

We have a speech signal sampled at 8 KHz, which is to be filtered into three bands. The specification of each filter is given in Figure 1, Figure 2 and Figure 3.

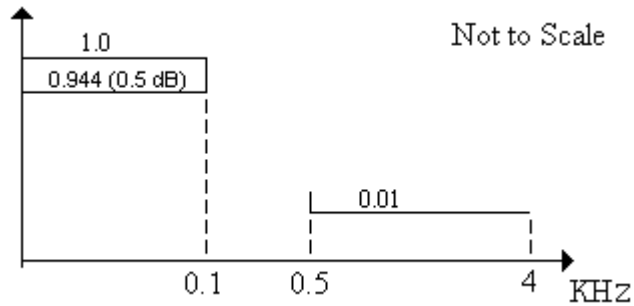


Figure 1. Low-Pass Filter Specification.

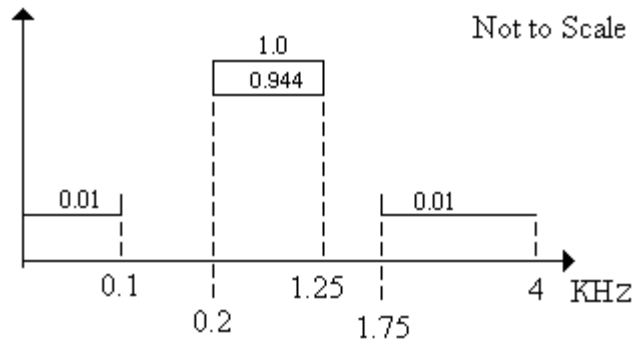


Figure 2. Band-Pass Filter Specification.

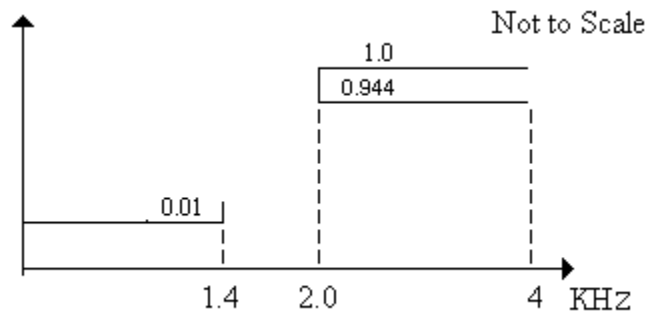


Figure 3. High-Pass Filter Specification.

Using the bilinear transformation technique to design a discrete IIR filter for each of the specifications given above. In each case we will evaluate the Butterworth versus the Chebyshev type 1 filter. Choose the filter, with the lowest order. If the two filter give the same order, choose the Butterworth. You will be using the Matlab functions, buttord, butter, cheb1ord, cheby1, zplane, freqz, and filter.

One important note about the buttord, which determines the order of a Butterworth filter. In class, we had Butterworth's always cutting off at 3 dB, however buttord, can make the cutoff any thing we want, by setting the ripple parameter. So we can do a direct comparison of a Butterworth and Chebyshev.

```

% The low-pass filter is built first.

% Using the frequencies and gains, we determine the order of Butterworth needed.
[nbwlp,wbwlp] = buttord( 0.1/4, 0.5/4, 0.5, 40 )

nbwlp = 4

wbwlp = 0.0400

Note that the cutoff is moved from 0.1/4 (= 0.025), which would be the 3 dB point, out to 0.04.
If the 3 dB point is at 0.04, the gain at 0.025 is 0.5 dB, matching our specifications.

% Using the frequencies and gains, we determine the order and gain for
% a Chebyshev needed.
[nchbylp,wchbylp] = cheblord( 0.1/4, 0.5/4, 0.5, 40 )

nchbylp = 3

wchbylp = 0.0250

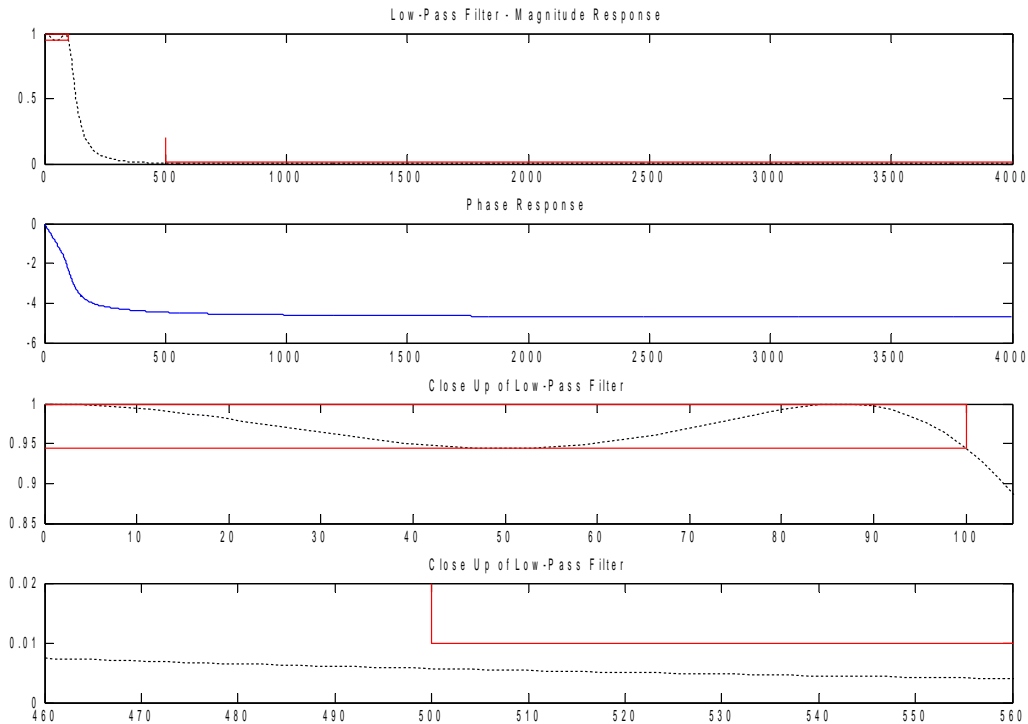
% Choose the Chebyshev, due to its lower order,
% and create the H(z) for the Chebyshev.
[ chbylpnz, chbylpdz ] = cheby1( nchbylp, 0.5, wchbylp );

% Generate impulse response of system.
d = zeros( 2048, 1 );
d(64) = 1.0;

hlp = filter( chbylpnz, chbylpdz, d );

% Produce a plot of the frequency response.
[Hlp,w] = freqz( chbylpnz, chbylpdz, 2048 );
figure(1);
subplot(411),plot(4000*w/pi,abs(Hlp),'k:', ...
    [0 100 100 0], [1 1 0.944 0.944], 'r-', ... % Adds spec's
    [4000 500 500], [ 0.01 0.01 0.2 ], 'r-'); % to plot
title('Low-Pass Filter - Magnitude Response');
subplot(412),plot(4000*w/pi,unwrap(angle(Hlp)));
title('Phase Response' );
subplot(413),plot(4000*w/pi,abs(Hlp),'k:', ...
    [0 100 100 0], [1 1 0.944 0.944], 'r-', ...
    [4000 500 500], [ 0.01 0.01 0.2 ], 'r-' );
xlim( [ 0 105 ] );
title( 'Close Up of Low-Pass Filter' );
subplot(414),plot(4000*w/pi,abs(Hlp),'k:', ...
    [0 100 100 0], [1 1 0.944 0.944], 'r-', ...
    [4000 500 500], [ 0.01 0.01 0.02 ], 'r-' );
xlim( [ 460 560 ] );
title( 'Close Up of Low-Pass Filter' );

```



These plots show good agreement with the specifications drawn in red.

```

% The band-pass filter is next.
[ nbwbp, wbwbp ] = buttord( [0.2/4 1.25/4], [0.1/4 1.75/4], 0.5, 40 )
nbwbp = 11

wbwbp = 0.0462 0.3341

% Test the Chebyshev.
[ nchbybp, wchbybp ] = cheblord( [0.2/4 1.25/4], [0.1/4 1.75/4], 0.5, 40 )
nchbybp = 6

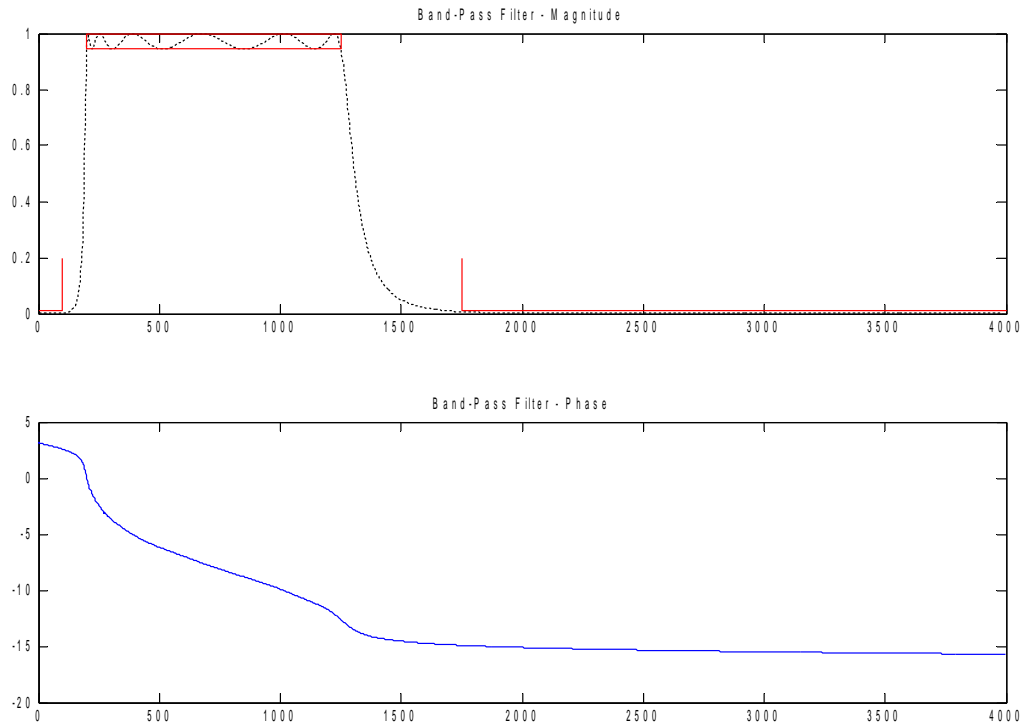
chbybp = 0.0500 0.3125

% Again we choose the Chebyshev based on the lower order.

[ chbybpnz, chbybpdz ] = cheby1( nchbybp, 0.5, wchbybp );

hbp = filter( chbybpnz, chbybpdz, d );
% Produce a plot of the frequency response.
Hbp = freqz( chbybpnz, chbybpdz, 2048 );
figure(2);
subplot( 211 ), plot(4000*w/pi, abs(Hbp), 'k:', ...
    [1250 200 200 1250 1250], [1 1 0.944 0.944 1], 'r-', ...
    [4000 1750 1750], [ 0.01 0.01 0.2 ], 'r-', ...
    [0 100 100], [ 0.01 0.01 0.2 ], 'r-' );
title('Band-Pass Filter - Magnitude');
subplot( 212 ), plot(4000*w/pi, unwrap(angle(Hbp)));
title('Band-Pass Filter - Phase');

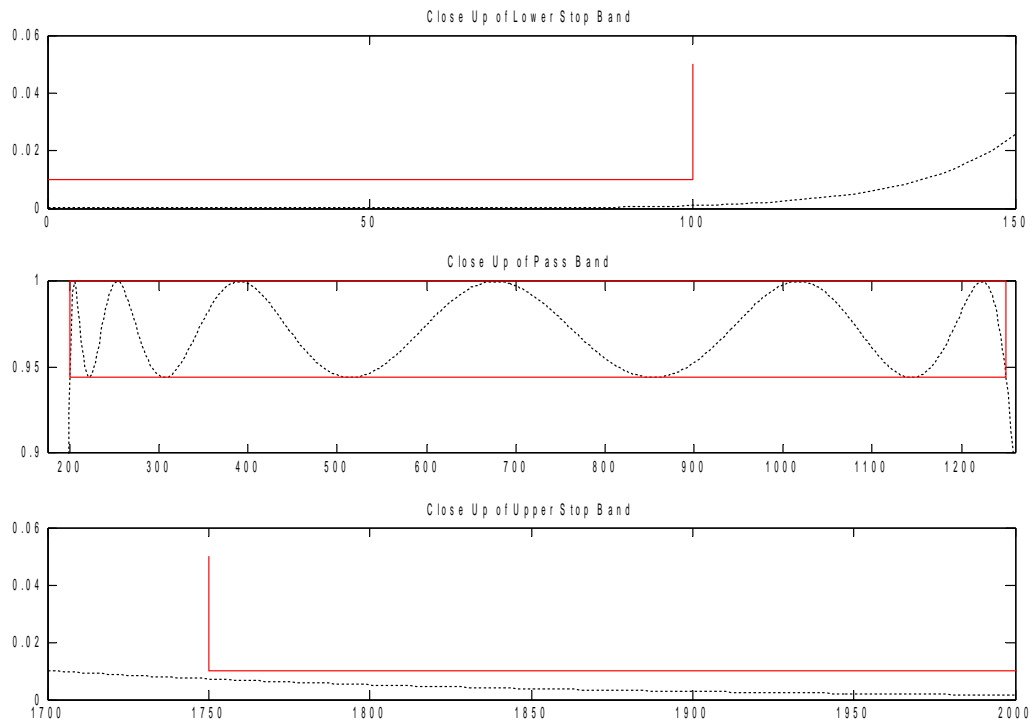
```



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figure(3);
subplot( 311 ),plot(4000*w/pi,abs(Hbp), 'k:', ...
    [1250 200 200 1250 1250], [1 1 0.944 0.944 1], 'r-', ...
    [4000 1750 1750], [ 0.01 0.01 0.05 ], 'r-', ...
    [0 100 100], [ 0.01 0.01 0.05 ], 'r-' );
xlim( [ 0 150 ] );
title( 'Close Up of Lower Stop Band' );
subplot( 312 ),plot(4000*w/pi,abs(Hbp), 'k:', ...
    [1250 200 200 1250 1250], [1 1 0.944 0.944 1], 'r-', ...
    [4000 1750 1750], [ 0.01 0.01 0.05 ], 'r-', ...
    [0 100 100], [ 0.01 0.01 0.05 ], 'r-' );
xlim( [ 175 1260 ] );
ylim( [ 0.9 1 ] );
title( 'Close Up of Pass Band' );
subplot( 313 ),plot(4000*w/pi,abs(Hbp), 'k:', ...
    [1250 200 200 1250 1250], [1 1 0.944 0.944 1], 'r-', ...
    [4000 1750 1750], [ 0.01 0.01 0.05 ], 'r-', ...
    [0 100 100], [ 0.01 0.01 0.05 ], 'r-' );
xlim( [ 1700 2000 ] );
title( 'Close Up of Upper Stop Band' );

```



```

% The high-pass filter is last.
[nbwhp,wbwhp] = buttord( 2.0/4, 1.4/4, 0.5, 40 )

% nbwhp = 12
%
% wbwhp = 0.4663

[nchbyhp,wchbyhp] = cheblord( 2.0/4, 1.4/4, 0.5, 40 )

% nchbyhp = 6
%
% wchbyhp = 0.5000

% Choosing Chebyshev

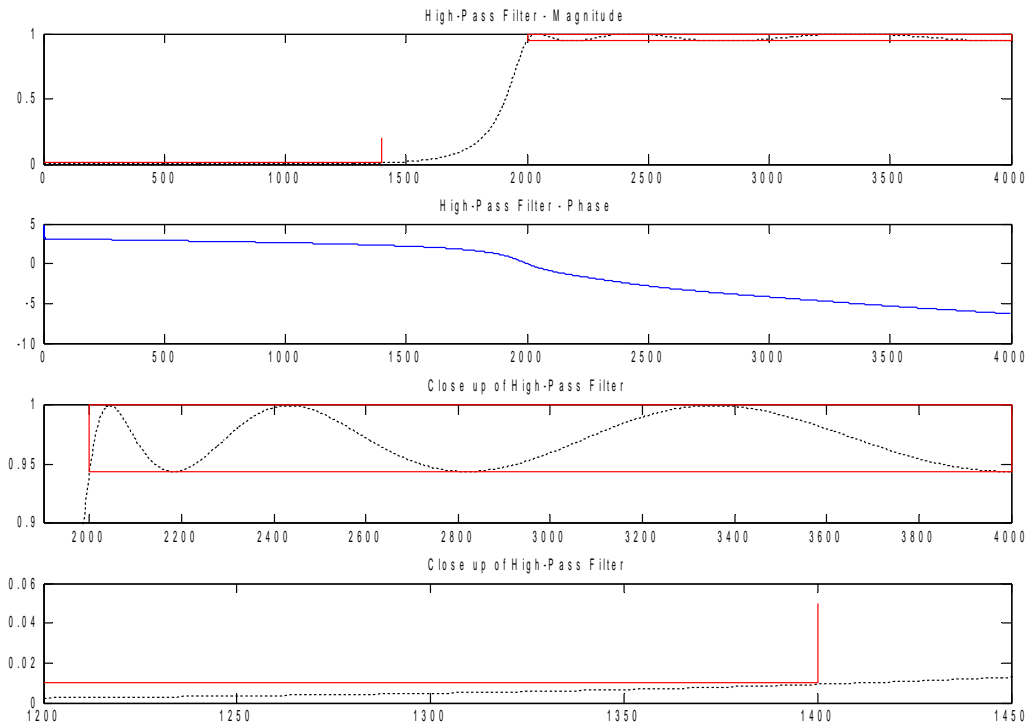
[ chbyhpnz, chbyhpdz ] = cheby1( nchbyhp, 0.5, wchbyhp, 'high' );
hnp = filter(chbyhpnz, chbyhpdz, d );
Hhp = freqz( chbyhpnz, chbyhpdz, 2048 );

```

```

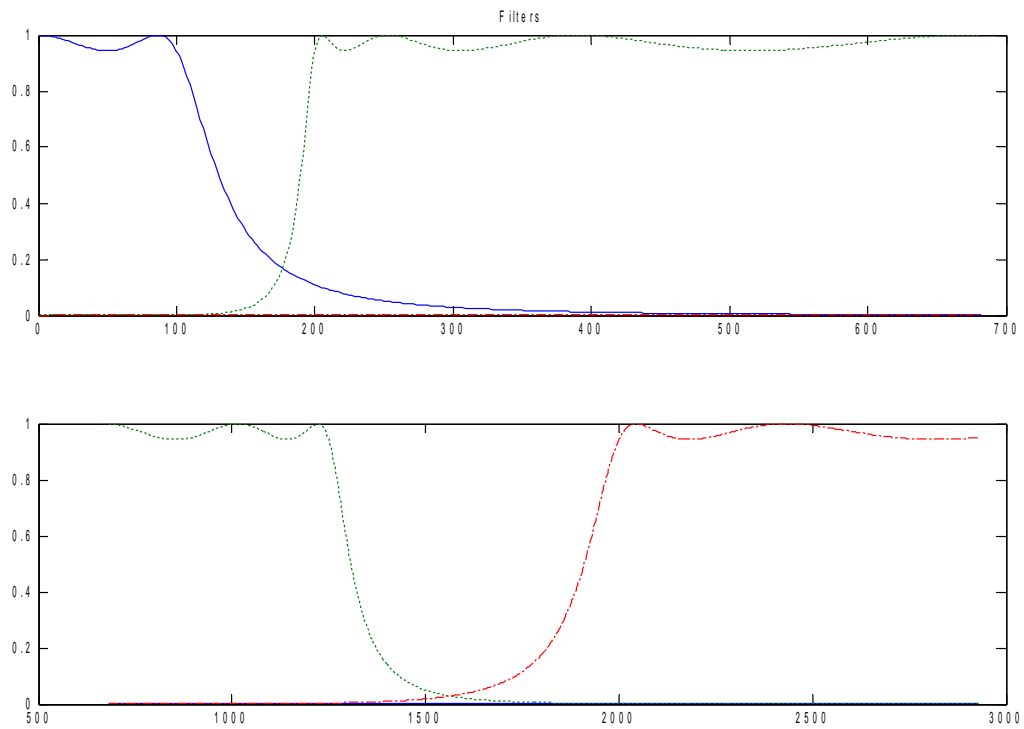
% Produce a plot of the frequency response.
figure(4);
subplot( 411 ), plot(4000*w/pi,abs(Hhp),'k:', ...
    [4000 2000 2000 4000 4000], [ 1 1 0.944 0.944 1 ], 'r-', ...
    [0 1400 1400], [ 0.01 0.01 0.2 ], 'r-');
title('High-Pass Filter - Magnitude');
subplot( 412 ), plot(4000*w/pi,unwrap(angle(Hhp)));
title('High-Pass Filter - Phase');
subplot( 413 ), plot(4000*w/pi,abs(Hhp),'k:', ...
    [4000 2000 2000 4000 4000], [ 1 1 0.944 0.944 1 ], 'r-', ...
    [0 1400 1400], [ 0.01 0.01 0.2 ], 'r-');
xlim([ 1900 4000 ] );
ylim([0.9 1.0] );
title('Close up of High-Pass Filter');
subplot( 414 ), plot(4000*w/pi,abs(Hhp),'k:', ...
    [4000 2000 2000 4000 4000], [ 1 1 0.944 0.944 1 ], 'r-', ...
    [0 1400 1400], [ 0.01 0.01 0.05 ], 'r-');
xlim([ 1200 1450 ] );
title('Close up of High-Pass Filter');

```



```
% Produce a plot of the frequency responses overlaid on one another.  
figure(5);
```

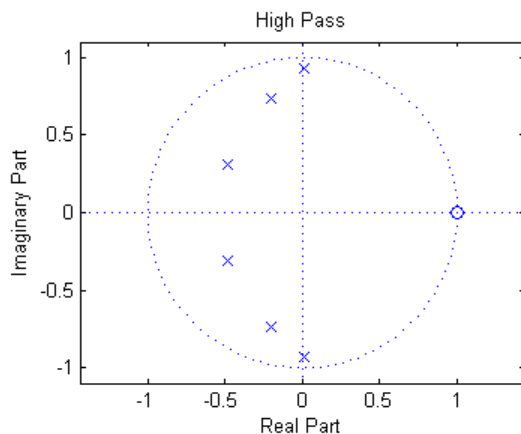
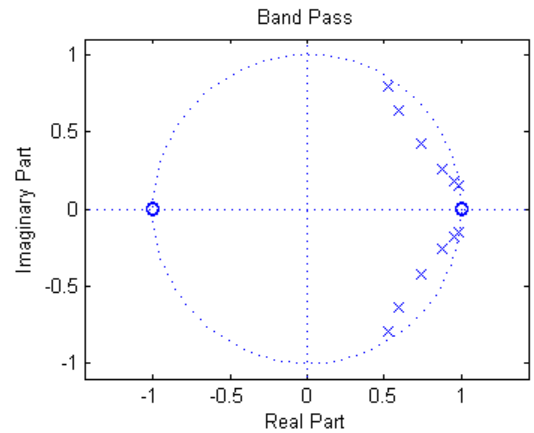
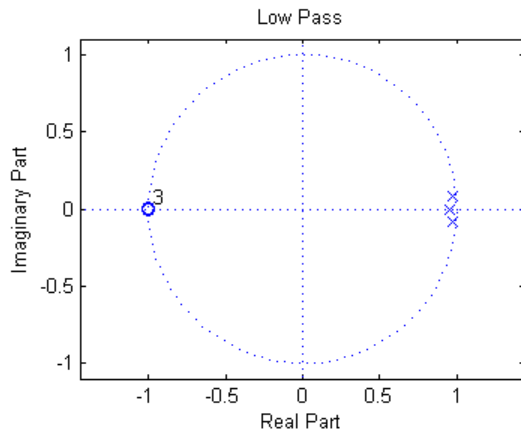
```
subplot(211),plot(4000*w(1:350)/pi,abs(Hlp(1:350)),'-',...  
                 4000*w(1:350)/pi,abs(Hbp(1:350)),':',...  
                 4000*w(1:350)/pi,abs(Hhp(1:350)),'-.'');  
title('Filters');  
subplot(212),plot(4000*w(350:1500)/pi,abs(Hlp(350:1500)),'-',...  
                 4000*w(350:1500)/pi,abs(Hbp(350:1500)),':',...  
                 4000*w(350:1500)/pi,abs(Hhp(350:1500)),'-.'');
```



```

% Produce the pole-zero plots as a way to visualize the character of the filters.
figure(6);
subplot( 221),zplane( chbylpnz, chbylpdz );
title( 'Low Pass' );
subplot( 222),zplane( chbybpnz, chbybpdz );
title( 'Band Pass' );
subplot( 223),zplane( chbyhpnz, chbyhpdz );
title( 'High Pass' );

```



It should be observed that as we get to higher order filters, certain anomalies start showing up. Most prominent is that the placement of the zeros in the band pass filter. There are 12 poles (x) and to compensate for this there should be 12 zeros (o), with 6 at +1 and 6 at -1. Looking at the low pass filter we see the three zeros at -1, are right on top of each other and are marked by a 3 beside the “o”. The zeros on the band pass filters are actually clustered around ± 1 .

The high order of the filter causes this effect. The source of this clustering is demonstrated in another posting along with an alternate approach, available in MATLAB that can overcome this problem.


```
% Plot the impulse response of the three filters.
```

```
figure(7);  
subplot( 311),plot( hlp(1:512) );  
title( 'Impulse Response of Low Pass' );  
subplot( 312),plot( hbp(1:256) );  
title( 'Impulse Response of Band Pass' );  
subplot( 313),plot( hhp(1:128) );  
title( 'Impulse Response of High Pass' );
```

```
% Note that the impulse responses are shifted over 64 points to aid in  
% the reader seeing the full plots. The lengths are also altered for clarity.
```

