Khulna University of Engineering & Technology

Dept. of Electronics and Communication Engineering

Session: 2022-2023

Open-ended Project: Explore the fundamental characteristics of FIR filters and analyze the frequency responses of noisy and enhanced samples by designing user-defined functions

Course Title: Digital Signal Processing Laboratory
Course No.: ECE-3204

Submitted by—
Arian Rahman Aditta
Roll: 2009028
Dept. of ECE, KUET.

Submitted to—
Dr. Md. Rabiul Islam
Professor
Dept. of ECE, KUET.

Shah Muhammad Azmatullah
Assistant Professor
Dept. of ECE, KUET.

Date of submission: 31 December, 2024

1. Objectives

The main objectives of this project are:

- Explore the design principles and characteristics of Finite Impulse Response (FIR) filters using windowing techniques.
- Understand and analyze the frequency and magnitude responses of different FIR filters.
- Implement custom Low-Pass, High-Pass, Band-Pass, and Band-Stop FIR filters, assessing their performance.
- Examine the impulse responses and evaluate how window selection influences filter characteristics.

2. Introduction

Finite Impulse Response (FIR) filters are a type of digital filter commonly employed in signal processing applications. Known for their inherent stability and linear phase response, they are ideal for scenarios where minimal phase distortion is critical. Designing FIR filters typically involves defining parameters such as filter length, cutoff frequencies, and a window function to shape the frequency response. Windowing techniques play a crucial role in balancing the trade-offs between main-lobe width and side-lobe attenuation, thereby optimizing the filter's performance.

3. Theory

3.1 Window Techniques for FIR Filters

Windowing is a method used to taper the infinite impulse response of an ideal filter to a finite length. Commonly used windows include:

- **Rectangular Window:** Simple truncation with poor frequency selectivity and high side-lobe levels.
- **Hann Window:** Smooth tapering with reduced side-lobe levels but slightly broader main lobe.
- **Hamming Window:** Similar to Hann but with better side-lobe attenuation.
- **Blackman Window:** Offers superior side-lobe attenuation at the cost of a wider main lobe.

3.2 Filtering and Tap Calculation

Filter Types:

- **Low-Pass:** Passes frequencies below the cutoff frequency. Its transfer function is represented by:

$$H_{LP}(z) = \sum_{n=0}^{N-1} h_{LP}[n] \, . \, z^{-n}$$

Here, $h_{LP}[n]$ = coefficient of Low pass Filter.

- **High-Pass:** Passes frequencies above the cutoff frequency. Its transfer function is represented by:

$$H_{HP}(z) = \sum_{n=0}^{N-1} h_{HP}[n] \, . z^{-n}$$

Here, $h_{HP}[n]$ = coefficient of High pass Filter.

- **Band-Pass:** Passes frequencies within a specified range. Its transfer function is represented by:

$$H_{BP}(z) = \sum_{n=0}^{N-1} h_{BP}[n] \, . z^{-n}$$

Here, $h_{BP}[n]$ = coefficient of Band Pass Filter.

- **Band-Stop:** Attenuates frequencies within a specified range. Its transfer function is represented by:

$$H_{BS}(z) = \sum_{n=0}^{N-1} h_{BS}[n] \, . z^{-n}$$

Here, $h_{BS}[n]$ = coefficient of Band Stop Filter.

Tap Calculation Process:

- Determine the desired filter length ('N') and window type.
- Compute the ideal impulse response using SINC functions for the desired frequency range.
- Apply the selected window function to the ideal impulse response to obtain the final FIR filter coefficients.

3.3 Magnitude Response

The magnitude response provides the gain of the filter at various frequencies. It illustrates the filter's ability to pass or attenuate specific frequencies.

3.4 Frequency Response

The frequency response represents the filter's behavior across the frequency spectrum, including both magnitude and phase characteristics.

3.5 Impulse Response

The impulse response of a FIR filter is the sequence of filter coefficients. It is finite and directly defines the filter's output for an input impulse signal.

4. Required Software

MATLAB (2023b) was used for filter design, implementation, and analysis. Its powerful signal processing toolbox allows for efficient computation of filter responses and visualization.

5. Filter Parameters Table

Window type	Filter Length	Passband Ripple (dB)	Stopband Attenuation (dB)
Rectangular	51	>= 0.7416	<=21
Hann	21	>= 0.0546	<=44
Hamming	31	>= 0.0194	<=53
Blackman	21	>= 0.0017	<=74

6. Implemented Design

The block diagram of the implemented design is given below:

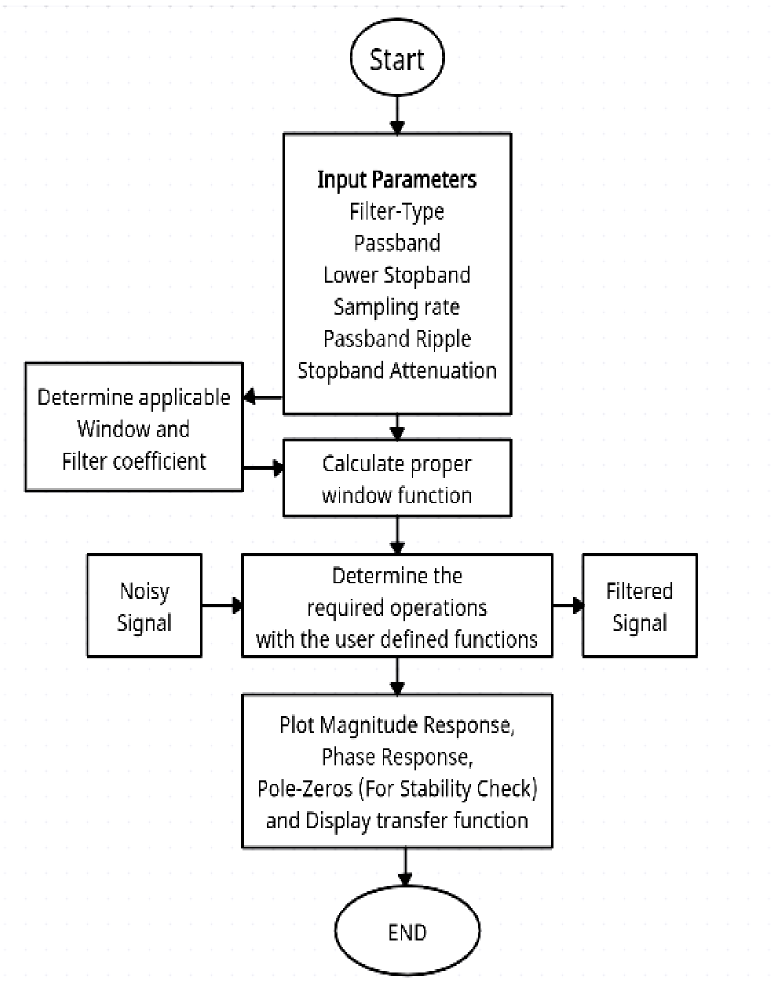
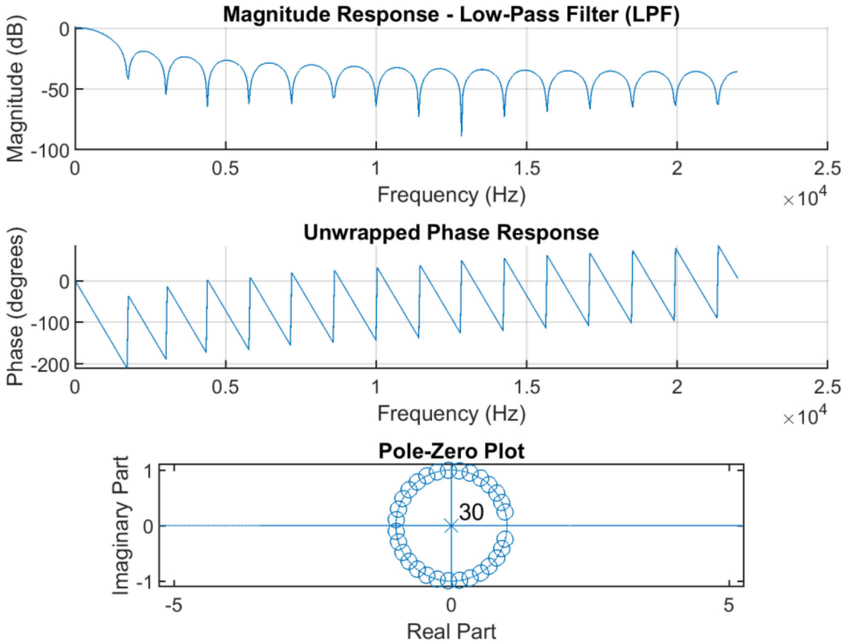


Figure-1: *Block diagram of the implemented design.*

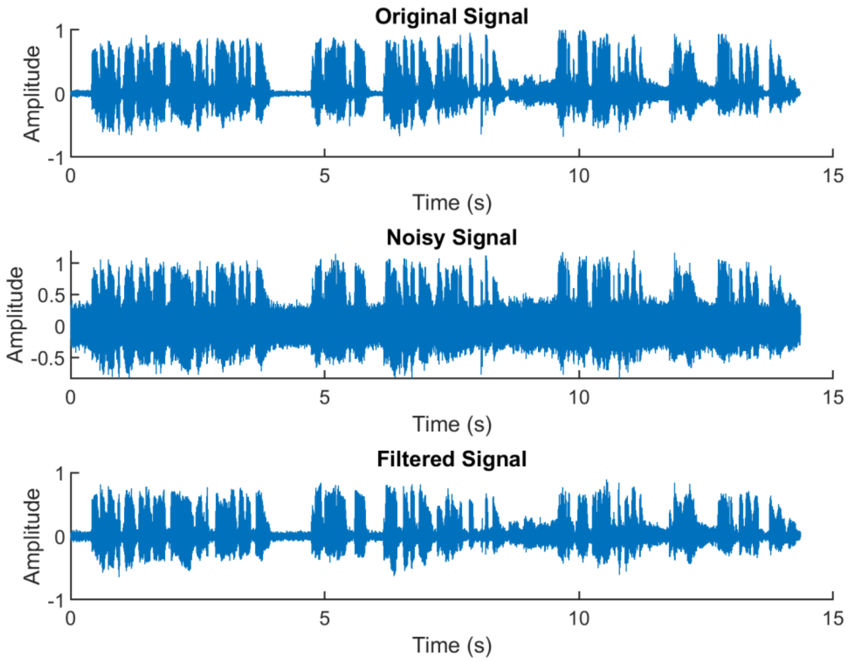
7. Result Analysis

Low Pass filter

The low-pass filter effectively attenuated frequencies above 1000 Hz, while preserving frequencies below the cutoff point with minimal distortion. The magnitude response confirmed the effectiveness of the filter in maintaining a sharp transition band and high attenuation in the stopband. The impulse response of the filter demonstrated symmetry, which is indicative of the filter's linear phase property. Additionally, the frequency response analysis revealed a smooth and consistent passband gain with significant attenuation beyond the cutoff frequency, confirming the filter's precision in isolating desired frequency components. The pole-zero plot showed the absence of poles outside the unit circle, reaffirming the stability of the FIR filter.



(a)

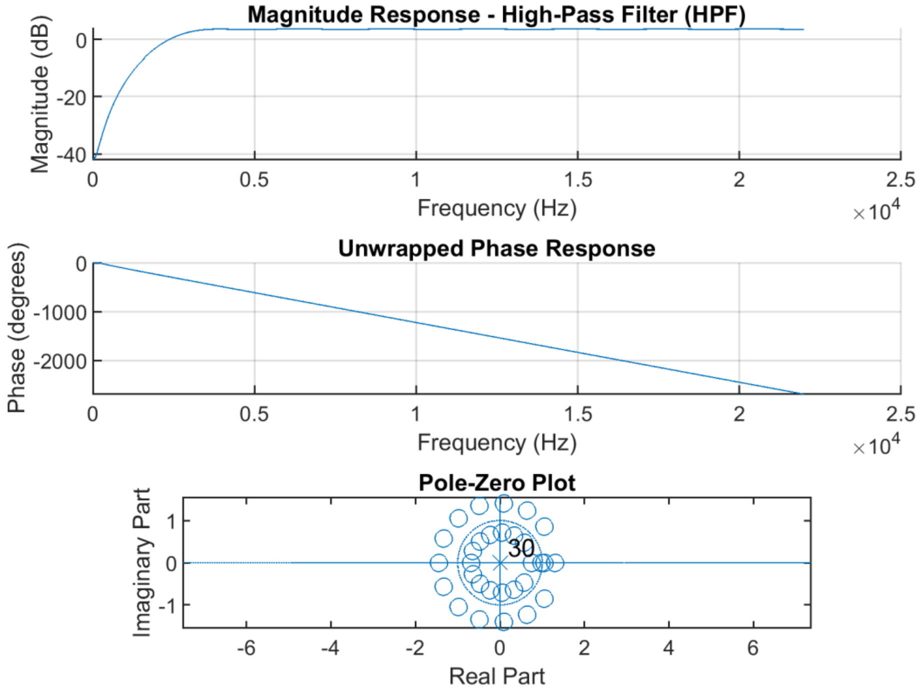


(b)

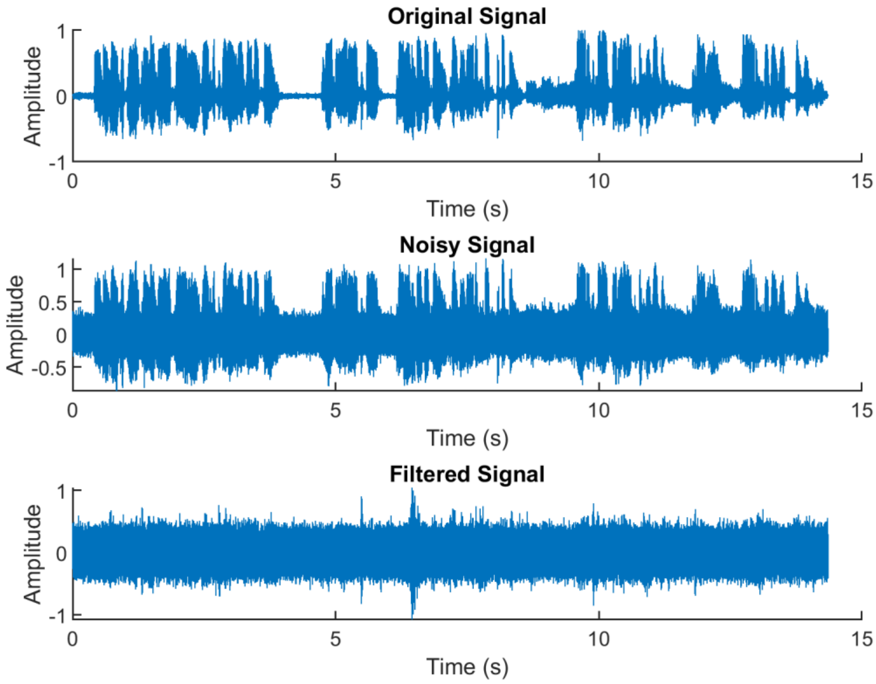
Figure-2: *Representation of (a) Magnitude response, Phase response and Pole-Zero plot, (b) Effect of LPF filter on an audio signal.*

High Pass Filter

The high-pass filter successfully retained frequencies above 1500 Hz while attenuating frequencies below the cutoff point. The magnitude response showcased a well-defined cutoff region with a sharp transition and high attenuation in the stopband. The impulse response indicated stability and a finite duration, confirming the accuracy of the filter coefficients. Furthermore, the frequency response analysis provided a detailed view of the filter's performance, highlighting its ability to suppress low-frequency components effectively while maintaining integrity in the high-frequency range. The pole-zero diagram showed no poles, as expected for FIR filters, confirming the design's inherent stability.



(a)

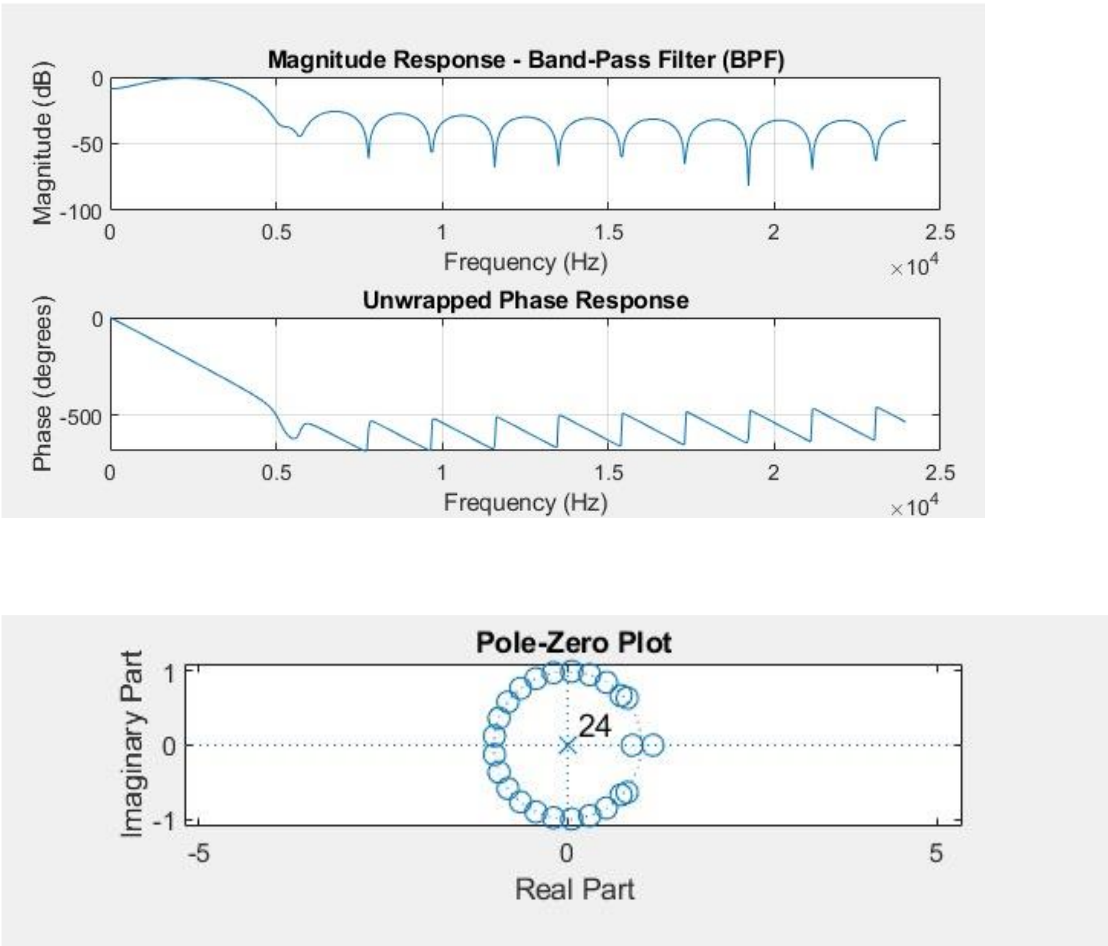


(b)

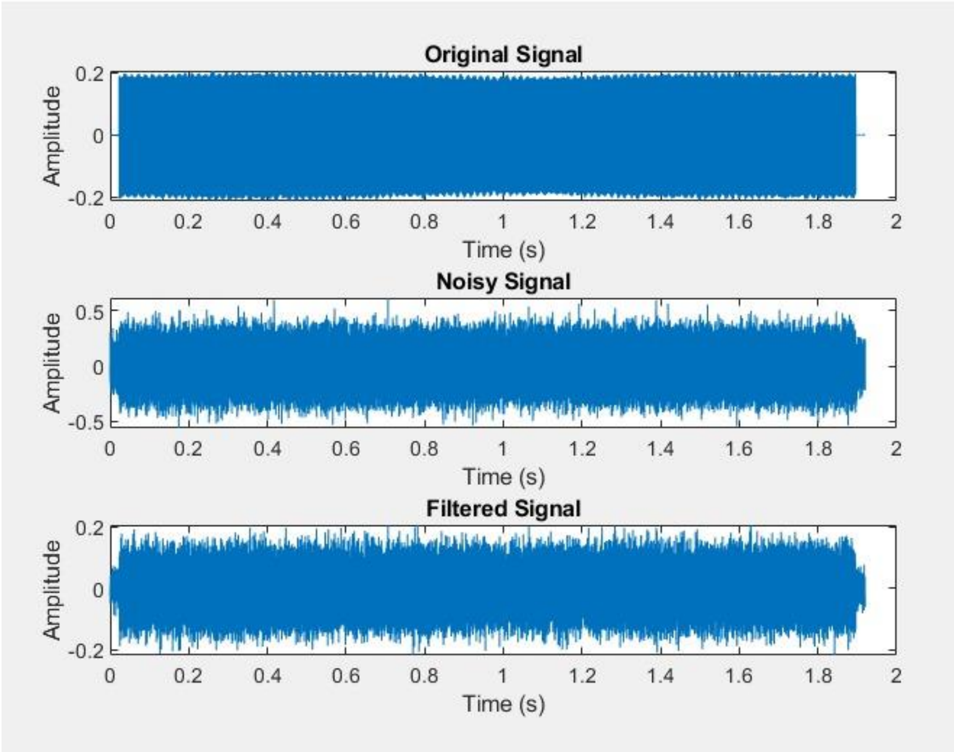
Figure-2: *Representation of (a) Magnitude response, Phase response and Pole-Zero plot, (b) Effect of HPF filter on an audio signal.*

Band-Pass Filter

The band-pass filter retained frequencies between **1500 Hz and 2750 Hz**, attenuating those outside this range. Using a Hanning window, the filter achieved a smooth transition and minimized side-lobe leakage. The magnitude response confirmed effective attenuation in the stopbands and consistent gain in the passband. The impulse response exhibited linear phase symmetry, and the pole-zero plot indicated stability with no poles outside the unit circle.



(a)



(b)

Figure-3: *Representation of (a) Magnitude response, Phase response and Pole-Zero plot, (b) Effect of Bandpass filter on an audio signal.*

8. Conclusion

The project successfully demonstrated the design and implementation of FIR filters using window techniques. The analysis of stability; magnitude, frequency, and impulse responses validated the theoretical expectations. The selection of window functions significantly influenced the trade-offs between transition width and side-lobe attenuation. This study reinforces the importance of window selection and filter parameter optimization in signal processing applications.