ECE 417 Lab Exercise # 4
FIR Filter Design

In this lab, you will design linear-phase FIR filters using Matlab commands. You will approximate desired frequency responses and examine the location of pole-zero plots for commonly used filters. You will also study the frequency responses of filters obtained by manipulating the impulse responses of commonly used filters.

You will again need the last three non-zero digits of your UIC ID #, say i, j, k. You will use the number $N_{ID} = ijk = 100 * i + 10 * j + k$ in this lab exercise.

Note that peak deviation of the magnitude response in a band is the maximum deviation from the desired magnitude in that band.

1 Design of FIR filters for common approximations

You will design FIR filters for some common approximations (lowpass, highpass, bandpass) using the "firpm" command based on the Parks-McClellan method. The desired passband magnitude in these designs is 1.0.

1.1 Linear-Phase FIR filter design: Lowpass filter

Define frequencies: $\omega_1 = 0.44\pi + 0.2 * N_{ID} * \pi/1000$ and $\omega_2 = \pi - \omega_1$. In Matlab, use the command "firpm" to design a lowpass filter with passband edge frequency $\omega_p = \omega_1$ and stopband edge frequency $\omega_s = \omega_2$. Use equal weights of 1.0 for the passband and the stopband. Denote this impulse response as h_{LP} and its z-transform as $H_{LP}(z)$. Design filters of order 6, 14, 22, 30, and 38 for these specifications.

Q4.1: What is the stopband peak absolute deviation (Δ_s) in each of the 5 designs? Plot $-20\log_{10}\Delta_s$ versus the filter order.

Q4.2: Estimate the filter order required to get $-20\log_{10}\Delta_s = 50$ from the plot in Q4.1. Verify using "firpm".

Q4.3: Show a stem plot of the impulse response $h_{LP}[n]$ that you obtained for filter order 14. Determine if any of the 15 values in its duration are zero (or almost zero, with extremely small magnitude due to round-off error) and if so whether the zeros appear in any symmetric pattern around the middle non-zero sample.

1.2 Linear-Phase FIR filter design: highpass filter

In Matlab, use the command "firpm" to design a highpass filter with stopband edge frequency $\omega_s = \omega_1$ and passband edge frequency $\omega_p = \omega_2$. Use filter order 14 and equal weights of 1.0 for the passband and the stopband. Call this impulse response h_{HP} and its z-transform $H_{HP}(z)$.

Q4.4: What is the stobband magnitude deviation in the design? Compare the filter impulse responses h_{LP} and h_{HP} and explain any relationship.

Q4.5 Plot absolute value of the sum of the frequency responses of the lowpass and highpass filters $|H_{LP}(e^{j\omega}) + H_{HP}(e^{j\omega})|$.

Q4.6: Obtain the pole-zero plots of $H_{LP}(z)$ and $H_{HP}(z)$ using the command "zplane". Determine the location of zeros on the unit circle in each of the two cases.

Q4.7: A signal $2\cos(\omega_0 n)$ is applied as input to the highpass filter with transfer function $H_{HP}(z)$. The output signal is $y[n] = 0$. Determine the possible values of ω_0.

2 Design of multiband filters with more general responses

Now you will design FIR filters with more general responses with the firpm program based on the Parks-McClellan method. The desired passband magnitude in these designs is not necessarily 1.0.

2.1 Linear-Phase FIR filter design: Three-band constant magnitude filter

We will consider the design of a generalized bandstop filter in which the desired magnitude in the two passbands may not be equal. Define frequency: $\omega_1 = 0.05\pi + 0.2 * N_{ID} * \pi/1000$. In Matlab, use the command "firpm" to design a 3-band filter with frequency "care"-bands $[0, \omega_1 + 0.1\pi]$, $[\omega_1 + 0.25\pi, \omega_1 +$

$0.45\pi]$, and $[\omega_1 + 0.6\pi, \pi]$, with desired constant magnitudes 2.0, 0.0, and 1.0, respectively, and with peak absolute magnitude deviation from the desired value in band 1 twice that in band 2 and three times that in band 3. Call the impulse response of the 3-band filter h_{3B} and its z-transform $H_{3B}(z)$. Use a filter of lowest sufficient (even) order so that the peak absolute magnitude deviation from the desired value in band 1 is at least 0.1.

Q4.8: Show the specifications used in the command “firpm” to obtain h_{3B}. Determine the required filter order of h_{3B}.

Q4.9 Find the peak absolute magnitude deviation from the desired value in each of the three bands. Show the filter magnitude plot.

Q4.10: Using the result of this design, how would you find the impulse response of a 3-band filter with desired constant magnitudes 3.0, 1.0, and 2.0, but with the same peak absolute magnitude deviation from the desired value requirements as above? (Hint: Modify a single coefficient.)

2.2 Linear-Phase FIR filter design: Multiband filter with non-constant desired magnitude

Define frequency: $\omega_1 = 0.05\pi + 0.2 * N_{ID} * \pi/1000$. In Matlab, use the command “firpm” to design a 3-band filter again with frequency “care”-bands $[0, \omega_1 + 0.1\pi]$, $[\omega_1 + 0.25\pi, \omega_1 + 0.4\pi]$, and $[\omega_1 + 0.6\pi, \pi]$. This time the desired magnitudes are piecewise linear with values [3.0-1.0], [0.0-0.0], and [1.0-3.0], with equal weight for peak absolute magnitude deviation from the desired values in the two “pass-bands” and double the weight for the peak absolute magnitude deviation from the desired value in the “stop”-band. Denote the impulse response of the piecewise linear magnitude filter as h_{PL} and its z-transform $H_{PL}(z)$. Use a filter of 20.

Q4.11: Show the specifications used in the command “firpm” to obtain h_{PL}. Show the magnitude plot of $H_{PL}(z)$.

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