Testatarbeit: Tunable Bandpass Filter for Embedded Devices

DSVB Part 1, HSLU-T&A, WaJ

```
close all;
clear all;
clc;
```

1. Parameter definition and verification

Primary parameters for IIR and FIR filter design:

```
f_L = 290e3;    % lower band edge frequency [Hz]
f_U = 305e3;    % upper band edge frequency [Hz]
f_S = 2e6;      % sampling frequency for digital filters [Hz]
N1 = 6;        % FIR filter order (for same # of mult as 2nd order FIR)        <<<=== To be de
N2 = 94;       % FIR filter order (for equivalent ampl. resp. as IIR filter)    <<<=== To be de
```

Secondary parameters for plotting and analysis:

```
nfp = 500;       % # of frequency points used in plotting amplitude/phase responses
```

Verify parameter values:

```
if f_U <= f_L     error('Lower band edge frequency > upper frequency'); end
if f_L < 0        error('Lower band edge frequency < 0 Hz'); end
if f_U >= f_S/2   error('Upper band edge frequency > f_S/2'); end
```

Derived parameters:

```
B = f_U - f_L;                      % bandwidth of passband (frequencies above -3 dB attenuatio
f_0 = sqrt(f_L*f_U);                % center frequency of passband filter
Q = f_0/B;                          % filter quality factor
om_0 = 2*pi*f_0;                    % angular center frequency
f_vec = linspace(0, f_S/2, nfp);    % vector of frequency points between 0 and f_S/2 for plotti
p_vec = 1i*2*pi*f_vec;              % vector of points on complex frequency axes to evaluate H(p
A=1
```

```
A = 1
```

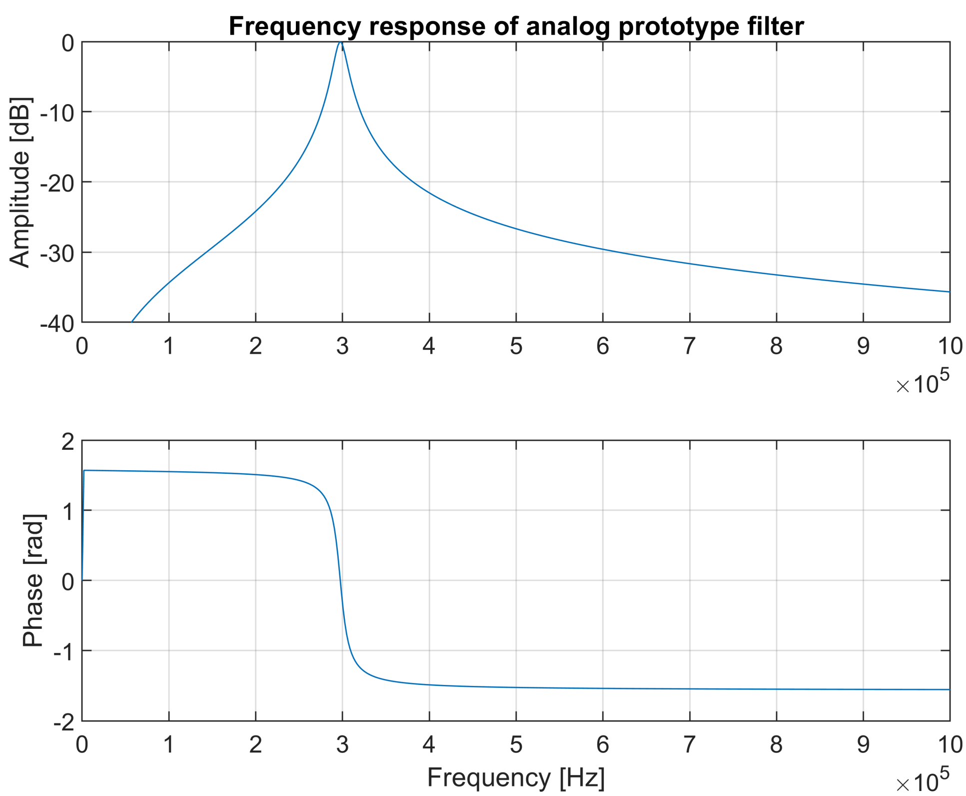
2. Analog Prototype Filter (Task 3a)

Define the continuous-time transfer function H(p) of the analog prototye filter by explicitly constructing the numerator and denominator poynomials using vector p_vec, and subsequenly element-wise division of these vectors.

```
b_p = A.*B./(f_0.*om_0).*p_vec;  % <<<<<<<< ToDo
a_p = 1+B./(f_0.*om_0).*p_vec+1./om_0^2.*p_vec.^2;  % <<<<<<<< ToDo
H_p = b_p ./ a_p;
```

Plot magnitude and phase response of the analog prototype filter in figure #1.

```
figure('name','figure 1')
subplot(2,1,1)
plot(f_vec,20*log10(abs(H_p)));
title('Frequency response of analog prototype filter')
ylabel('Amplitude [dB]')
axis([0 f_S/2 -40 0])
grid on;
subplot(2,1,2)
plot(f_vec,angle(H_p))
axis([0 f_S/2 -2 2])
grid on;
ylabel('Phase [rad]')
xlabel('Frequency [Hz]')
```



3. IIR Bandpass Filter (Task 3b)

Get the IIR filter coefficients using the bilinear transform of the analog prototype filter without and with prewarping.

```
[b_iir_nopw,a_iir_nopw,K_iir_nopw] = bp_iir_bilin(f_L, f_U, f_S, 'no prewarp');
[b_iir_pw,a_iir_pw,K_iir_pw]       = bp_iir_bilin(f_L, f_U, f_S, 'prewarp');
```

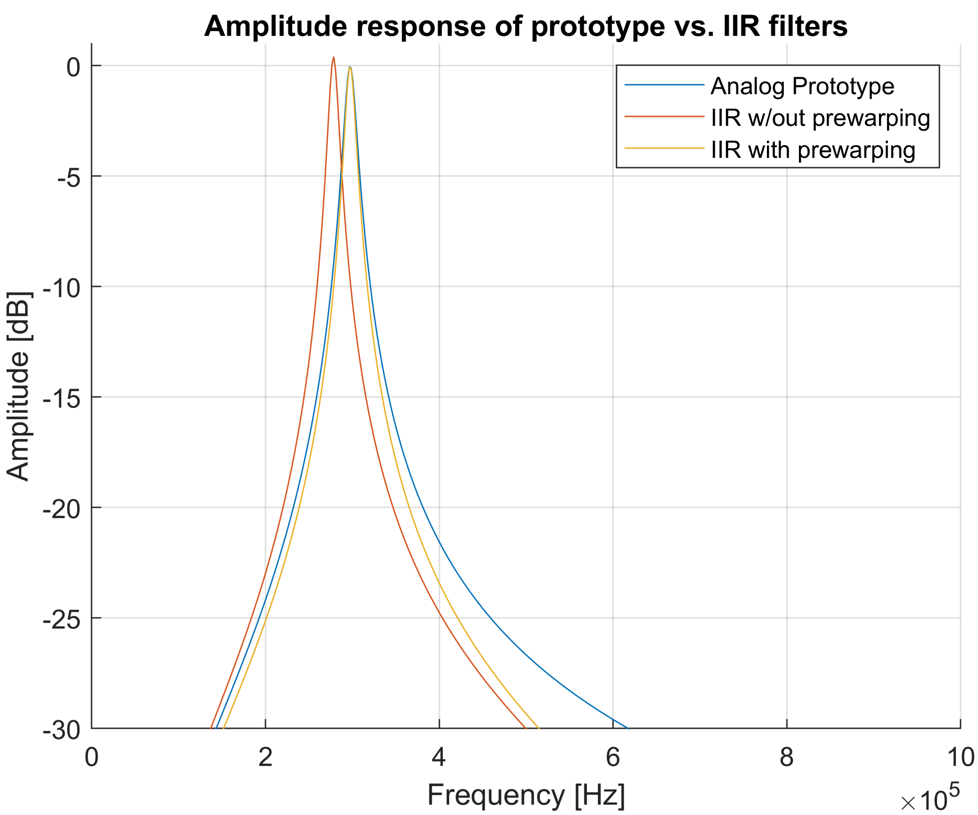
Compute the frequency response of the two IIR filters at the same frequency points used for computing the frequency response of the analog prototype filter.

```
[H_iir_nopw] =freqz(K_iir_pw.*b_iir_nopw,a_iir_nopw,2*pi*f_vec/f_S);  % <<<<<<<< ToDo
[H_iir_pw]   =freqz(K_iir_pw.*b_iir_pw,a_iir_pw,2*pi*f_vec/f_S) ;  % <<<<<<<< ToDo
```

Plot magnitude response of analog prototype filter, and two IIR filters designed with and without frequency prewarping in figure #2.

```
figure('name','figure 2')

% <<<<<<<< ToDo
hold on
plot(f_vec,20*log10(abs(H_p)));
plot(f_vec,20*log10(abs(H_iir_nopw)));
plot(f_vec,20*log10(abs(H_iir_pw)));
hold off
axis([0 f_S/2 -30 1])
grid on;
ylabel('Amplitude [dB]')
xlabel('Frequency [Hz]')
title('Amplitude response of prototype vs. IIR filters')
legend('Analog Prototype','IIR w/out prewarping','IIR with prewarping','Location','NorthEast')
```



4. FIR Bandpass Filter (Task 3c)

Get the FIR filter coefficients using the window design method with a rectangular window and two diffrent filter order:

```
b_fir_rect_N1=bp_fir_win(f_L, f_U, N1, f_S,'');%
```

```
b_fir_rect_N2=bp_fir_win(f_L, f_U, N2, f_S,'');%
```

Compute the frequency response of the two FIR filters at the same frequency points used for computing the frequency response of the IIR filters.

```
[H_fir_rect_N1] = freqz(b_fir_rect_N1,1,2*pi*f_vec/f_S);
% [H_fir_rect_N1] = freqz(b_fir_rect_N1,1,500);
% [H_fir_rect_N2] = freqz(b_fir_rect_N2,1,500);
[H_fir_rect_N2] = freqz(b_fir_rect_N2,1,2*pi*f_vec/f_S);
```

Scale the frequency response such that the gain is 1 at the passband center frequency f_0. For this, first get gain of the current frequency response at the center frequency, and then divide the frequency response by this value.

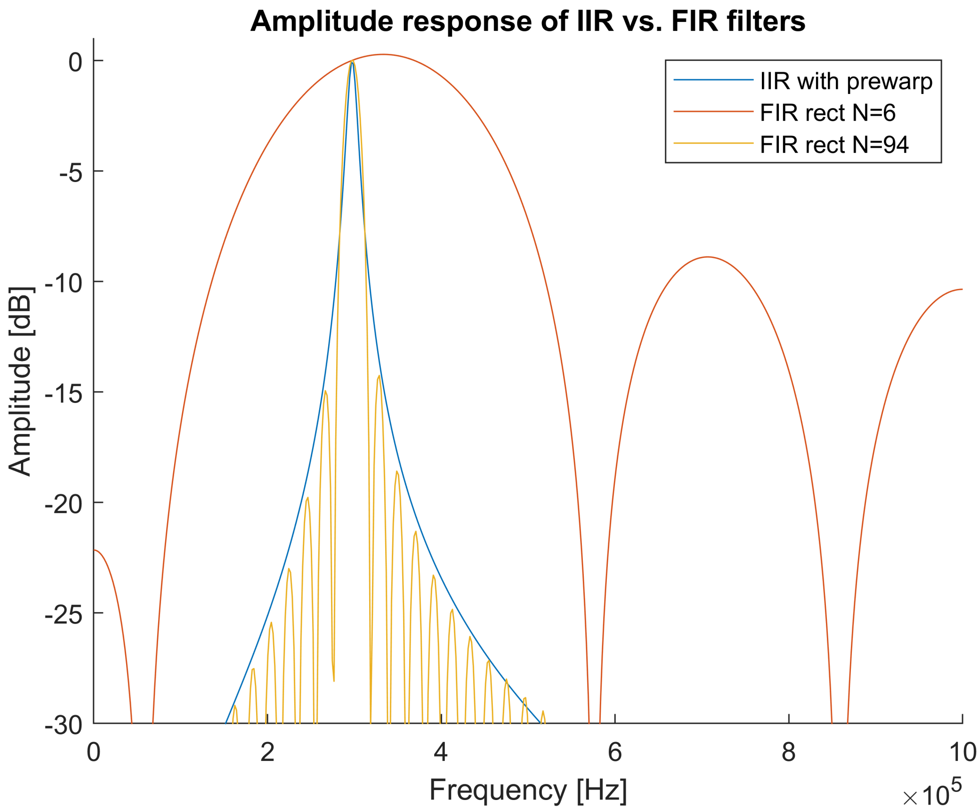
```
% G1_f_0_custom = abs(H_fir_rect_N1(ceil(length(H_fir_rect_N1)/2)));
G1_f_0 = abs(H_fir_rect_N1(round(nfp*2*f_0/f_S)));
H_fir_rect_N1 = H_fir_rect_N1/G1_f_0;
% G2_f_0_custom = abs(H_fir_rect_N2(ceil(length(H_fir_rect_N2)/2)));
G2_f_0= abs(H_fir_rect_N2(round(nfp*2*f_0/f_S)));
H_fir_rect_N2 = H_fir_rect_N2/G2_f_0;
```

Plot magnitude response of the IIR filter obtained with prewarping together with the two FIR filters designed with the windowing methods and two different filter orders in figure #3.

```

figure('name','figure 3')
hold on
plot(f_vec,20*log10(abs(H_iir_pw)));
plot(f_vec,20*log10(abs(H_fir_rect_N1)));
plot(f_vec,20*log10(abs(H_fir_rect_N2)));
hold off

axis([0 f_S/2 -30 1])
ylabel('Amplitude [dB]')
xlabel('Frequency [Hz]')
title('Amplitude response of IIR vs. FIR filters')
legend('IIR with prewarp',['FIR rect N=' num2str(N1)],['FIR rect N=' num2str(N2)],'Location','N
```



Amplitude response of IIR vs. FIR filters
IIR with prewarp
FIR rect N=6
FIR rect N=94
Amplitude [dB]
0
-5
-10
-15
-20
-25
-30
0
2
4
6
8
10
Frequency [Hz]
$\times 10^5$

Notes:

$$p = v \cdot \frac{z-1}{z+1} \quad , \quad v = \frac{2\pi\hat{f}}{\tan\left(\frac{2\pi\hat{f} \cdot T_s}{2}\right)} \searrow \frac{2}{T_s}$$

$$\mu = \frac{B}{f_0 \cdot w_0}$$

$$) = A \cdot \frac{\mu \cdot v \cdot \frac{z-1}{z+1}}{1 + \mu \cdot v \cdot \frac{z-1}{z+1} + \frac{1}{w_0^2} \cdot v^2 \cdot \frac{(z-1)^2}{(z+1)^2}} \quad \Bigg| \cdot \frac{(z+1)^2}{(z+1)^2}$$

$$= A \cdot \frac{\mu \cdot v \cdot (z-1)(z+1)}{(z+1)^2 + \mu \cdot v \cdot (z-1)(z+1) + \frac{1}{w_0^2} v^2 (z-1)^2}$$

$$= \frac{A\mu v(z^2-1)}{z^2+2z+1+\mu v(z^2-1)+\frac{1}{w_0^2}v^2(z^2-2z+1)}$$

$$= \frac{z^2 A\mu v - A\mu v}{z^2+2z+1+z^2\mu v-\mu v+\frac{1}{w_0^2}v^2z^2-\frac{1}{w_0^2}v^2 2z+\frac{1}{w_0^2}v^2} \quad \Bigg| \cdot z^{-2}$$

$$\frac{A\mu v - A\mu v z^{-2}}{1 + 2z^{-1} + 2z^{-2} + \underline{\mu v} - \mu v z^{-2} + \frac{1}{w_0^2}v^2 - \frac{1}{w_0^2}v^2 2z^{-1} + \frac{1}{w_0^2}v^2 z^{-2}}$$

$$= A\mu v \cdot \frac{\overset{b_0}{1} - \overset{b_2}{z^{-2}}}{\underbrace{\mu v + 1}_{h} + \underbrace{\frac{1}{w_0^2}v^2}_{a_0} + \underbrace{2z^{-1}\left(1 - \frac{1}{w_0^2}v^2\right)}_{2 \cdot a_1} \ldots}$$

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$$= \frac{A\mu v}{\underbrace{1 + \frac{1}{w_0^2}v^2 + \mu v}_{h}} \cdot \frac{\overset{b_0}{1} - \overset{b_2}{z^2}}{\underbrace{1}_{a_0} + z^{-1}\underbrace{\frac{2 \cdot (1 - \frac{1}{w_0^2} \ldots}{1 + \frac{1}{w_0^2} \ldots}}_{a_1} \ldots}$$