Theoretical aspects

- nonminimum phase system
- Negative feedback structure
- Stability NYQUIST criterion

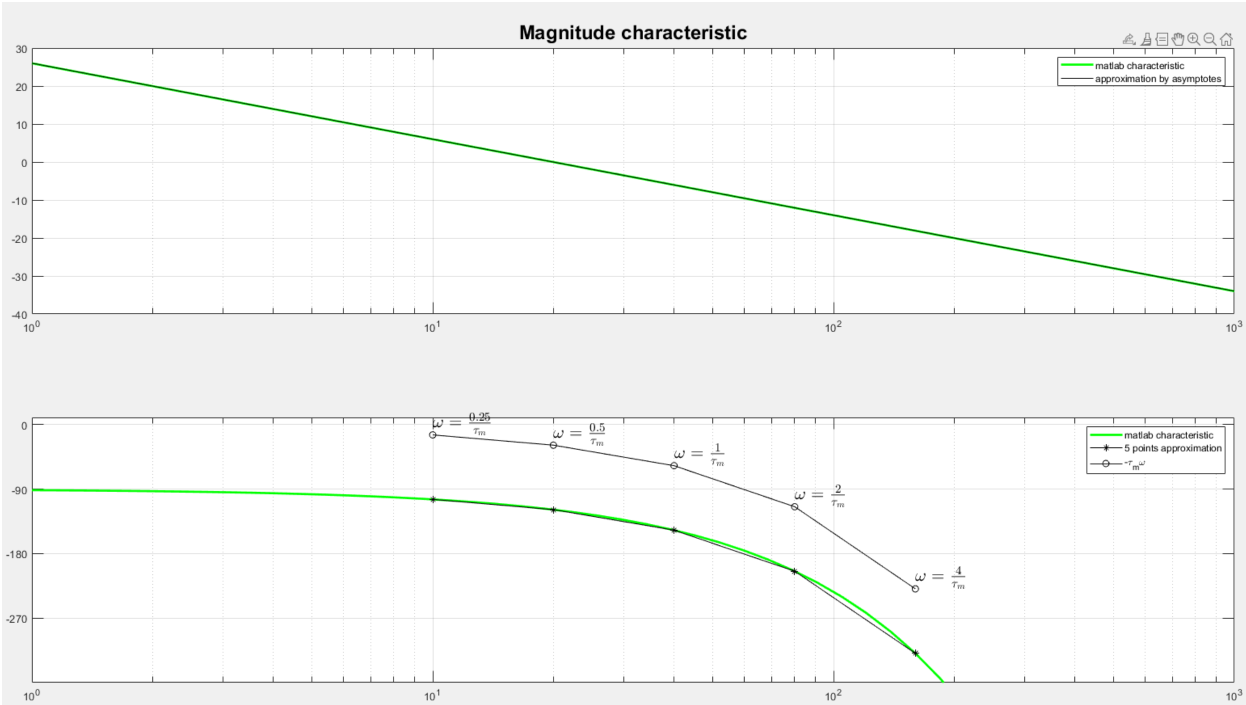
Time delay systems

As a nonminimum phase term, only the phase characteristic will be affected. Having a simple example of a delayed integration with the transfer function $H(s) = \frac{20}{s} e^{-s \cdot 0.025}$, the following Matlab script can be used to evaluate the frequency response:

```
clear;clc
tau_m=0.025;% time delay given in seconds
H=tf(20,[1 0],'IOdelay',tau_m);

w=logspace(0,3);[m,f]=bode(H,w);mm(1,:)=m(1,1,:);ff(1,:)=f(1,1,:);

subplot(211)
semilogx([1 10 20 1e2 1e3],[26 6 0 -14 -34],'g','LineWidth',2);grid
hold;semilogx(w,20*log10(mm),'k');
legend('matlab characteristic','approximation by asymptotes');
title('Magnitude characteristic','FontSize',18);
hold

subplot(212);semilogx(w,ff,'g','LineWidth',2);hold;
wtm=1/tau_m;% frequency of interest fro time delay
semilogx([0.25 0.5 1 2 4]*wtm,-90-180/pi*[0.25 0.5 1 2 4],'*k-')
semilogx([0.25 0.5 1 2 4]*wtm,-180/pi*[0.25 0.5 1 2 4],'ok-')
info={'$\omega=\frac{0.25}{\tau_m}$','$\omega=\frac{0.5}{\tau_m}$','$\omega=
\frac{1}{\tau_m}$','$\omega=\frac{2}{\tau_m}$','$\omega=\frac{4}{\tau_m}$'}
text([0.25 0.5 1 2 4]*wtm,-57*[0.25 0.5 1 2 4]+15…
…,info,'Color','k','interpreter','Latex','FontSize',16);
hold
legend('matlab characteristic','5 points approximation','-\tau_m\omega');
axis([1,1e3,-360,10]);grid
set(gca,'YTick',[-270,-180,-90,0]);shg
```

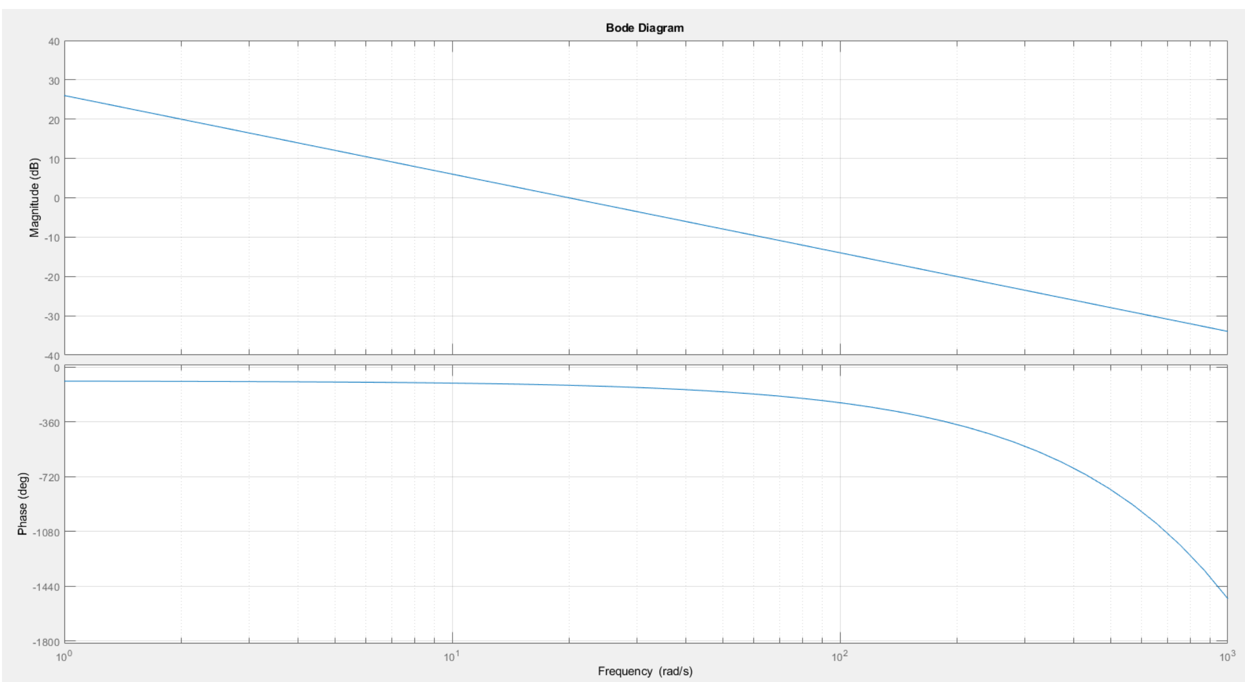
Evaluate (read/understand) the script to notice the range of frequencies for which time delay starts affecting considerably the phase characteristic.

Be aware also of the phase amount which is till -360 degrees (around -180 degrees) which is sufficient for stability analysis

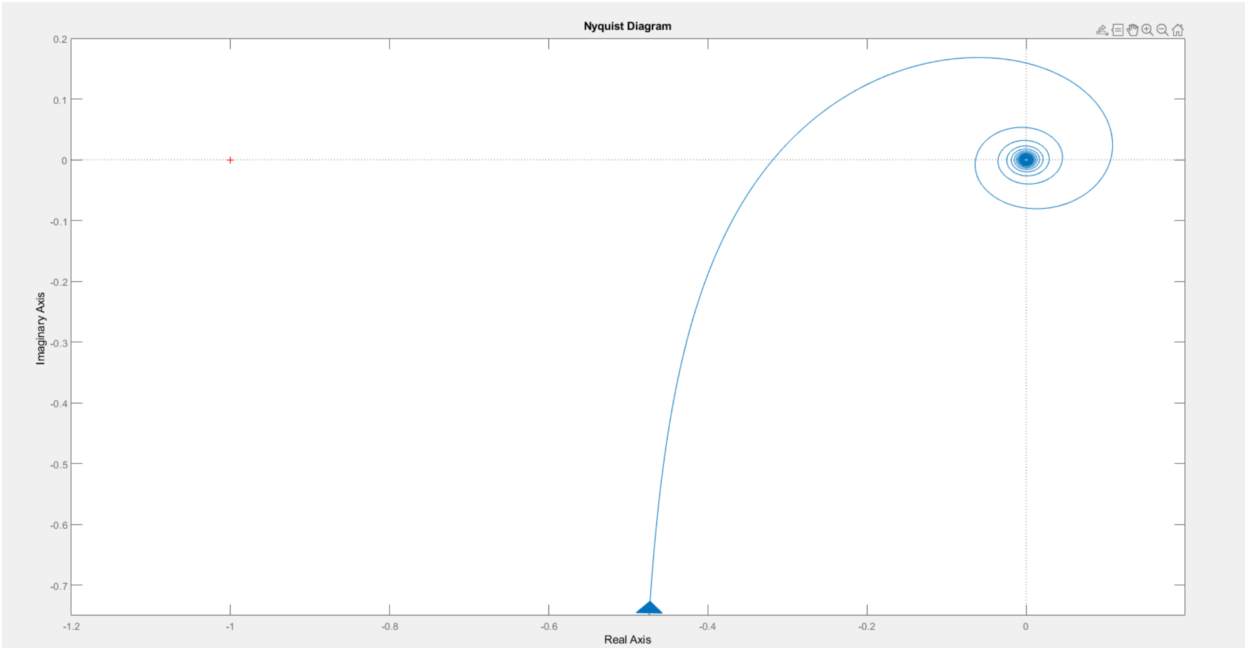


Problem

Write a matlab script (as short as possible) in order to plot the Bode diagram for $H(s) = \frac{20}{s} e^{-s \cdot 0.025}$, using matlab bode function, as in the next figure; notice the amount of phaseshift over the HFR (last decade)



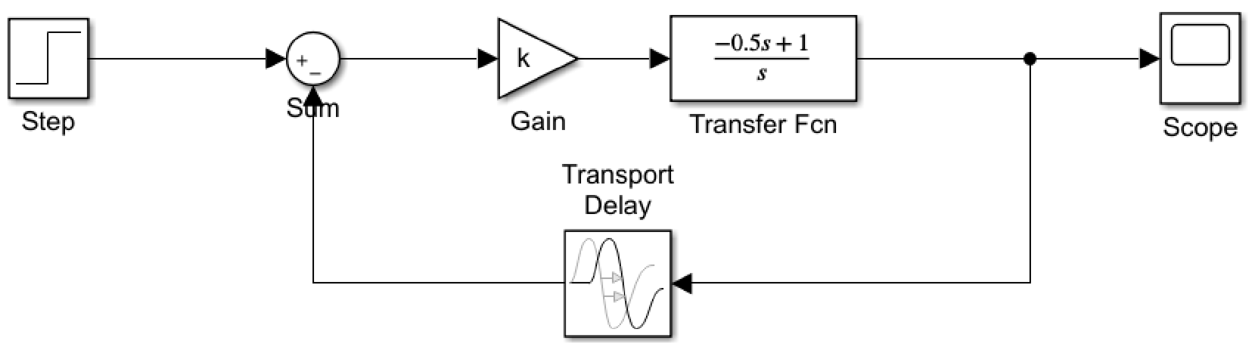
Write a matlab script in order to plot the Nyquist diagram for $H(s) = \frac{20}{s} e^{-s \cdot 0.025}$; conclude in words how the HFR phaseshift is 'visible' on the diagram; see the next figure for the requested plot:



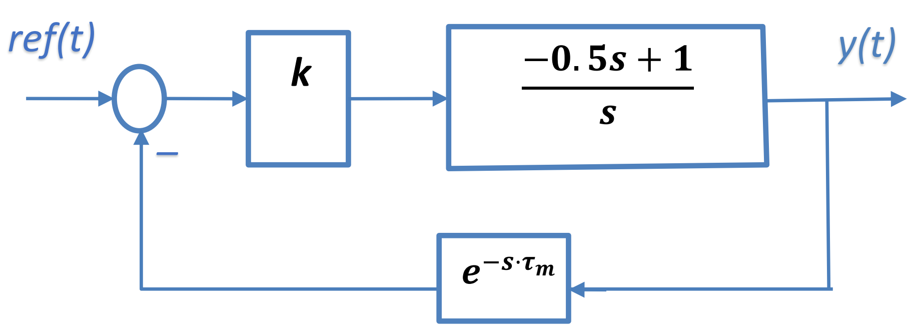
Stability analysis of negative feedback structures

Given the next control structure:

- as a Matlab/Simulink model:



- as a block diagram representation:



Follow the next problems regarding closed loop stability analysis:

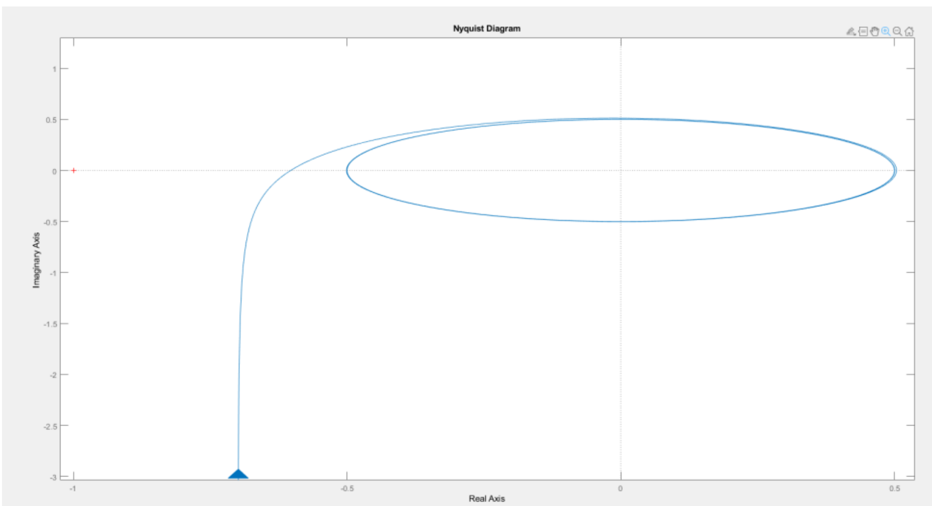
1. For direct path gain k=1 and a time delay $\tau_m = 0.2\ sec.$, analyse the stability of the closed loop.
2. For a time delay of 0.5 seconds, how must be the direct path gain such that stable closed-loop system
3. For direct path amplification / gain k=2, how much the time delay can increase in order to maintain the closed loop stability

Solutions (using Matlab)

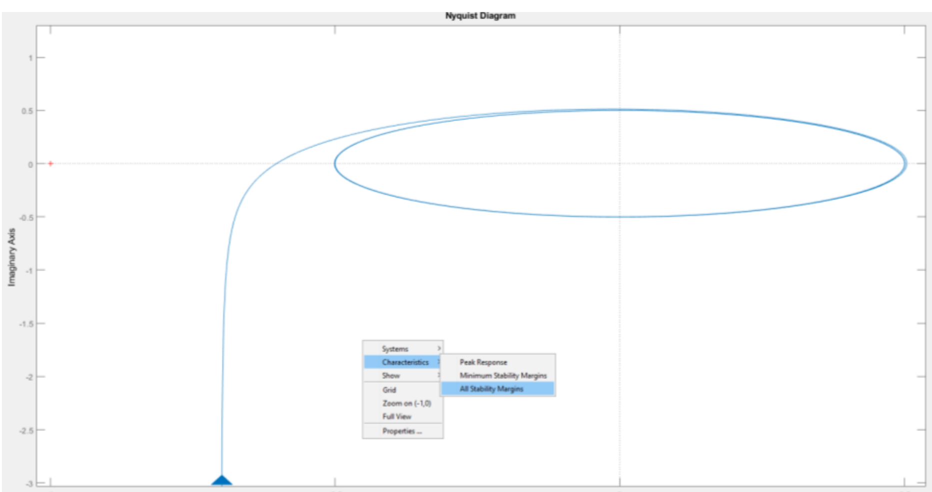
- Declare in Matlab the **open loop** transfer function:

```
H_ol =

                    -0.5 s + 1
  exp(-0.2*s) * ----------
                        s

Continuous-time transfer function.
```

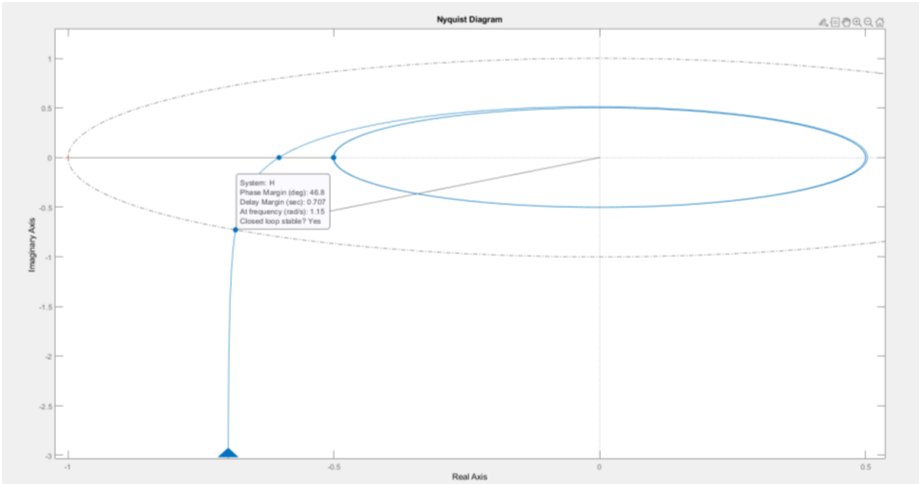
- Plot the Nyquist Diagram (without Negative Frequencies):



- Activate the „stability analysis”



- Read the conclusions returned by the ALGHORITHM (under Matlab)



Questions

1. How to choose the range of frequencies when time delay is present? Practice on the following case: $H(s) = \frac{30}{s^2+s+25} e^{-s\cdot 2}$ and indicate the range of frequencies that should be evaluated on FR (frequency response) plots; Answer: $\omega_n = 5, \omega_{\{\tau_m\}} = 0.5 \Rightarrow \omega \in (10^{-2}, 10^2)$
2. Matlab functions useful for closed loop time response: feedback, step, lsim

Problems

Follow the same steps in order to analyze the closed loop stability for the next open loop transfer functions:

a) $H_{ol}(s) = \frac{10}{s+3} e^{-s}$	h) $H_{ol}(s) = k \frac{1}{s(s+1)(s+4)}$
b) $H_{ol}(s) = k \frac{s+900}{s+500}$	
c) $H_{ol}(s) = k \frac{s-9\cdot 10^6}{s+5\cdot 10^6}$	
d) $H_{ol}(s) = k \frac{s+9}{s-5}$	
e) $H_{ol}(s) = k \frac{-s+9}{s+5}$	
f) $H_{ol}(s) = k \frac{s+9}{-s+5}$	
g) $H_{ol}(s) = k \frac{-s+9}{s-5}$	

Difficult Problem

Based on General Nyquist Criterion (see the course) implement an alghoritm in Matlab capable to „make the analysis" of the closed loop stability.