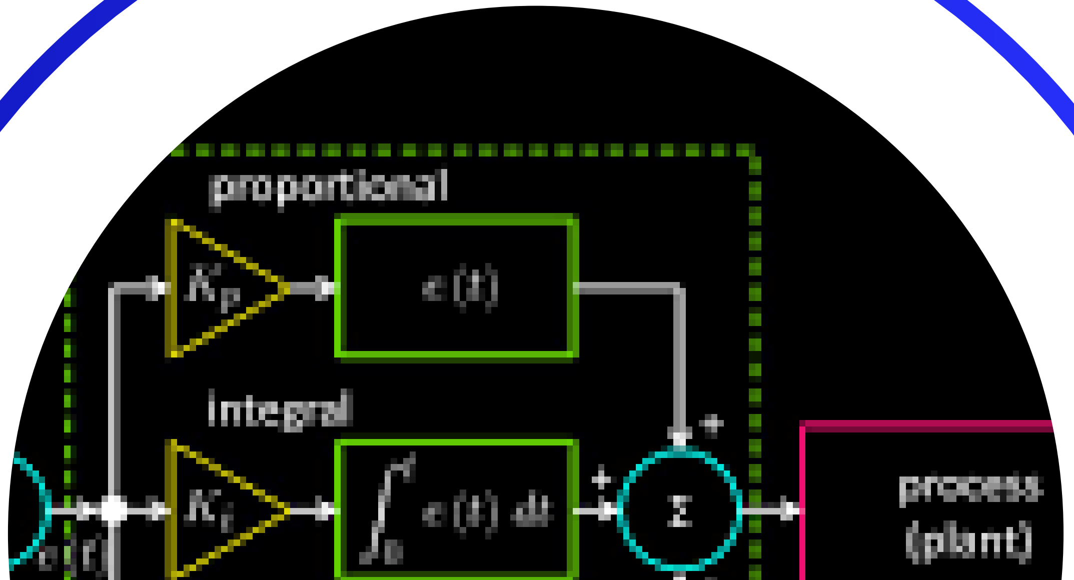
Project 8: Magnetic Levitation Train Control

Control Systems - MENG-3510-0NA



2025

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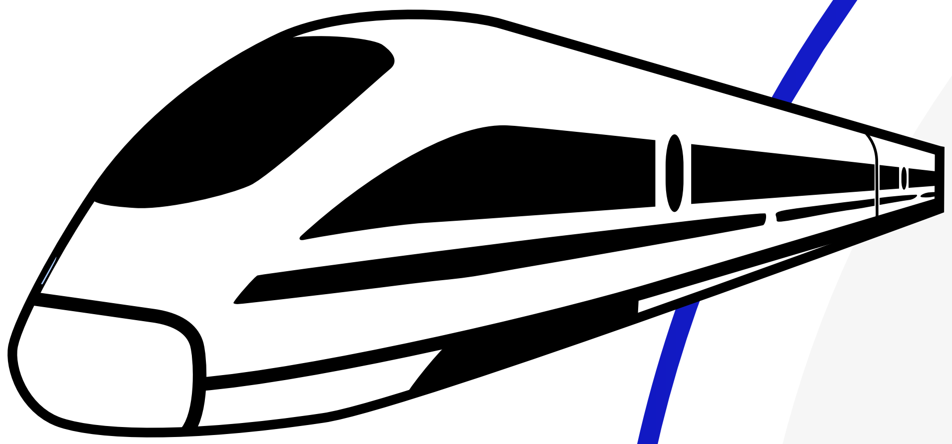
Agenda

Problem statement

Investigate the suspension bogie to maintain a proper air gap between the rail and electromagnet despite external forces (e.g. Crosswinds, Weight, and more) being applied on the system.

Objective

Design a PID control system capable of receiving feedback from external forces and providing a response that regulates the air gap over time with a transient settling time of no more than 1 second and a maximum variation of less than 10%.

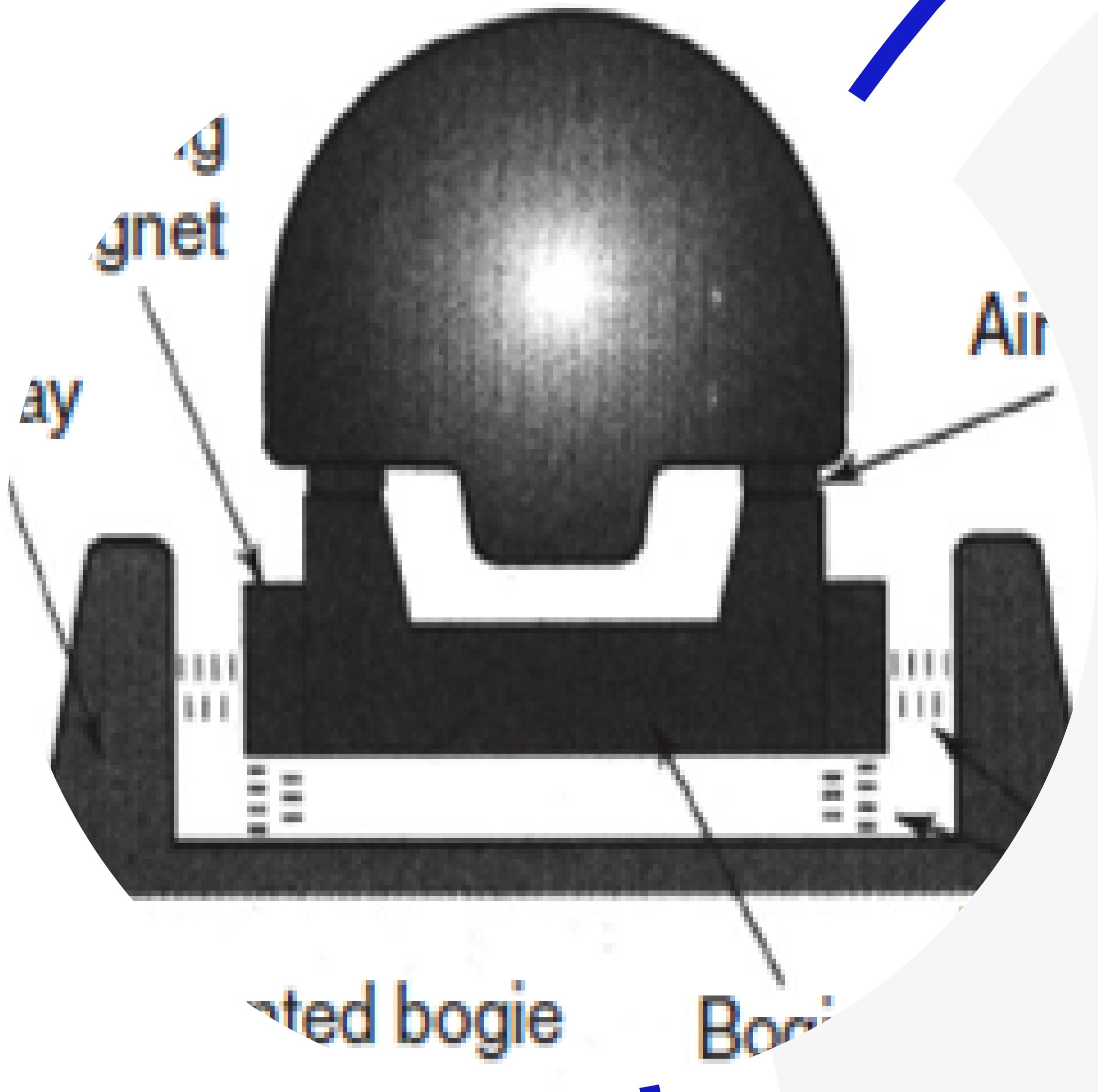


Why?

Maglev trains use magnetic forces to levitate and move without touching the track, allowing high speeds and smooth, quiet rides. They reduce travel time and emissions but face high costs, complex controls, and sensitivity to power loss and weather. Despite challenges, they offer a promising future for fast, clean transport.

Real-world applications China and Japan

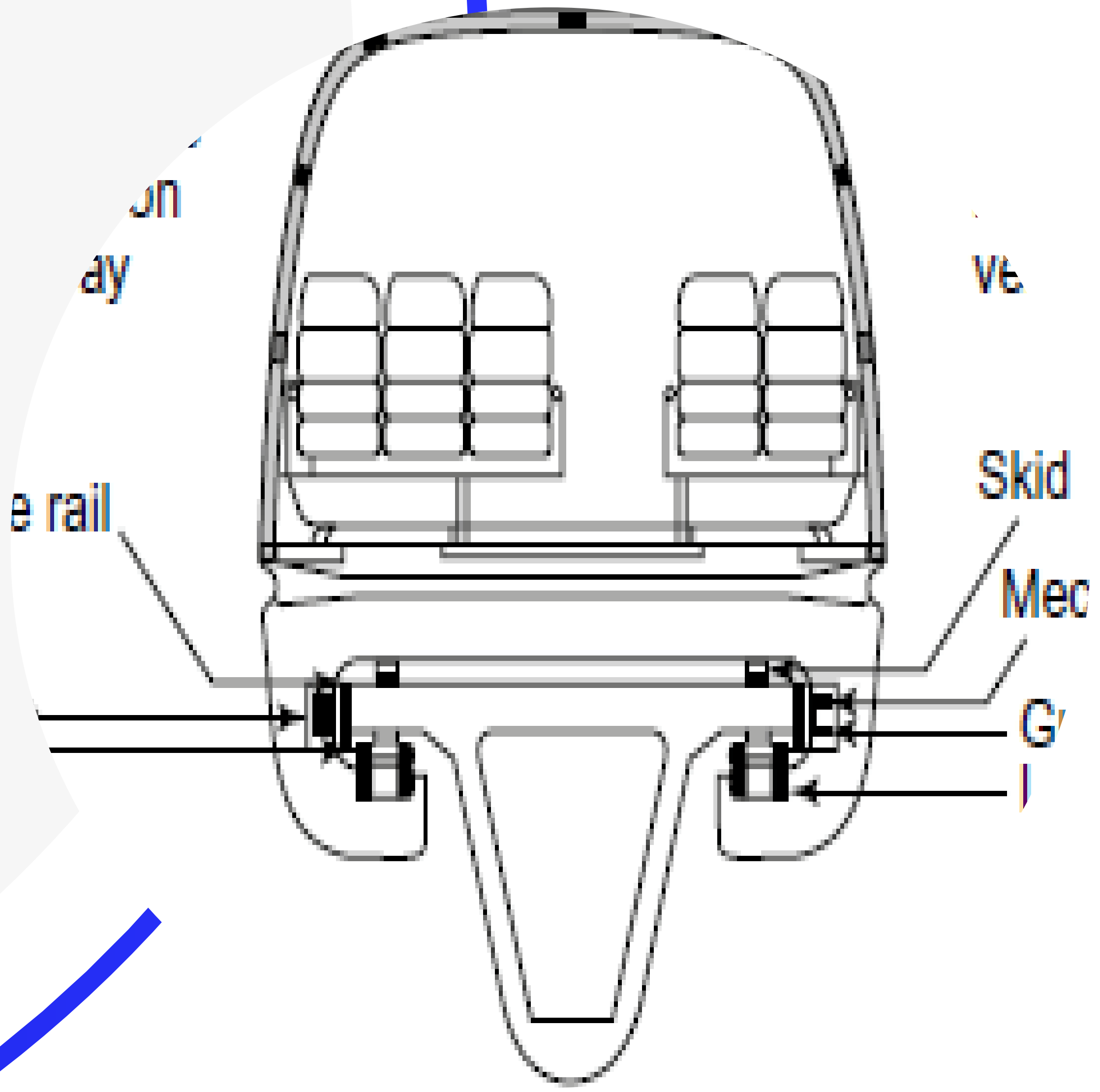
- significant benefits in reducing commute times
- environmental impact



Suspension Bogie

This system is a critical component especially in maglev trains that allow for levitation, guidance and shock absorption

This allows the train to float above the track and move smoothly.



How it works

A Maglev train carries multiple bogies with their own levitation system.

Bogies are designed to absorb shocks, vibrations, and relies on electromagnets that generate attractive & repulsive forces.

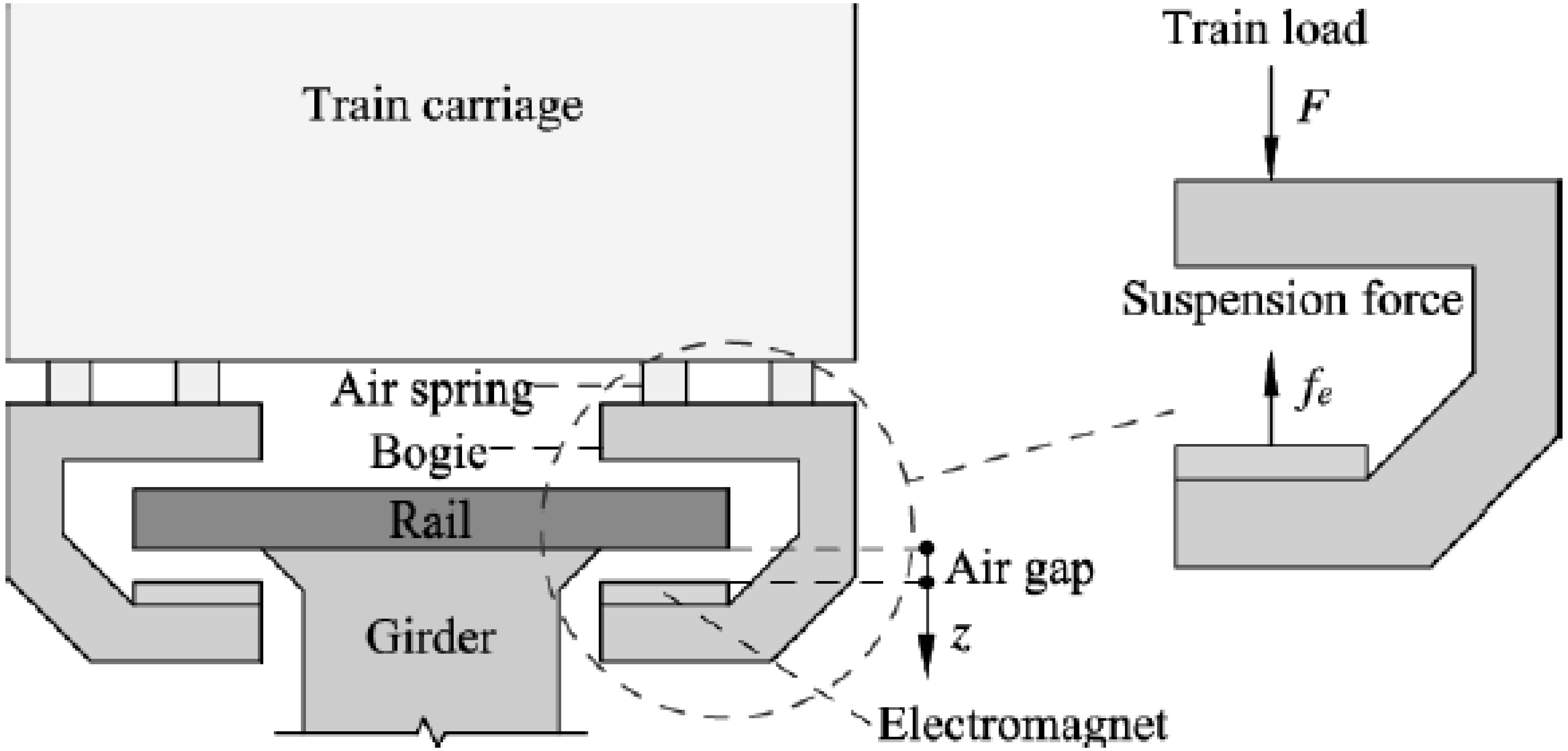


Figure 2: Schematic diagram of the EMS maglev train

Actuators and Sensors

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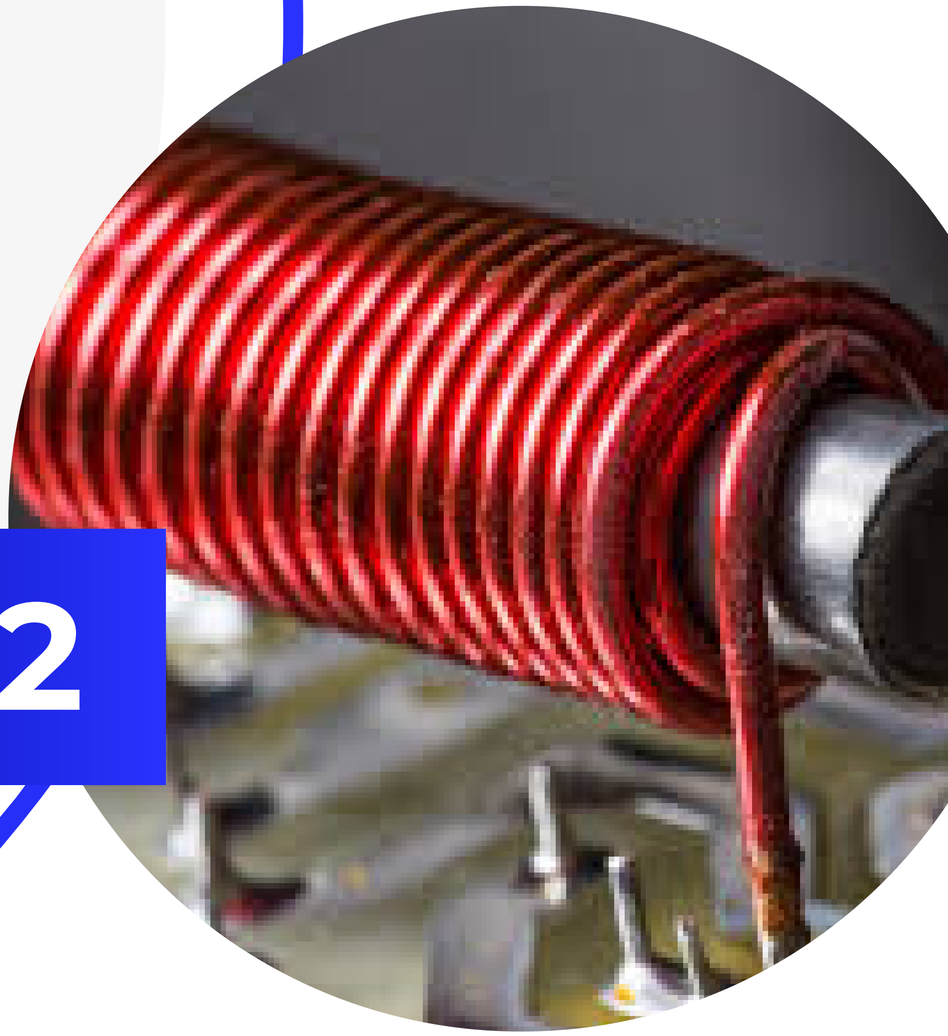
Sensors

Lateral displacement sensor
Weight sensor
Current sensor
Speedometer
Vibration Sensor

Actuator:

Electromagnetic Coil
Dynamic Load Balancing Actuators
Aerodynamic Flaps

22



Transfer functions

$$m\frac{d^2z(t)}{dt^2} = \left(\frac{\mu_0 A N^2 i_0^2}{2z_0^3}\right) z(t) - \left(\frac{\mu_0 A N^2 i_0}{2z_0^2}\right) i(t) + F$$

$$L_0\frac{di(t)}{dt} = V(t) - Ri(t) + \left(\frac{\mu_0 A N^2 i_0}{2z_0^2}\right)\frac{dz(t)}{dt}$$

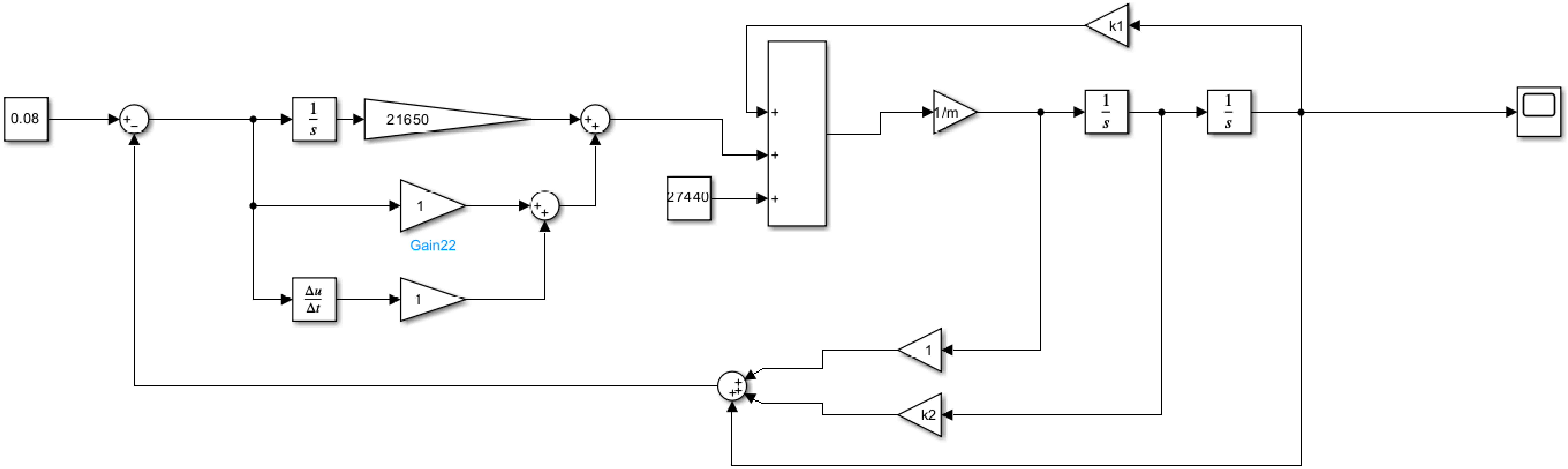
$$\Rightarrow \quad \frac{(-k2/m)/Lo}{Lo/Lo \cdot s^3 + R/Lo \cdot s^2 - ((1/m) * ((k1 * Lo) - (k2\wedge 2)))/Los - ((k1 * R)/m)/Lo}$$

$$\frac{((1/m) * Lo)/Los + ((1/m) * R)/Lo}{Lo \cdot s^3 + R \cdot s^2 - ((1/m) * ((k1 * Lo) - (k2\wedge 2)))s - ((k1 * R)/m)}$$

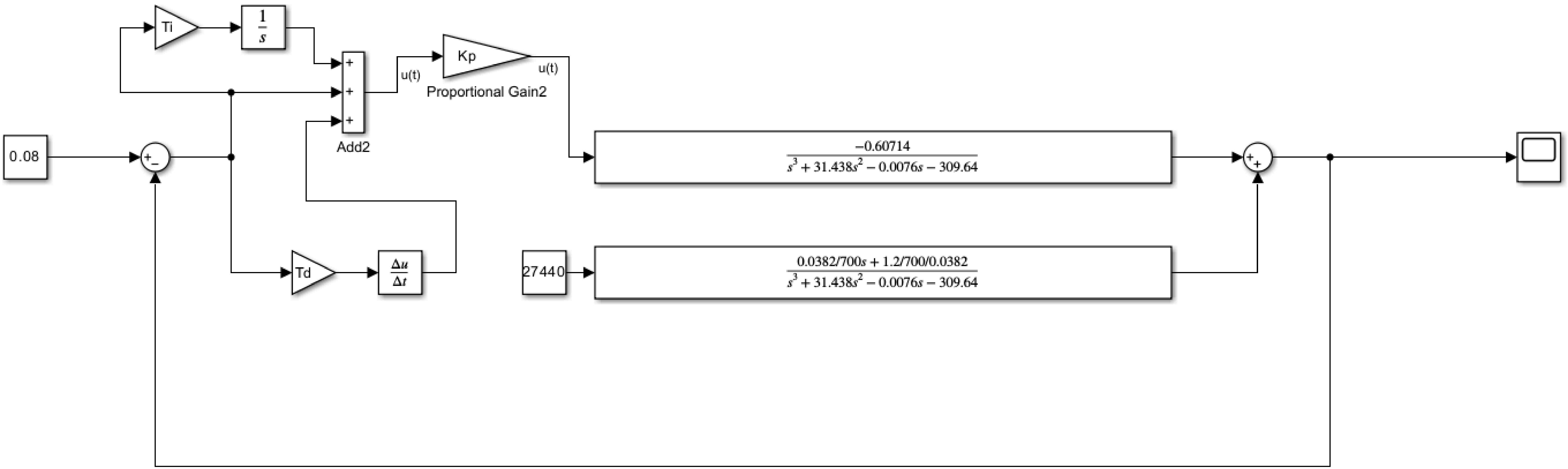
$$\Rightarrow \quad \frac{-0.60714}{s^3 + 31.438s^2 - 0.0076s - 309.64}$$

$$\frac{0.0014286s + 0.044911}{s^3 + 31.438s^2 - 0.0076s - 309.64}$$

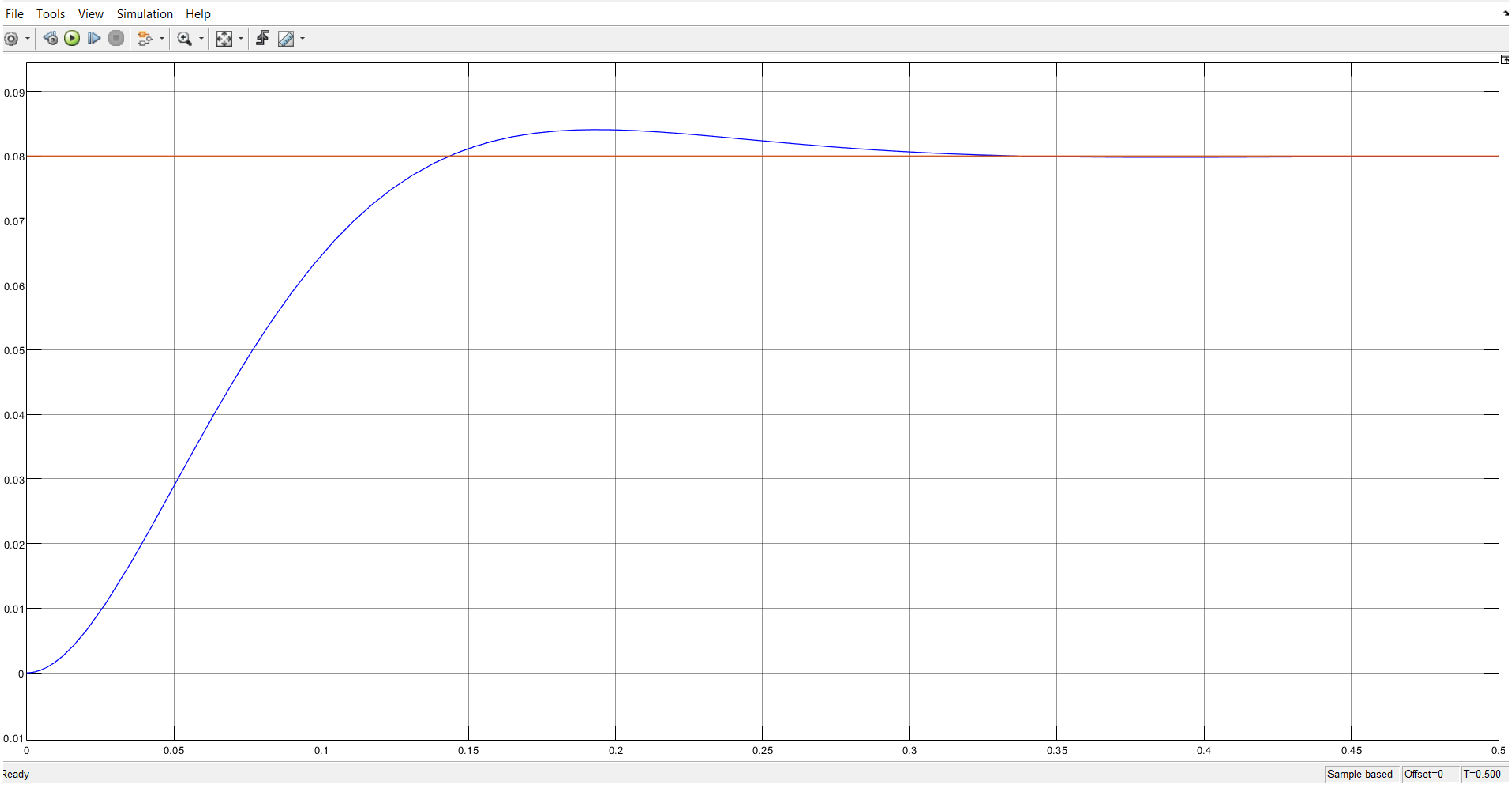
Block Diagram



Block Diagram



Desired Response



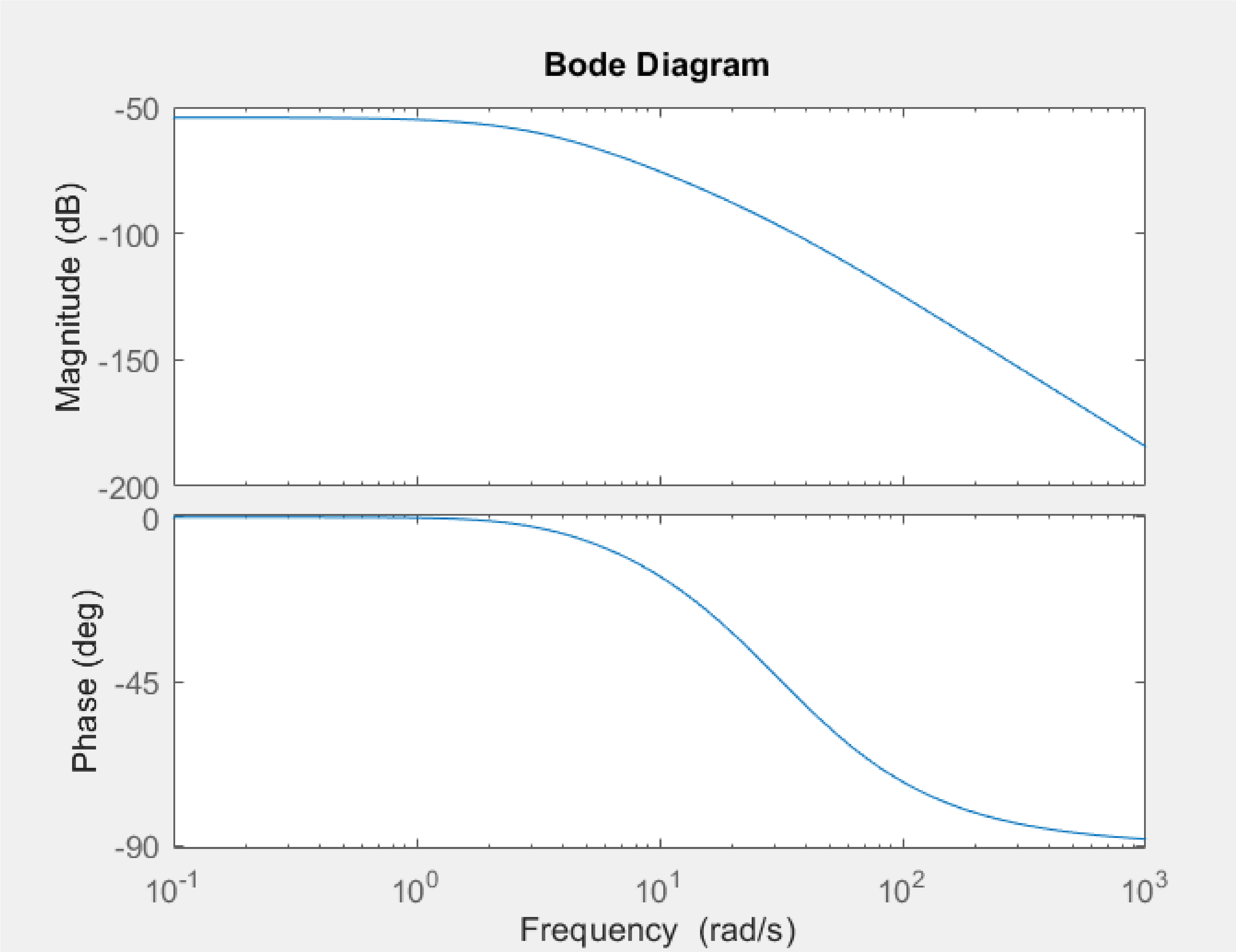
Roots

-31.1185

-3.3182

2.9987

Bode plot


Bode Diagram
Magnitude (dB)
-50
-100
-150
-200
Phase (deg)
0
-45
-90
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Frequency (rad/s)

Root Locus

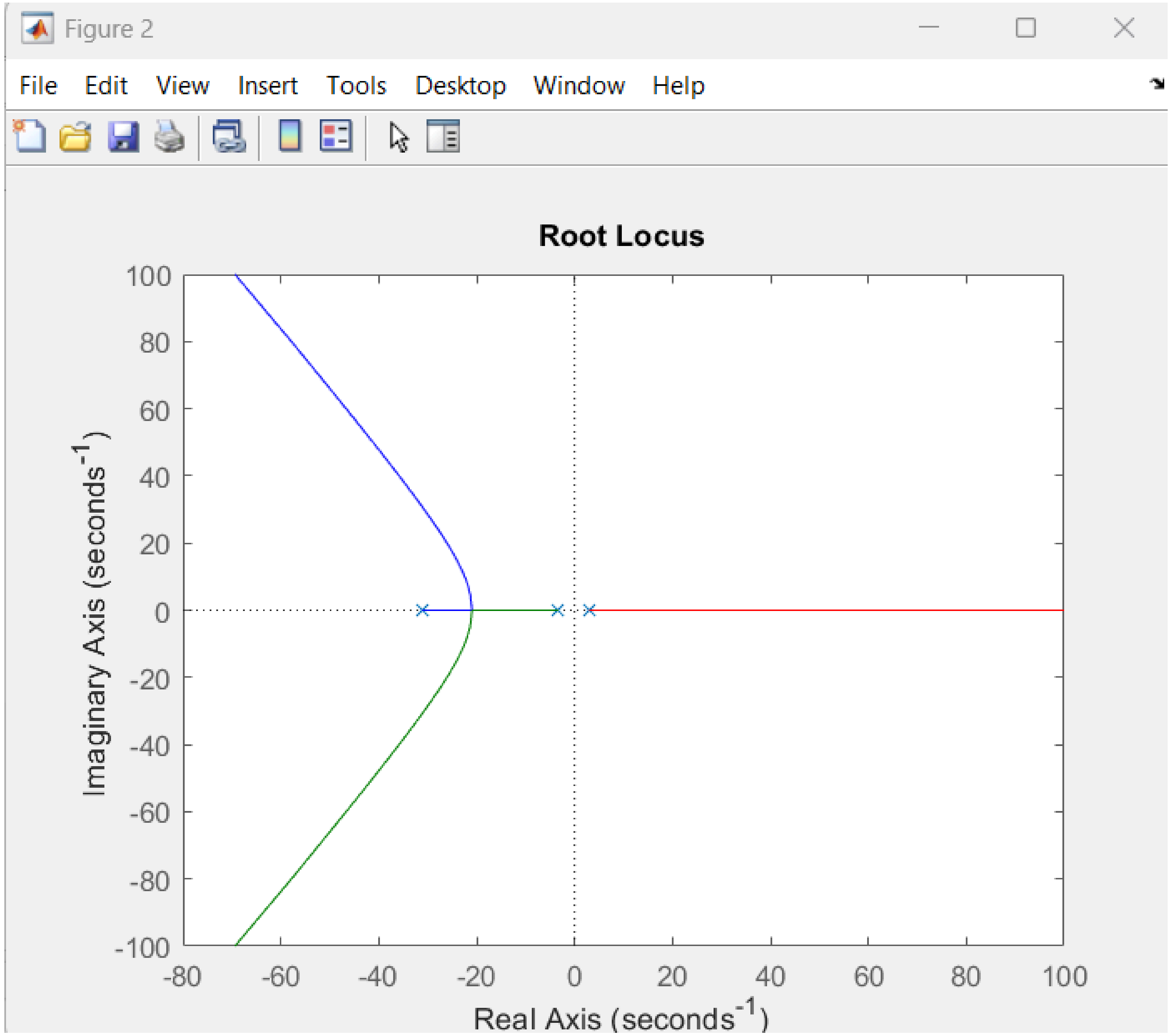
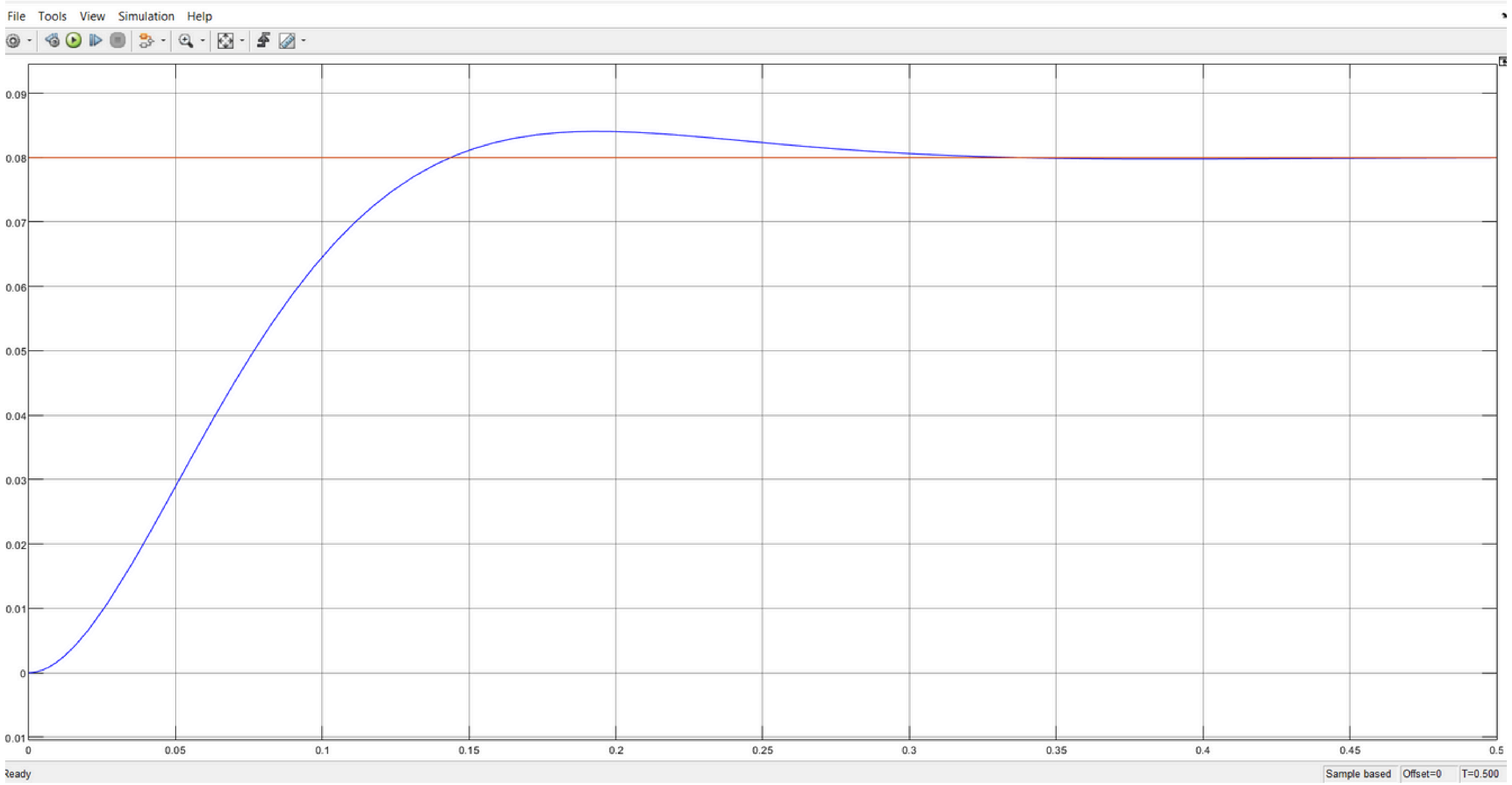


Figure 2
File
Edit
View
Insert
Tools
Desktop
Window
Help
Root Locus
Imaginary Axis (seconds^-1)
Real Axis (seconds^-1)
100
80
60
40
20
0
-20
-40
-60
-80
-100
-80
-60
-40
-20
0
20
40
60
80
100

Performance

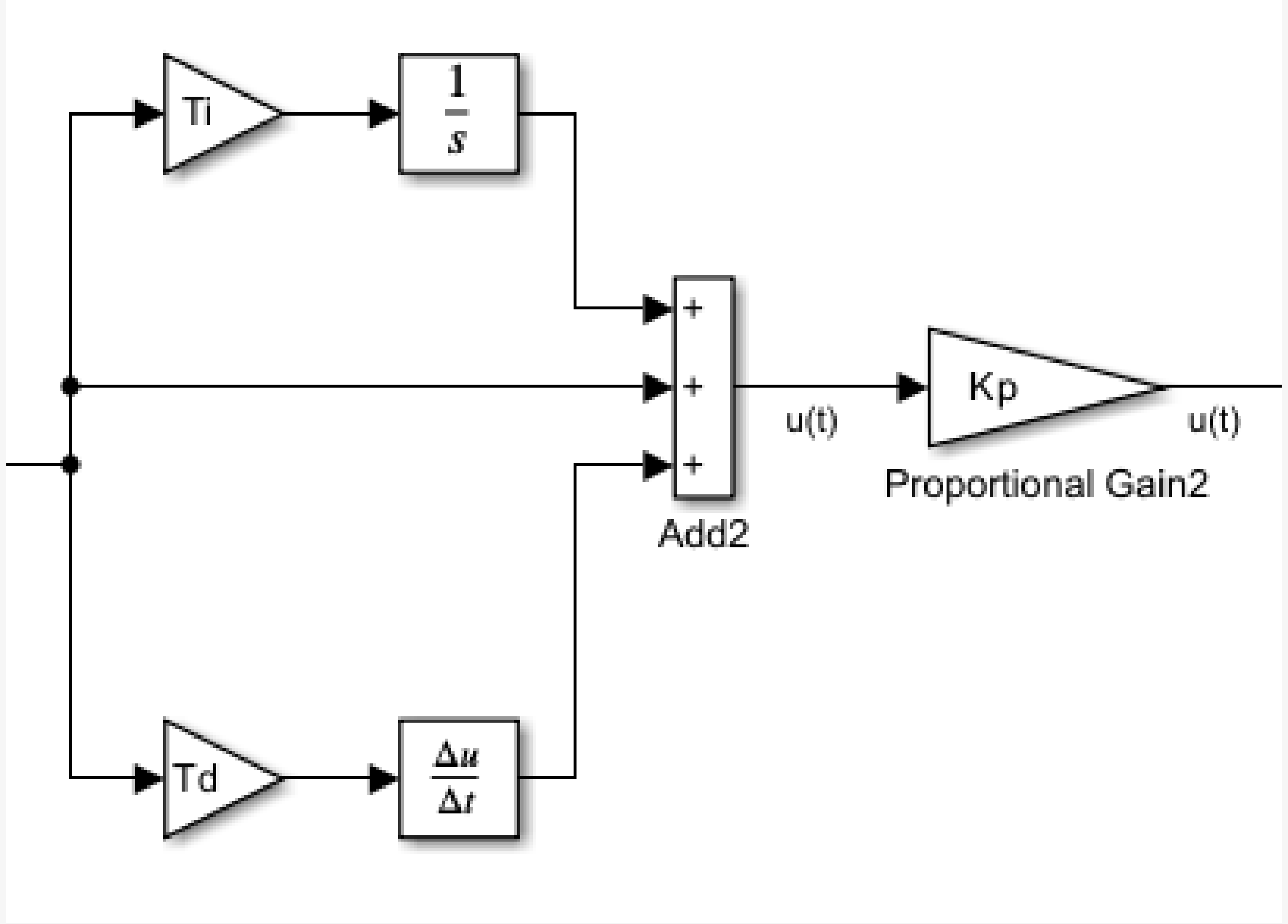


Overshoot: 5%

Settling time: 0.324 sec

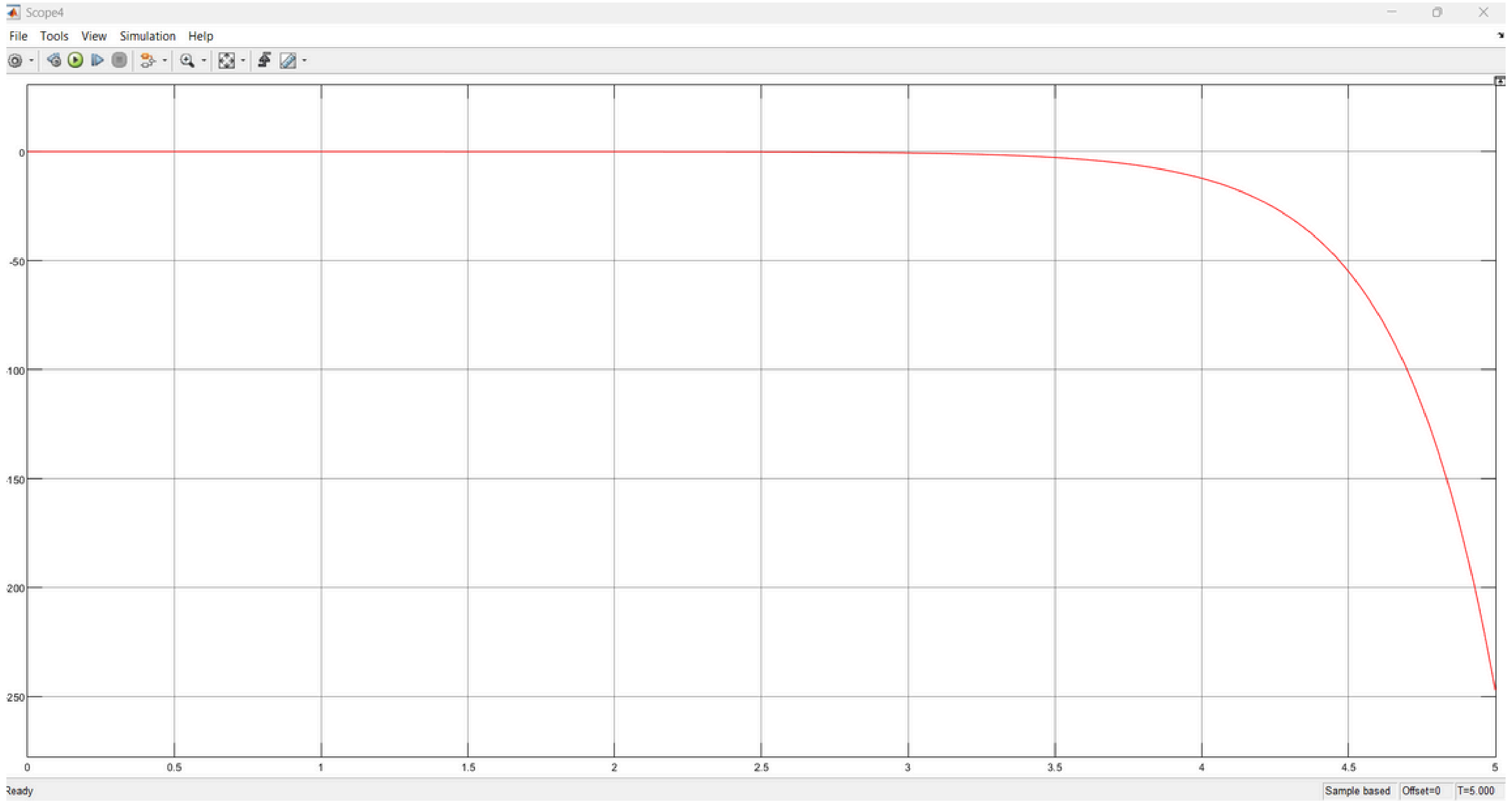
Control Strategy Design

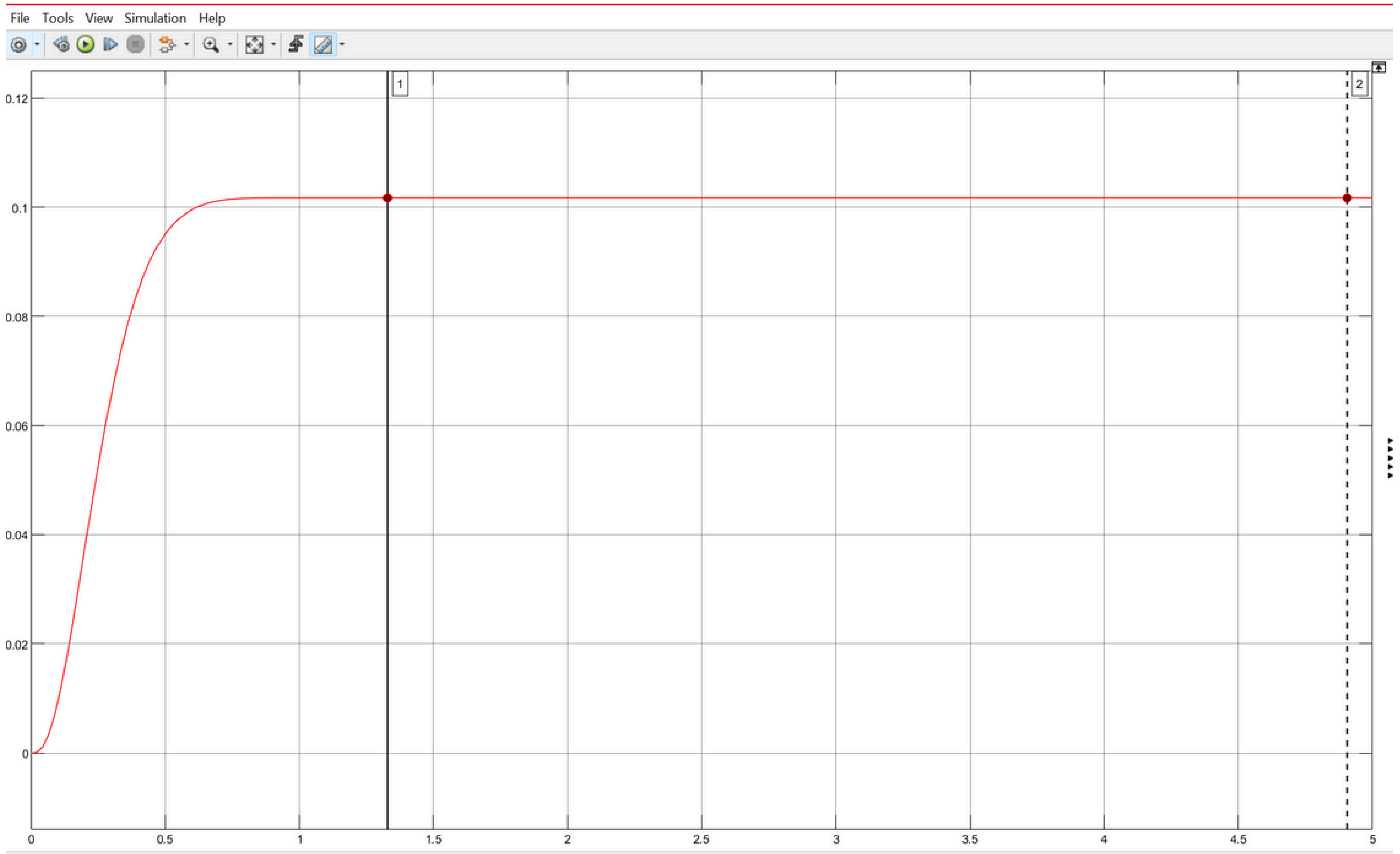
The control strategy design we went with is the PID design which is shown as follows



Without tuning

With tuning





Reason for chosen tuning parameters

Chosen parameters:

Kp= -2389.18
Td= 0.207
Ti= ~

Calculating the PD controller values

From transfer function

$$G(s) = \frac{Z(s)}{V(s)} = \frac{-0.6071}{s^3 + 31.44s^2 - 0.0076s - 309.64}$$

-31.1185
-3.3182
2.9987

$$G(s) = \frac{num}{(s + 3.3184)(s - 2.9986)} = \frac{num}{s^2 + 0.319s - 9.95}$$

$$\lim_{s=0} G(s) = \frac{-0.6071}{0^3 + 31.44 * 0^2 - 0.0076 * 0 - 309.64}$$

$$\lim_{s=0} G(s) = \frac{-0.6071}{-309.64}$$

$$DC \ \ gain = 0.00196$$

$$G(s) = \frac{0.0195}{s^2 + 0.319s - 9.95}$$

$$\zeta = \frac{-\ln(O.S)}{\sqrt{\pi^2 + \ln^2(O.S))}}$$

$$\zeta = \frac{-\ln(0.01)}{\sqrt{\pi^2 + \ln^2(0.01)}}$$

$$\zeta = 0.826$$

$$ts = \frac{4}{\zeta * wn}$$

$$wn = \frac{4}{\zeta * ts}$$

$$wn = \frac{4}{0.826 * 0.8}$$

$$wn = 6.053$$

$$G(s) = s^2 + 2 * wn * \zeta + wn^2$$

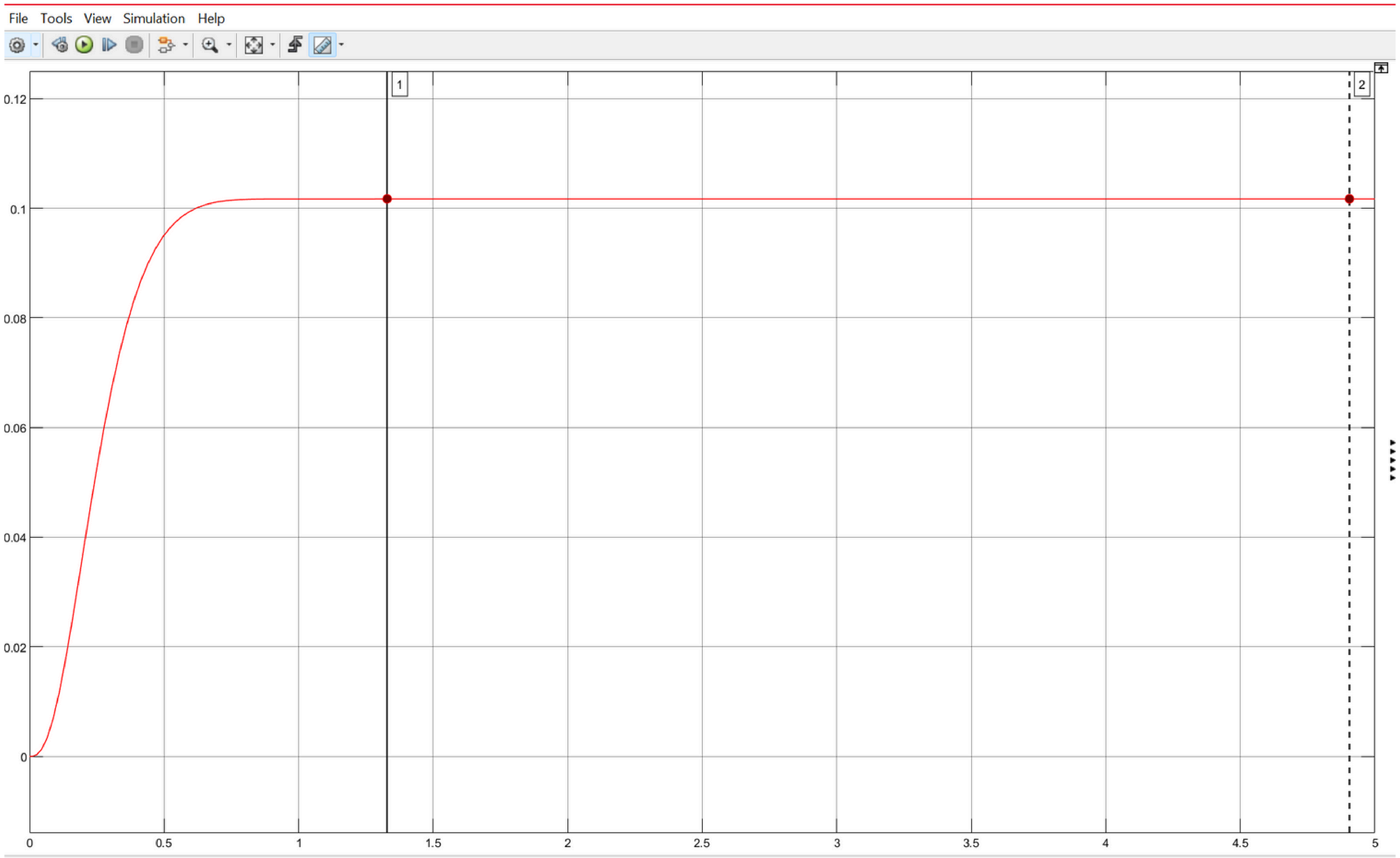
$$G(s) = s^2 + 2 * 6.053 * 0.826 + 6.053^2$$

$$G(s) = s^2 + 9.963s + 36.6388$$

$$G(s) = \frac{-0.0195 - 0.0195 * Kp * Tds}{s^2 + (0.319 - 0.0195 * Kp * Td)s - 9,95 - 0.0195 * Kp}$$

$$Kp = -2389.18$$

$$Td = 0.207$$



Overshoot: 1%

Settling time: 0.8 sec

Calculating the PID

$$G(s) = s^2 + 9.963s + 36.6388$$

$$Ti \geq \frac{2}{|Re\{pcl\}|}$$

Challenges

- Developing the Block Diagram
- Tuning of the PID controller

Conclusion

Thank you for listening