University of Engineering & Technology, Taxila

Electrical Engineering Department

PROBLEM BASED LEARNING (PBL)

Title:

Antenna Azimuth Position Control System

BY

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TO

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SUBMITTED ON

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Table Content

➢ Introduction:

An antenna azimuth position control system consists of two potentiometers, a preamplifier, a power amplifier, a motor and a load. The position (direction) of the antenna can be changed via one potentiometer (input transducer). The second potentiometer (output transducer) is used to obtain the actual azimuth position of the antenna. The input potentiometer converts the desired angular position to a voltage, while the differential amplifier provides the error signal between the desired and real antenna position signals. A power amplifier is used to amplify the control signal applied to the motor. The antenna position control is usually achieved by the help of a set of gears.

This project is Problem Based Learning (PBL). We are going to design a compensator to meet our requirements. In this we address the position control of antenna azimuth using lead compensators, lag compensator and proportional, integral and Derivative (PID) controller. The fractional order lead compensator is proposed for enhancing the closed loop performance of azimuth position control of antenna system. From the comparison of the closed loop responses, the proposed lead compensator delivers a superior closed loop performance when compared with PI controller and lead compensator. Here we required best azimuth positioning control with a little settling time, some value of overshoot and no steady-state error is detected. Frequency ranges were utilized for the PID controller in the system, while Ziegler-Nichols was used to tune the PID parameter gains. MATLAB Simulink platform was used for the system simulation. The antenna azimuth position control system turns the input command in output position. This system is widely used in antennas, robots and computers disks. Here we present the systems that are managed with azimuth antenna. We're going to show how the system works and how its performance can be improved. The purpose of this system is the input angle to be turned into an output angle of the antenna. The potentiometer converts the angular rotating in voltage. Similar to that, on the output angle rotations are turning into voltage of potentiometer, which is connected to the feedback. Signal and gain are increasing the difference between the input and output voltage. Rest of the system description given below in problem statement section. Here the functional block diagram shown below:

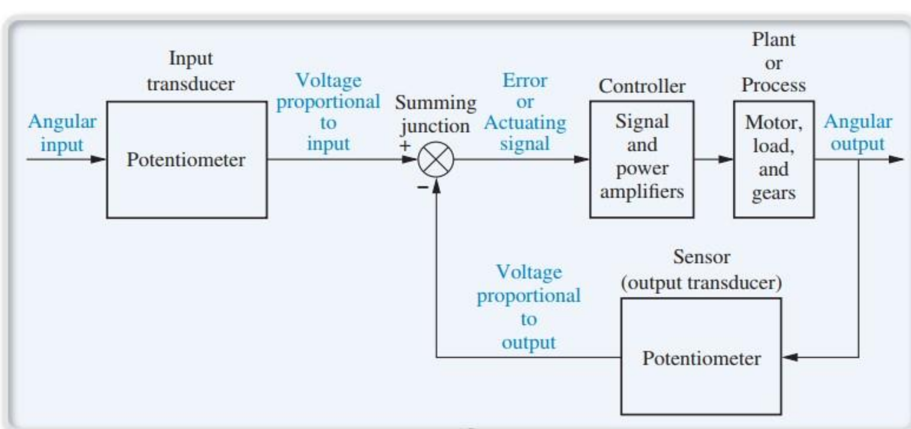
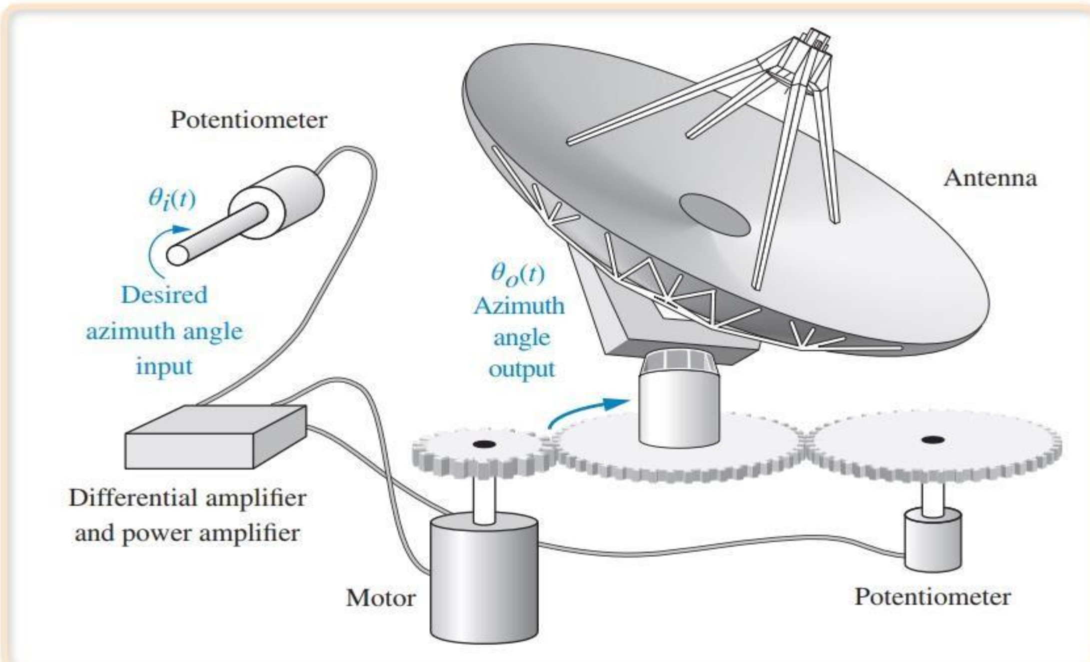


Figure 1 - Layout of the position control system of antenna azimuth

➢ System Description:

An antenna azimuth position control system consists of two potentiometers, a preamplifier, a power amplifier, a motor and a load. The position (direction) of the antenna can be changed via one potentiometer (input transducer). The second potentiometer (output transducer) is used to obtain the actual azimuth position of the antenna. The input potentiometer converts the desired angular position to a voltage, while the differential amplifier provides the error signal between the desired and real antenna position signals. A power amplifier is used to amplify the control signal applied to the motor. The antenna position control is usually achieved by the help of a set of gears.



➢ Project Objective:

The purpose of this report is to describe the management system of the antenna position in the frequency range (with transfer functions) and in the state space representation (state time equations), also known as time–domain approach. The results of analytical calculations and programming package MATLAB/Simulink will give the clear explanation of the response of the system. It will emphasize the importance of the results and indicate the possibility of further theoretical and experimental work on the same problem as well as the contributions in this field.

➢ Revised Concepts of Control Systems:

- Open/Close loop system
- Stability and Instability
- Pole-zero analysis
- Root locus plot
- Bode plots
- Gain & Phase Margin
- Lead & Lag Compensators
- PID Controller
- Step & Ramp Response
- Time domain performance
- Rise time, Settling time, Overshoot, Steady state error

➢ MATLAB Tools:

- Basic commands
- Simulink
- SISO tool

Finally, start to implementation of mathematically modelling in MATLAB, analyzed, made assumptions (hit and trial), and got the required OS%, Ts, Tr, ess, PM and GM. Analysis and designed controller using MATLAB codes, Simulink blocks and SISO tool.

System description, mathematically modelling, Simulations, analysis in different domains, Results & References are given in respective sections

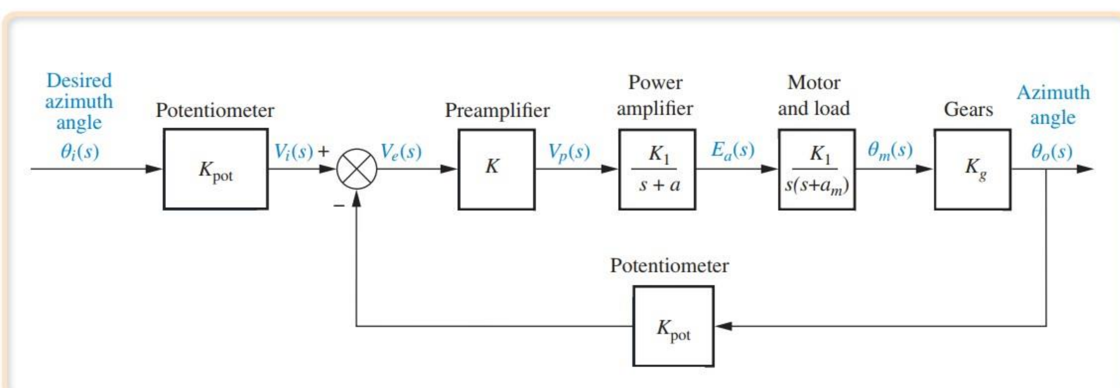


Figure 2: The closed-loop system scheme

Parameter	K_{pot}	K_1	K_g	K_m	a	a_m
Value	0.318	100	0.2	2	$50 + Reg\ \#$	2.5

In a group of students, Reg # of smallest Roll number will be taken as the value of "a". For example, group 1 of A1 group consists of three students having Reg # of 09, 49 & 89.

Value of parameter "a=21 +50 = 71"

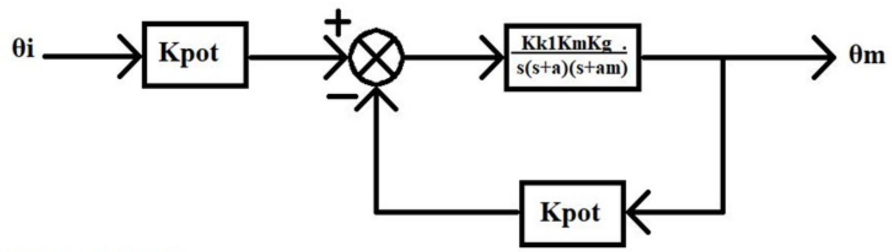
Methodology

1. First we derive the open loop and close loop transfer function.
2. Then we obtain open loop root locus , pole zero map and bode plot.
3. Then we obtain close loop step response to obtain the time domain parameters like rise time , settling time , peak time , overshoot and steady state etc.
4. Then according to given requirements we design lead compensator.
5. Also, we design lag compensator.
6. Then we connect lead lag compensator in series with system to see the waveform.
7. Then we replace lead-lag compensator with PID controller to see the waveform.
8. Then we analyze the time domain parameters of compensated waveforms.

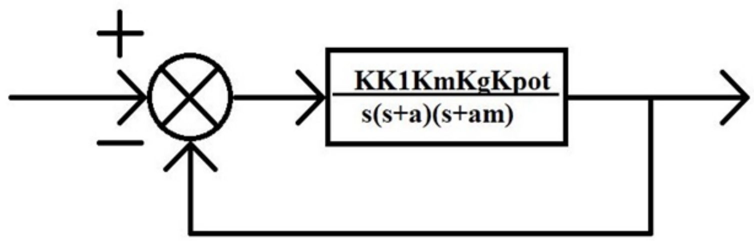
- **System Description**

Open and Close Loop Transfer Function:

Handwritten:



THEN



OPEN LOOP:

$$O.L = \frac{KK_1K_mK_gK_{pot}}{s(s+a)(s+a_m)}$$

$$O.L = \frac{12.72K}{s(s^2+73.5s+177.5)}$$

$$O.L = \frac{12.72K}{s^3+73.5s^2+177.5s}$$

CLOSE LOOP:

$$\frac{\theta_o(s)}{\theta_m(s)} = C.L = \frac{\frac{KK_1K_mK_gK_{pot}}{s(s+a)(s+a_m)}}{1+\frac{KK_1K_mK_gK_{pot}}{s(s+a)(s+a_m)}}$$

$$C.L = \frac{KK_1K_mK_gK_{pot}}{s(s+a)(s+a_m) + KK_1K_mK_gK_{pot}}$$

$$C.L = \frac{12.72K}{s^3 + 73.5s^2 + 177.5s + 12.72K}$$

Code:

```
Kpot=0.318
K1=100
Kg=0.2
Km=2
num=[Kpot*K1*Km*Kg] %K=1
den=[1 73.5 177.5 0]
OpenLoop=tf(num,den) %OpenLoop=GH
Forward=K1*Kg*Km
Gp=tf(Forward,den)
Gp1=feedback(Gp,Kpot)
CloseLoop=Kpot*Gp1 %CloseLoop=Kpot(forward/1+GH)
```

```
OpenLoop =

          12.72
  ------------------------
  s^3 + 73.5 s^2 + 177.5 s

Continuous-time transfer function.
```

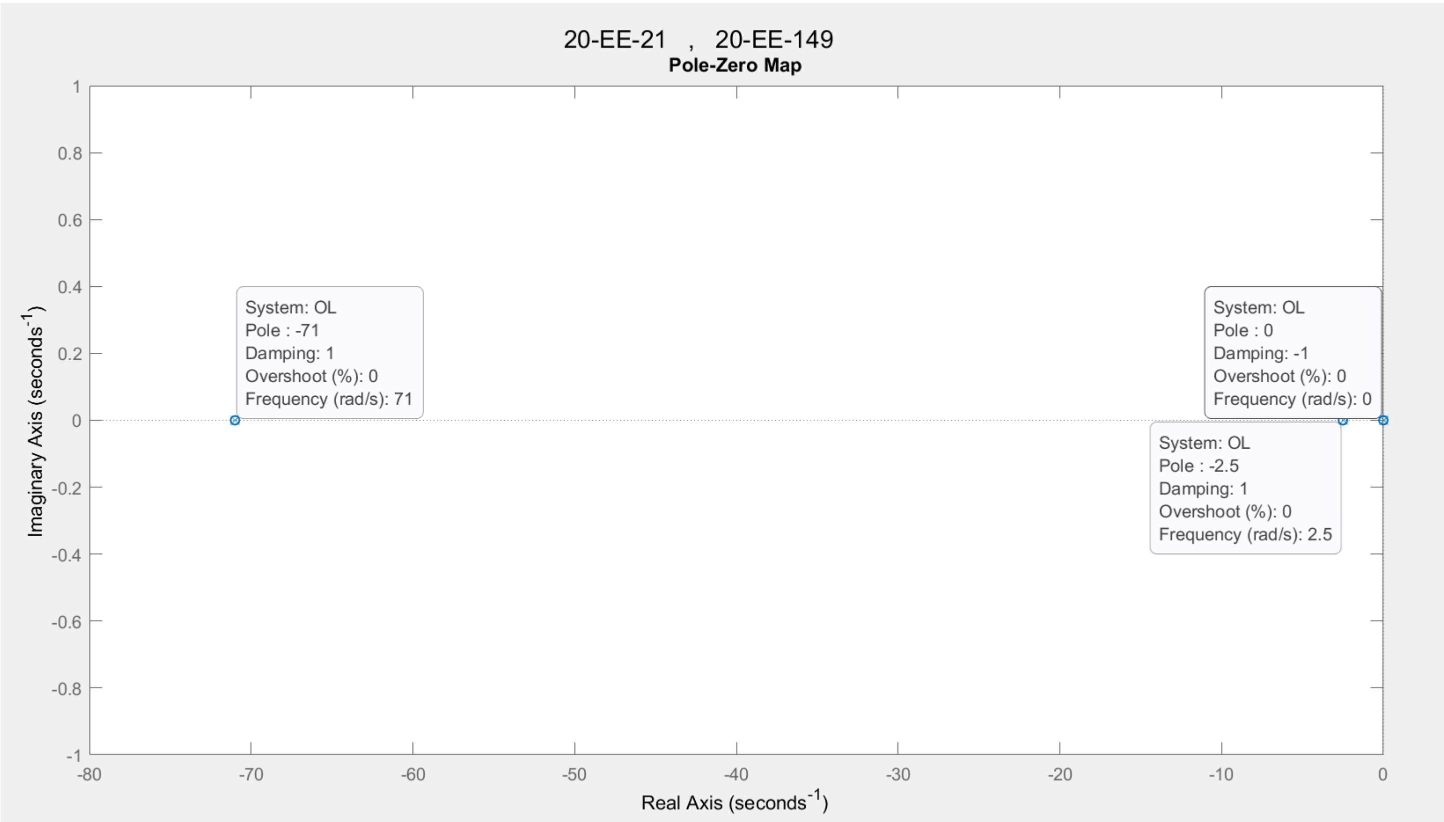
```
CloseLoop =

              12.72
  -------------------------------
  s^3 + 73.5 s^2 + 177.5 s + 12.72

Continuous-time transfer function.
```

➢ Uncompensated System Analysis in Time and Frequency Domain

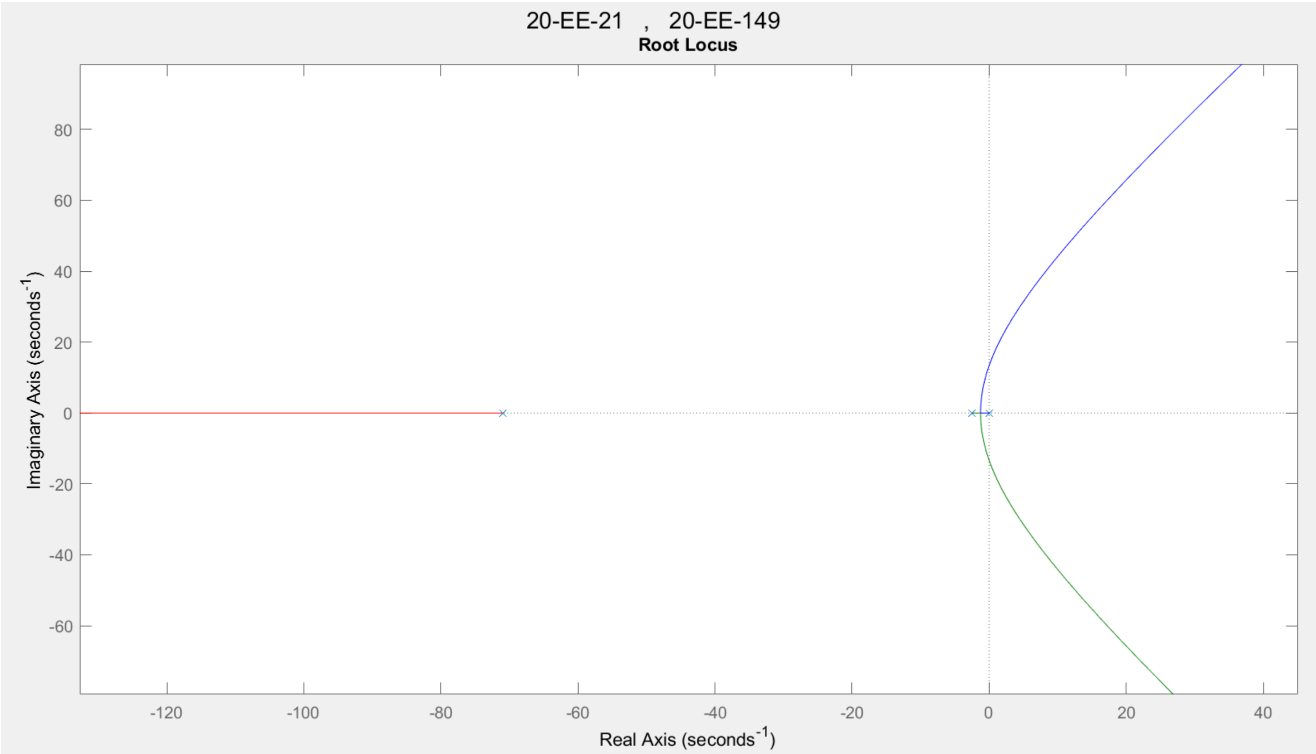
Code:

```
%20-EE-21
%20-EE-149
close all
num=[12.72]
den=[1 73.5 177.5 0]
num1=[12.72*23.8]
OL=tf(num,den)
OL1=tf(num1,den)
figure
pzmap(OL)
suptitle('20-EE-21    ,    20-EE-149')
figure(2)
rlocus(OL)
suptitle('20-EE-21    ,    20-EE-149')
figure(3)
margin(OL1)
```

Open Loop Pole-Zero Analysis:

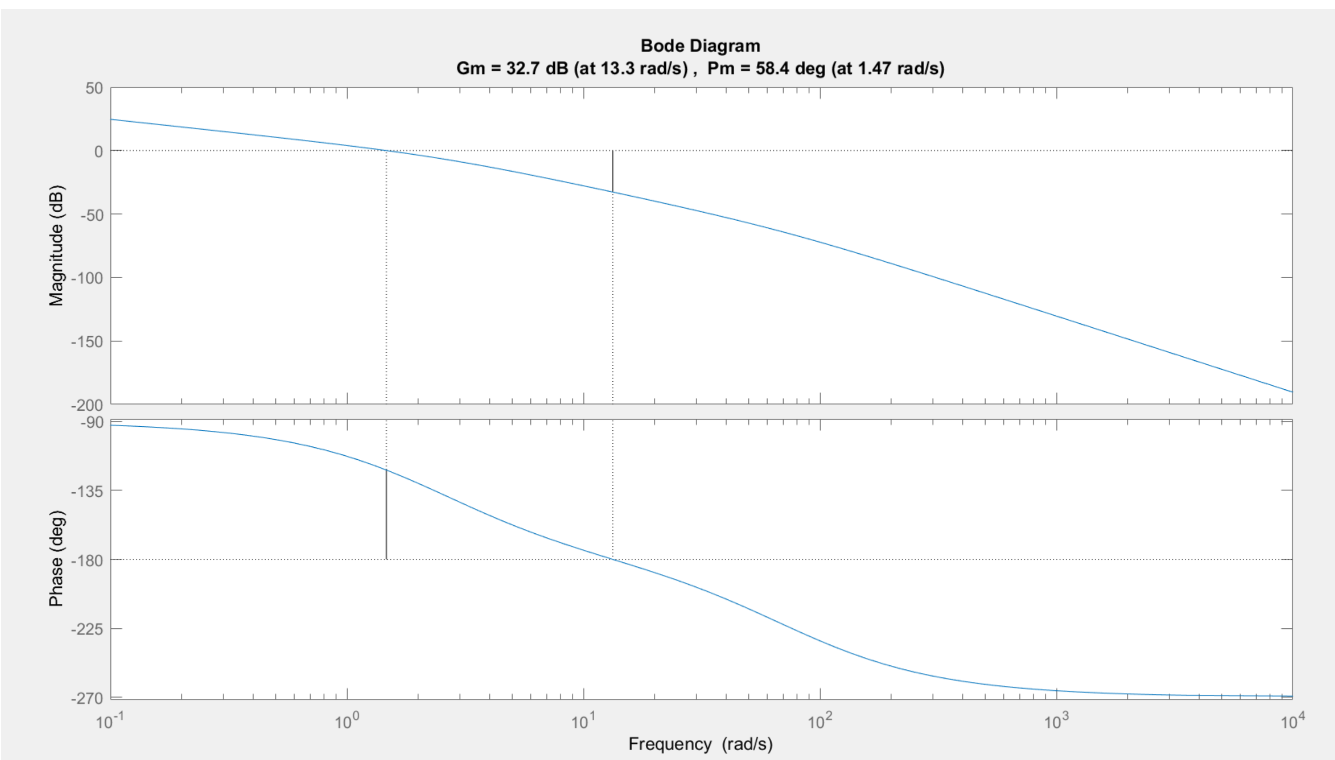


Root Locus Plot:



Note: *In root locus plot at 10% overshoot, we have found k=23.8*

Bode Plot:

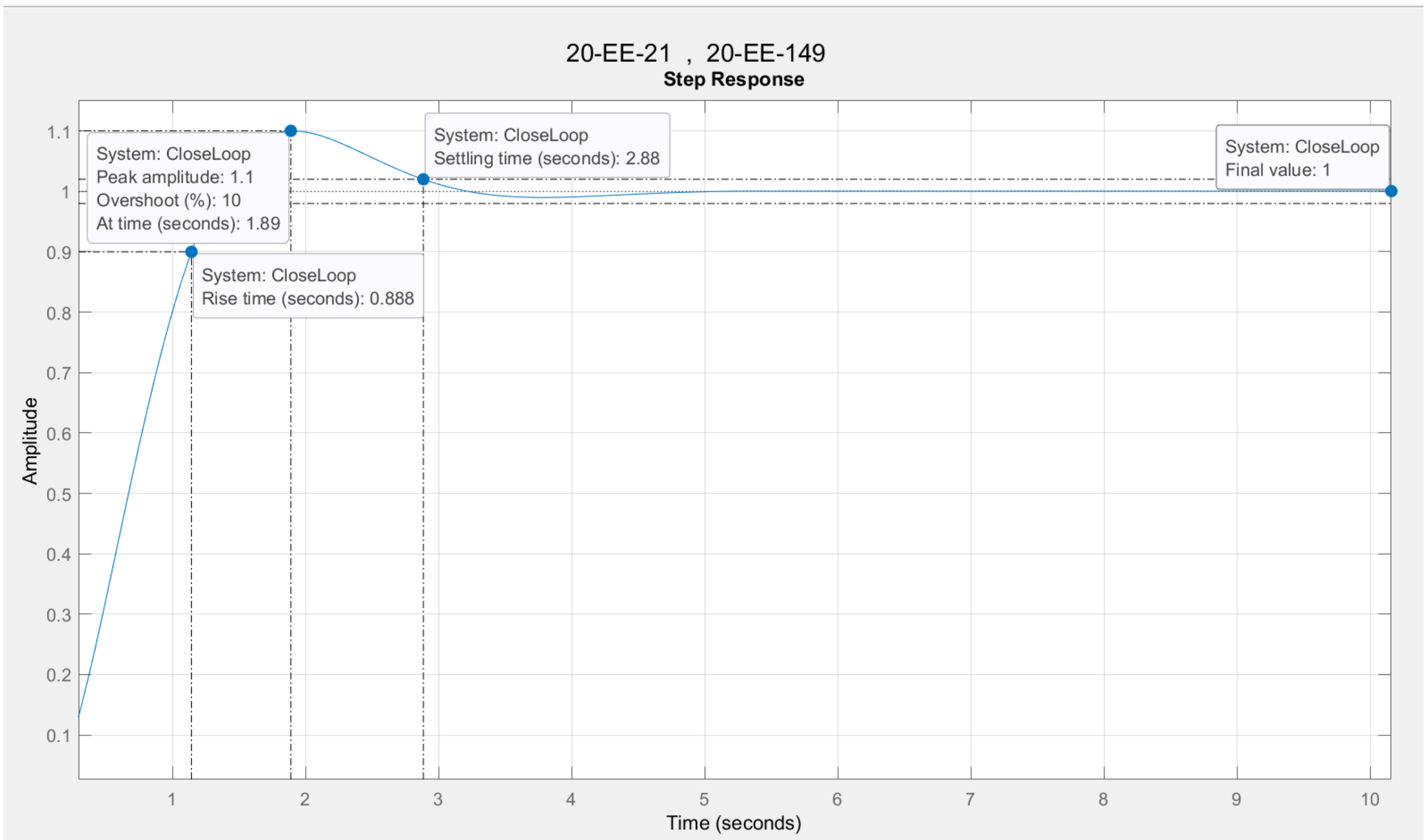


Closed-Loop Step Response:

Code:

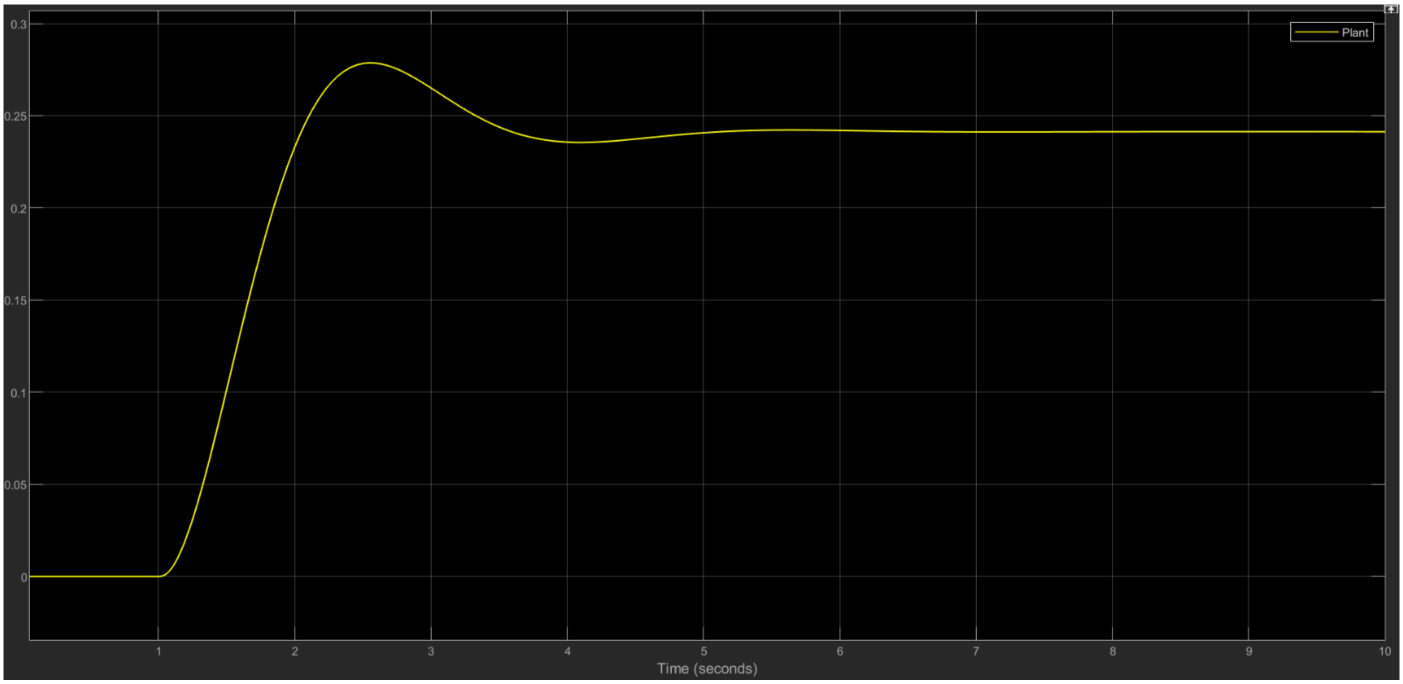
```
%20-EE-21
%20-EE-149
K=23.83
num=[302.736]
den=[1 73.5 177.5 302.736]
CloseLoop=tf(num,den)
figure
step(CloseLoop)
suptitle('20-EE-21  ,  20-EE-149')
```

Step Response:



Circuit on Simulink:

Step Response on Simulink:



Comment:

- ❖ System is Stable.
- ❖ Type of Response is Underdamped.

Response	PM & GM	Rise time	Settling time	Overshoot	e_{ss}
Uncompensated	GM = 32.7 dB PM = 58.4 ^{o}	0.888 s	2.88 s	10 %	0 %

➢ Compensators Design and Evaluation

Design Requirements:

- Overshoot of less than 10%
- Rise time is half of the uncompensated system or equal to (Tr<=0.5Tr) i.e. Tr<=0.4495 s
- Settling time should be less than or equal to 2 sec. (Ts<= 2sec.)
- Phase margin between 45 and 65 degree, and Gain margin of at least 6 dB.
- There is tenfold improvement in steady state error.

Lead-Lag Compensator Design:

Lead Compensator

$T_r \le 0.4495$

$\% \, O.S = 10\%$

$\xi = 0.5912$

From $T_s = \dfrac{4}{\xi W_n}$

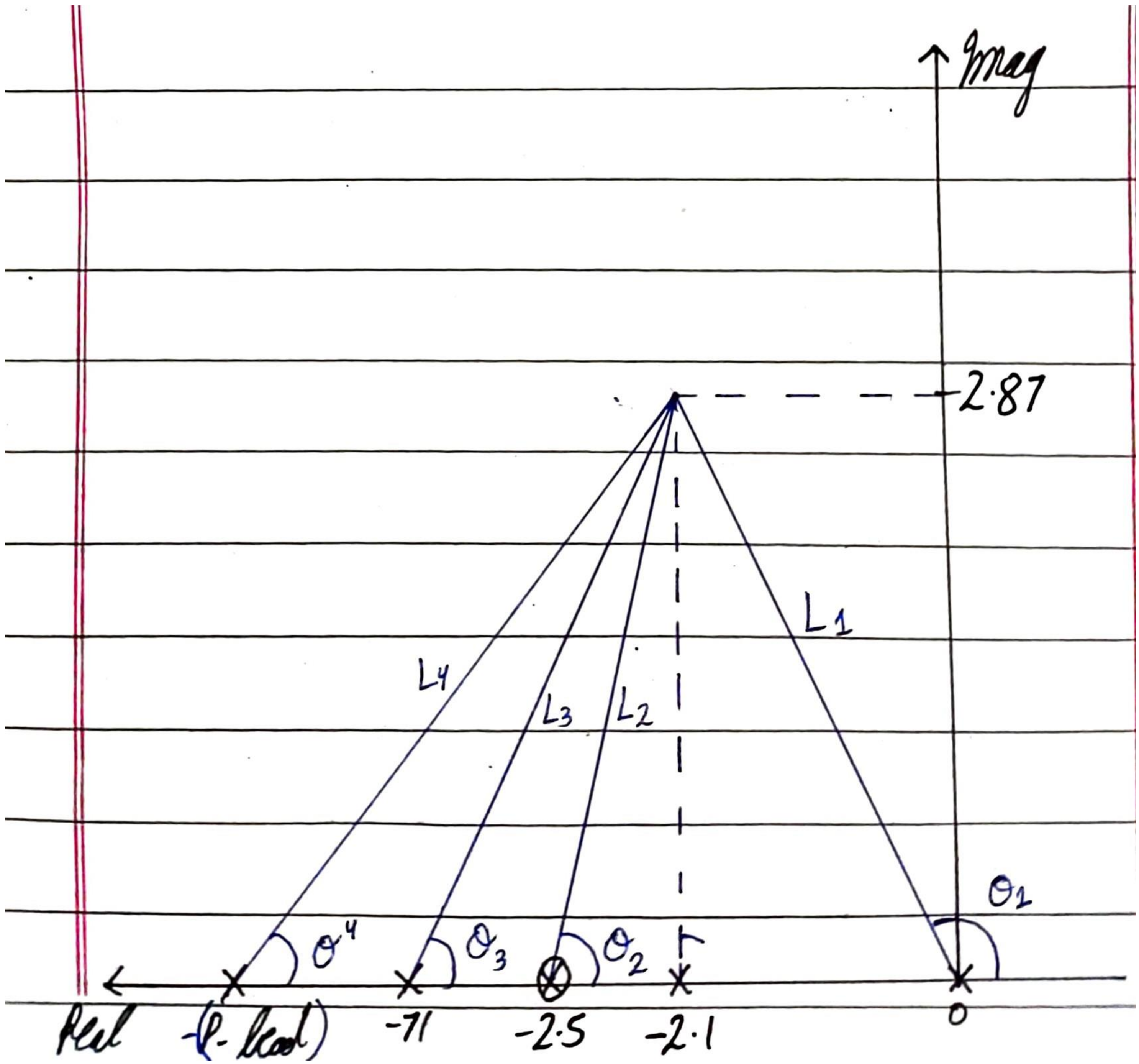
$1.9 = \dfrac{4}{(0.5912)(W_n)}$

$\therefore W_n = \dfrac{4}{1.123} = 3.56 \text{ rad/s}$

Poles $= S_{1,2} = -\xi W_n \pm \sqrt{1-\xi^2} \cdot jW_n$

$= -(0.59)(3.56) \pm \sqrt{1-(0.59)^2} \, j \cdot W_n$

$\boxed{= -2.1 \pm 2.87j}$


Imag
2.87
L1
L2
L3
L4
θ1
θ2
θ3
θ4
Real
-(P-lead)
-71
-2.5
-2.1
0

$$\Sigma\theta_z - \Sigma\theta_p = -180'$$

$\Rightarrow$ $\theta_1 = ?$

$$\theta_1 = \tan^{-1}\left(\frac{2.81}{2}\right) + 90^\circ$$

$$\theta_1 = 145.128^\circ$$

$\Rightarrow$ $\theta_2 = ?$

$$\theta_2 = \tan^{-1}\left(\frac{2.87}{0.4}\right)$$

$$\theta_2 = 82.06^\circ$$

$\Rightarrow$ $\theta_3 = ?$

$$\theta_3 = \tan^{-1}\left(\frac{2.87}{68.9}\right)$$

$$\theta_3 = 2.4^\circ$$

Now,

$$\Sigma\theta_z - \Sigma\theta_p = -180^\circ$$

$$\theta_z - (\theta_1 + \theta_2 + \theta_3 + \dots) = -180^\circ$$

$$\theta_1 + \theta_3 + \theta_4 = 180^\circ$$

$\Rightarrow$

$$\theta_4 = 32.472^\circ$$

$$\tan(32.742) = \frac{2.87}{P\text{-lead} - 2.1}$$

$\Rightarrow$ $P_{lead} = 6.61$

$L_1 = 3.556$

$L_2 = 2.87$

$L_3 = 68.97$

$L_4 = 5.34$

$\therefore K_c \text{ overall} = \frac{\pi L_p}{\pi L_z} = L_1 L_3 L_4$

$K_{c_{overall}} = 1310.703$

$\Rightarrow K_c = \frac{1310.73}{302.736} = 4.33$

$\Rightarrow G_{c(Lead)} = \frac{4.33(s+2.5)}{s+6.61}$

Lag - Compensator :-

$$\beta = \frac{K_{v\text{-}req}}{K_{v\text{-}plant}}$$

$$\beta = \frac{1/0.1e_{ss\text{-}plant}}{1/e_{ss\text{-}plant}}$$

where $\beta = 10$

So, $\frac{z}{p} = 10$

Let $z = 0.01$

$0.01 = 10p$

$P = 0.001$

$$G_{c\text{-}lag} = \frac{s+0.01}{s+0.001}$$

So,

As ess is zero, lag compensator can also be $G_c\text{-}lag = 1$

PID Compensator Design:

PID:-

As $e_{ss} = 0$, let $K_i = 0$

And,

$$\phi_{m\text{-}req} = 100\,\xi$$

$$\phi_{m\text{-}req} = 59.12^\circ$$

Let $\phi_{m\text{-}req} = 60^\circ$

So,

$$W_1 = \frac{8}{T_s(\tan 60^\circ)}$$

As condition says $T_s < 2$,

→ using $T_s = 1.5s$

$$W_1 = \frac{8}{1.5(1.73)} = \frac{8}{2.6}$$

$$W_1 = 3.1 \text{ rad}$$

And:-

$$|GH|_{w=3.1} = \frac{302.736}{3.1j\,(2.5+3.1j)(71+3.1j)}$$

$$= \frac{302.736}{3.1\angle 90^\circ (4\angle 51.11)(71.06\angle 2.5)}$$

$$= 0.342 \angle -143.61^\circ$$

$\theta = -180 + \phi m - (\arg G(jw_1)(H(jw_1))$

$\theta = -180 - 60 - (-143.61)$

$\theta = 23.61$

Now

$K_p = \dfrac{\cos\theta}{|GH|}$

$K_p = \dfrac{\cos(23.61)}{0.342}$

$K_p = 2.6$

$K_D = \dfrac{\sin\theta}{w_1(|GH|)}$

$K_D = \dfrac{\sin(23.61)}{(3.1)(0.342)}$

$K_D = 0.37$

$\boxed{G_c = 0.37s + 2.6}$

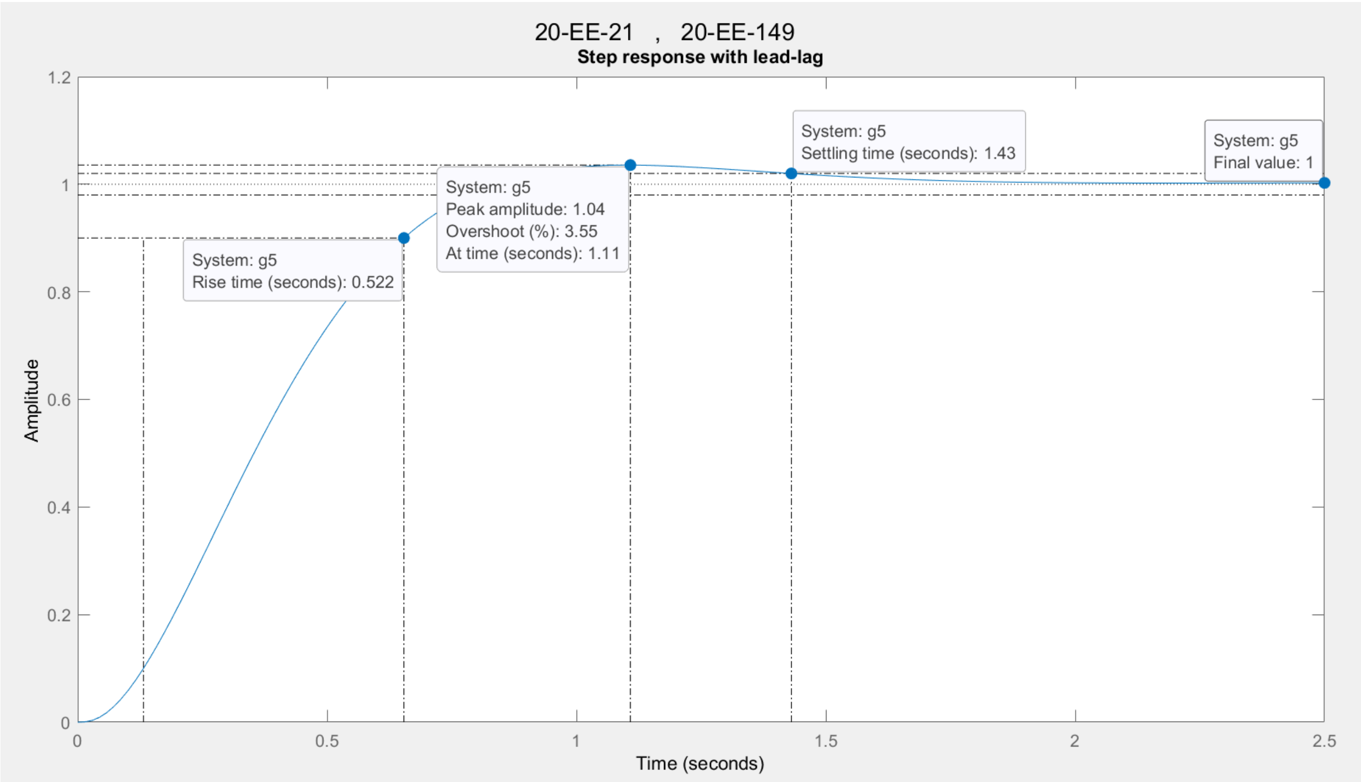
Code:

```
close all
t=[-10:0.01:50]
unitstep=zeros(size(t))
unitstep(t>=0)=10
num=[952]
den=[1 73.5 177.5 0]
Gp=tf(num,den)

lead=tf(4.33*[1 2.5],[1 6.61])
lag=tf([1 0.01],[1 0.001])
pid=tf([0.37 2.6],[1])

g0=Gp*pid
g1=feedback(g0,0.318)
g2=g1*0.318          %close loop with PID
g3=Gp*lead*lag
g4=feedback(g3,0.318)
g5=0.318*g4          %close loop with lead-lag

figure
step(g2) %Step response with PID
title('Step response with PID')
suptitle('20-EE-21   ,   20-EE-149')

figure
step(g5)        %Step response with lead-lag
title('Step response with lead-lag')
suptitle('20-EE-21   ,   20-EE-149')

figure
margin(g0*0.318)      %Bode plot with PID

figure
margin(g3*0.318)      %Bode plot with lead-lag
figure
lsim(unitstep,t,g2)    %step response with 10 unit step(PID)
title('Step response with PID with 10u(t)')
suptitle('20-EE-21   ,   20-EE-149')
figure
lsim(unitstep,t,g5)    %step response with 10 unit step(lead-lag)
title('Step response with lead lag with 10u(t)')
suptitle('20-EE-21   ,   20-EE-149')
```

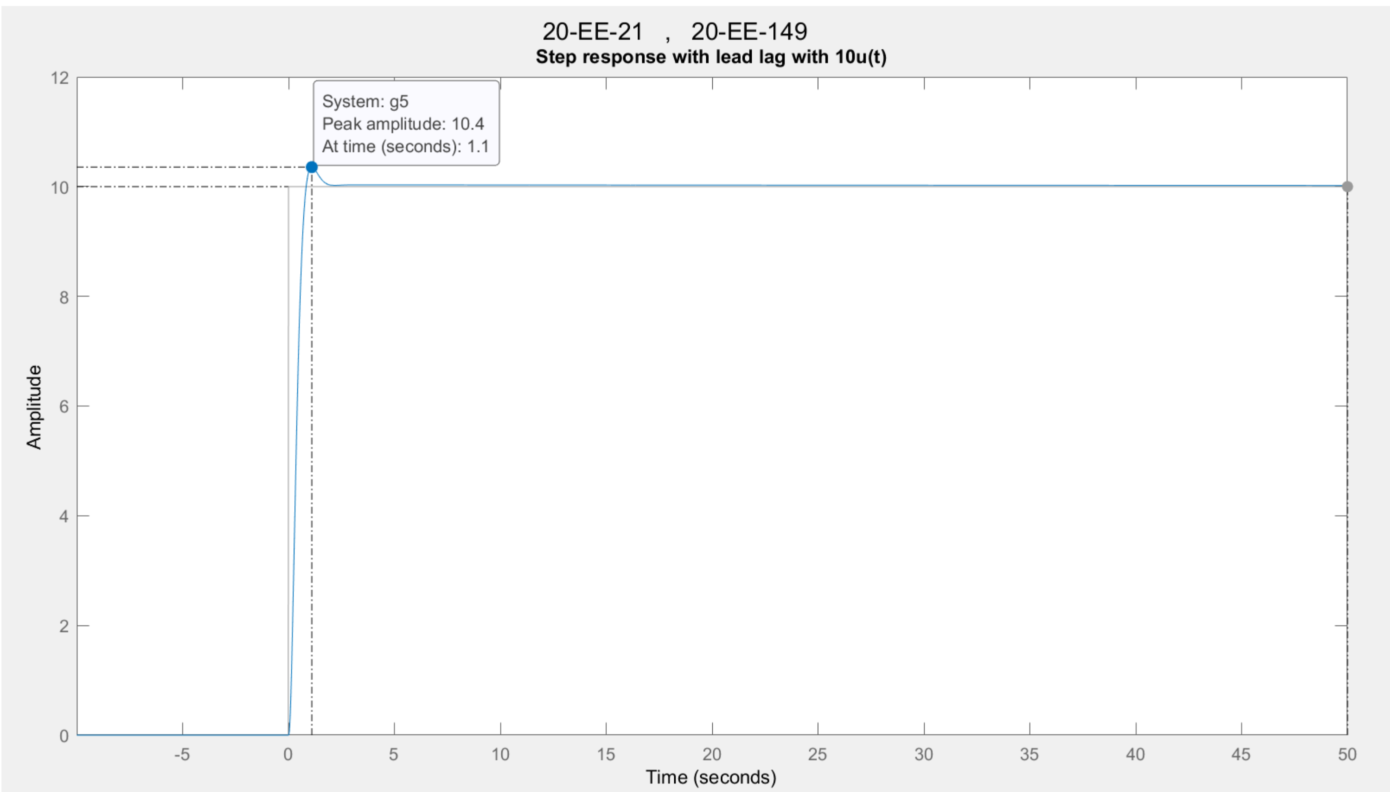
Waveform:

Lead-Lag Compensator:

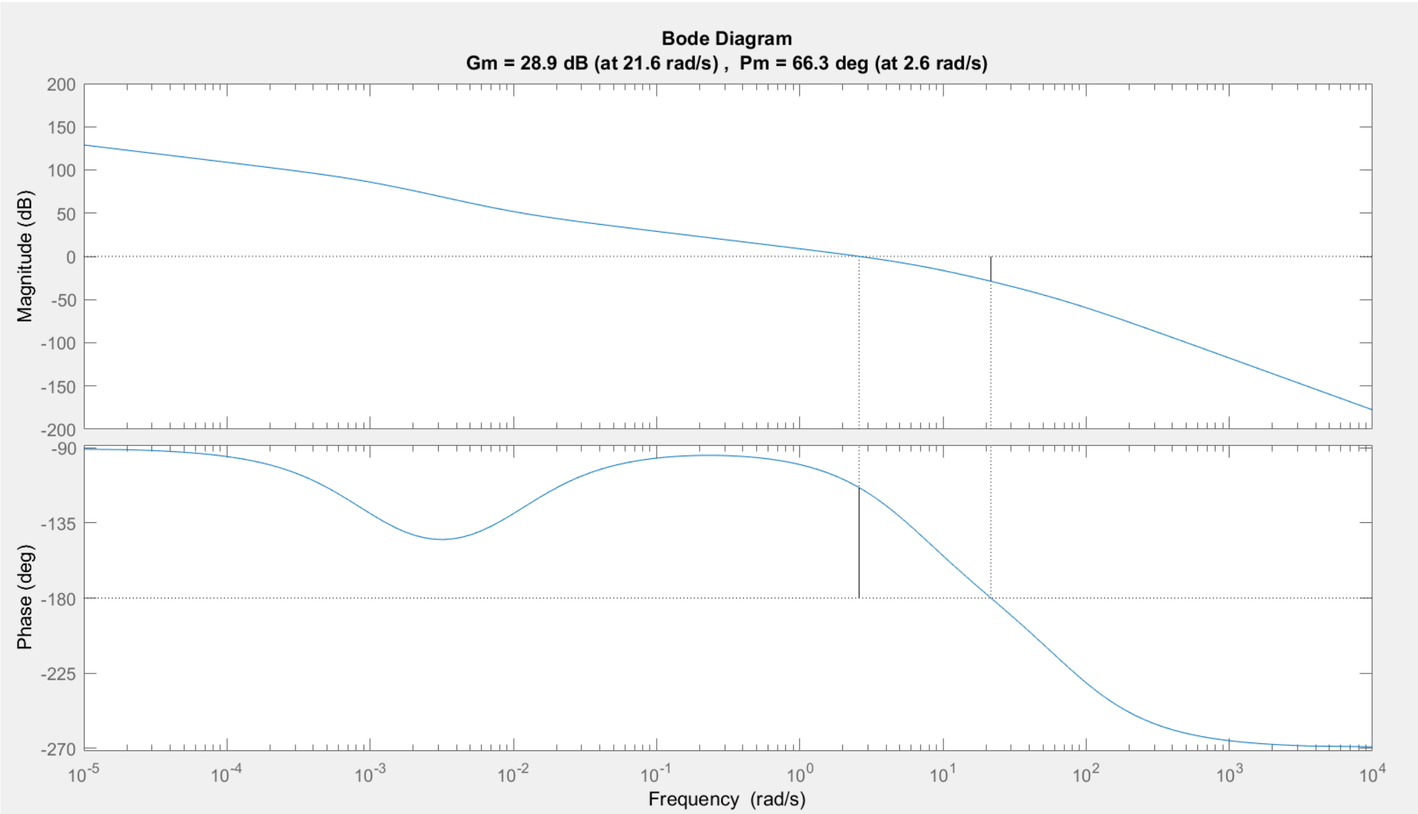
Step input:



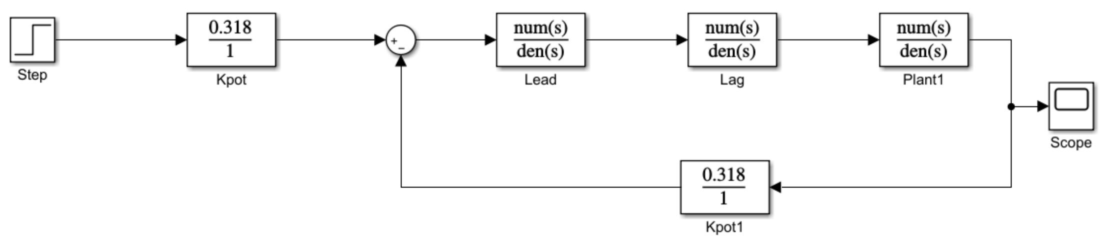
10 step input:



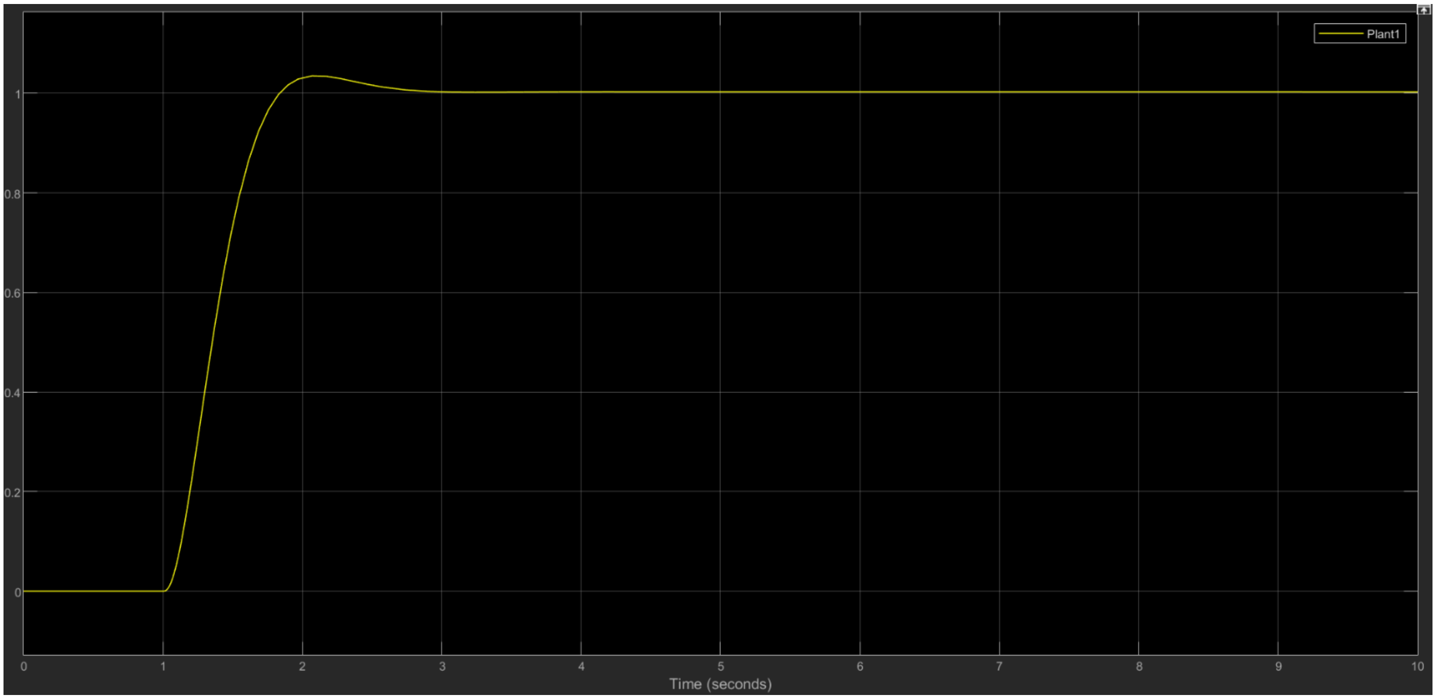
Bode Plot Compensated:



Circuit on Simulink:

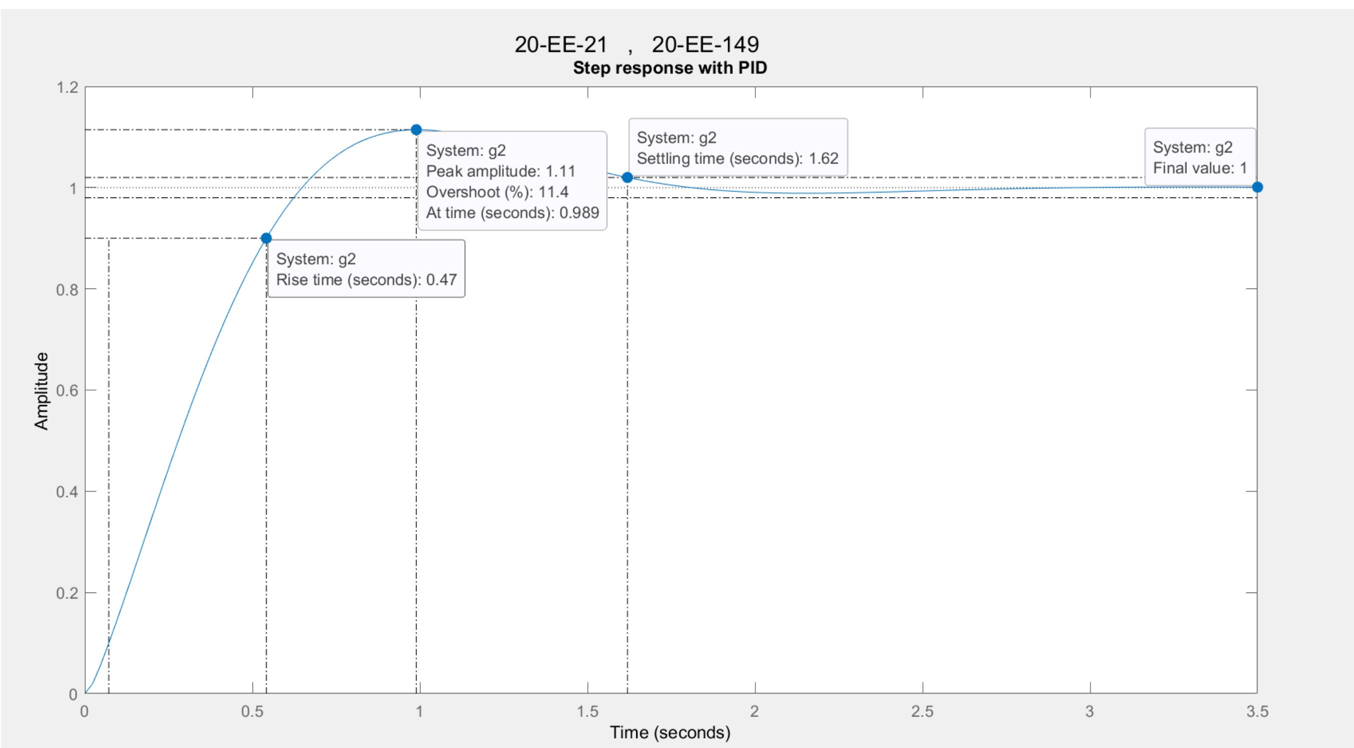


Step response on Simulink:

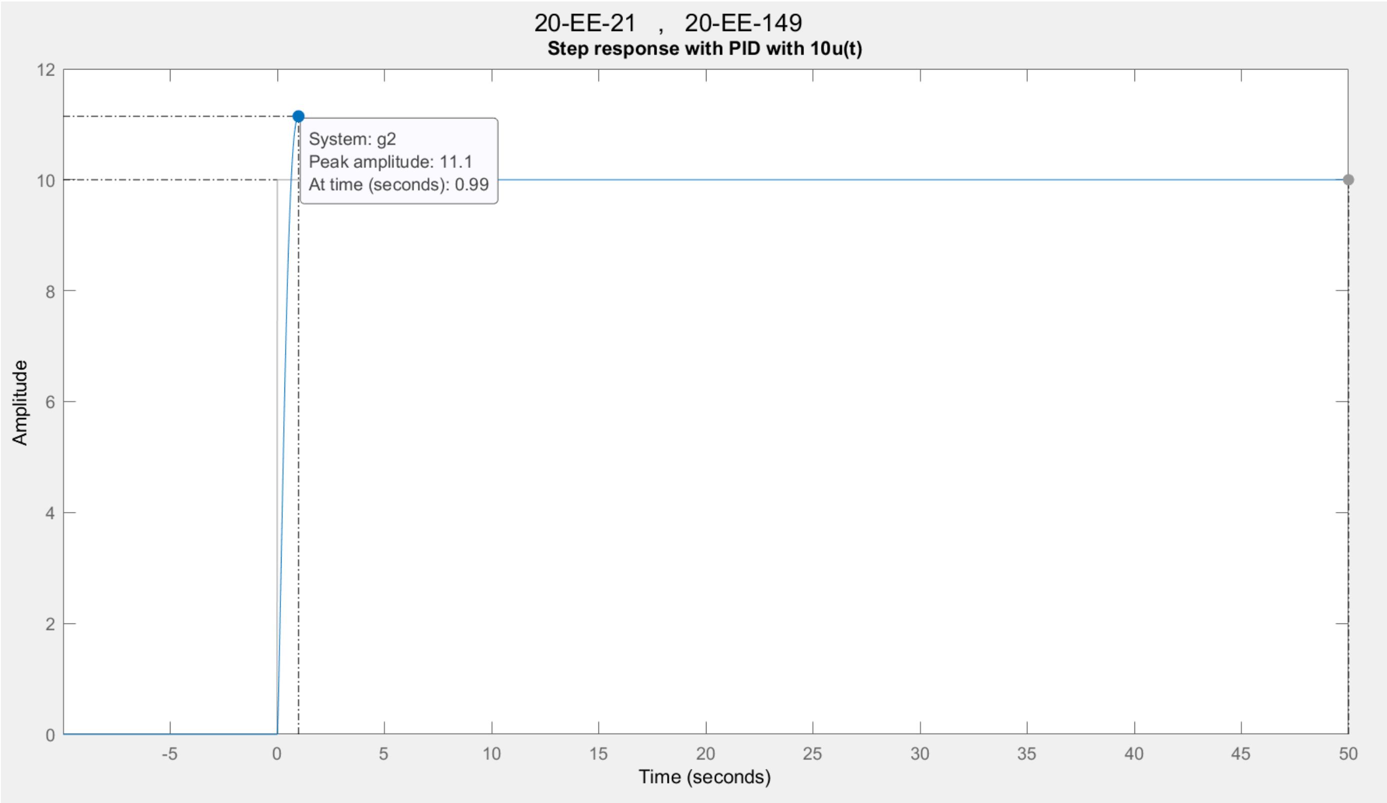


PID Controller:

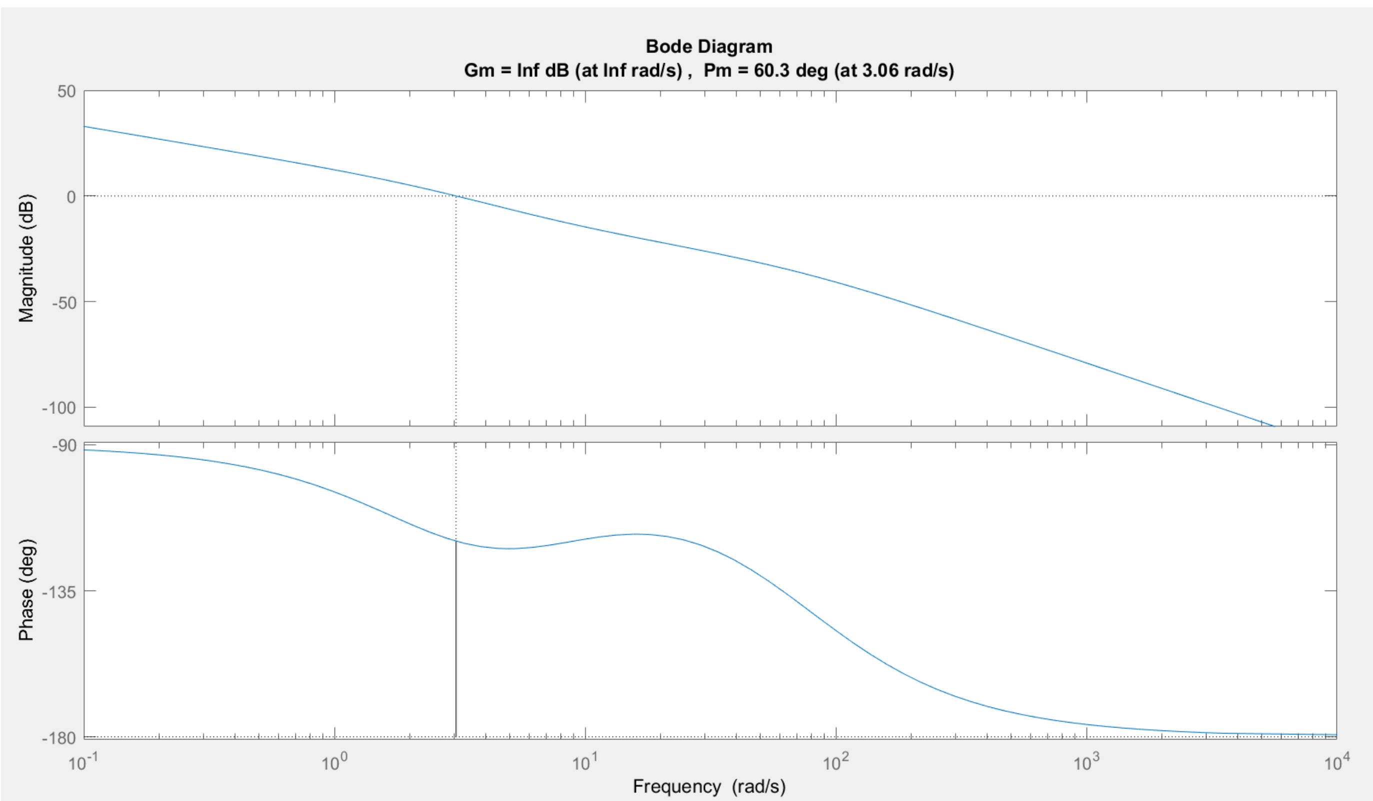
Step input:



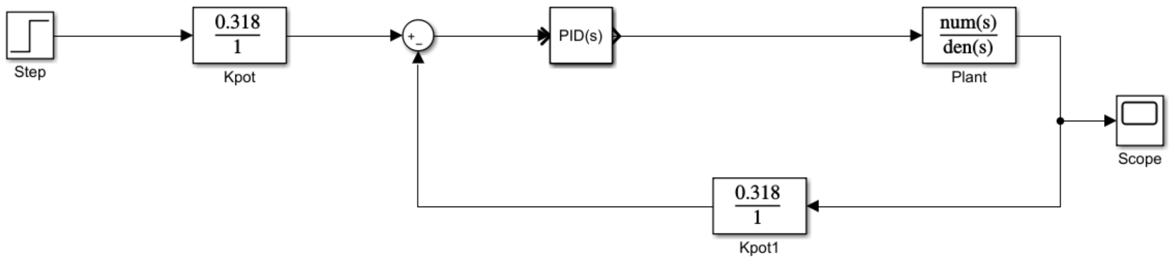
10 step input:



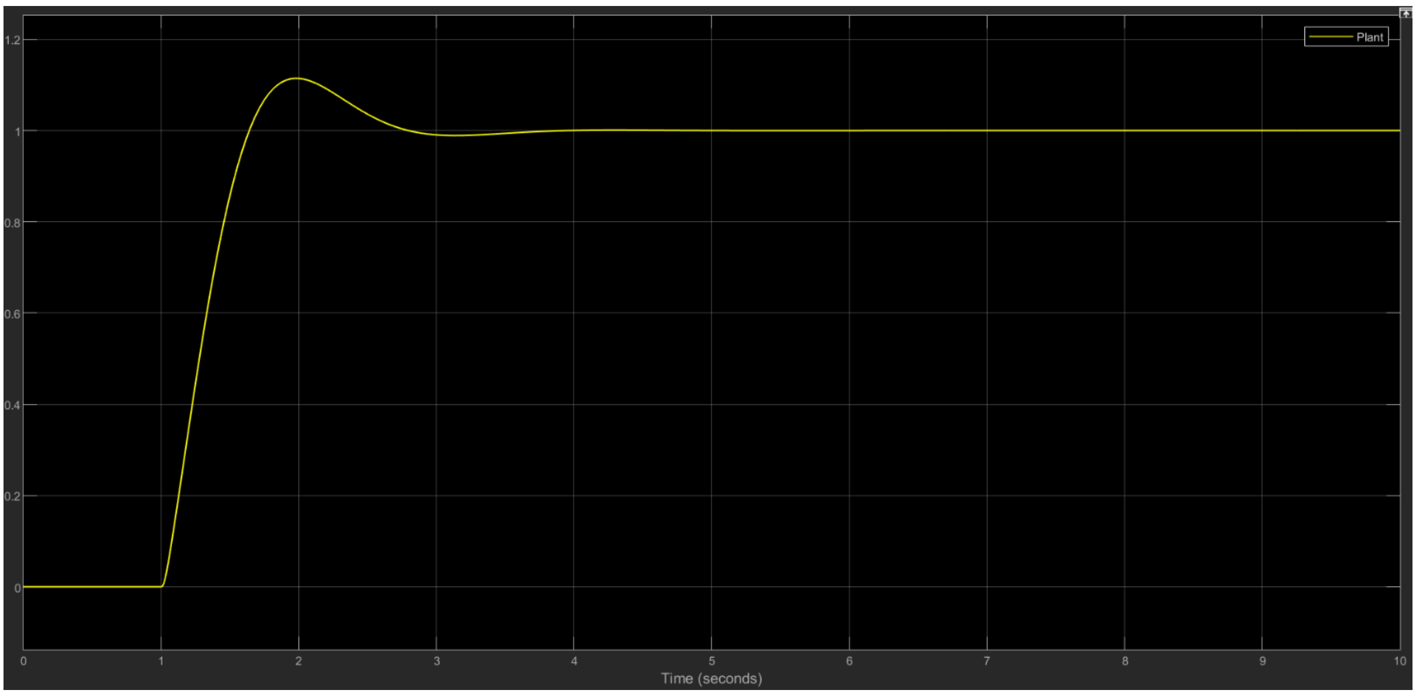
Bode Plot Compensated:



Circuit on Simulink:



Step Response on Simulink:



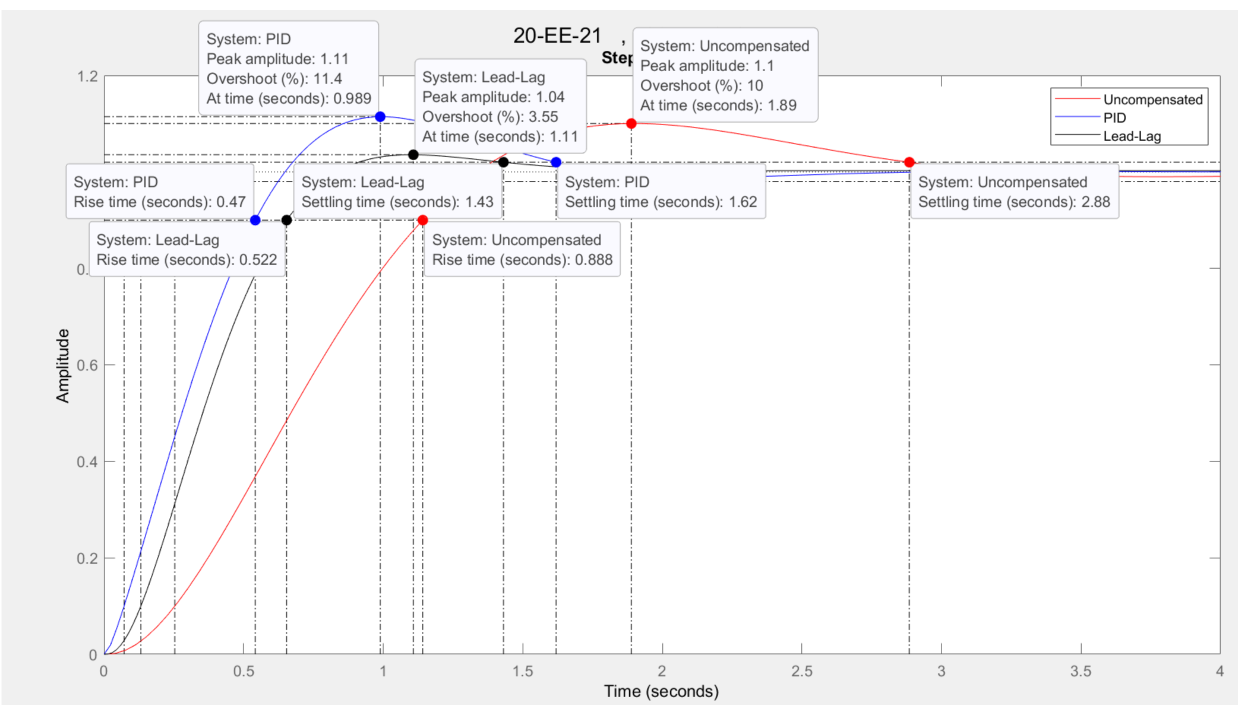
Controller	PM & GM	Rise time	Settling time	Overshoot	e_{ss}
Compensator 1 (Lead-Lag)	GM = 28.9 dB PM = 66.3 ^{o}	0.52 s	1.43 s	3.55 %	0 %
Compensator 2 (PID)	GM = infinite PM = 60.3 ^{o}	0.47 s	1.62 s	11.4 %	0 %

➢ Results and Comparative Analysis

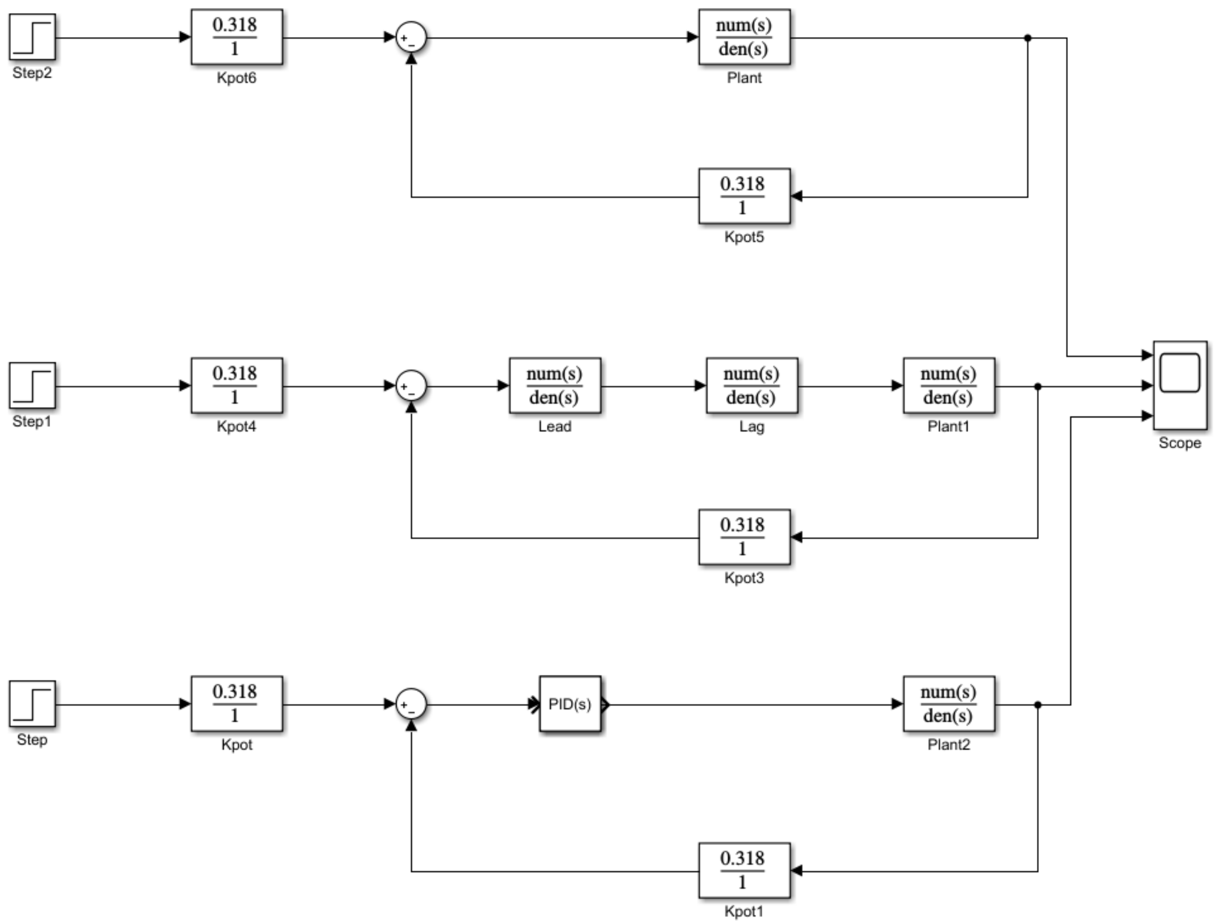
Code:

```
close all
num=[952]
den=[1 73.5 177.5 0]
Gp=tf(num,den)
Gclose=tf([302.73],[1 73.5 177.5 302.73])
Lead=tf(4.33*[1 2.5],[1 6.61])
Lag=tf([1 0.01],[1 0.001])
PID=tf([0.37 2.6],[1])
g0=Gp*PID
g1=feedback(g0,0.318)
g2=g1*0.318           %close loop with PID figure

g3=Gp*Lead*Lag
g4=feedback(g3,0.318)
g5=0.318*g4    %close loop with lead-lag figure

step(Gclose,'red')    %Uncompensated step response
hold on
step(g2,'blue') %Step response with PID
hold on
step(g5,'black')      %Step response with lead-lag

legend('Uncompensated','PID','Lead-Lag')
suptitle('20-EE-21   ,   20-EE-149')
```

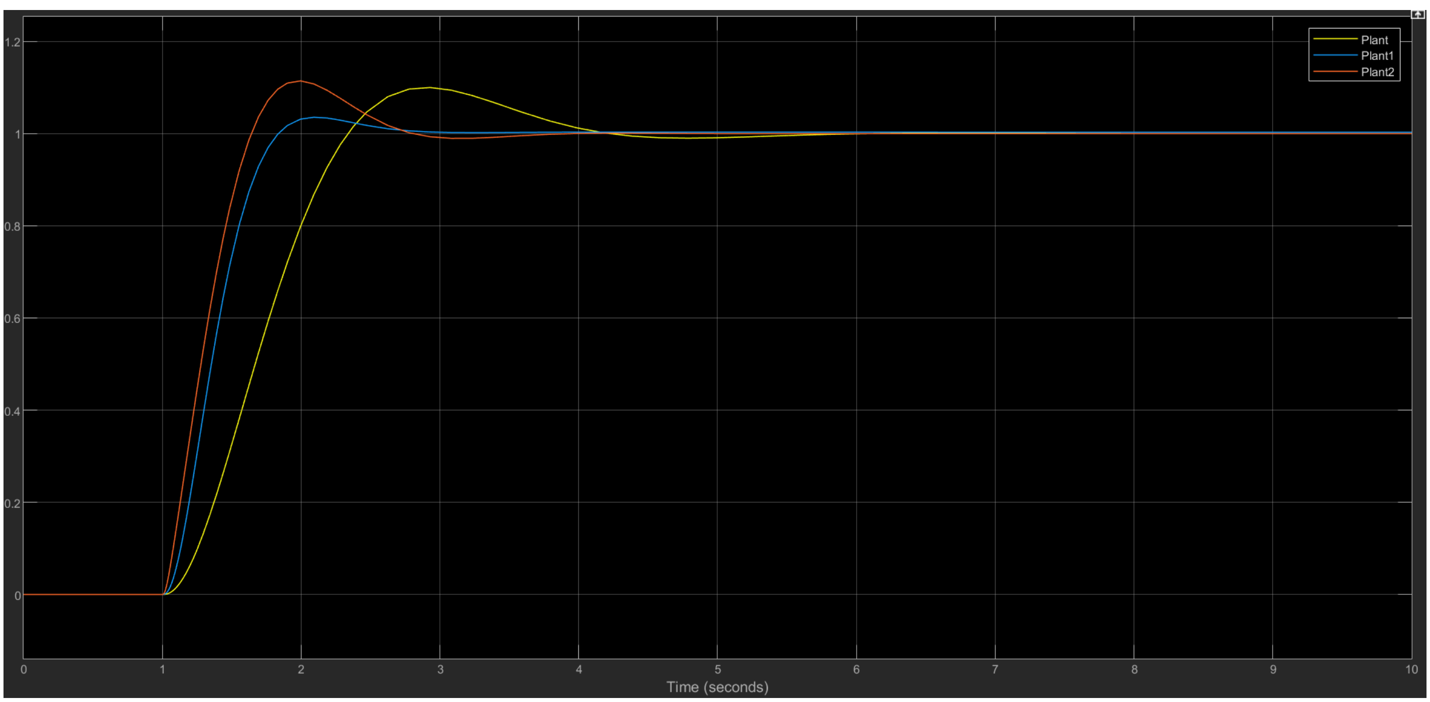
Waveform:



Circuit on Simulink:



Step Response on Simulink:



Controller	PM & GM	Rise time	Settling time	Overshoot	e_{ss}
Uncompensated	GM = 32.7 dB PM = 58.4 ^{o}	0.888 s	2.88 s	10 %	0 %
Compensator 1 (Lead-Lag)	GM = 28.9 dB PM = 66.3 ^{o}	0.52 s	1.43 s	3.55 %	0 %
Compensator 2 (PID)	GM = infinite PM = 60.3 ^{o}	0.47 s	1.62 s	11.4 %	0 %

Hence,

For PID:

- Overshoot is almost **10%.**
- Settling time is less than 2 sec.
- Phase margin between **45 ^{o} and 65 ^{o} degree (60.3 ^{o})**, and Gain margin of infinite.
- Rise time is less than uncompensated system.
- There is tenfold improvement in the steady state error.

For Lead-Lag:

- Overshoot is less than **10%**
- Settling time is less than 2 sec.
- Phase margin between **45 ^{o} and 65 ^{o} degree (66.3 ^{o})** and Gain margin is **28.9dB**.
- Rise time is less than uncompensated system.
- There is tenfold improvement in the steady state error.

➢ Comparative Analysis

Comparison between uncompensated and compensated system can be observed clearly, without compensator phase margin was not lie in our required range but after adding the appropriate compensator in the system both phase margin and gain margin fulfils our requirement, we was talking about Bode plot which was analysis in frequency domain. Now come towards time domain, the difference between uncompensated and compensated system rise time, settling time and overshoot. In uncompensated system rise time, settling time and overshoot was 0.888s, 2.88s and 10 % respectively. In compensated system rise time, settling time and overshoot is 0.52s, 1.43s and 3.55% respectively and most important fulfils our requirement. The last thing for comparison is steady state error (ess). In uncompensated system the value of steady state error is 0. In compensated system the error value is again 0. Uncompensated system is not stable in other hand compensated system is stable and efficient. Compensator shifts the root locus to the left, which enhances the responsiveness and stability of the system. For the Compensated system we designed two types of compensators one was phase lead compensator which stated above but PID has their own space and own functionality. In this technique we can make controller of different combination like PI , PD and PID etc. PID has different techniques for its tuning.

➢ Conclusion

When we first analyze the system without compensator and observed rise time, which was showing very poor performance

of system for enhancing the system performance improved rise time, settling time, overshoot and improved phase and gain margin using phase lead compensator and PID Controller, then we design required lead lag compensator and then see the compensated step response and after that we design PID controller and replace the lead lag compensator with that PID and again see the step response and observe that the lead lag compensated response and PID compensated response is almost same with small change in parameters but in our required parameters domain. In this project, I developed the phase lead compensator for enhancing the closed loop performance of azimuth position control of antenna system using MATLAB/Simulink/SISO-tool. We compared the responses in terms of time domain specifications for unit step input using lead compensator controller as well as PID controller. I learned a lot from this project, now I can design any compensator with more improvements. Stability of this compensator can be more improve if we consume more time to this project.

➢ References

- ❖ Google
- ❖ Lab slides
- ❖ Lab manuals
- ❖ Theory Lectures

➢ Appendix

- ❖ Different Websites