This project examines the effect of nonlinear phase (non-constant group delay) in the context of a filtering problem. One application in which constant group delay is important involves filtering to extract a narrow-time pulse from noise and then estimating the time origin of the pulse. This often arises in radar and sonar systems where the range to a reflector is obtained by determining the time difference between the transmitted and received pulses. If in the process of filtering out additive noise, the received pulse is dispersed in time (due to nonuniform group delay), the arrival time estimation becomes more difficult. This exercise explores aspects of this problem using several test signals and two different types of filters.

Your solutions to this assignment should include plots and Matlab code for each exercise along with any necessary explanations or answers to questions. The latter may be handwritten or typed, whichever you prefer.

1 Preliminaries

Do problem 5.57 in Oppenheim and Schafer.

The remainder of this project uses the data file `gdeldata.mat` to define the filters and test signals. If the data file is loaded via the Matlab `load` command, the following signals will be defined:

- `[b, a]`: filter coefficients of an 8th-order IIR (elliptic) filter
- `h`: impulse response (coefficients) of a 33-point FIR filter
- `x1, x2`: narrowband test signals; created using Hamming-windowed sine waves
- `pulse`: pulse starting at `n = 0`; pulse is relatively well-localized in time
- `noise`: sample of the out-of-band noise that will be added
- `pnd_1`: represents the received signal and consists of a different sample of the noise added to the pulse, which has been delayed by an amount to be estimated
- `pnd_2`: represents the received signal from a different “reflector” (i.e., it is the sum of a different noise sample and the pulse with a different delay)

For the group delay computations, use Matlab’s `grpdelay` function.
2 Group delay of the IIR filter

(a) Generate and plot the first 150 points of the impulse response of the IIR filter.

(b) Compute and plot its frequency response magnitude and group delay.

(c) Plot the signals x1 and x2 and their Fourier transforms. Use these plots and the plots of the magnitude and group delay from part b to predict the output you will get from running each sequence through the IIR system.

(d) Verify your prediction in part c by explicitly computing the outputs due to x1 and x2 using filter.

3 Group delay of the FIR filter

(a) Plot the impulse response of the FIR filter. Then generate and plot its frequency response magnitude and group delay. Could you have anticipated from the impulse response that the group delay would be constant?

(b) For the signals x1 and x2, what output do you expect to get from processing each sequence with the FIR system?

(c) Verify your prediction by explicitly computing the outputs due to x1 and x2.

4 Pulse distortion

(a) Filter the signal pulse with the IIR filter and compare to processing with the FIR filter.

(b) Note that when you processed the narrowband signals x1 and x2 with the IIR filter or FIR filter, they were scaled and delayed with little distortion of the pulse shape; but when you process the signal pulse through the IIR filter, its pulse shape is severely distorted and dispersed in time. Explain why this happens.

5 Filtering a pulse from noise

Filter the signals pnd_1 and pnd_2 with both the IIR and FIR filters. Since the noise occupies a different frequency band from the signal, either filter should remove the noise and make it easy to find the pulse.

(a) Plot the output signals for the IIR filter, and from these plots estimate (as best you can) the time delay of the pulse in each of the two received signals. Explain your time-delay measurements in terms of the group delay curves plotted in the exercises above.

(b) Repeat part a with the FIR filter.

(c) Describe any difference in pulse shape that you observe. Explain how the constant group delay of the FIR filter and nonuniform group delay of the IIR filter determine the quality of the output signal. Which filter, FIR or IIR, performs better for this application?