REPORT ON REGELTECHNIEK WPO SESSION

FIRST AND SECOND SESSIONS - EXERCISES

1. Consider the following system $H(s) = \frac{2}{s^2+3s+2}$

a) *Realize the system in transfer function form*

```
% version 1, using symbolic s variable
s=tf('s');
H=2/(s^2+3*s+2);
% version 2, classical way
H=tf([2], [1 3 2]);
```

b) *Calculate the zeros and poles. Is the system stable/unstable (explain!)*

```
z=roots(H.Numerator{:})
p=roots(H.Denominator{:})
% the system is stable because the poles are on the left hand-side
```

c) *Define the Zero-Pole-Gain form*

1) *with numerical analysis (calculate yourself)*

2) *with automatic Matlab conversion*

```
% by analytical way: the zp form is already given by z and p as 1/((s+2)*(s+1))
% to define k: the static gain is tf and zpk form should be the same
% static gain can be obtained by setting s=0, H(0)=2/(0^2+3*0+2)=1,
% static gain by matlab command is dcgain(H), so k=2 resulting 2/((s+2)*(s+1))
% by automatic matlab command:
Hzpk=zpk(H)
```

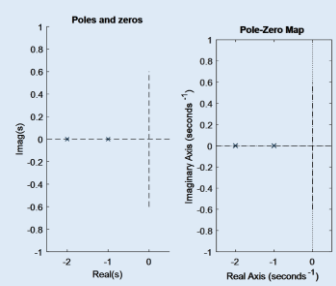
d) *Verify in Matlab that the Zero-Pole-Gain representation is equal to the transfer function representation*

```
% check the difference between tf and zpk form, the result should be
% theoretically 0, but as we seen it is a small number instead (due to
% the solver)
H-Hzpk
```

e) *Plot the poles and zeros on the S plane and make sure that 1) and 2) give exactly the same results*

1) *Using your own Matlab commands (e.g. plot)*

2) *Using pzplot command*

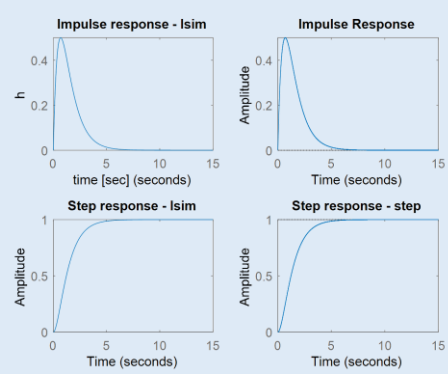



```
% solution 1)
figure
subplot 121; hold on;
plot(real(z),imag(z),'o'); plot(real(p), imag(p),'x');
plot([-2.5 0.5],[0 0],'k--'); plot([0 0],[-0.6 0.6],'k--')
xlabel('Real(s)'); ylabel('Imag(s)'); title('Poles and zeros')
xlim([-2.5 0.5]); ylim([-1 1])
% solution 2)
subplot 122; hold on;
pzmap(H);
plot([-2.5 0.5],[0 0],'k--'); plot([0 0],[-0.6 0.6],'k--');
xlim([-2.5 0.5]); ylim([-1 1])
```

f) *Simulate and display impulse and step responses with the following parameters: fs=1 kHz, t=[0...15] sec. Make sure that 1) and 2) give exactly the same results*

1) *Using your lsim command*

2) *Using impulse and step commands*



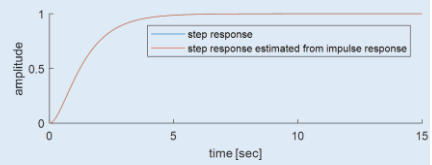

```
% classical way with linear simulation
fs=1e3; t0=1/fs;
tmin=0; tmax=15;
t=tmin:t0:tmax;
N=length(t);
u_dirac=zeros(1,N);
u_dirac(1)=1/t0;
figure
subplot(221)
lsim(H,u_dirac,t);
title('Impulse response - lsim'); xlabel('time [sec]');ylabel('h');
ylim([0 0.5])
% impulse function of the control toolbox
subplot(222)
title('Impulse response - impulse');
impulse(H,t); ylim([0 0.5])
% step response classical way
subplot(223)
u_step=1*ones(1,N);
lsim(H,u_step,t)
title('Step response - lsim');
% with step function
subplot(224)
step(H,t)
title('Step response - step');
```

g) *How do you obtain the step response if only the impulse response is available?*

1) *Show the codes of the computation in Matlab*

3) *Compare the step response estimates from point g) and f)*

```
h=lsim(H,u_dirac,t);
s=lsim(H,u_step,t);
% 'discrete intergral' is calculated as
s_from_h=cumsum(h)*t0;
figure; hold on;
plot(t,s); plot(t,s_from_h);
xlabel('time [sec]');ylabel('amplitude');
legend({'step response','step response estimated from impulse response'});
```



2. Consider the following systems $H_1(s) = \frac{1}{s^2+3s+2}$ and $H_2(s) = \frac{s+1}{s+2}$

a) *Realize the systems in transfer function form*

```
s=tf('s');
H1=1/(s^2+3*s+2);
H2=(s+1)/(s+2);
```

b) *Calculate the resulting plant model from the serial connection of the systems considered*

1) *using * operator*

2) *using series command*

3) *check if 1) and 2) provide the same results*

4) *store the results in Hs variable, use zpk (Zero-Pole-Gain) form*

```
Hs_1=H1*H2;
Hs_2=series(H1,H2);
Hs_1-Hs_2 % there is no difference here
Hs=zpk(Hs_1);
```

c) *Calculate the resulting plant model from the parallel connection of the systems considered*

1) *using + operator*

2) *using parallel command*

3) *check if 1) and 2) provide the same results*

4) *store the results in Hp variable, use zpk form*

```
Hp_1=H1+H2;
Hp_2=parallel(H1,H2);
Hp_1-Hp_2 % there is no difference here
Hp=zpk(Hp_1);
```

d) *Simplify Hs and Hp*

1) *in analytic way (show your equations)*

2) *using minreal command*

3) *check if 1) and 2) provide the same results*

4) *store the results in Hs and Hp variables, respectively*

```
% Hs=(s+1)/((s+2)^2*(s+1)) --> easy to see that we can simplify with s+1
Hs=minreal(Hs); % it worked
% Hp =(s+2)*(s^2 + 2*s + 2)/ ((s+2)^2*(s+1)) --> we can simplify with s+2
Hp=minreal(Hp); % as you can see it fails to simplify
```

e) *Place Hs in the forward loop and apply a negative feedback (-1 gain)*

1) *using * and - operators*

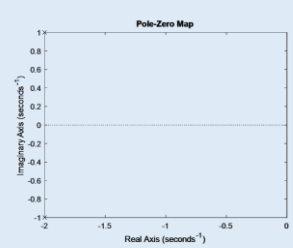
2) *using feedback command*

3) *check if 1) and 2) provide the same results*

4) *simplify the results using minreal command*

5) *is the system stable? (explain)*

6) *store the result in Hfs variable*




```
Hfs_1=Hs/(1+Hs);
Hfs_2=feedback(Hs,1); % the provided result is is simplier
Hfs_1-Hfs_2 % there is a small difference, due the the solver
Hfs=minreal(Hfs_2);
figure; pzmap(Hfs) % --> the system is stable, the poles are on the left hand-side
```

f) Place Hs in the forward loop and Hp in a negative feedback loop

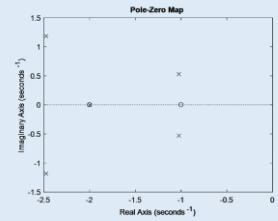
*1) using * and + operators*

2) using feedback command

3) check if 1) and 2) provide the same results

4) simplify the results using minreal command

5) is the system stable? (explain)




```
Hfp_1=Hs/(1+Hs*Hp);
Hfp_2=feedback(Hs,Hp);
Hfp_1-Hfp_2 % there is a small difference, due the the solver
Hfp=minreal(Hfp_2);
figure; pzmap(Hfp) % --> the system is stable, the poles are on the left hand-side
```

g) Plot the step responses of Hfs and Hfp

Use lsim to simulate the responses with fs=1 kHz, choose an appropriate time interval for the simulation

1) compare the different responses

2) estimate with the help of step response figures the static gain, rise time, settling time, peak-time, dominant time constant. Show clearly on your plot how you estimate the different quantities

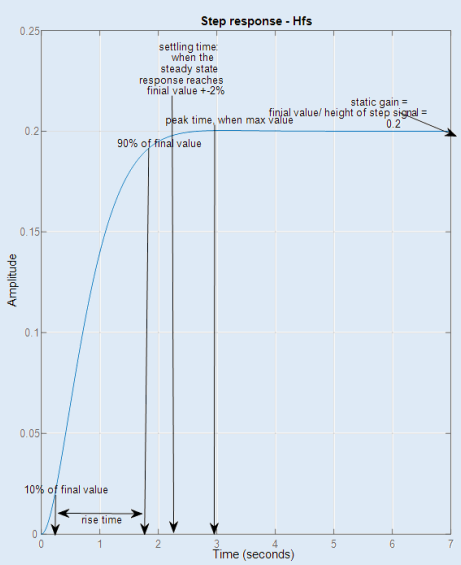
3) Compare your results from 2) with the results of stepinfo and other related commands used to obtain the above-mentioned quantities. Explain the differences. Use a table to compare the quantities

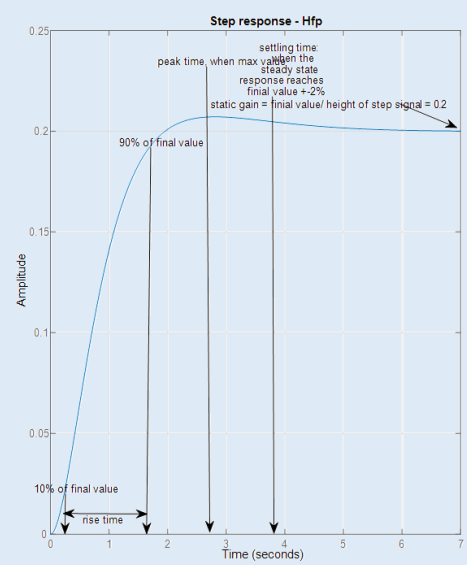
```
fs=1e3; t0=1/fs; tmin=0; tmax=7;
t=tmin:t0:tmax; N=length(t);
u_step=1*ones(1,N);

figure; subplot(121)
lsim(Hfs,u_step,t)
title('Step response - Hs'); ylim([0 0.25]); grid on;

subplot(122); lsim(Hfp,u_step,t)
title('Step response - Hfs'); ylim([0 0.25]); grid on;
```

Quantity	Hfs		Hfp	
	From plot	Matlab	From plot	Matlab
Static gain	0.2	0.2 use dcgain(Hfs)	0.2	0.2 use dcgain(Hfs)
Settling time	2.04 s	2.0749 s	3.86 s	4.0123 s
Rise time	1.266 s (1.5-0.234)	1.2783 s	1.217 s (1.44-0.223)	1.2115 s
Time constant	0.884 s	Use the 1/real(dominant pole)	0.881 s	Use the 1/real(dominant pole)
Peak time	2.51 s	3.1315 s	2.51	2.8276





Warning: the figures are only qualitative

3. Consider the following systems $H_1(s) = \frac{10s+1}{s+1}$ and $H_2(s) = \frac{s}{(10s+1)(5s+1)}$

a) *Realize the systems*

xxxx

b) *Calculate the resulting plant model from the serial connection of the systems considered and store the result in Hs variable, simplify if it is possible*

xxxx

c) *Calculate the resulting plant model from the parallel connection of the systems considered and store the result in Hp variable, simplify if it is possible*

xxxx

d) *Place Hs in the forward loop and apply a negative feedback (-1 gain) and store the results in Hfs variable*

xxxx

e) *Place Hs in the forward loop and Hp in the negative feedback loop and store the results in Hfp variable*

xxxx

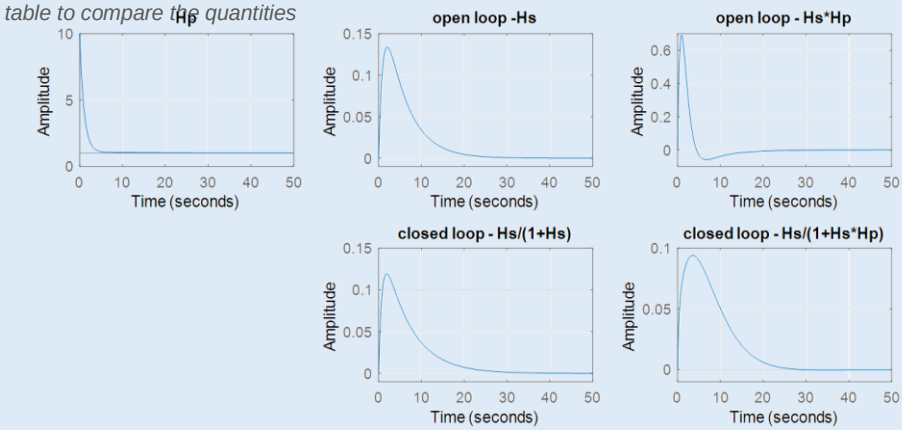
f) *Plot the step responses of Hp; and Hfs and Hfp for open and closed loop cases. Use lsim command with fs=1 kHz. Choose carefully the simulation time and the limits on y-axis*

   4) *compare the different responses in one figure*

   5) *estimate with the help of step response figures the static gain, rise time, settling time, peak-time, overshoot. Show clearly on your plot how you estimate the different quantities*

   6) *Compare your results from 2) with the results of stepinfo command. Explain the differences. Use a table to compare the quantities*

xxxxx




```
% quantitiy       Hp            Hs          Hs/(1+Hs)        Hs*Hp        Hs/(1+Hs*Hp)
% static gain      1/1           0/0            0/0            0/0            0/0
% rise time       2.235*/2.2343  0/0            0/0            0/0            0/0
%1+9*0.9<>1+9*0.1
% 2.34-0.105=2.235s
% * or 0, depending upon definition
% settling time    19.3/4.2004   22.6/22.68     23.6/26.9829  15.9/15.9314   23.9/23.9079
%                        0.1337*0.02=0.0027
%                                                 0-0.69*0.02=-0.0138
% peak-time        0/0       1.98/2.0263    1.86/1.8591    0.93/0.921      0.92/0.9210
% overshoot        900%/900%     inf            inf            inf             inf
```

g) *Define the characteristic function (polynomial) and loop (gain) function of Hfs and Hfp*

xxxx

h) *Create Bode plot of Hfs and Hfp by bode command between* $[10^{-4}; 10^{4}]\frac{rad}{sec}$ *with* $10^{-4}\frac{rad}{sec}$ *resolution.*

   Be very careful: transfer function you use should be not the closed loop but the open loop one (i.e. the loop (gain) function)

   1) *compare the different Bode plots in one figure*

   2) *estimate with the help plots the static gain, time constants (which one is the dominant one), gain margin, phase margin, cross-over frequency. Show clearly on your plot how you estimate the different quantities. Provide the results both dB and magnitude, rad/sec and Hz values.*

   3) *Compare your results from 2) with the results of margin command. Explain the differences. Use a table to compare the quantities*

xxxx

```
% static gain -80dB/-INF (0.0001/0)          -80dB/-INF (0.0001/0)
% cross-over   NaN                           1rad/sec (0.1592Hz) / NaN
% phase margin Inf           Inf             180 degree (pi) / Inf
% gain margin Inf            Inf             Inf / Inf
```