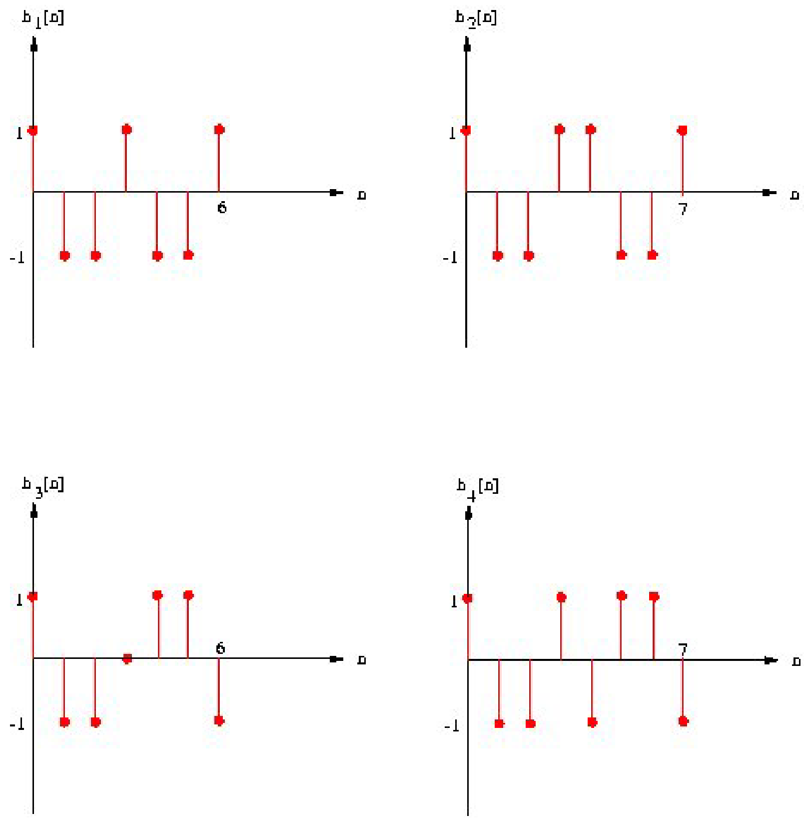
J-DSP Lab 4: FIR and IIR Filter Design

Introduction

Lab 4 concentrates on FIR and IIR filter design.

Problem 4-1: FIR Linear Phase Systems

Consider the following four impulse responses:



a) For each impulse response, find the transfer function. Use J-DSP to plot the frequency response (magnitude and phase) of each system.

   (Hint: these are FIR filters - see if they have symmetries)

b) For each system, describe the symmetries of the zeros of H(z).

   (Hint: use J-DSP to find the roots).

c) Determine the group delay of each system. Use the tabulated values in the output dialog box to derive the exact group delay.

   (Hint: plot the phase response and measure its slope)

d) Use J-DSP to obtain pole-zero plots and note symmetries in the z plane.

Problem 4-2: FIR Design by Windowing

Let

$$h(n) = 0.2 sinc(\frac{\pi n}{5})$$

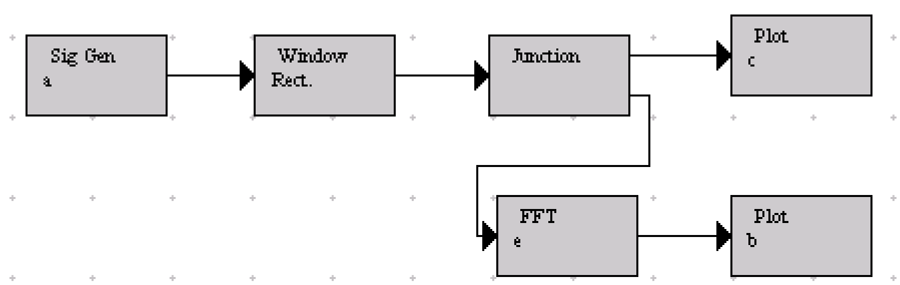
be the ideal impulse response of a low-pass filter with a cutoff at 0.2π. To construct a truncated version of this impulse response we will generate a sequence as follows:

- Signal type: Sinc
- Amplitude: 0.2
- Pulse width: 120 samples
- Periodic: No
- Period T: 10 samples
- Time Shift: 30 samples

These settings provide you with a truncated, shifted, and causal version of the impulse response. Use a ***Window*** block and check the frequency characteristics for each window in the following order:

a) Rectangular (default)
b) Bartlett (Triangular)
c) Hamming

The J-DSP flow-gram should look like this:



a) Check the magnitude and phase response for each impulse response.

b) Observe that all designs are linear phase. (why?)

c) Observe that with rectangular window truncation you get the narrowest transition but the worst ripple effect.

d) Note that tapered windows have better behaved side lobes and hence better-behaved ripple effect relative to the rectangular window.

Problem 4-3: FIR Design using the Kaiser Window

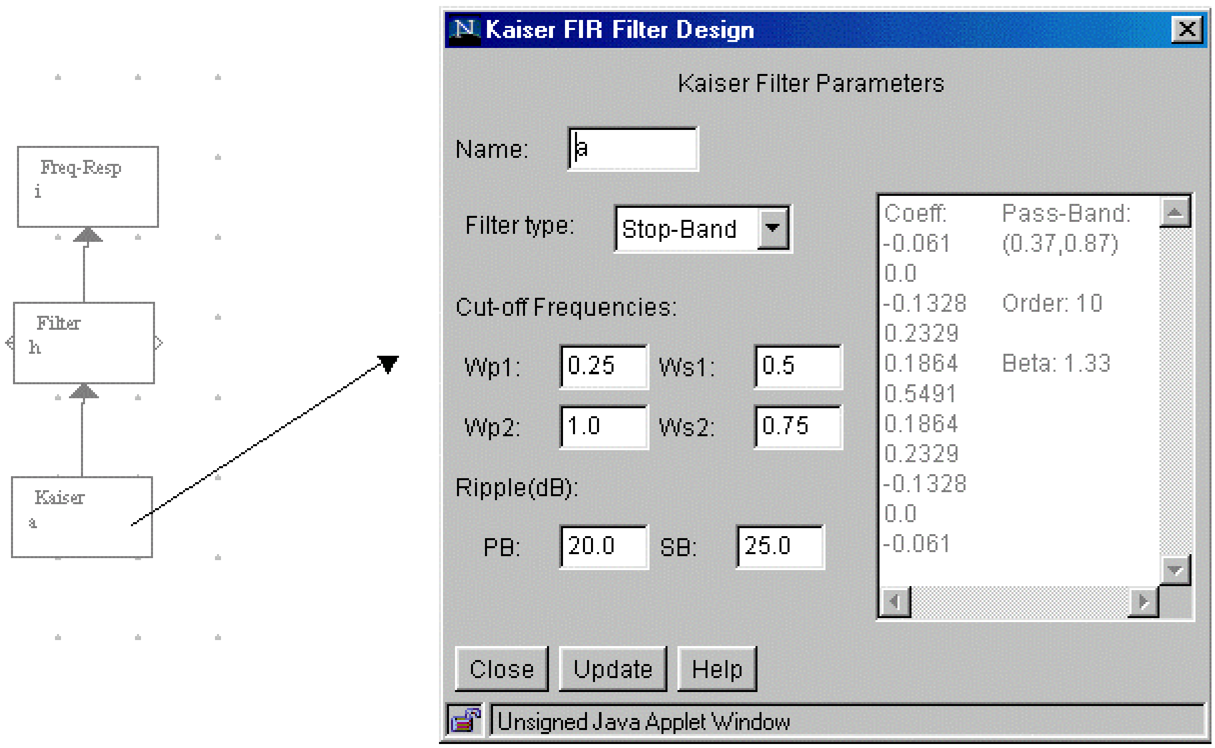
Design a high-pass filter with generalized linear phase using the Kaiser window method.

Use the following specifications:

$$\left|H(e^{j\Omega})\right| \le 0.05 \;\; \text{for } 0 \le \Omega \le 0.375\pi$$

$$0.95 \le \left|H(e^{j\Omega})\right| \le 1.05 \;\; \text{for } 0.425 \le \Omega \le \pi$$

Use the ***Kaiser*** block for the filter coefficients and plot the frequency response of the filter. Use the following J-DSP flow-gram. Double click on the ***Kaiser*** block and enter appropriate parameters. Convert tolerances in dB.



Problem 4-4: IIR Filter Design

In this part, you will design an IIR filter with J-DSP. The filter will be designed using four different IIR methods (Butterworth, Chebychev I, Chebychev II and Elliptic) so that results of the 4 different methods can be compared. The specifications for the filter are shown below.

- Filter Type = Low-pass
- Cutoff frequencies: $\omega_{p1} = 0.4\pi$ and $\omega_{s1} = 0.6\pi$
- Tolerance in pass-band = 1.0dB
- Tolerance (rejection) in stop-band = -45.0dB

The design can be done using the ***IIR*** block under the filter blocks menu in J-DSP. This block will automatically calculate the filter coefficients based on the filter specifications provided, using a bilinear transformation for any of the four design methods mentioned above. Attach the output of the ***IIR*** block to a ***Freq-Resp*** block to get a plot of the filter's frequency response or to a ***PZ-Plot*** block to see a plot of its poles and zeros, or both through a junction block. Note that the ***IIR*** block will calculate filters with a maximum of 10 filter coefficients. Enter the cutoff frequencies into the ***IIR*** block as fractions of the sampling frequency. For $\omega_{p1}=0.4\pi$ simply enter 0.4.

For each of the four filter designs, do the following:

1. Plot the filter's frequency response.
2. Create a pole-zero plot of the filter.
3. Note the order of the filter.
4. Examine the filter's frequency response in the pass-band and in the stop-band.
5. Observe the phase response of each design.

Design the filter using each of the following four methods.

1. Design an IIR Butterworth filter according to the given specifications.
2. Redesign the filter using the Chebyshev I method.
3. Repeat the process using a Chebyshev II filter. Plot the frequency response on a dB scale.
4. Finally, design using an Elliptic filter. Observe its frequency response in the pass-band on a linear scale and its response in the stop-band on a dB scale.

Try to provide answers to the following questions:

- Which filter requires the highest order to meet the specifications?
- Which filter requires the lowest order to meet the specifications?
- Do any of the four filters have linear phase?
- Where does the greatest deviation from constant group delay occur?
- Which of the four filters is equi-ripple in the pass-band and monotonic in the stop-band?
- Which of the four filters is monotonic in the pass-band and equi-ripple in the stop-band?
- Which of the four filters is equi-ripple in both the stop-band and the pass-band?
- Which of the four filters is monotonic in both the stop-band and the pass-band?
- For the filters, which are monotonic in the pass-band, where are all the zeros located?

If you have time, try the above exercise using a high-pass filter and a band-pass filter of your choice.