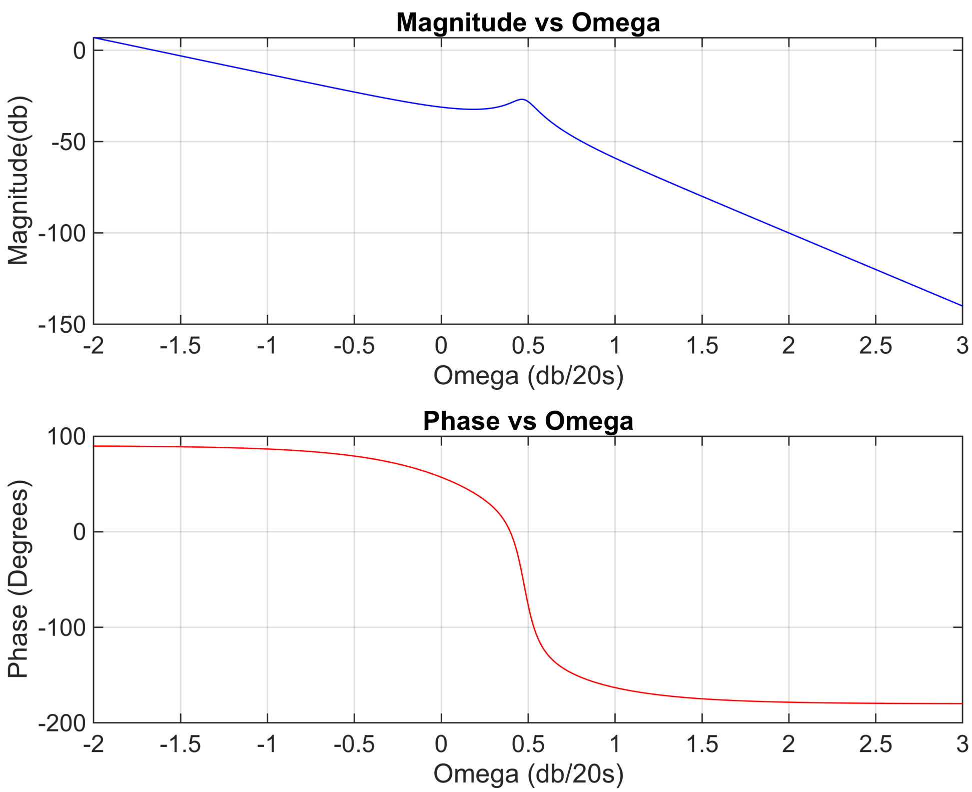
# 1.Bode extraction

## 1.1.Load the data

```
load('Data.mat');
omega = log10(Data.omega);
magnitude = 20.*log10(Data.magnitude);
phase = Data.phase ;
```

## 1.2.Plot

```
figure;
subplot(2,1,1);
plot(omega, magnitude, 'b');    % Plot Magnitude vs Omega
xlabel('Omega (db/20s)');
ylabel('Magnitude(db)');
title('Magnitude vs Omega');
grid on;
subplot(2,1,2);
plot(omega, phase, 'r');        % Plot Phase vs Omega
xlabel('Omega (db/20s)');
ylabel('Phase (Degrees)');
title('Phase vs Omega');
grid on;
```



# 2.System identification

## 2.1.System type

As the slope in the Magnitude part is -20dB/dec, we assume that we have a pole in the Origin so obviously the answer to step function should be "0" and the system is type 1.

## 2.2.System order

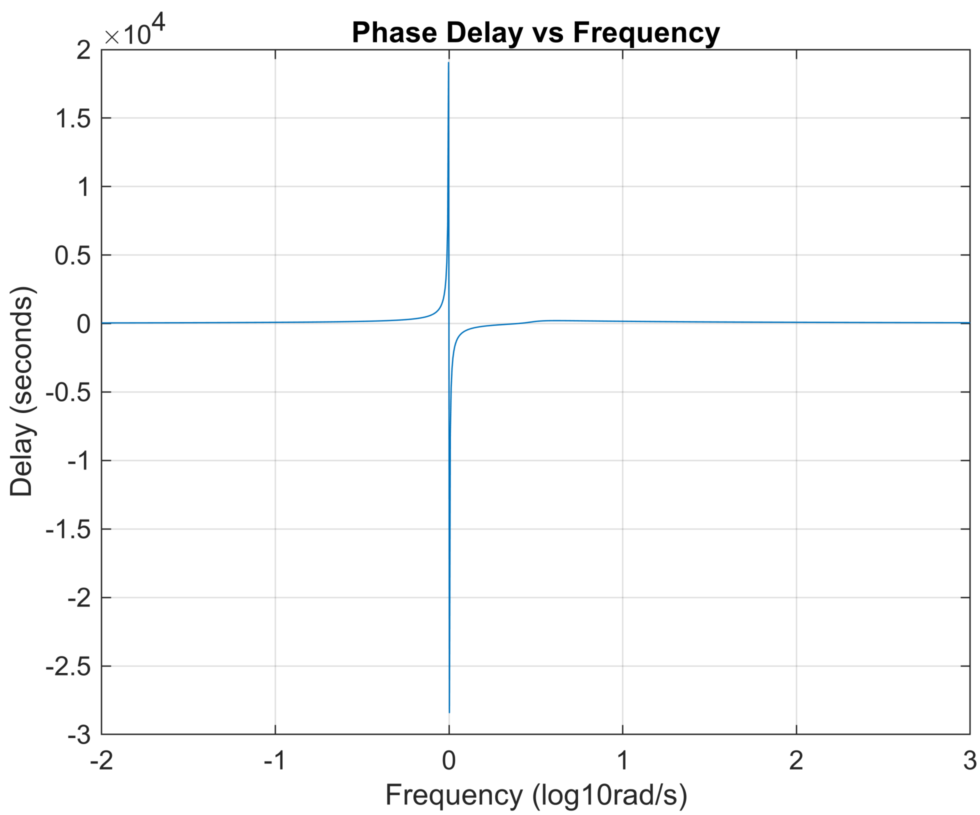
As explained in section 2.4 we have 3 poles so the system is from the third order.

## 2.3.System delay

To estimate the delay $\tau$, you can calculate the slope of the phase curve at different frequencies.

```
delay = -phase  ./ omega;  % Phase delay at each frequency (in seconds)

figure;
plot(omega,delay) % Plot delay vs frequency (log scale for omega)
xlabel('Frequency (log10rad/s)');
ylabel('Delay (seconds)');
grid on;
title('Phase Delay vs Frequency');
```



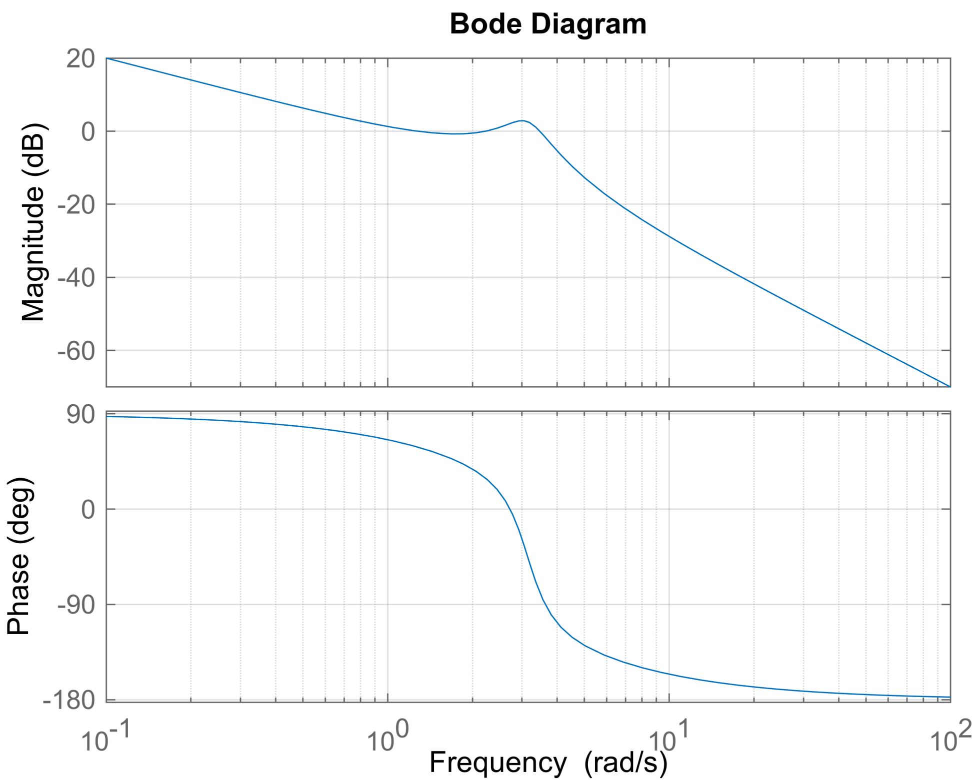
## 2.4.Minimum phase

As it can be seen in the Bode diagram, we start the magnitude with a -20dB/dec slope and a phase of 90 which shows that we have a "-s" and a second order func pole with positive middle coefficient and a zero at the same frequency, So it has a minimum phase zero.

# 3.Transfer function

The estimated transfer function is gonna be like the following

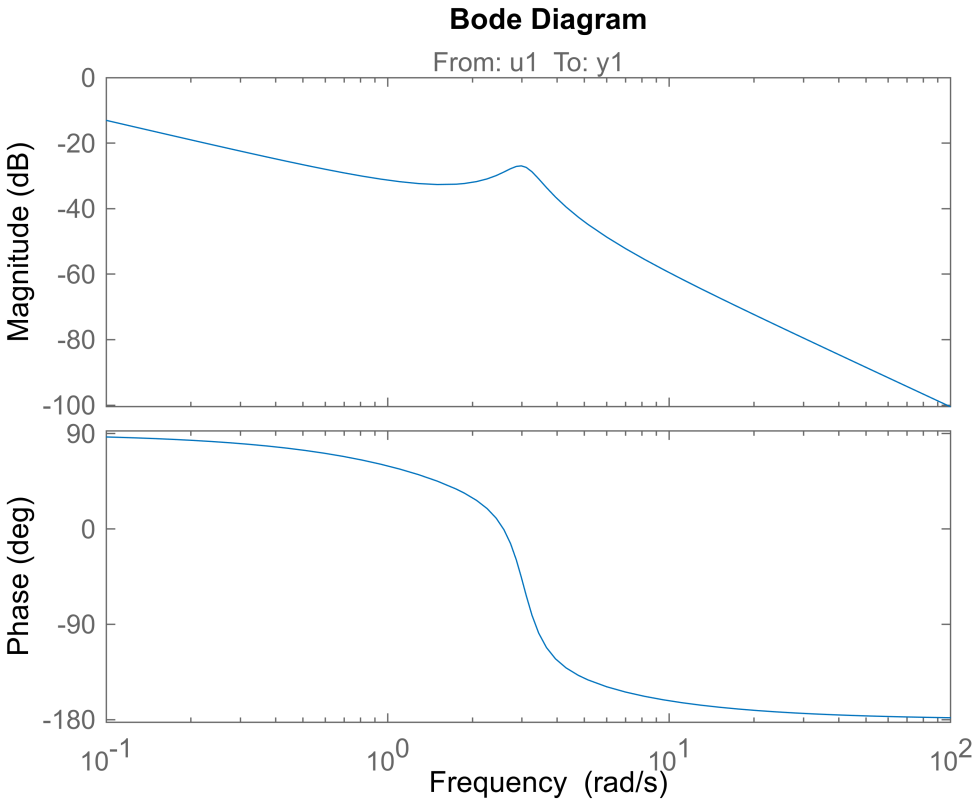
```
num = [1/pi -1];
den = conv([1/(pi^2) 1/(3*pi) 1], [1 0]);
sys = tf(num,den);
bode(sys);
grid on;
```




which actually looks the same as the upper expresion.

## 3.1.Optional first

```
systemIdentification;
bode(tf1);
```




```
tf1
```

```
tf1 =
  From input "u1" to output "y1":
           0.09401 s - 0.2059
  ------------------------------------
  s^3 + 0.861 s^2 + 9.266 s - 8.868e-07

Name: tf1
Continuous-time identified transfer function.

Parameterization:
   Number of poles: 3   Number of zeros: 1
   Number of free coefficients: 5
   Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

Status:
Estimated using TFEST on frequency response data "mydata".
Fit to estimation data: 99.82%
FPE: 7.3e-07, MSE: 7.196e-07

Model Properties
```

# 4.Ruth hurwitz

```
syms s;

% Define the characteristic equation
char_eq = (1/(pi^2)) * s^3 + (1/(3*pi)) * s^2 + 1 * s;
```

```
% Get the coefficients as a numeric vector
coeffs = double(sym2poly(char_eq));  % Ensure numeric values

% Compute the Routh array
routh_table = routh_hurwitz(coeffs);

% Display Routh-Hurwitz Table in Live Script
disp('Routh-Hurwitz Table:');
```

```
Routh-Hurwitz Table:
```

```
disp(routh_table);
```

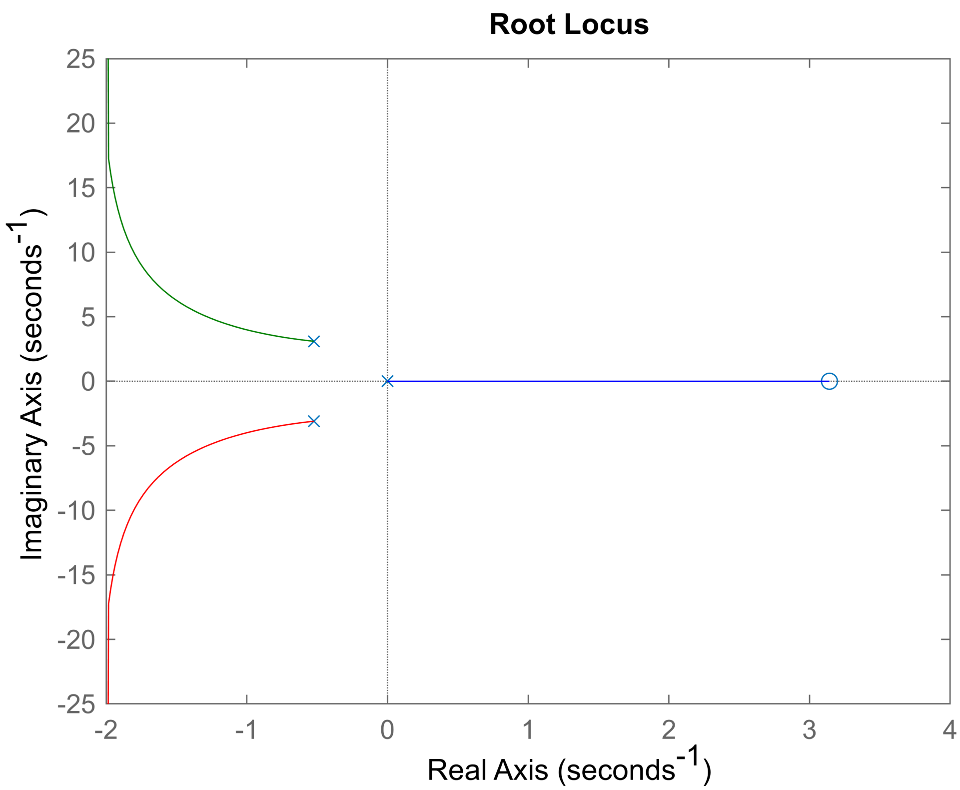
```
    0.1013    1.0000
    0.1061         0
    1.0000         0
         0         0
```

I tried to do the computing completly on matlab but I couldnt figure it out, the computing goes on by writing the characteristic equation considering K and being close loop. It converts to $\frac{s^3}{\pi^2} + \frac{s^2}{3\pi} + (1+k)s - k\pi$ which translates to the ruths tables first column to be $\frac{1}{\pi^2}$ $\frac{1}{3\pi}$ $(1+4k)$ $-k\pi$ which means that k is to be $-\frac{1}{4} < k < 0$

# 5.Ruth locus analysis

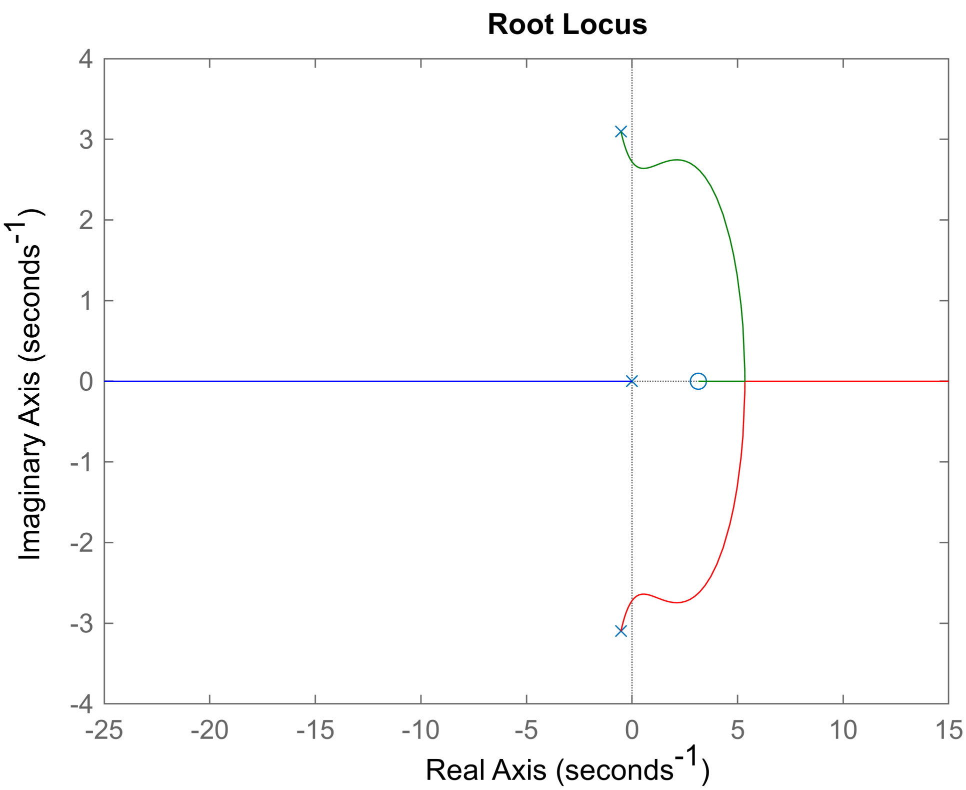
## 5.1.Ploting

```
rlocus(sys);
```




As seen, we have a complete branch in the ORHP which means that we can't manage stablizing the system using only the k coefficient.

```
rlocus(-sys);
```

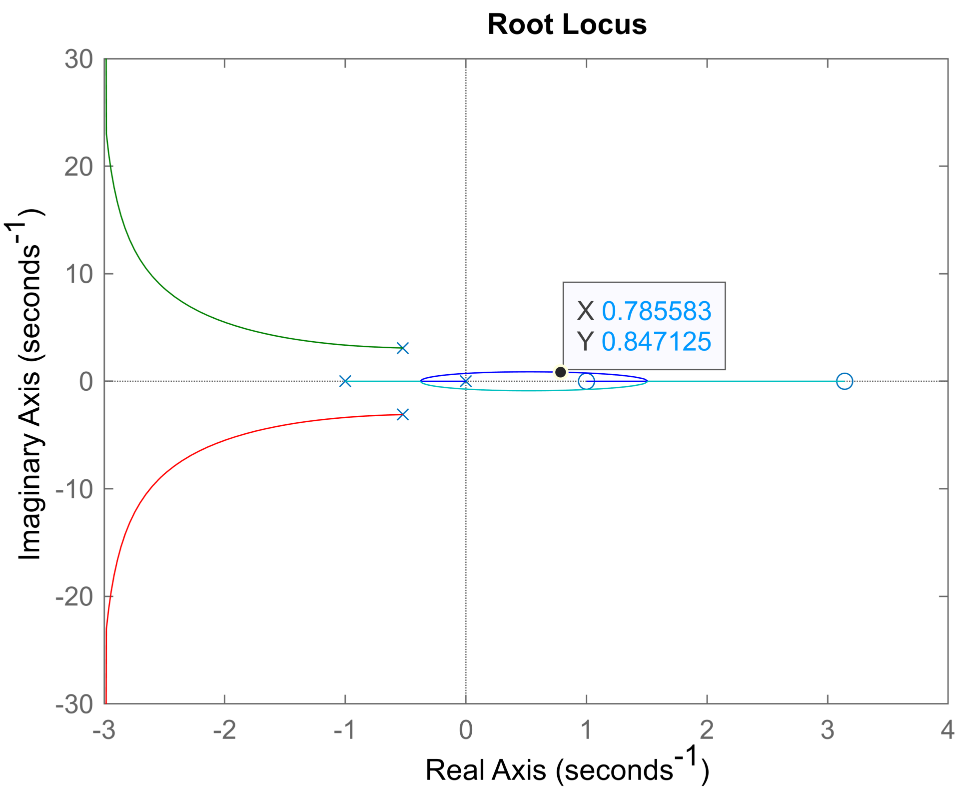



Working with the negative Ks, we have a really small gap in the branches to work with which actually matches what we saw in ruth's method.

## 5.2.Configure a PI or PD controller

We can add another minimum phase zero and another pole in the PLHP so that it leads to apearing a new branch moving from the OLHP to ORHP so that we find the chance to consider areas for K to bring all the poles in the OLHP so it shapes a PID.

```
num = conv([1/pi -1] , [1 -1]);
den = conv([1/(pi^2) 1/(3*pi) 1], [1 1 0]);
sys_rc = tf(num,den);
rlocus(sys_rc);
```




As you see now we have a little area in positive Ks to bring all the poles in the OLHP and make the system stable.

## 6.Control overshoot

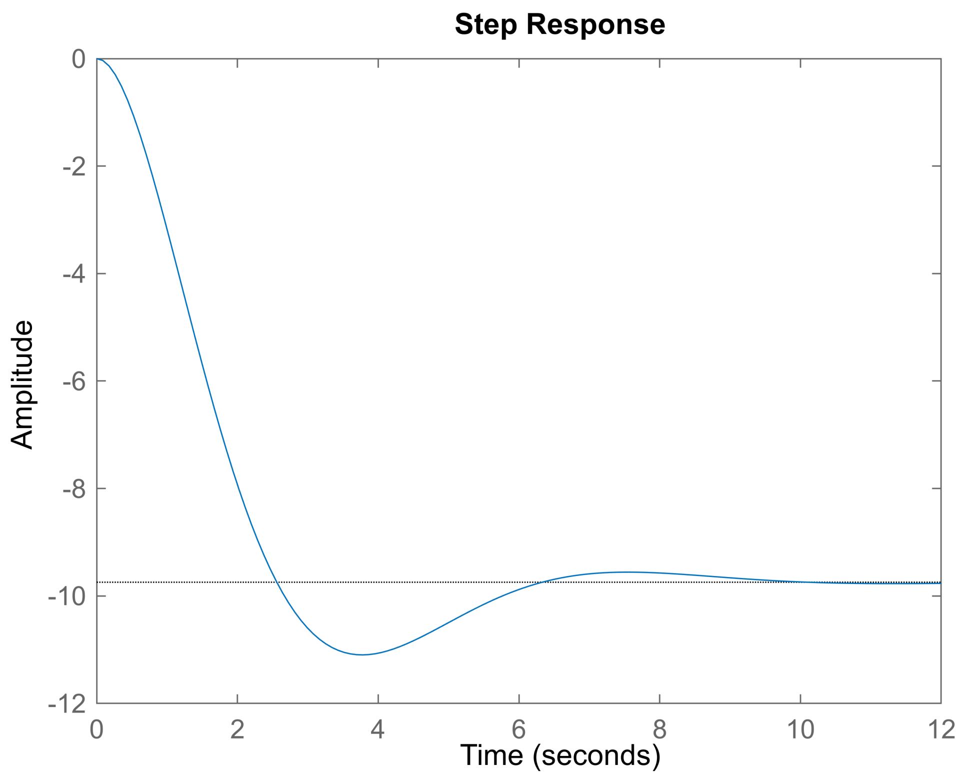
Our closed loop transfer function will be $\frac{k\pi^2}{s^2+\frac{\pi}{3}s+(k+1)\pi^2}$ which is a shape of $\frac{k{\omega_n}^2}{s^2+2\xi\omega_n s+\omega_n^2}$ and as

$M_p = e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}}$ it concludes that $3.96 < \zeta < 5.8$ and settling time with a $\delta = 2\%$ is equal to $\frac{4}{\xi\omega_n}$ so we conclude

that $\xi > \frac{4}{10\pi\sqrt{k+1}}$ and we can consider $-\frac{63}{64} > k > -\frac{3339}{3364}$ and we can find a k between these using an old rule :)))

$k = -\frac{63+3339}{64+3364}$

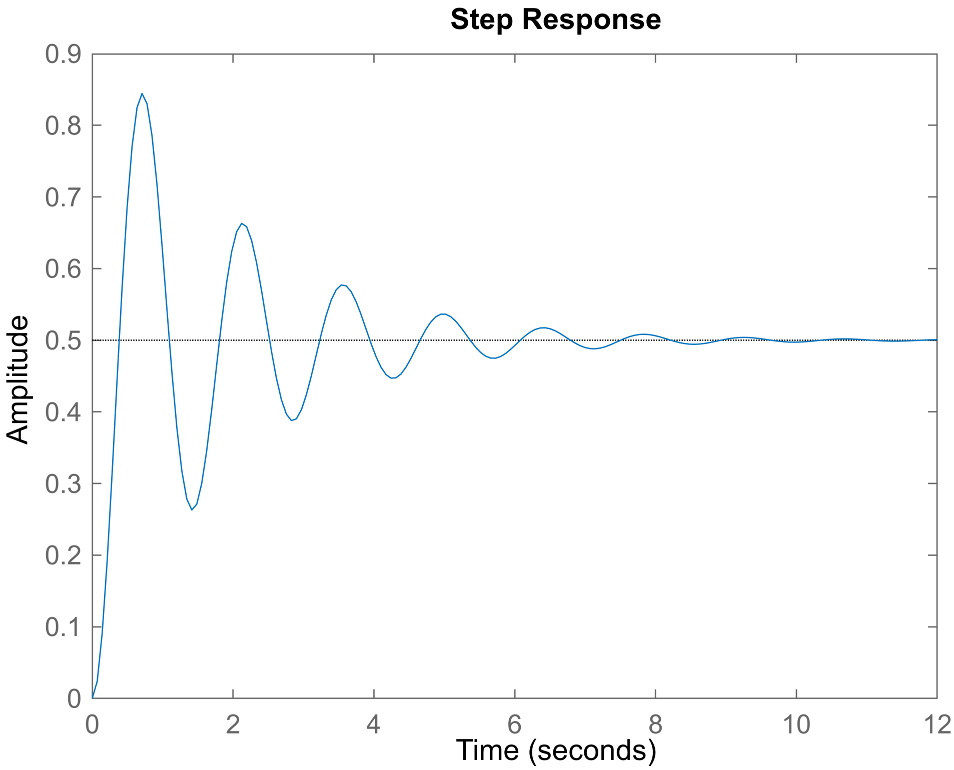
```
num = -9.432;
den = [1 pi/3 0.968];                % a little help from instincs :)
sys_c = tf(num,den);
step(sys_c);
```




```
stepinfo(sys_c)
```

```
ans = struct with fields:
         RiseTime: 1.7318
    TransientTime: 5.8792
     SettlingTime: 5.8792
      SettlingMin: -11.0961
      SettlingMax: -8.9610
        Overshoot: 13.8785
       Undershoot: 0
             Peak: 11.0961
         PeakTime: 3.7819
```

```
num = pi^2;
den = [1 pi/3 2*pi^2];
sys_uc = tf(num,den);
step(sys_uc);
```




```
stepinfo(sys_uc)
```

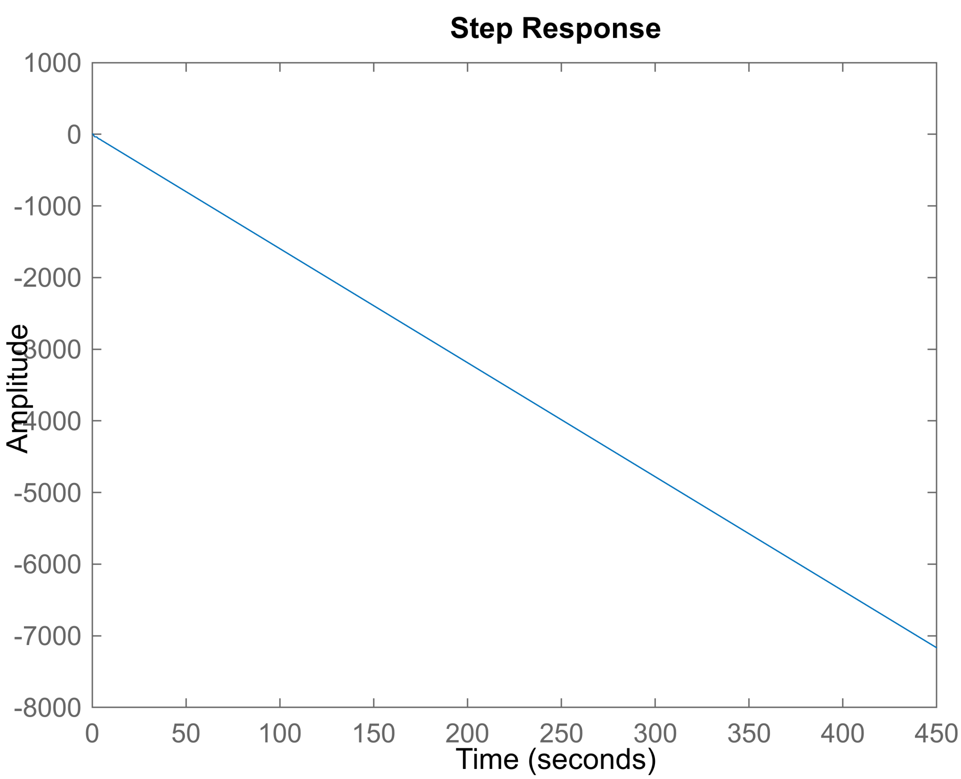
```
ans = struct with fields:
         RiseTime: 0.2575
    TransientTime: 7.2524
     SettlingTime: 7.2524
      SettlingMin: 0.2630
      SettlingMax: 0.8443
        Overshoot: 68.8609
       Undershoot: 0
             Peak: 0.8443
         PeakTime: 0.7071
```

# 7.Controller design

## 7.1.Maximum of 2% for $e_{sr}$

$\frac{1}{s}S(s) = \frac{1}{s^2(1+L(s))}$ so $y(s) = \frac{1}{s^3(1+L(s))}$ and the $e_{sr} = \lim_{s \longrightarrow 0} \frac{1}{s\left(1+\frac{s-\pi}{s\left(\frac{s^2}{\pi^2}+\frac{s}{3\pi}+1\right)}\right)} = -\frac{1}{\pi} = \frac{1}{k_v} < \frac{1}{50}$ so we need a $\frac{50}{\pi}$ gain to reach the wanted result. Also we add a zero at orgin.

```
K = (50/pi) -1;
T = (1/25)*(((K/0.05)^2)-1)^0.5;
num = conv([T 50/pi] , [1/pi -1 0]);
den = conv([1/(pi^2) 1/(3*pi) 1] , [1 0 0]); %having ramp response is equal to adding
sys_fc = tf(num,den);                         %a pole at orgin then computing the step
step(sys_fc);                                 %response.
```




Thanks for your attention!

Iman Bidi 40116503 Linear Control Final project

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