Homework Assignment 6
Digital Filter Design and Evaluation

ECEN 463 - Digital Signal Processing
University of Nebraska-Lincoln
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Due: December 12, 2025

Assignment Overview

This MATLAB assignment focuses on the design, simulation, and performance evaluation of IIR and FIR digital filters. You will design bandpass filters using different design methods, analyze their frequency and time-domain characteristics, and evaluate their performance with various input signals.

Instructions

- Complete all programming tasks with detailed MATLAB implementation

- Submit your solutions as a **single PDF report** via Canvas

- Attach your **MATLAB code as an appendix**

- Include well-labeled plots with clear axes and titles

- Provide concise descriptions of results with predictions and observations

- A premium will be placed on **brief and complete** descriptions

- IEEE formatting templates available at: `https://www.ieee.org/conferences/publishing/templates.html`

Problem Statement

Design and evaluate three bandpass filters using different design methodologies. Assume a sampling rate of $F_s = 32$ kHz throughout this assignment.

Filter Design Requirements

Design the following three bandpass filters with **identical specifications**:

(i) **Elliptical IIR Filter**

(ii) **Chebyshev IIR Filter** (either Type I or Type II - your choice)

(iii) **FIR Filter** with linear phase

Filter Specifications

Specifications 1: Personalized Parameters

Your phone number can be written as: **1 (X_1,X_2,X_3) Y_1,Y_2,Y_3-Z_1,Z_2,Z_3,Z_4**

- **Center Frequency (f_c):** Z_1,Z_2,Z_3,Z_4 Hz

    - If $Z_1 = 0$, left-shift the digits and use Z_2,Z_3,Z_4,0 Hz
    - If $Z_2 = 0$, continue left-shifting as needed

- **Bandwidth (BW):** Y_1,Y_2,Y_3 Hz

    - If $Y_1 = 0$, contact your phone provider for a new number

Specifications 2: Performance Parameters

You must choose the following parameters (use **same specifications for all three filters**):

- **Stopband Attenuation:** ≥ 40 dB (you choose the exact value)

- **Passband Ripple:** ≤ 1 dB (you choose the exact value)

- **Stopband Frequencies:** You must define appropriate stopband edge frequencies based on your center frequency and bandwidth

Note: If your filters don't provide the specified magnitude response, relax your specifications slightly to avoid numerical issues. Some phone number digit combinations may be challenging - don't hesitate to ask for assistance.

Analysis Requirements

Part 1: Frequency Domain Analysis

For each of the three filters, generate and analyze:

1. **Magnitude Response Plot**

    - Linear and/or logarithmic (dB) scale
    - Clearly show passband, transition band, and stopband regions
    - Verify that specifications are met

2. **Phase Response Plot**

    - Show phase characteristics across the frequency range
    - Note any phase linearity (especially for FIR filter)

Part 2: Time Domain Performance Evaluation

Test each filter with sinusoidal inputs at three different frequencies:

1. One sinusoid in the **passband**

2. One sinusoid in the **stopband**

3. One sinusoid in the **transition band**

For each test:

- Plot the output signal in the time domain

- Compare the observed output with the expected result

- Determine when each filter reaches **steady state**

Part 3: Impulse Response Analysis

For each filter:

- Plot the complete impulse response - zoom in to evaluate the characteristics

- Compare IIR vs. FIR responses

- Include comments about observations in your write-up

Part 4: Random Noise Input Testing

Test all three filters with random noise input:

- Generate white noise using `randn()`

- Filter the noise and analyze in the time domain

- Optionally, analyze in the frequency domain using `pwelch()`, Goldwave, Audacity, or other spectral analysis tools

- Verify that the filter properly attenuates out-of-band noise

- Have fun.

1   Reference Code: FIR Lowpass Filter Design Example

The following MATLAB code demonstrates the design and visualization of an FIR lowpass filter using the `fir1()` function.

```matlab
% Specifications
fp = 929;              % passband edge in Hz
Fs = 20000;            % sampling frequency
Feby2 = Fs / 2;        % useful for our plotting ranges
Rp = 1;                % passband ripple in dB
Rs = 40;               % stop band attenuation in dB

fdco = 1.2 * fp;       % design cut-off freq (-6dB point for FIR1)
fst = fp * 1.5;        % stop band start frequency

fpass = [0 fp fp]; % used for plotting specs below
Rpass = [-Rp -Rp -Rs];

fstop = [fst fst Feby2]; % used for plotting specs below
Rstop = [-Rp -Rs -Rs];

Wm = [fdco / Feby2]; % design cut-off spec in Matlab normalized freq

% Nlo = 2/((fst - fdco)/Feby2);
% N = ceil(Nlo);    % pick a filter length
N = 128;

% wblkbar = window(@blackmanharris, N+1);
% BloN = fir1(N, Wm, wblkbar);

BloN = fir1(N, Wm);
[HlOW, fplot] = freqz(BloN, 1, 2^16, Fs);

plot(fplot, 20*log10(abs(HlOW)), fpass, Rpass, 'r--', fstop, Rstop, 'r', '
    linewidth', 2)
axis([0 Feby2 -100 10])
xlabel('frequency in Hz')
ylabel('magnitude in dB')
title('lowpass FIR filter')
grid on
legend('filter response', 'passband spec', 'stopband spec')
```

Listing 1: FIR Lowpass Filter Design Example

2   Reference Code: IIR Bandpass Filter Design Example

The following MATLAB code demonstrates the design and visualization of IIR bandpass filters using multiple design methods.

```matlab
% bandpass filter design
% wp and ws here are normalized frequencies in the range [0 1],
% where 1 corresponds to pi rad/sample (MATLAB's normalized freq).
wp = [0.3 0.5]; % passband cutoff (fraction of Nyquist = 0..1)
ws = [0.2 0.6]; % stopband start (fraction of Nyquist = 0..1)

Rp = 1;  % passband amplitude variation in dB
Rs = 30; % stopband amplitude attenuation in dB

% Butterworth
[N, Wn] = buttord(wp, ws, Rp, Rs);
[b, a] = butter(N, Wn);

% % Chebyshev Type 1 (ripple in passband)
% [N, Wn] = cheb1ord(wp, ws, Rp, Rs);
% [b, a] = cheby1(N, Rp, Wn);

% % Chebyshev Type 2 (ripple in stopband)
% [N, Wn] = cheb2ord(wp, ws, Rp, Rs);
% [b, a] = cheby2(N, Rs, Wn);

% % Elliptical (ripple in pass and stop bands)
% [N, Wn] = ellipord(wp, ws, Rp, Rs);
% [b, a] = ellip(N, Rp, Rs, Wn);

[H, w] = freqz(b, a, 1024);

plot(w/pi, 20*log10(abs(H)), 'b', ...
     [0 ws(1) ws(1)], [-Rs -Rs 0], 'r', ...
     [wp(1) wp(1) wp(2) wp(2)], [-1000 -Rp -Rp -1000], 'r', ...
     [ws(2) ws(2) 1], [0 -Rs -Rs], 'r')
axis([0 1 -2*Rs, 5])
grid on
xlabel('Matlab normalized freq')
ylabel('Magnitude in dB')

% Display order and coefficient sizes
N
size(b)
size(a)
```

Listing 2: IIR Bandpass Filter Design Example

Report Requirements

Your write-up must include:

1. **Filter Specifications:**

   - Center frequency and bandwidth
   - Passband ripple, stopband attenuation
   - Passband and stopband edge frequencies
   - Resulting filter orders for each design

2. **Design Methodology:**

   - Brief description of design approach for each filter type

3. **Frequency Response Plots:**

   - Magnitude and phase for all three filters
   - Consider plotting multiple curves on one plot for comparison
   - Ensure all plots have complete labels

4. **Time Domain Results:**

   - Sinusoidal input/output plots
   - Steady-state analysis
   - Impulse response plots and observations
   - Random noise filtering results

5. **Analysis and Observations:**

   - Compare filter performance (IIR vs. FIR)
   - Discuss computational complexity (filter orders)
   - Note any interesting characteristics or unexpected results
   - Predictions vs. actual results

6. **MATLAB Code:**

   - Attach program at the end of the report
   - Include comments in your code

Academic Integrity

This is an individual assignment. While you may discuss general concepts with classmates, all submitted work must be your own. Copying solutions from other students, online sources, or solution manuals constitutes academic dishonesty and will result in a failing grade for the assignment and potential disciplinary action.