ESE2014: Filters

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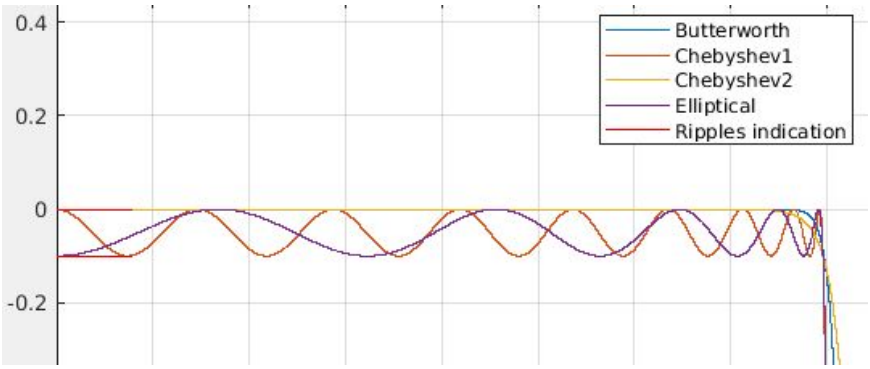
1) Design an anti-aliasing CT filter to limit the bandwidth of an analog signal to 16 kHz:

Rp = 0.1 dB, Rs = 80 dB, Fpass=16 kHz, Fstop=20 kHz;

Plot your Butterworth, Chebyshev I/II, and Elliptical Designs that meet this magnitude response on a common plot. Indicate the specification boundaries using red solid lines (consult the Matlab documentation to find some ways you might do this). Which filter has the smoothest passband response? Which filter meets the specifications with the lowest order?

ANSWER

- The Butterworth and chebyshev2 filters have the flattest pass-band without any ripples.



- The elliptical filter has the lowest order of 10.

Script:

```
clc, clear, close all;

%Filter specs
fpass=16e3;
fstop=20e3;
Apass=0.1;
Astop=80;
```

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```
Wrange = linspace(0,2*pi*fpass,1000000); %linear freq range for plotting
Frange = (1/(2*pi))*Wrange;
spec_pbr_pos = 1; % upper ripple limit as a unitless quantity
spec_pbr_neg = 10^(-Apass/20); % lower ripple limit as a unitless quantity
spec_sba = 10^(-Astop/20); % stopband attenuation, converted from dB
Ypbrpos = spec_pbr_pos*ones(size(Wrange));
Ypbrneg = spec_pbr_neg*ones(size(Wrange));
Ysba = spec_sba*ones(size(Wrange));

    %Butterworth filter
    [Nb, Wnb] = buttord(fpass, fstop, Apass, Astop, 's')
    %to get the min order of the butter
    [NumHbw, denHbw] = butter(Nb,Wnb,'s');
    Hbw = tf(NumHbw,denHbw); %transfer function of butter
    [Ybw_mag, Ybw_ph]= bode(Hbw, Wrange); %to get mag and phase response
    Ybw_mag=reshape(Ybw_mag,[1 max(size(Ybw_mag))]);
    Ybw_ph=reshape(Ybw_ph,[1 max(size(Ybw_ph))]);

    %Chebyshev 1
    [Nc1, Wnc1] = cheb1ord(fpass, fstop, Apass, Astop, 's')
    %to get min order of cheby1
    [NumHc1, denHc1] = cheby1(Nc1,Apass,Wnc1,'s');
    Hc1 = tf(NumHc1,denHc1);
    [Yc1_mag, Yc1_ph]= bode(Hc1, Wrange);
    Yc1_mag=reshape(Yc1_mag,[1 max(size(Yc1_mag))]);
    Yc1_ph=reshape(Yc1_ph,[1 max(size(Yc1_ph))]);

    %Chebyshev 2
    [Nc2, Wsc2] = cheb2ord(fpass, fstop, Apass, Astop, 's')
    [NumHc2, denHc2] = cheby2(Nc2,Astop,Wsc2,'s');
    Hc2 = tf(NumHc2,denHc2);
    [Yc2_mag, Yc2_ph]= bode(Hc2, Wrange);
    Yc2_mag=reshape(Yc2_mag,[1 max(size(Yc2_mag))]);
    Yc2_ph=reshape(Yc2_ph,[1 max(size(Yc2_ph))]);

    %Elliptical
    [Ne, Wne] = ellipord(fpass, fstop, Apass, Astop, 's')
    [NumHe, denHe] = ellip(Ne,Apass,Astop,Wne,'s');
    He = tf(NumHe,denHe);
    [Ye_mag, Ye_ph]= bode(He, Wrange);
    Ye_mag=reshape(Ye_mag,[1 max(size(Ye_mag))]);
    Ye_ph=reshape(Ye_ph,[1 max(size(Ye_ph))]);

    %Magnitude response plot of all four filters
    figure;
    plot(20*log10(Ybw_mag))
    hold on;
```

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```
    plot(20*log10(Yc1_mag))
    plot(20*log10(Yc2_mag))
    plot(20*log10(Ye_mag))
    grid
    plot(Frange,20*log10(Ypbrpos),'r-',
Frange,20*log10(Ypbrneg),'r-',Frange*2,20*log10(Ysba),'r-')
    axis([0 300e3 -100 5]) %to crop to our desired locations
    xlabel("Frequency in Hz")
    ylabel("Magnitude in dB")
    legend('Butterworth','Chebyshev1','Chebyshev2','Elliptical','Ripples
           indication')

    %Phase response plot of all four filters
    figure;
    plot(Ybw_ph)
    hold on;
    plot(Yc1_ph)
    plot(Yc2_ph)
    plot(Ye_ph)
    xlabel("Frequency in Hz")
    ylabel("Phase in radians")
    legend('Butterworth','Chebyshev1','Chebyshev2','Elliptical')
```

Result:

Command window: Filter order and cut-off frequency of Butterworth, chebyshev1, chebyshev2 and elliptic filter respectively:

```
Nb =
    50

Wnb =
   1.6635e+04

Nc1 =
    17

Wnc1 =
       16000

Nc2 =
    17

Wsc2 =
   2.0000e+04

Ne =
    10

Wne =
       16000
```

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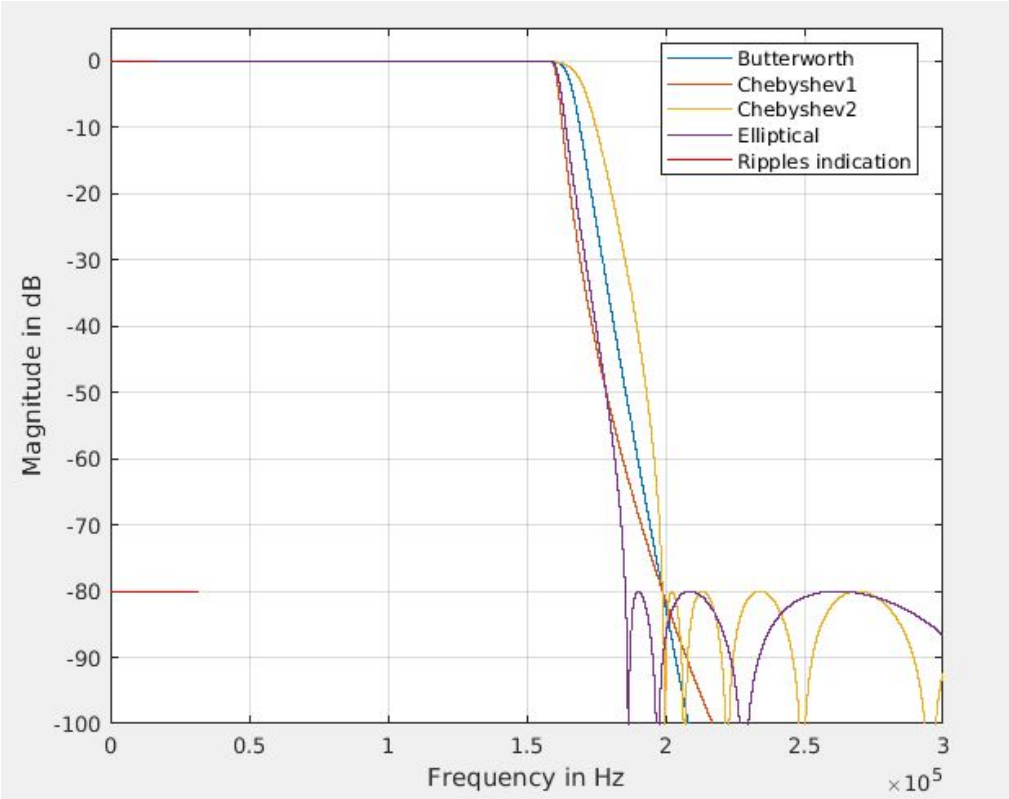
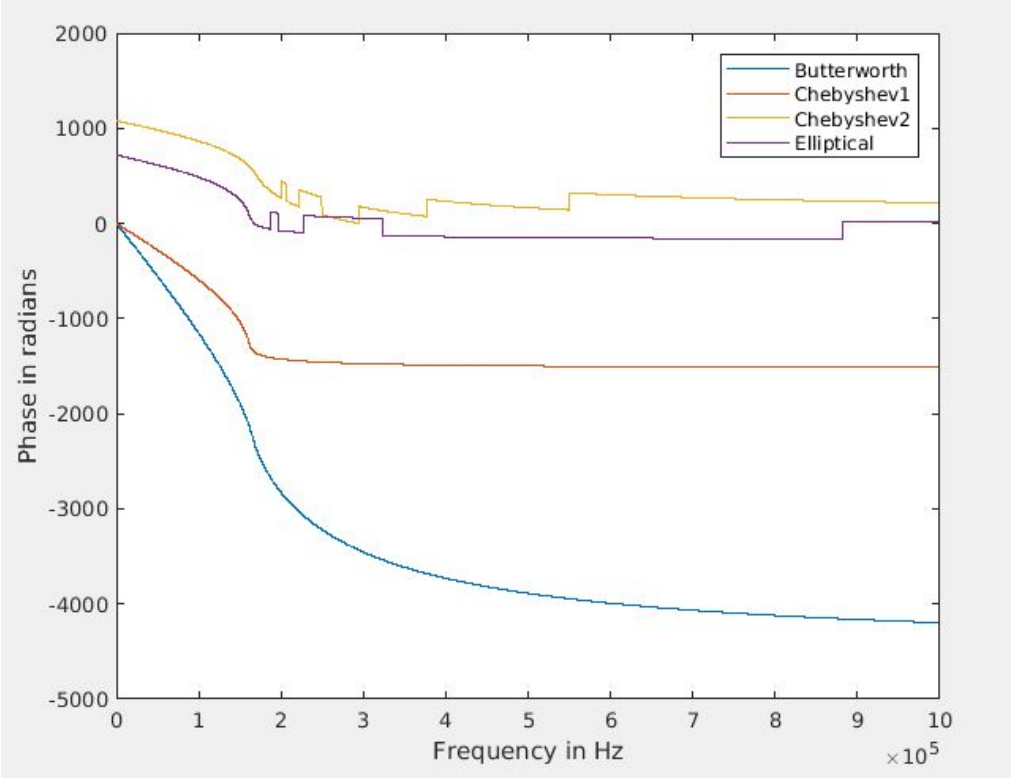
Plots:





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2) Design a digital noise-reducing IIR filter:

Rp=0.3 dB, Rs = 100 dB, Fpass = 50 kHz, Fstop = 80 kHz, Fs = 1 MHz.

Use the same filter families. Which filter has the most linear phase response in the passband? Which filter has the lowest order?

ANSWER

- The Butterworth filter has the most linear phase-response. We can get the order of any filter by using the function filtord()
- The elliptical filter has the fasted transition rate. Hence it has the lowest order. We can also observe it in the phase-response plot below

Script:

```
close all; clear; clc;
Fp = 50e3;
Fst = 80e3;
Rp = 0.3;
Rs = 100;
Fs = 1e6;

butterf =
designfilt('lowpassiir','PassbandFrequency',Fp,'StopbandFrequency',Fs
t,'PassbandRipple',Rp,'StopbandAttenuation',Rs,'SampleRate',Fs,'Desig
nMethod','butter');
cheby1f =
designfilt('lowpassiir','PassbandFrequency',Fp,'StopbandFrequency',Fs
t,'PassbandRipple',Rp,'StopbandAttenuation',Rs,'SampleRate',Fs,'Desig
nMethod','cheby1');
cheby2f =
designfilt('lowpassiir','PassbandFrequency',Fp,'StopbandFrequency',Fs
t,'PassbandRipple',Rp,'StopbandAttenuation',Rs,'SampleRate',Fs,'Desig
nMethod','cheby2');
ellipf =
designfilt('lowpassiir','PassbandFrequency',Fp,'StopbandFrequency',Fs
t,'PassbandRipple',Rp,'StopbandAttenuation',Rs,'SampleRate',Fs,'Desig
nMethod','ellip');
```

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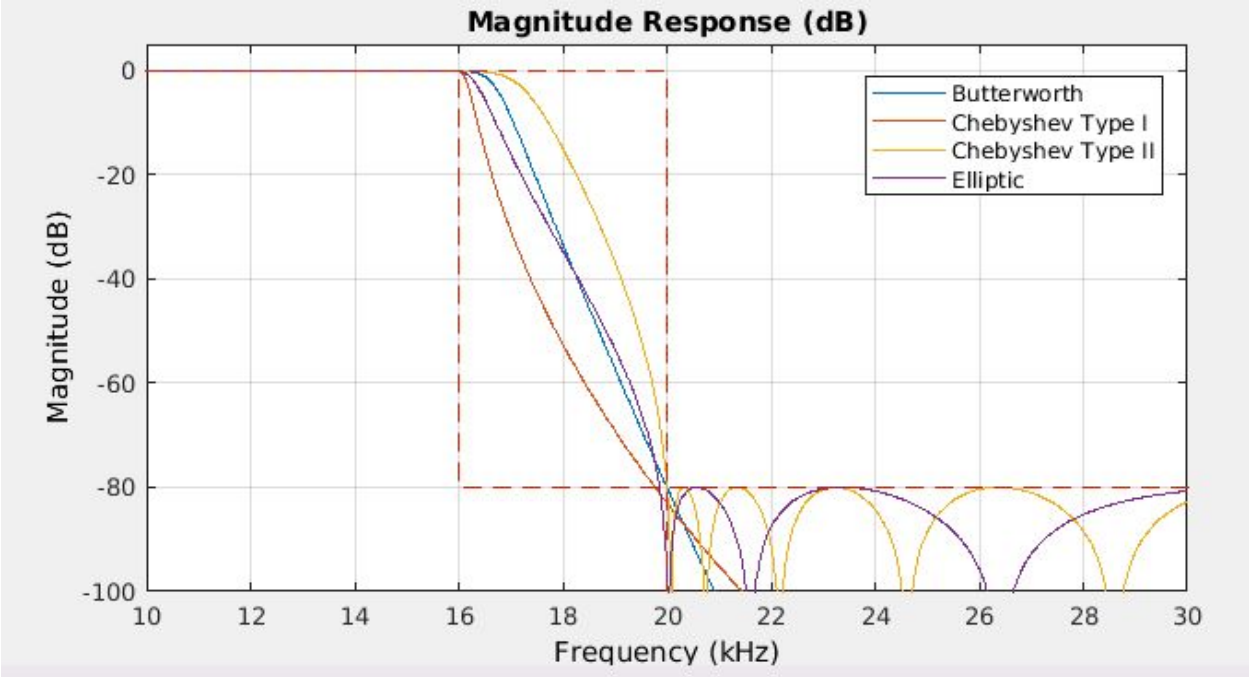
```
hfvt = fvtool(butterf,cheby1f,cheby2f,ellipf); %opens
filter-visualisation tool
rectangle('Position',[50,-30,30,30], 'EdgeColor','r'); %to highlight
the transition in phase-response
legend(hfvt,'Butterworth', 'Chebyshev Type I','Chebyshev Type
II','Elliptic') %labeling the responses
FilterOrders = [filtord(butterf) filtord(cheby1f) filtord(cheby2f)
filtord(ellipf)] %to know the order of filter families
```

Result:

```
>> IIR_FilFam

FilterOrders =

    27    13    13     9
```



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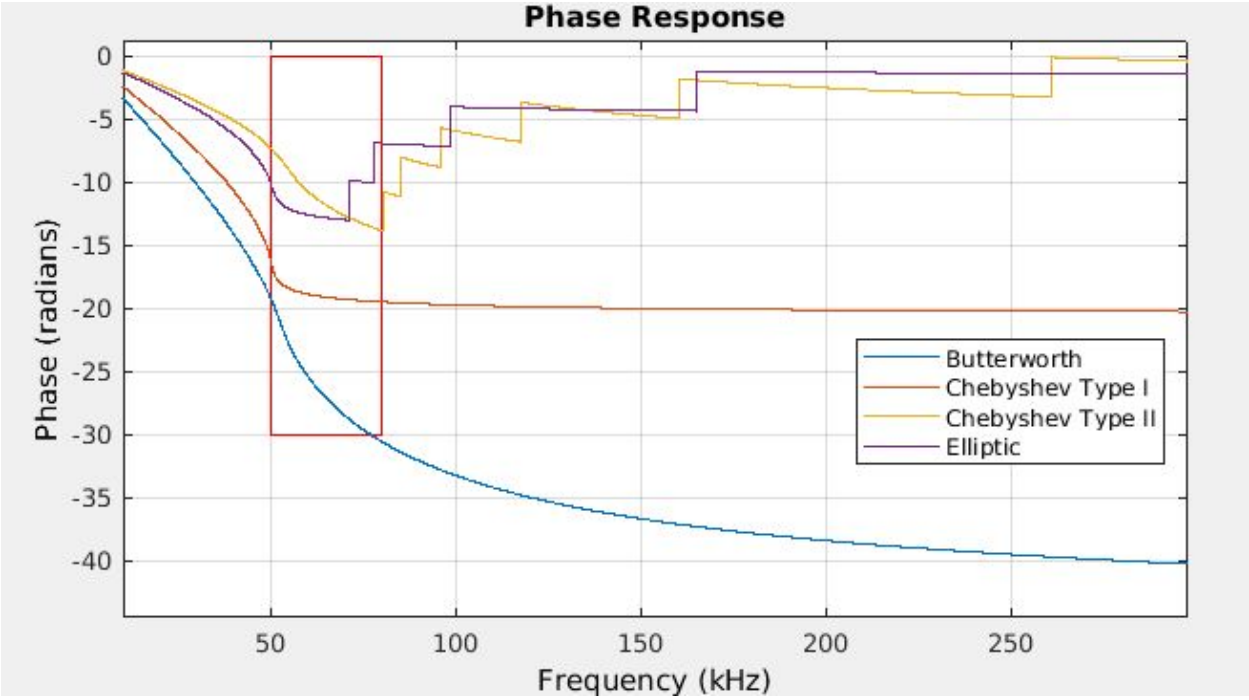

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