wch, G=slope from wc2 to wch * log10|wch/wc2| + Gain at wc2 = -60*log10(50/10) - 12.04 dB= **-54 dB**
Mark these points on the semilogx graph loq w vs G in dB

5. Obtain phase angle for different frequencies
At wl, $\measuredangle(G(jw)) = -90 - \tan^{-1}(0.4w) - \tan^{-1}(0.1w) = -92$
At wc1, $\measuredangle(G(jw)) = -90 - \tan^{-1}(0.4w) - \tan^{-1}(0.1w) = -150$
At wc2, $\measuredangle(G(jw)) = -90 - \tan^{-1}(0.4w) - \tan^{-1}(0.1w) = -210$
At wch, $\measuredangle(G(jw)) = -90 - \tan^{-1}(0.4w) - \tan^{-1}(0.1w) = -255$
Mark these points on the semilogx graph loq w vs angle in degrees
6. From the obtained bode plot determine **gain margin, phase margin, phase cross over frequency and gain cross over frequency.** If the phase cross over frequency is greater than the gain cross over frequency then the system is stable.

7. FORMULA / CALCULATIONS:

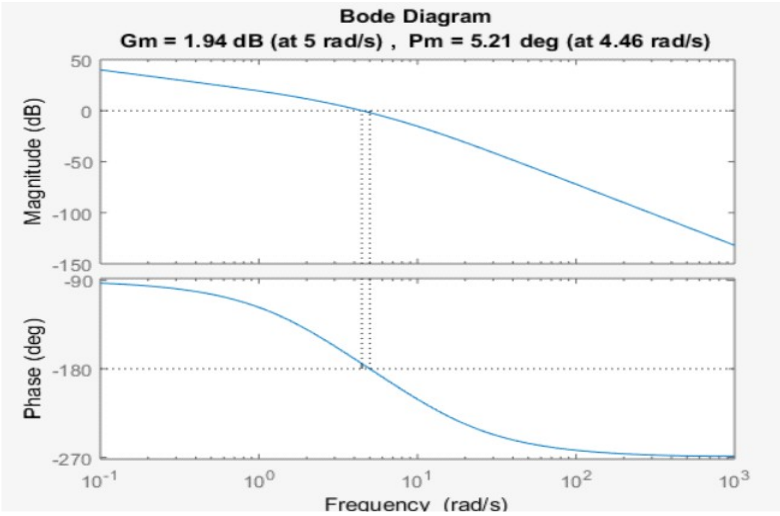
8. PROCEDURE / PROGRAMME / ACTIVITY

```
%Stability check using Bode plot
clc;clear all;close all;
nr=[10];
dr=[0.04,0.5,1,0];
sys=tf(nr,dr);
bode(sys);
margin(sys);
[gm,pm,wgc,wpc]=margin(sys);
```

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:

10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:



12. RESULTS & CONCLUSIONS:

- Determined Gain crossover frequency, Phase crossover frequency, Gain margin, Phase margin form the bode plot. As phase crossover frequency is greater than gain crossover frequency the system is stable

13. LEARNING OUTCOMES:

- Understand how to develop bode plot and determine the stability

14. APPLICATION AREAS:

15. REMARKS:

1. EXPERIMENT NO:10

2. TITLE: Analyze the stability of the given system using Nyquist plot

3. LEARNING OBJECTIVES:

- To determine stability of LTI open loop system using Nyquist plot

4. AIM: To analyze the stability of given system using Nyquist criterion

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:

- The Nyquist plot is a powerful tool used in control systems and signal processing to determine the stability of a system based on its open-loop frequency response. It is particularly useful for analyzing the stability of feedback systems.

Steps to determine stability using Nyquist plot

1. **Open-Loop Transfer Function:** Start with the open-loop transfer function G(s).
2. **Nyquist Path**: Construct the Nyquist path, which typically encircles the entire right-half of the complex plane, including the imaginary axis. For practical purposes, this often involves plotting the frequency response of G(jω) varying w from −∞ to +∞
3. **Plotting the Nyquist Diagram**: Plot the complex values of G(jω) on the complex plane as ω varies from −∞-−∞ to +∞
4. **Encirclement of the Critical Point:** Analyze how the Nyquist plot encircles the critical point (−1,0).
5. **Applying the Nyquist Criterion**:

- Count the number of encirclements(N) of the critical point (−1,0).
- Determine the number of poles P of G(s)H(s) that are in the right-half of the s-plane.

- The number of clockwise encirclements around (−1,0) must satisfy the relation:

  N=P-Z, where Z is the number of closed-loop poles in the right-half s-plane

6. **Nyquist Stability Criterion**

- **Stable System**: The system is stable if Z=0, meaning there are no poles of the closed-loop system in the right-half s-plane. This implies that the number of clockwise encirclements N of (−1,0) should equal the number of open-loop poles P in the right-half s-plane.
- **Unstable System**: The system is unstable if Z>0, meaning there are one or more poles of the closed-loop system in the right-half s-plane. This implies that the number of clockwise encirclements N of (−1,0) is greater than the number of open-loop poles P in the right-half s-plane.

Eg: Let G(s) = 50 / (s+1)(s+2)

G(jw) = 50/(jw+1)(jw+2) ,

$$|(G(jw))| = 50/(\sqrt{(1^2+w^2)}\sqrt{(2^2+w^2)})$$

$$\measuredangle(G(jw)) = -\tan^{-1} w - \tan^{-1} w/2$$

w	0	1	2	10	20	100	∞
|G(jw)|	25	16	8	0.5	0.1	0.01	0
<G(jw)	0	-72	-108	-163	-171	-178	-180

Mark the above values on the polar plot, radius (magnitude) and angle(phase).

7. FORMULA / CALCULATIONS:

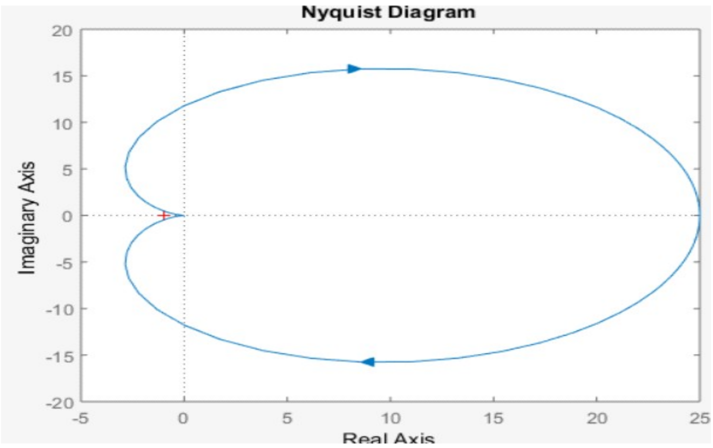
8. PROCEDURE / PROGRAMME / ACTIVITY

```
%Stability check using Nyquist plot
clc;clear all;close all;
nr=[50];
dr=[1,3,2];
sys=tf(nr,dr);
nyquist(sys);
```

9. BLOCK / CIRCUIT / MODEL DIAGRAM / REACTION EQUATION:

10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:



12. RESULTS & CONCLUSIONS:
- The given open loop transfer function is stable as P=0, also the closed loop transfer function is stable, since Z=0.

13. LEARNING OUTCOMES:
- Understand how to develop Nyquist plot for the open loop transfer function and determine the stability.

14. APPLICATION AREAS:

15. REMARKS:

1. EXPERIMENT NO:11

2. TITLE: Obtain the time response from state model of a system.

3. LEARNING OBJECTIVES:
- To convert transfer function into state-space model
- To convert state-space model into transfer function

4. AIM: To plot root locus and bode plot for the given transfer function

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:
- A state-space model is a mathematical representation used in control theory, signal processing, and various engineering fields to describe the behavior of a system over time. It consists of two main components
- **State equations:** These equations describe how the state variables of the system evolve over time based on internal dynamics and external inputs. They are typically represented as differential or different equations.

$$\dot{x}(t)=Ax(t)+Bu(t)$$

- **Output equations:** These equations describe how the observed outputs of the system relate to its internal state variables and possibly external inputs

$$y(t)=cx(t)+Du(t)$$

- To find the value of A, B, C and D we have

$$H(s)=\frac{(b_0+b_1 s+b_2 s^2+..+b_m s^m)}{(a_0+a_1 s+a_2 s^2+..+a_n s^n)}$$

$$A=\begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & 1 \\ -a_0 & -a_1 & -a_2 & \cdots & -a_{n-1} \end{bmatrix} \qquad B=\begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \\ 1 \end{bmatrix}$$

$$C=\begin{bmatrix} b_0 & b_1 & b_2 & \cdots & b_{n-1} \end{bmatrix} \qquad D=[0]$$

- To convert state space representation to transfer function we use the following equation

$$H(s)=\frac{\mathbf{Y}(s)}{\mathbf{U}(s)}=C(sI-A)^{-1}B+D$$

COURSE PLAN

8. PROCEDURE / PROGRAMME / ACTIVITY:

```
%Convert transfer function to state model
nr=[1,1];
dr=[1,2,1];
tf1=tf(nr,dr);
[A,B,C,D]=tf2ss(nr,dr);
display(A);
display(B);
display(C);
display(D);
%Convert  state model to transfer function
clc;clear all;close all;
A=[-2,-1;1,0];
B=[1;0];
C=[1,1];
D=[0];
[b,a]=ss2tf(A,B,C,D);
tf1=tf(b,a);
s=tf('s');
M=(b(1)*s^2 + b(2)*s + b(3))/(a(1)*s^2 + a(2)*s + a(3));
t=0:0.005:20;
c=impulse(M,t);
plot(t,c) ;
```

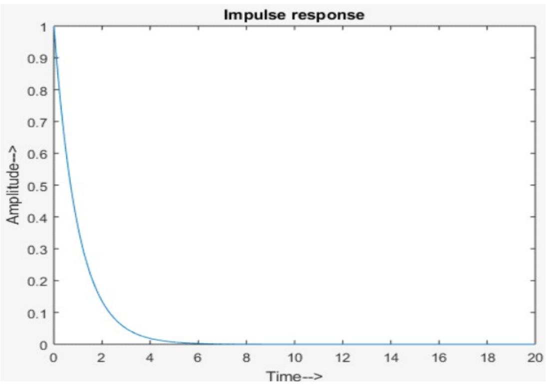
10. OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11. GRAPHS / OUTPUTS:

(a)

Enter the value of Numerator coeff=[1 1]
Enter the value of Denominator coeff=[1 2 1]

```
A =

   -2    -1
    1     0

B =

    1
    0

C =

    1     1

D =

    0
```



(b)

```
A=[-2,-1;1,0];
B=[1;0];
C=[1,1];
D=[0];
```

```
      s + 1
  -------------
  s^2 + 2 s + 1

Continuous-time transfer function.
```

12. RESULTS & CONCLUSIONS:
- State space equations derived from transfer function. Also the time response of the system is displayed from the state-space variables.

13. LEARNING OUTCOMES:
- Understand how to convert transfer function into state-space variables
- Understand how to convert state-space variables into transfer function.

14. APPLICATION AREAS:
- State-space models are used to model non-linear systems
- To model multiple input multiple output systems(MIMO)

15. REMARKS:

1. EXPERIMENT NO:12

2. TITLE: Implement PI and PD controllers

3. LEARNING OBJECTIVES:
- To analyze the effect of Proportional plus Integrator controller on second order system for unit step input
- To analyze the effect of Proportional plus Differentiation controller on second order system for unit step input

4. AIM: To analyze the effects of PI and PD controller for unit step input

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:
- A controller in the forward path, which changes the controller output corresponding to proportional plus derivative of error signal is called PD controller
- A controller in the forward path, which changes the controller output corresponding to proportional plus integral of error signal is called PI controller

7. FORMULA / CALCULATIONS:

Output of the PD controller is given by the expression

$$u(t)=K_p e(t)+K_p T_d \frac{d}{dt}(e(t))$$

$$u(t)=K_p e(t)+K_D \frac{d}{dt}(e(t)) \qquad \text{Where } K_D = K_P T_D$$

Transfer function of PD controller

TF = U(s)/E(s)= (K_P + K_D S)

Closed loop transfer of the PD controller

$$C(s)/R(s)=\frac{(K_p+K_D S)*(G(s))}{(1+((K_p+K_D S)*G(s)))}$$

Output of the PI controller is given by the expression

$$u(t)=K_p e(t)+K_p(1/T_I)\int(e(t)dt)$$

$$u(t)=K_p e(t)+K_I\int(e(t)dt) \qquad \text{Where } K_I = K_P (1/T_I)$$

Transfer function of PI controller

TF = U(s)/E(s)= (K_P + K_I/ S)

Closed loop transfer of the PI controller

$$C(s)/R(s)=\frac{(K_p+K_I(1/S))*(G(s))}{(1+((K_p+K_I(1/S))*G(s)))}$$

8. PROGRAMME

```
%Effect of PD and PI controllers on second order system with unit step function
clc;
s=tf('s');
%Open loop TF of G(s) = 1/s(s+1) kp=100, ki=10, kd=0.01
M1= 1/(s^2 + s + 1);
t=0:0.005:20;
s1=step(M1,t);
plot(t,s1);
hold on;
%closed loop TF of PD controller
M2= (100+0.01*s)/(s^2 + 1.01*s + 100);
s2=step(M2,t);
plot(t,s2);
hold on;
%closed loop TF of PI controller
M3= (100*s + 10)/(s^3 + s^2 + 100*s + 10);
s3=step(M3,t);
plot(t,s3);
hold on;
```

9. BLOCK DIAGRAM:

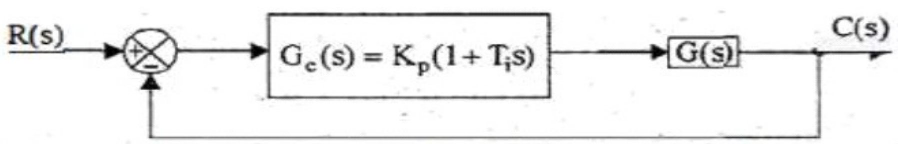


Fig.1. Block diagram of feedback system with PD controller

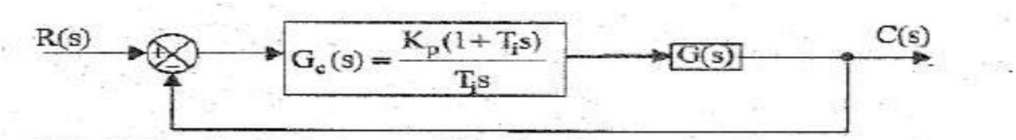
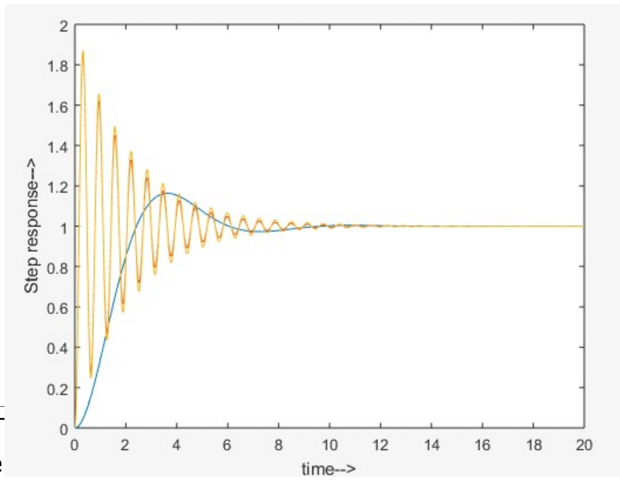


Fig.2. Block diagram of feedback system with PI controller

10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:



12. RESULTS & CONCLUSIONS:
- Observed the effects of PD and PI controller on second order systems on unit step input

13. LEARNING OUTCOMES:
- Understand the effects of PD controller on second order systems
- Understand the effects of PI controller on second order systems

14. APPLICATION AREAS:
- Vibration control(PD controller)
- Voltage regulation(PI controller)

15. REMARKS:

1. EXPERIMENT NO:13

2. TITLE: Implement PID controllers

3. LEARNING OBJECTIVES:
- To analyze the effect of Proportional plus Integrator plus derivative (PID) controller on second order system for unit step input

4. AIM: To analyze the effects of PI and PD controller for unit step input

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:
- A controller in the forward path, which changes the controller output corresponding to proportional plus integrator plus derivative of error signal is called PID controller

7. FORMULA / CALCULATIONS:

Output of the PID controller is given by the expression

$$u(t)=K_p e(t)++K_I\int(e(t))+K_D\frac{d}{dt}(e(t))$$

Transfer function of PD controller

TF = U(s)/E(s)= (K_P + K_I/S + K_D S)

Closed loop transfer of the PD controller

$$C(s)/R(s)=\frac{(K_p+K_I/S+K_D S)*(G(s))}{(1+((K_p+K_I/S+K_D S)*G(s)))}$$

8. PROGRAMME

```
%Effect of PID controllers on second order system with unit step function
clc;
s=tf('s');
%Open loop TF of G(s) = 1/s(s+1) kp=100, ki=10, kd=0.01
M1= 1/(s^2 + s + 1);
t=0:0.005:20;
s1=step(M1,t);
plot(t,s1);
hold on;
%closed loop TF of PID controller
M2= (100+0.01*s)/(s^2 + 1.01*s + 100);
s2=step(M2,t);
plot(t,s2);
hold on;
```

9. BLOCK DIAGRAM:

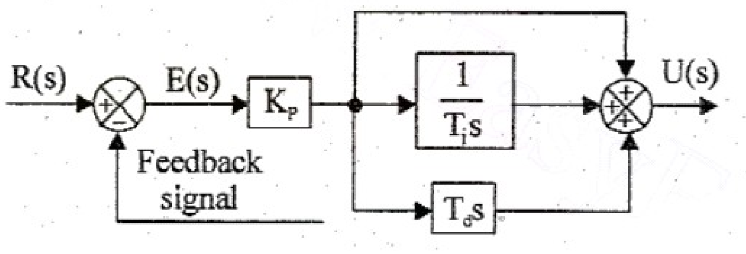
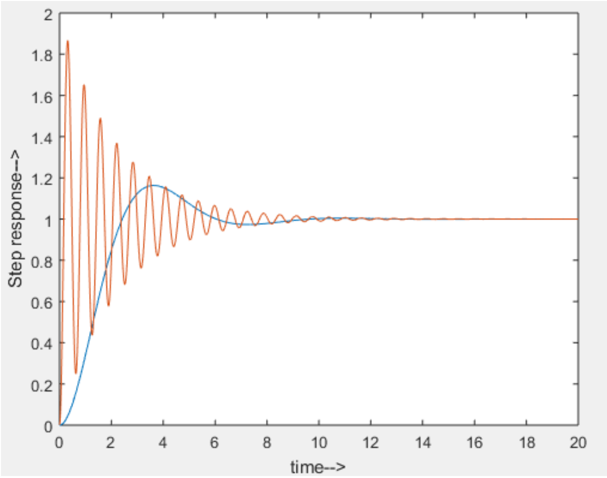


Fig.1. Block diagram of feedback system with PID controller

10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:



12. RESULTS & CONCLUSIONS:

- Observed the effects of PID controller on second order systems on unit step input

13. LEARNING OUTCOMES:

- Understand the effects of PID controller on second order systems

14. APPLICATION AREAS:

- Vibration control(PD controller)
- Voltage regulation(PI controller)

15. REMARKS:

1. EXPERIMENT NO:14

2. TITLE: Demonstrate the effect of PI, PD and PID controller on the system response.

3. LEARNING OBJECTIVES:

- To analyze the effect of PI,PD and PID controller on second order system for unit impulse input

4. AIM: To analyze the effects of PI, PD and PID controller for unit impulse input

5. MATERIAL / EQUIPMENT REQUIRED: Matlab 2015 with control system toolbox installed

6. THEORY / HYPOTHESIS:

A controller in the forward path, which changes the controller output corresponding to proportional plus integrator plus derivative of error signal is called PID controller

7. FORMULA / CALCULATIONS:

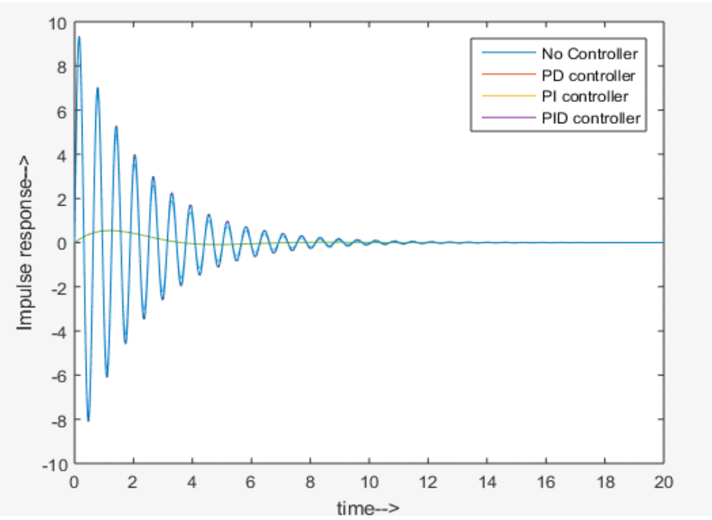
8. PROGRAMME

```
%Effect of PI,PD and PID controllers on second order systems
clc;
s=tf('s');
%closed loop TF of G(s) = 1/s(s+1)
M1= 1/(s^2 + s + 1);
t=0:0.005:20;
s1=impulse(M1,t);
plot(t,s1);
xlabel('time-->');
ylabel('Impulse response-->');
hold on;
%closed loop TF of PD controller
M2= (100+0.01*s)/(s^2 + 1.01*s + 100);
s2=impulse(M2,t);
plot(t,s2);
hold on;
%closed loop TF of PI controller
M3= (100*s + 10)/(s^3 + s^2 + 100*s + 10);
s3=impulse(M3,t);
plot(t,s3);
hold on;
%closed loop TF of PID controller
M4= (0.01*s^2 + 100*s +10)/(s^3 + 1.01*s^2 + 100*s + 10);
s4=impulse(M4,t);
plot(t,s4);
hold on;
legend('No Controller','PD controller','PI controller','PID controller');
```

9. BLOCK DIAGRAM:

10.OBSERVATION TABLE / LOOKUP TABLE / TRUTH TABLE:

11.GRAPHS / OUTPUTS:



12. RESULTS & CONCLUSIONS:

- Observed the effects of PI, PD and PID controller on second order systems

13. LEARNING OUTCOMES:

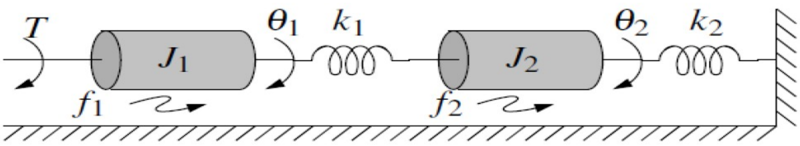
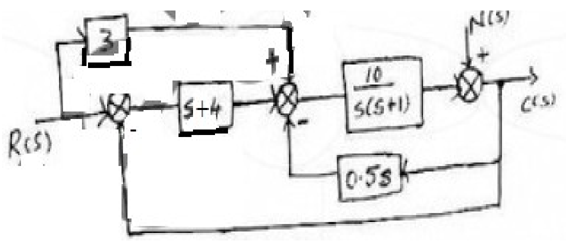
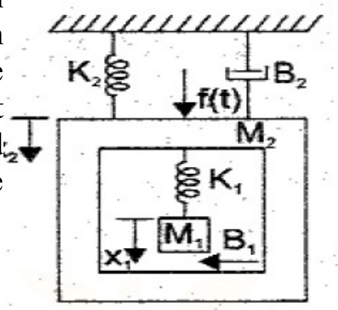
- Understand the effects of PI, PD and PID controller on second order systems

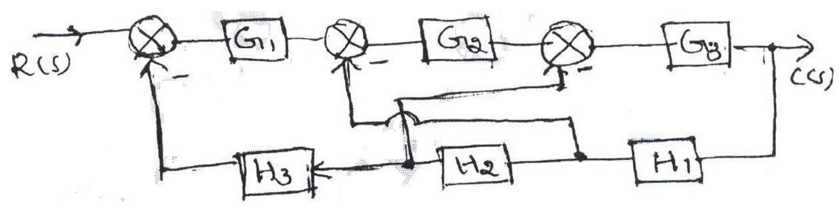
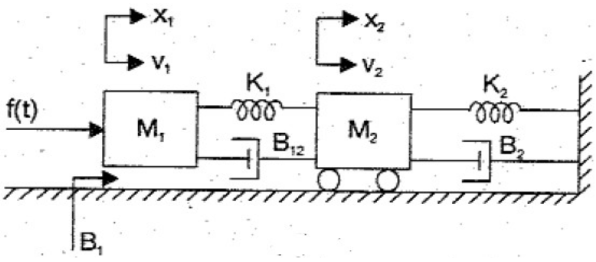
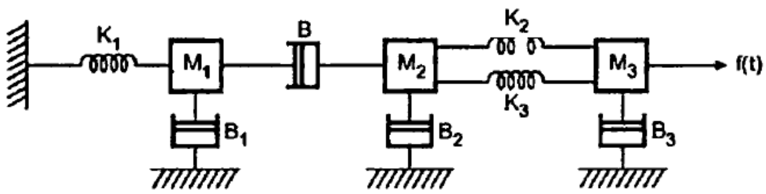
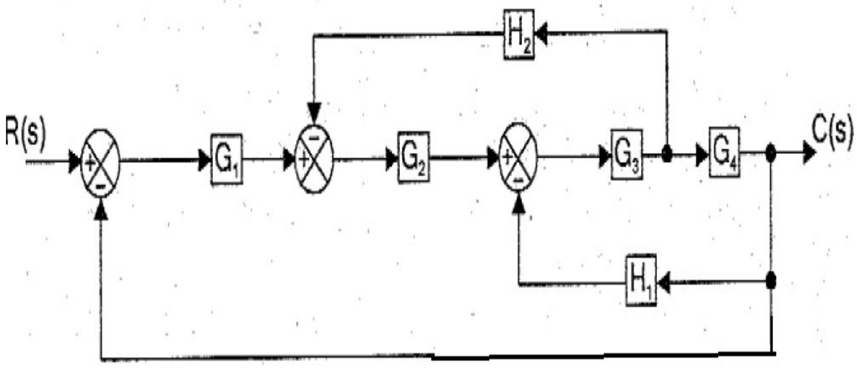
14.	APPLICATION AREAS:
15. REMARKS:	

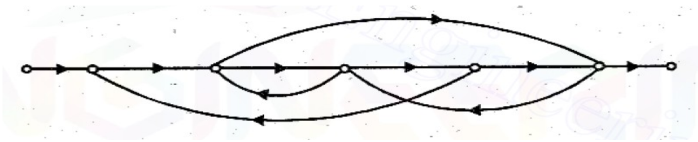
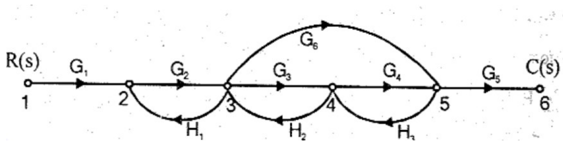
G. INTERNAL ASSESSMENT TEST MODEL QUESTION PAPER

Dept: EC	Sem / Div:IV	Course:Control Systems	Course Code: BEC403
Date:	Time: 90 Min.	Max Marks: 50	Elective: N

Note: Answer any 2 full questions, choosing one full question from each part.

<table>
<tr><th colspan="2">QN</th><th>Questions</th><th>Marks</th><th>RBT</th><th>CO's</th></tr>
<tr><td colspan="6">PART A</td></tr>
<tr><td>1</td><td>a</td><td>Draw the electrical network based on torque-current analogy give all the differential equations for the circuit below
</td><td>10</td><td>L3</td><td>CO1</td></tr>
<tr><td></td><td>b</td><td>The system block diagram is shown in fig below find C(s)/ N(s) using block diagram reduction technique.
</td><td>8</td><td>L3</td><td>CO2</td></tr>
<tr><td></td><td>c</td><td>Define control system. Compare open loop and closed loop system.</td><td>7</td><td>L2</td><td>CO1</td></tr>
<tr><td colspan="6">OR</td></tr>
<tr><td></td><td>a</td><td>Write the differential equation governing the mechanical system shown in figure below draw the force voltage and force current electrical analogous circuit and verify by writing mesh and node equation
</td><td>10</td><td>L3</td><td>CO1</td></tr>
<tr><td>2</td><td>b</td><td>Determine using block diagram reduction rules for figure 9</td><td>8</td><td>L3</td><td>CO2</td></tr>
</table>

		 Fig. 9			
	c	Apply the differential equation governing the mechanical system for the system shown below and draw the force voltage and force current electrical analogous circuit. Also verify by writing mesh and node equations 	7	L3	CO1
PART B					
3	a	Draw the analogous electrical network based on 	10	L3	CO2
	b	Explain the significance of a transfer function stating its advantages and features.	5	L2	CO1
	c	Determine the transfer function from the following blocks 	10	L3	CO2
OR					
4	a	Write the Mason's gain formula. For the given figure identify the number of forward path and number of individual loop	10	L2	CO2

					
	b	List the requirements of an ideal control system	5	L2	CO1
	c	Find the closed loop transfer function from the signal flow graph below 	10	L3	CO2

H. CONTINUOUS INTERNAL EVALUATION

Evaluation	Weightage in Marks
IA Test – 1	15
IA Test – 2	**15**
Laboratory Component	**25**
Marks for Different Components: Additional Assessment Tools (AATs) – (Assignments/ Open Book Test/ Written Quiz/ Seminar/ Report Writing/ Conduction of Experiments/ Micro-Project)	**10** To deepen student's understanding and increase his/her confidence in the topics studied. Further, to improve the oral, written skills and engineering aptitudes.
Final CIE	15+10+25=50