Frequency Method to design gain control and lag compensator for cruise control

AN ABSTRACT REPORT
Control Systems
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INTRODUCTION: Cruise control is a widely used technology in automobiles that allows a vehicle to maintain a steady speed without the need for constant driver intervention. To ensure optimal performance, gain control and lag compensators are often employed in cruise control systems. This report focuses on the frequency method, a common approach used for the design of gain control and lag compensators in cruise control systems.

AIM: To design gain control and lag compensator for cruise control using frequency method.

TOOLS: matlab Simulink, control system designer, control system toolbox.

- The model of the cruise control system is relatively simple. If the inertia of the wheels is neglected, and it is assumed that friction (which is proportional to the car's speed) is what is opposing the motion of the car, then the problem is reduced to the simple mass and damper system shown below. Using Newton's law, modeling equations for this system becomes

  mv’+bv=u

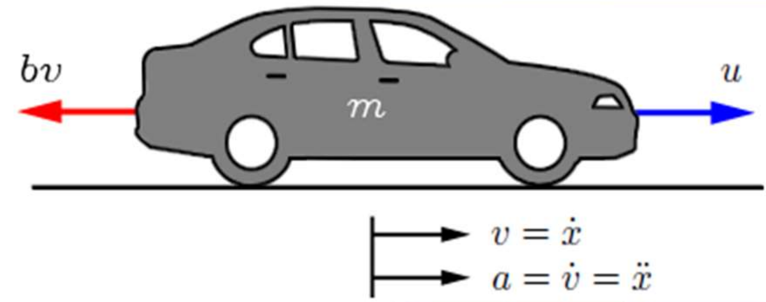
  y=v

  where u is the force from the engine, let’s assume that

  m=1000kg

  b=50Nsec/m

  u=500N



Design requirements

The next step in modeling this system is to come up with some design criteria. When the engine gives a 500 Newton force, the car will reach a maximum velocity of 10 m/s (22 mph). An automobile should be able to accelerate up to that speed in less than 5 seconds. Since this is only a cruise control system, a 10% overshoot on the velocity will not do much damage. A 2% steady-state error is also acceptable for the same reason.

Design criteria:

Rise time < 5 sec

Overshoot < 10%

Steady state error < 2%

Transfer Function

To find the transfer function of the above system, we need to take the Laplace transform of the modeling equations. **When finding the transfer function, zero initial conditions must be assumed.** Laplace transforms of the two equations are shown below.

Since our output is the velocity, let's substitute V(s) in terms of Y(s)

The transfer function of the system becomes

$$msV(s) + bV(s) = U(s)$$

$$Y(s) = V(s)$$

$$msY(s) + bY(s) = U(s)$$

$$\frac{Y(s)}{U(s)} = \frac{1}{ms + b}$$

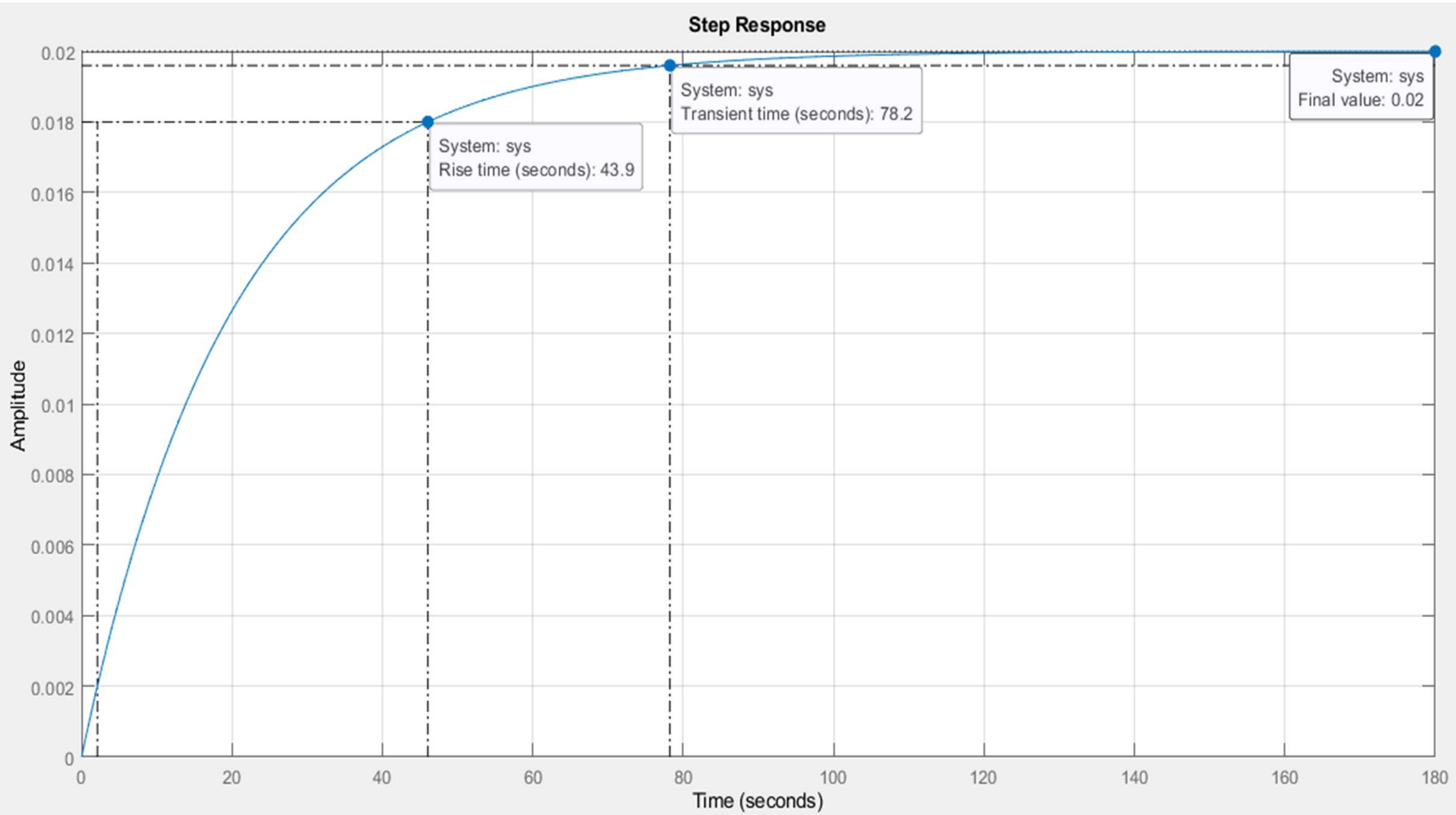
a. Determine the desired closed-loop transfer function: Define the desired system response in terms of the closed-loop transfer function, taking into account the desired steady-state error, rise time, settling time, and other performance criteria.

b. Identify the open-loop transfer function: Derive the open-loop transfer function by considering the plant dynamics (vehicle dynamics) and the controller dynamics.

c. Plot the Bode plot: Plot the magnitude and phase of the open-loop transfer function on a Bode plot. Analyze the plot to determine the gain crossover frequency (the frequency at which the magnitude is unity) and the phase margin (the amount of phase lag before instability occurs).

d. Adjust the gain: Modify the gain of the system to achieve the desired gain crossover frequency and phase margin. This can be done by multiplying the open-loop transfer function by a gain constant.

e. Verify stability and performance: Simulate the closed-loop system with the adjusted gain to verify stability and performance against the desired specifications

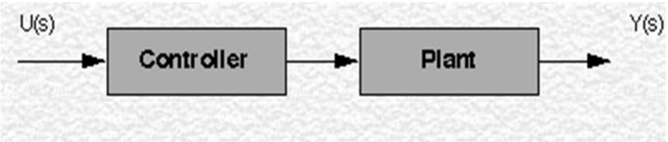


Step Response
System: sys
Rise time (seconds): 43.9
System: sys
Transient time (seconds): 78.2
System: sys
Final value: 0.02
Amplitude
Time (seconds)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
0
20
40
60
80
100
120
140
160
180

Gain Control Design

In cruise control systems, gain control is necessary to adjust the response of the system to changes in desired speed or disturbances. The frequency method can be employed to design gain control.

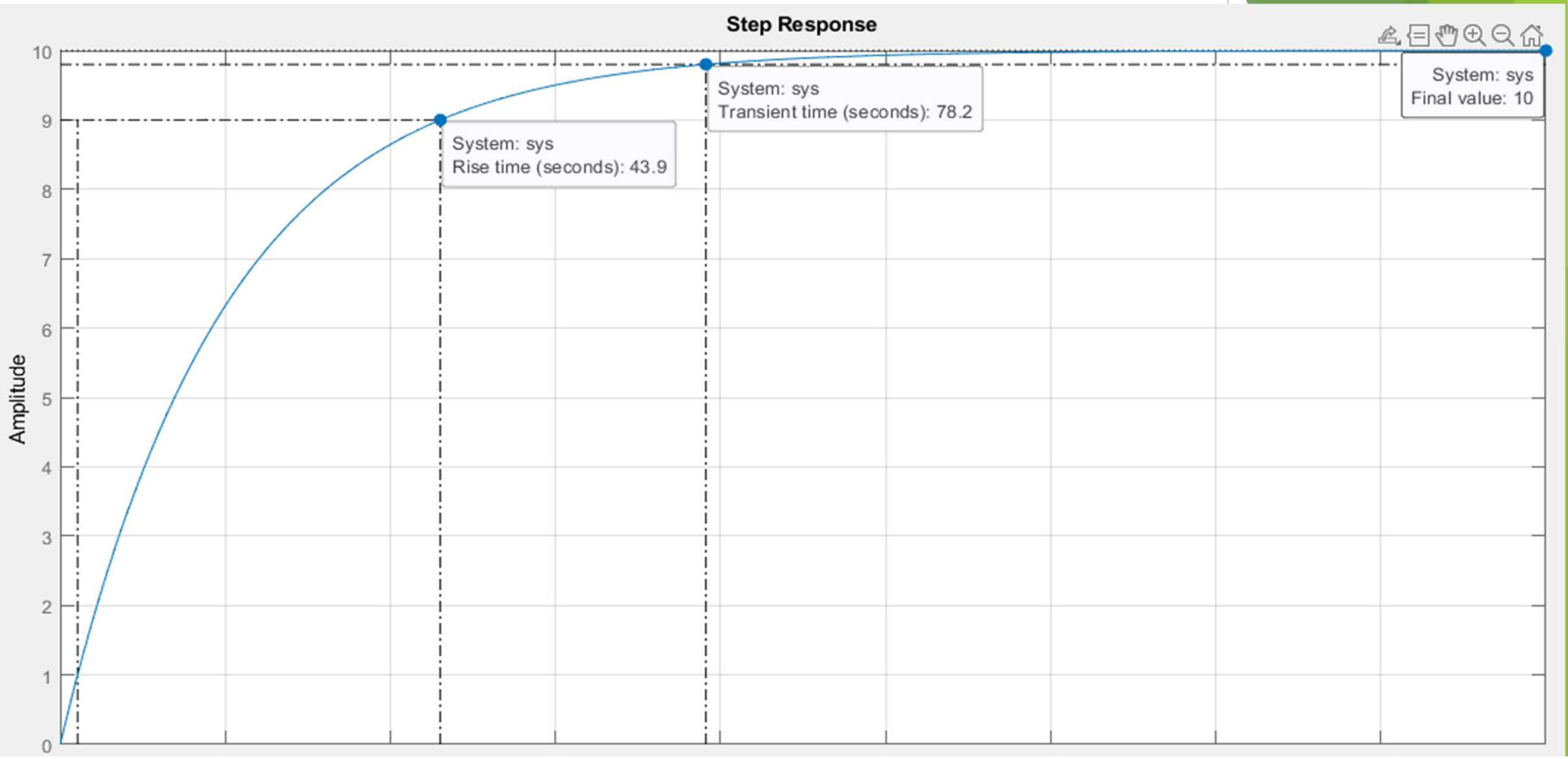
The first step in solving this problem using frequency response is to determine what open-loop transfer function to use. We will only use a proportional controller to solve the problem. The block diagram and the open-loop transfer function are shown below.



$$\frac{Y(s)}{U(s)} = \frac{K_p}{ms + b}$$

In order to use a Bode plot, the open-loop response must be stable.Let kp equal to 1.

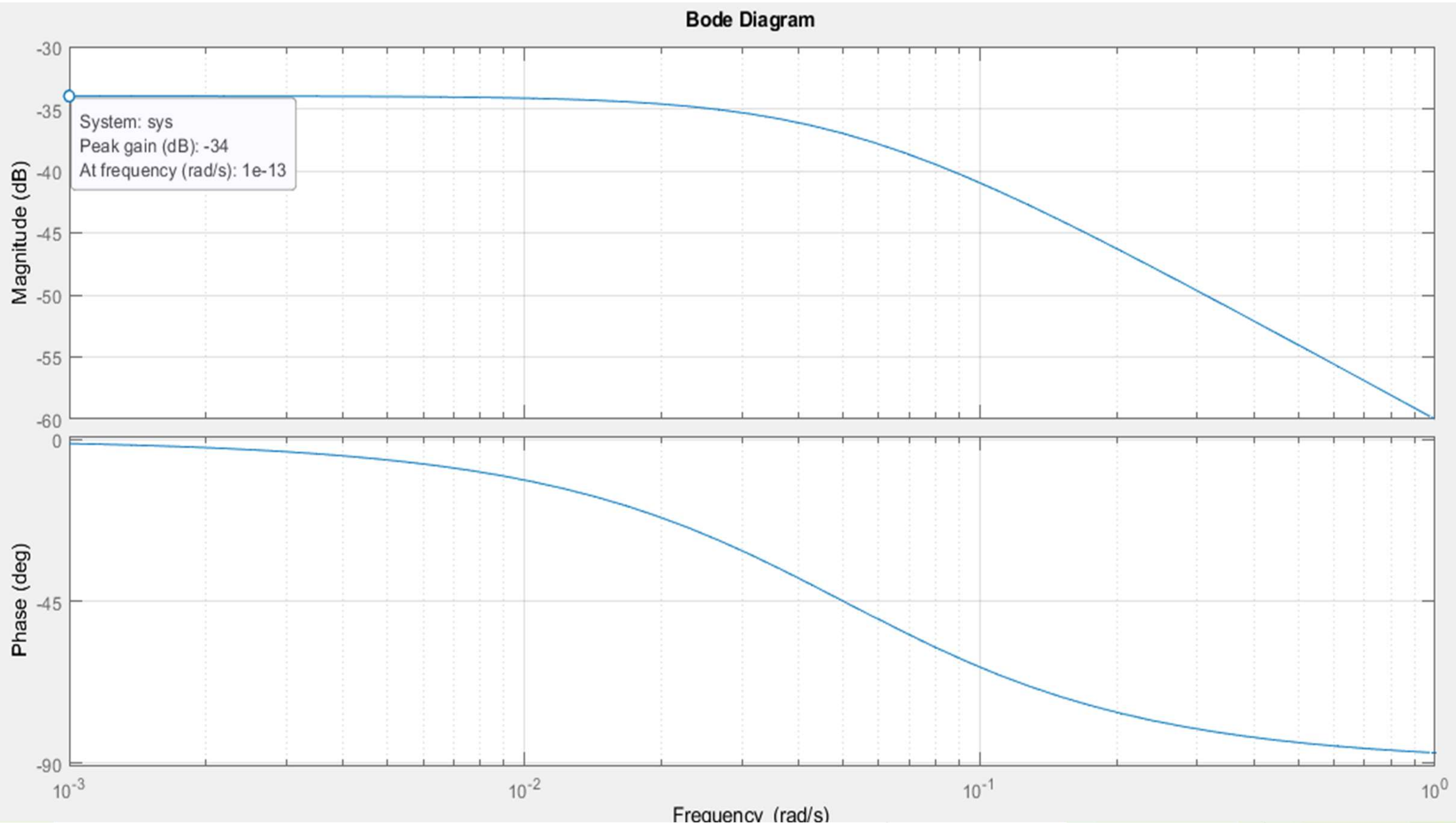
Vehicle takes more than 100sec to reach steady state speed of 10m/s. Rise time is more than 5 sec



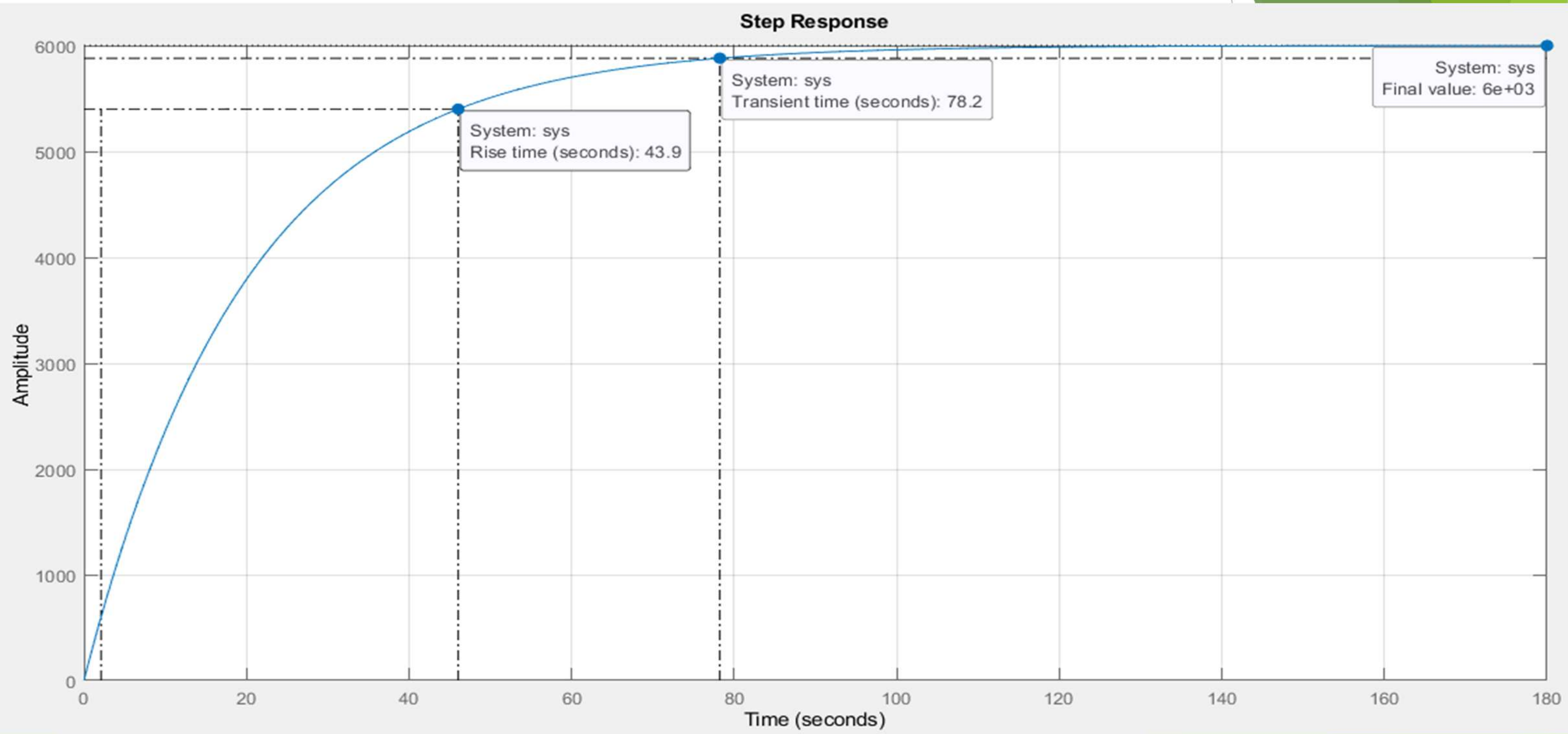
code

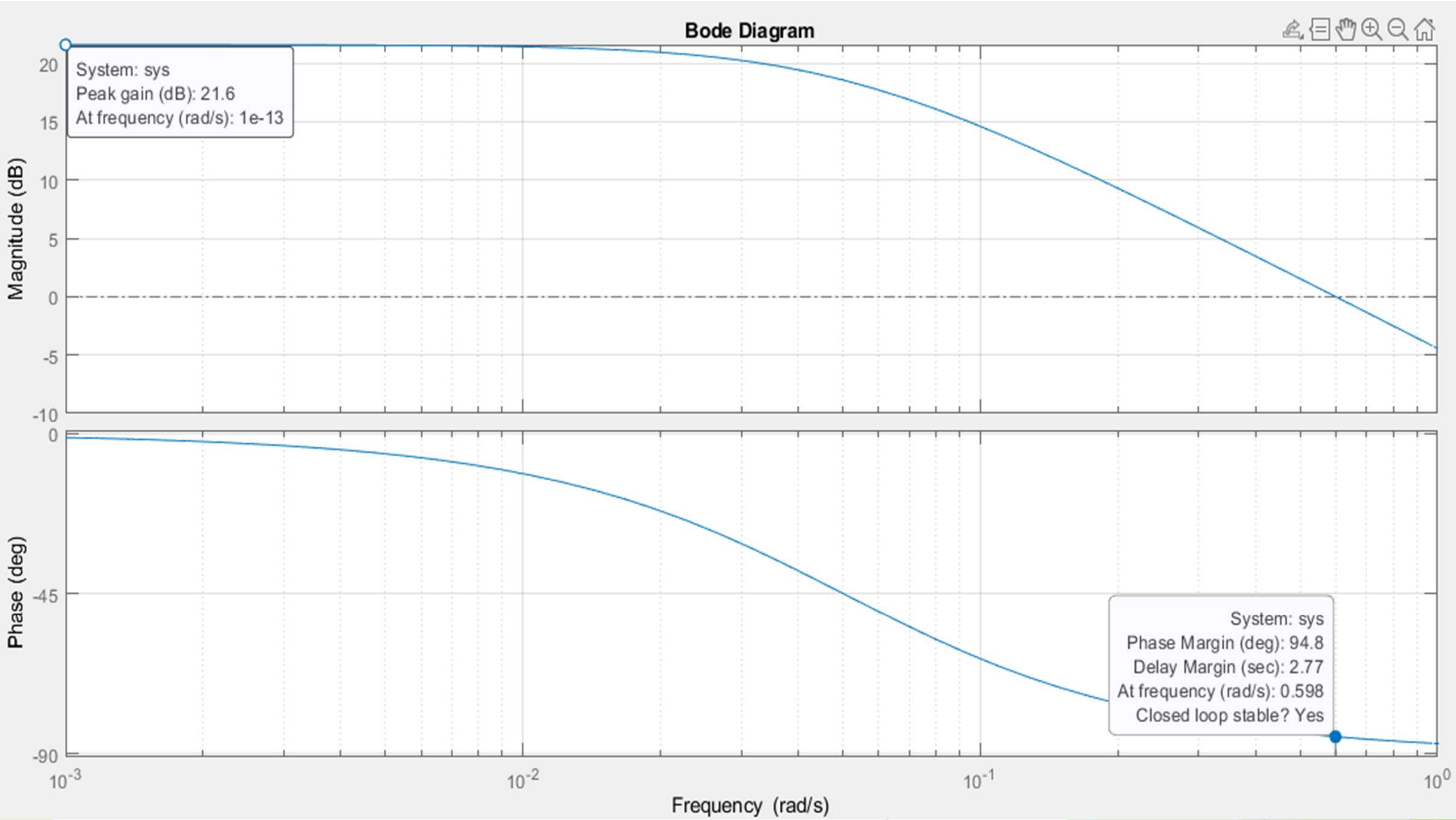
```
m = 1000;
 b = 50;
u = 500; Kp=1;
numo=[Kp];
deno=[m b];
step (u*numo,deno)
```

```
m = 1000;
 b = 50;
u = 10;
Kp=100;
numo=[Kp/b];
deno=[m/b 1];
bode(numo,deno)
```


Bode Diagram
Magnitude (dB)
Phase (deg)
Frequency (rad/s)
System: sys
Peak gain (dB): -34
At frequency (rad/s): 1e-13
-30
-35
-40
-45
-50
-55
-60
0
-45
-90
10^{-3}
10^{-2}
10^{-1}
10^{0}

By increasing the proportional gain, the rise time becomes too fast for steady state error to reach desired value.

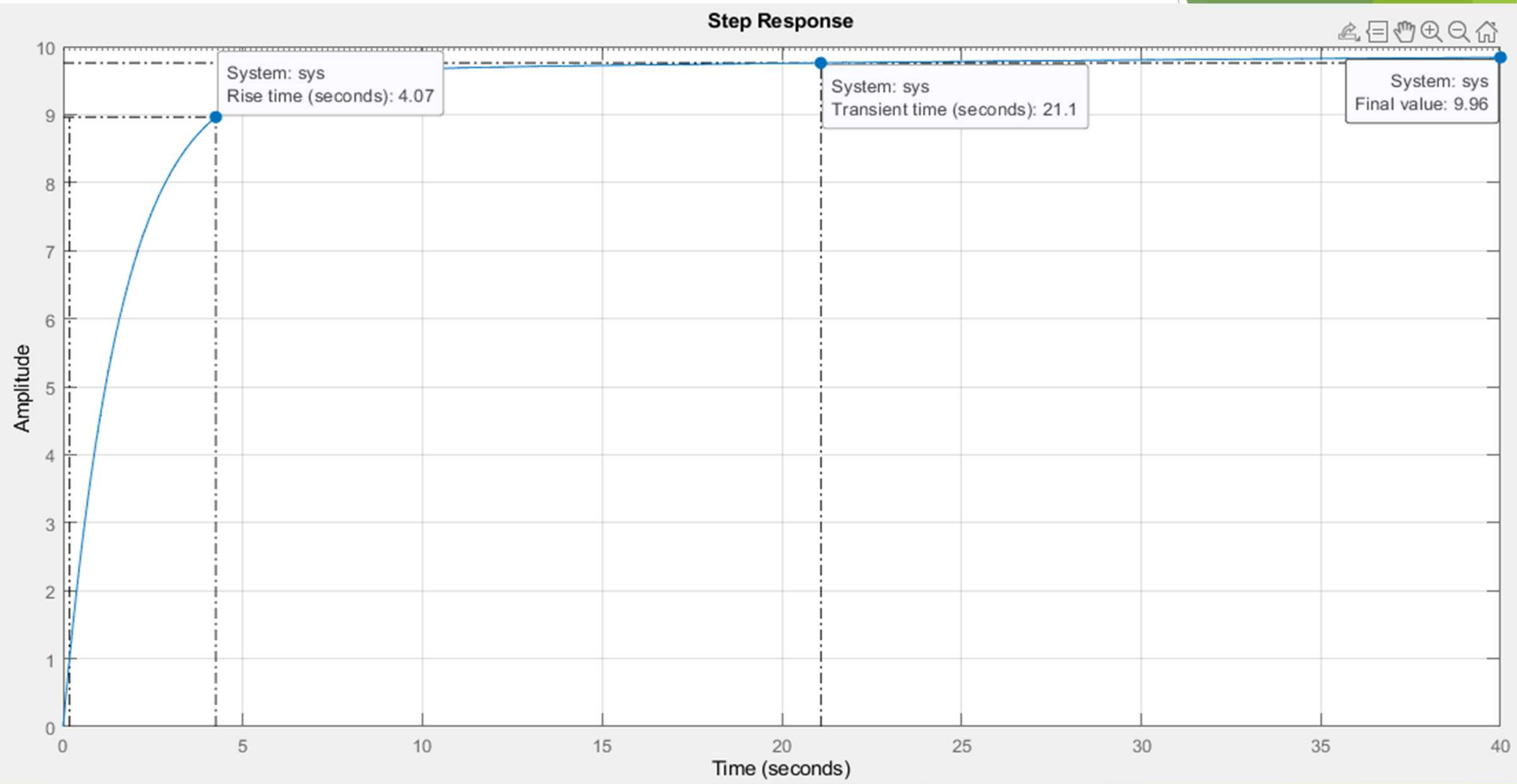


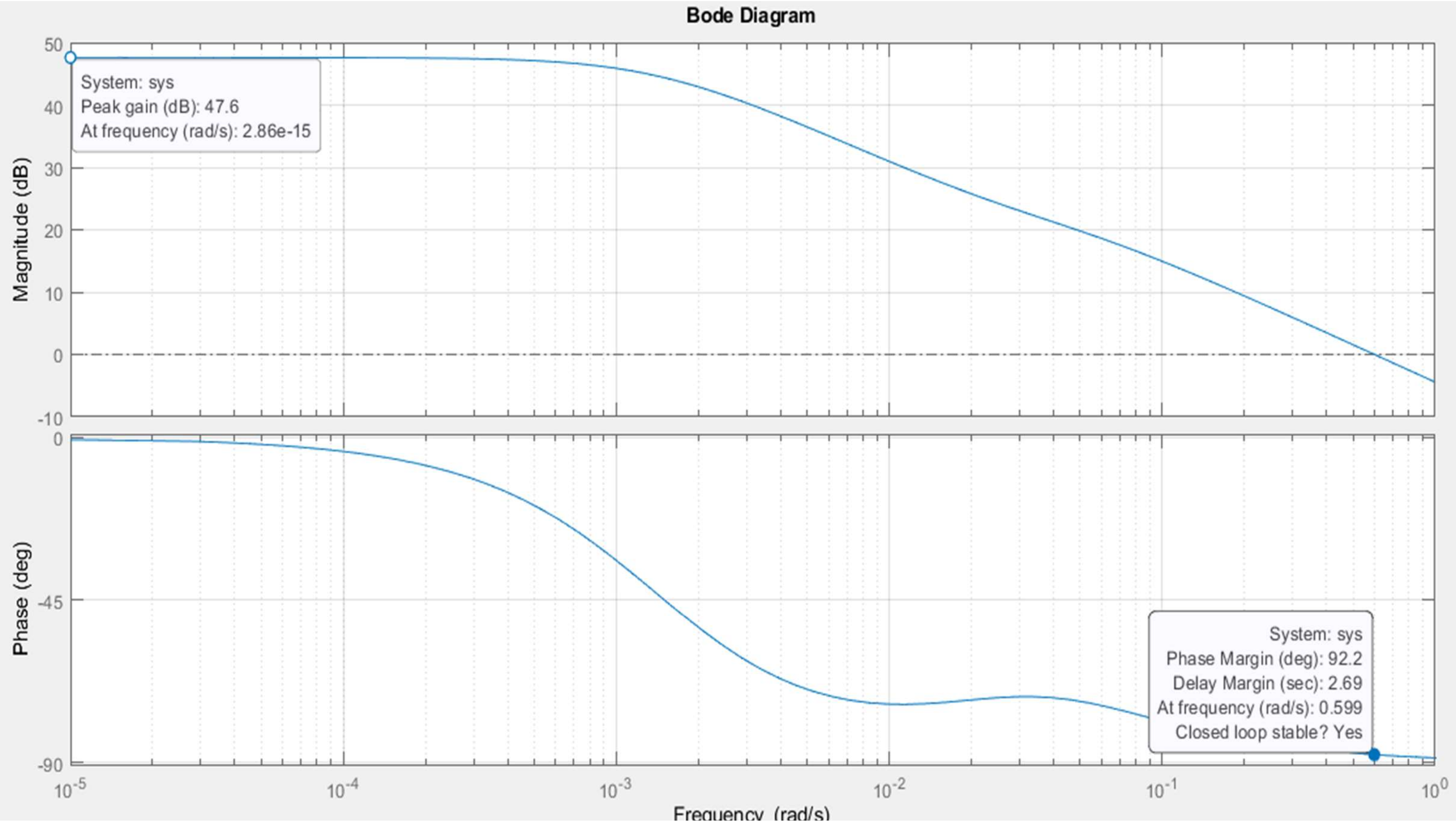

Bode Diagram
System: sys
Peak gain (dB): 21.6
At frequency (rad/s): 1e-13
Magnitude (dB)
20
15
10
5
0
-5
-10
Phase (deg)
0
-45
-90
System: sys
Phase Margin (deg): 94.8
Delay Margin (sec): 2.77
At frequency (rad/s): 0.598
Closed loop stable? Yes
10^{-3}
10^{-2}
10^{-1}
10^{0}
Frequency (rad/s)

LAG COMPENSATOR DESIGN

- Lag compensators are often used in cruise control systems to improve system stability and response. The frequency method can be utilized for lag compensator design as follows:
- STEPS TO DESIGN LAG COMPENSATOR:
- The open-loop transfer function of the compensated system is
- Gc(s)G(s) = K(Ts + 1)/ (bTs + 1) G(s) = Ts + 1 /(bTs + 1)KG(s) = (Ts + 1)/ (bTs + 1) G1(s)
- Determine gain K to satisfy the requirement on the given static velocity error constant.
- If the gain-adjusted but uncompensated system G1(jw)=KG(jw) does not satisfy the specifications on the phase and gain margins, then find the frequency point where the phase angle of the open-loop transfer function is equal to –180° plus the required phase margin. The required phase margin is the specified phase margin plus 5° to 12°. (The addition of 5° to 12° compensates for the phase lag of the lag compensator.) Choose this frequency as the new gain crossover frequency.

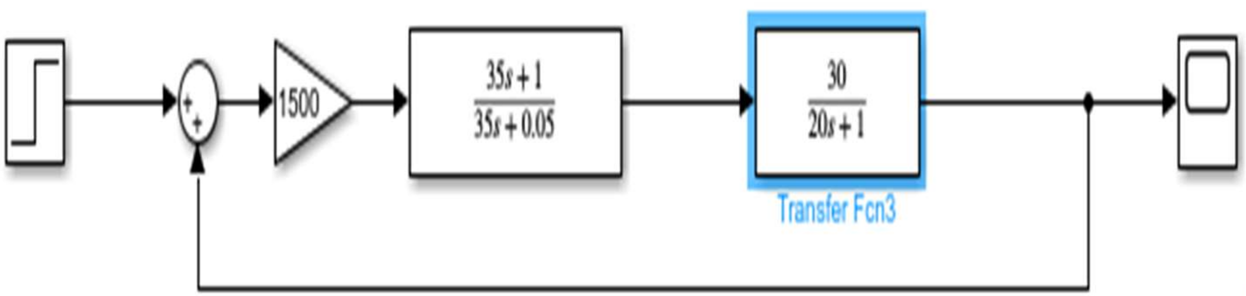
When kp=600,settling time is too long

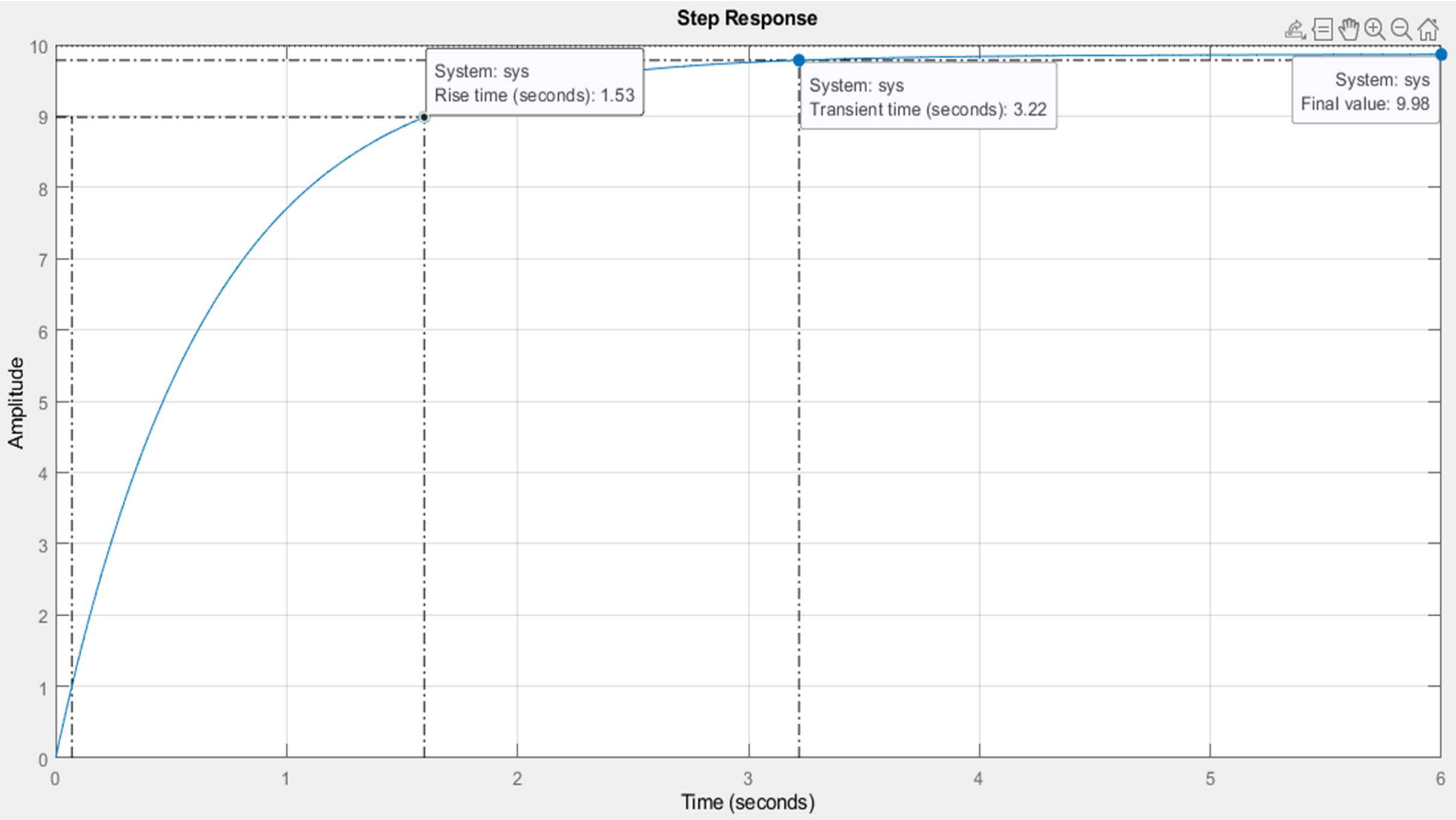




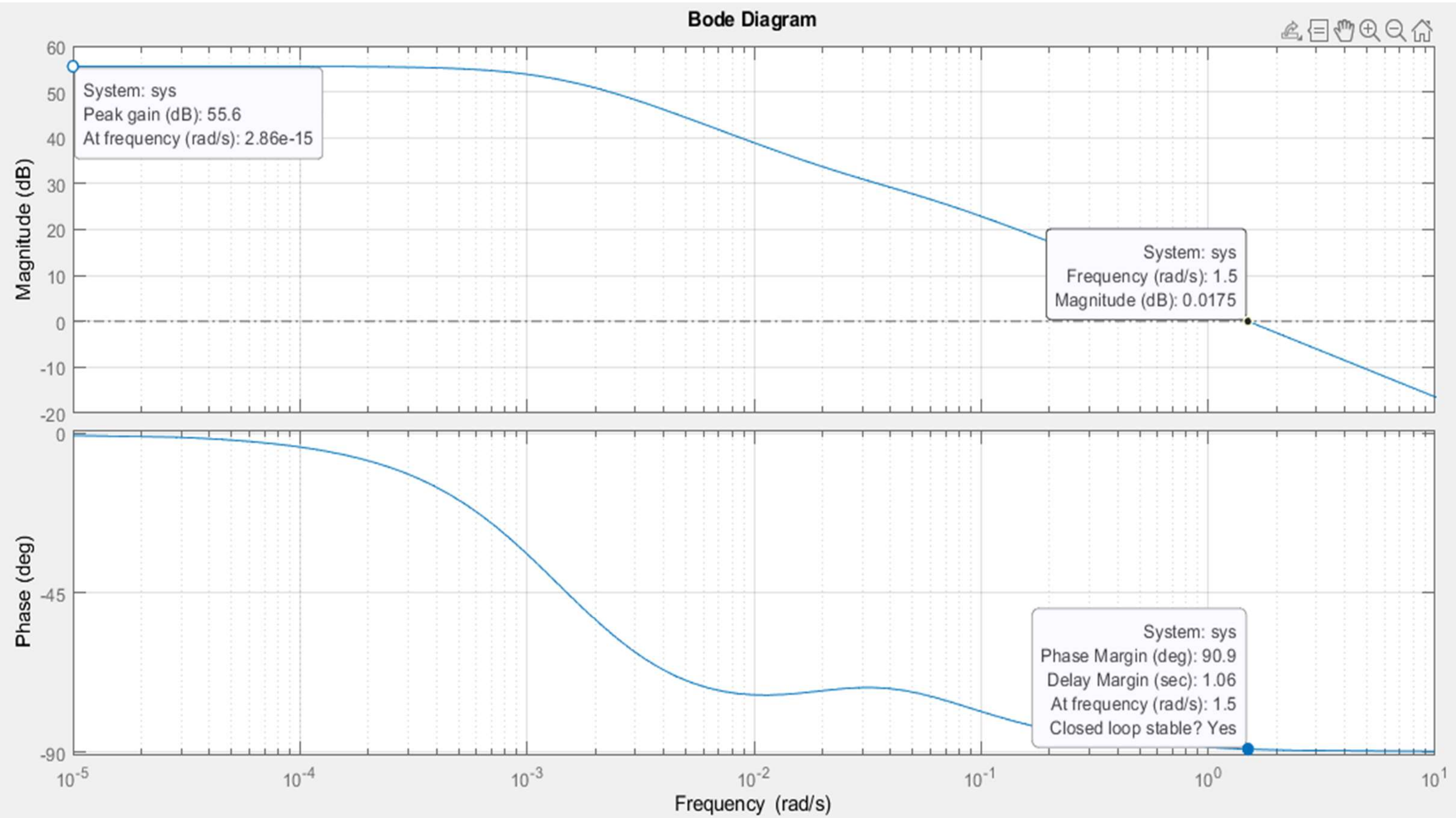
Bode Diagram
System: sys
Peak gain (dB): 47.6
At frequency (rad/s): 2.86e-15
Magnitude (dB)
50
40
30
20
10
0
-10
Phase (deg)
0
-45
-90
System: sys
Phase Margin (deg): 92.2
Delay Margin (sec): 2.69
At frequency (rad/s): 0.599
Closed loop stable? Yes
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
Frequency (rad/s)

Gain=1500
C(s)=(1+ats)/(a+ats),where a=0.05Nsec/m and t=700sec
G(s)=kp/(ms+b),where kp=1500,m=1000kg
rise time=1.53 sec
settling time=3.22 sec
steady state error (close to zero)
no overshoot





Step Response
System: sys
Rise time (seconds): 1.53
System: sys
Transient time (seconds): 3.22
System: sys
Final value: 9.98
Amplitude
Time (seconds)
0
1
2
3
4
5
6
7
8
9
10



Bode Diagram
Magnitude (dB)
Phase (deg)
Frequency (rad/s)
System: sys
Peak gain (dB): 55.6
At frequency (rad/s): 2.86e-15
System: sys
Frequency (rad/s): 1.5
Magnitude (dB): 0.0175
System: sys
Phase Margin (deg): 90.9
Delay Margin (sec): 1.06
At frequency (rad/s): 1.5
Closed loop stable? Yes
60
50
40
30
20
10
0
-10
-20
0
-45
-90
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^1

code

```
m = 1000;
b = 50;
u = 10;
Kp=1500;
numo=[Kp/b];
deno=[m/b 1];
a = 0.05;
T=700;
numlag = [a*T 1];
denlag = a*[T 1];
newnum = conv(numo,numlag);
newden = conv(deno,denlag);
bode(newnum,newden)
[numc,denc]=cloop(newnum,newden);
step (u*numc,denc)
```

CONCLUSION:

The frequency method provides a systematic approach to design gain control and lag compensators in cruise control systems. By utilizing the Bode plot, engineers can analyze the system's frequency response characteristics, identify appropriate design parameters, and optimize the system performance. Proper gain control and lag compensator design are crucial for achieving stability, responsiveness, and accurate results.