DESIGN AND PERFORMANCE ANALYSIS OF FIR LOW PASS FILTER USING KAISER AND HANNINGWINDOW TECHNIQUES

[1]**Mrs.B.Manjula,** Assistant professor, ECE, Vignan's Institute of Engineering For Women
[2]**K.Priyanka**, [3]**K. Sowjanya Sai**, [4]**K.Vasrhini**, [5]**K.Gowthami**, Student, ECE, Vignan's Institute of Engineering For Women

ABSTRACT

The project includes the design and performance analysis of a low pass filter for ECG signal using two windowing techniques from Kaiser and Hanning. The purpose of this project is to compare the performance of both window techniques and determine which technique produces the best results. ECG signals are often corrupted by noise and interference, which can affect the accuracy of diagnosis and treatment. Filtering is a common technique used to remove unwanted noise and improve signal quality. FIR filters are commonly used in ECG signal processing due to their linear phase response and ease of implementation. Kaiser and Hanning window techniques are commonly used in FIR filter design. Kaiser windows are used to design filters with a specified stop band attenuation and transition width, while Hanning windows are used to design filters with smooth frequency response and minimal sidelobe levels. The performance analysis results provide valuable insight into the effectiveness of the Kaiser and Hanning window techniques in ECG signal filtering.

INTRODUCTION

In digital signal processing, finite impulse response(FIR) filters are commonly used to remove unwanted noise or frequency components from a signal. A low-pass FIR filter allows only low-frequency components to pass through while attenuating higher-frequency components.

In this project, we will design and analyze the performance of a low-pass FIR filter using two different windowing techniques: Kaiser and Hanning. The filter will be designed to process an Electro Cardio Gram(ECG) signal, which is a biomedical signal that records the electrical activity of the heart.

The ECG signal is a complex waveform that contains a range of frequency components, with the important information contained in the lower frequency range. By using a low-pass filter, we can remove unwanted high-frequency noise and interference, while preserving the important information in the ECGsignal.

The Kaiser and Hanning windowing techniques are commonly used to design FIR filters, with each technique having its advantages and disadvantages. The Kaiser window has a flexible parameter that allows for precise control over the transition bandwidth and passband ripple, while the Hanning window has a simpler design and provides a better trade-off between the transition bandwidth and pass band ripple.

In this project, we will compare the performance of the Kaiser and Hanning windowing techniques by analyzing the filter's frequency response, phase response, and group delay. We will also evaluate the filter's performance by measuring its ability to attenuate high-frequency noise and interference while preserving the important features of the ECG signal.

Overall, this project aims to demonstrate the importance of selecting an appropriate windowing technique for FIR filter design and to provide a comparative analysis of two commonly used techniques. The results of this project can be applied in various biomedical signal processing applications, includingECG signal processing and analysis.

LITERATURE SURVEY

[1] Manira Khatun " Design Technique of Low-Pass Filter Using Different Window" Vol. 3 Issue 2, February – 2014.

This paper presents the design of a low-pass filter by using various window methods. Also provides a comparative study of lowpass filters using Hanning, Blackman, Kaiser, and Hamming window functions.

This paper concludes that Kaiser is better compared to Hanning, Hamming, and Blackman's window.

This paper is focused only on the width of the main lobe of the FIR lowpass filter using a different window with less transition and more ripples.

[2] Anshul, Kavitha Rathi " Comparison of Various Window Techniques for Design FIR Digital Filter"2017 IEEE.

This paper presents the different techniques for designing filters and then compared them.

This paper concludes that the equivalent noise bandwidth of the modified hamming window is reducedin comparison to others.

The equivalent noise bandwidth of the modified hamming window is reduced in comparison to others.

[3] Kamal Kant Chandra, Mohan Lal Prajapati, Mr. Pranay Kumar Rahi "Designing a Low-Pass FIR Digital Filter by Using Rectangular, Hanning. and Triangular Window Technique" Vol 6, Issue 3, March2017.

This paper presents design techniques of the low-pass filter using Rectangular, Hanning, and Triangularwindow techniques of order (15). Also shows that filter design by using the Rectangular window technique is better as provides a better result in terms of magnitude, phase, impulse, step responses, andpole-zero plot.

This paper concludes by comparing values of both magnitude and phase response of the filter using bothtechniques at the same frequency present with the wanted signal too.

The comparative values of both magnitude and phase response of the filter using both techniques at thesame frequency are only mentioned.

[4] Ankita Kurariya, Prof. Prateek Mishra " Design and analysis of FIR filters based on MATLAB" Vol.7 Issue 5, October-2019.

This paper presents how to simplify the complicated computation in simulation and improve the performance by designing the FIR filter in MATLAB.

This paper concludes that the window method is relative simplicity as compared to other methods for FIR filter designing.

The comparison of amplitude-frequency response diagrams to obtain a linear phase and casual FIR filter.

Filter Design

There are various types of digital filters, and they can be classified based on different criteria, such as their frequency response, order, and function. Here are some common types of filters:

1. Low Pass Filter (LPF)
2. High Pass Filter (HPF)
3. Band Pass Filter (BPF)
4. Band Stop Filter (BSF) Digital filters are classified as:

a. Finite Impulse Response (FIR) Filters

b. Infinite Impulse Response (IIR) Filters

FIR Filters are characterized by a finite impulse response, meaning that the output of the filter is affectedonly by a finite number of past inputs. On the other hand, IIR filters are characterized by an infinite impulse response, meaning that the output of the filter is affected by an infinite number of past inputs.

Design techniques of FIR filters:

1. Fourier Series Method
2. Frequency Sampling Technique
3. Window Technique

One of the main reasons why windowing is used to filter signals is to reduce the amount of noise or unwanted signal components in the data. In many cases, signals are corrupted by various types of noise, such as random fluctuations or interference from other sources. By applying a window function to the signal, it is possible to selectively reduce the amplitude of certain frequency components in the signal, effectively filtering out noise.

Kaiser Window

The Kaiser window function is a commonly used signal-processing tool for designing digital filters andanalyzing spectra. It is a type of tapering window that is often used to improve the performance of finiteimpulse response (FIR) filters.

The kaiser window is designed to have a finite duration and a smooth transition between the passband and the stopband of a filter. It is characterized by a parameter called the beta value, which determines the shape of the window. A higher beta value results in a more narrow transition region, while a lower beta value results in a wider transition region.

The Kaiser window function is mathematically designed as:

$$WK(n) = \begin{cases} \frac{I0\beta 1}{I_0(a)} ; for -\frac{N-1}{2} \le n \le \frac{N-1}{2} \\ 0 ; other\ n \end{cases}$$

Hanning Window

The Hanning window is a widely used windowing function in digital signal processing. It is a type of cosine window that is commonly used to smooth out spectral leakage when analyzing signals with Fourier transform.

The Hanning window function is mathematically designed as:

$$(n) = \begin{cases} 0.5 + 0.5\cos\frac{2\pi n}{N-1} \ ; for -\frac{N-1}{2} \le n \le \frac{N-1}{2} \\ 0 \ ; other\ n \end{cases}$$

Hanning window function has a bell-shaped curve, with the maximum value of 1 occurring at the center of the window and tapering off to zero at the edges. This tapered shape reduces spectral leakage by minimizing the abrupt changes at the boundaries of the window. The Hanning window also has a side lobe attenuation of about 31dB, which is better than some other windowing functions.

Window Measurements

There are various factors that can be determined to improve the efficiency of the different types ofwindow filters; there we'll explain some of the important factors:

Coherent Gain (CG):

Coherent gain is the relation between two signals. It is commonly used to estimate the power transferbetween input and output.

The formula for calculating Coherent Gain :

$$CG = \frac{1}{N}\sum_{n=0}^{N-1} w(n)$$

Equivalent Noise Bandwidth (ENBW):

The noise bandwidth is an important parameter to specify the noise power at the output of a bandpasslinear system.

The formula for calculating ENBW :

$$ENBW = \frac{N\sum_{n=0}^{N-1}|(n)|^2}{(\sum_{n=0}^{N-1} w(n))^2}$$

Signal-to-Noise Ratio:

It is the ratio of signal power to noise power. It compares the desired signal level to the unwanted signallevel. High SNR is good for transmitting and receiving signals.

The formula for calculating SNR :

$$SNR = \frac{(output\ signal\ power)}{(noise\ signal\ power)}$$

It can be expressed in decibels (dB):

$$SNR = 10 * log10 \frac{(output\ signal\ power)}{(noise\ signal\ power)} dB$$

Mean Square Error:

It is a metric calculated by taking the average of the squared differences between corresponding samplesof the two signals.

The formula for calculating MSE:

$$MSE = \frac{1}{N}\sum((x-y)2)$$

Processing Gain:

Processing gain increases the signal-to-noise ratio (SNR) and it measures the improvement of signalquality after the signal is processed.

The formula for calculating Processing Gain :

$$PG = \frac{1}{ENBW}$$

The Processing Gain also can be represented in decibels:

$$PG = 10\,log10\,\frac{1}{ENBW}$$

Leakage Factor:

Leakage Factor means the ability to integrate data against noise.The formula for calculating the

Leakage Factor :

$$LG = \frac{(main\ lobe\ power)}{(passband\ power)}$$

Relative Side Lobe Attenuation:

The relation between the main lobe and the largest side lobe is called Relative Side Lobe

Attenuation.The formula for calculating Relative Side Lobe Attenuation :

$$RSLA = \frac{(main\ lobe\ power)}{highest\ sidelobe\ power)}$$

Main Lobe Width:

The Main Lobe Width is a measure of the width of the main lobe of the filter’s frequency response.

The formula for calculating Main Lobe Width :

$$MLW = (width\ of\ the\ main\ lobe\ at\ half\ of\ the\ maximum\ power)$$

RESULT

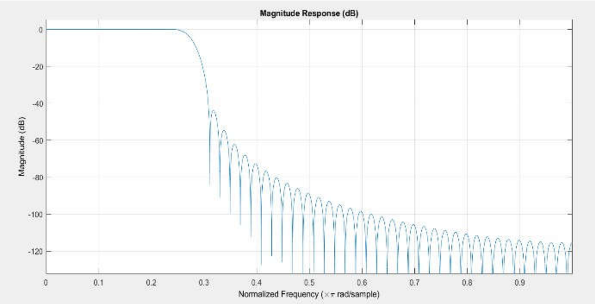

Fig 1: Magnitude response of Hanning window

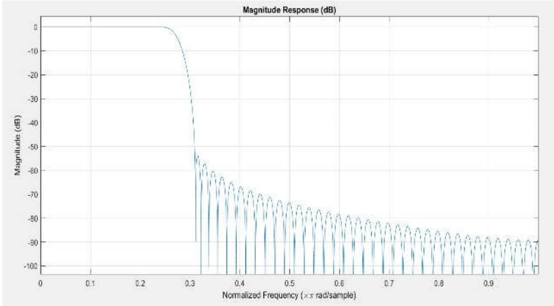

Fig 6: Magnitude response of Kaiser window at (β = 5)

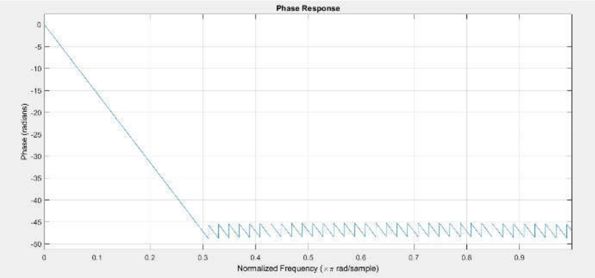

Fig 2: Phase response of Hanning window

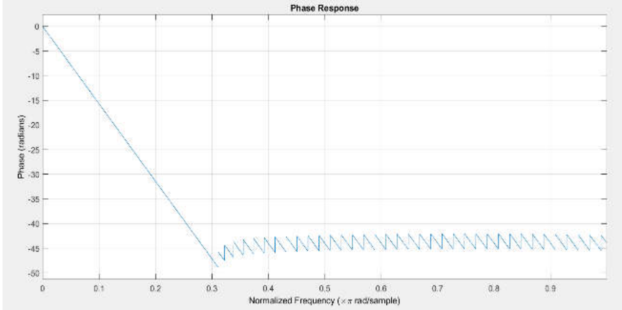

Fig 7: Phase response of Kaiser window(β = 5)

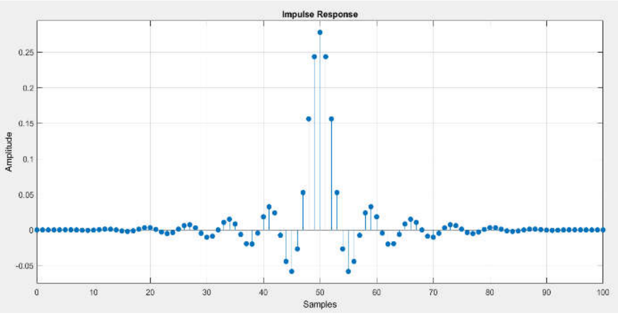

Fig 3: Impulse response of Hanning window

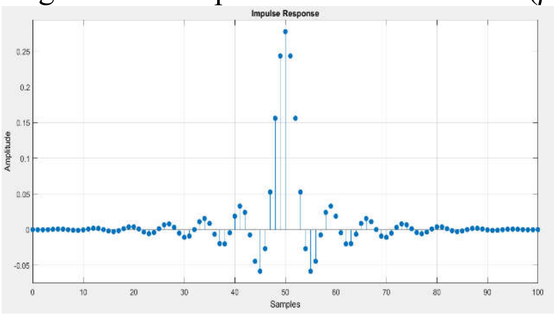

Fig 8: Impulse response of Kaiser window(β = 5)

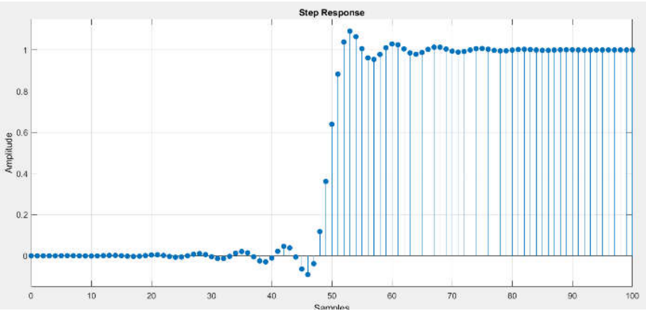

Fig 4: Step response of Hanning window

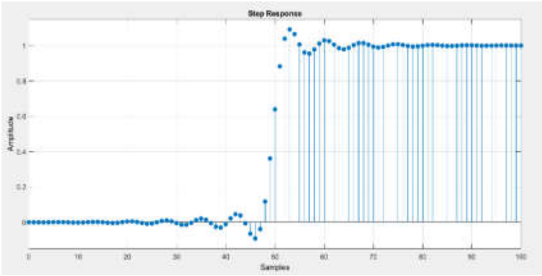

Fig 9: Step response of Kaiser window(β = 5)

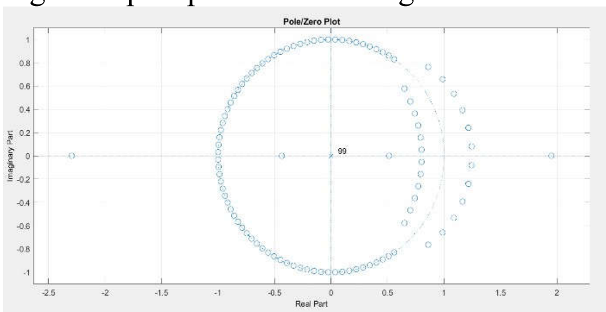

Fig 5: Pole-Zero plot of Hanning window

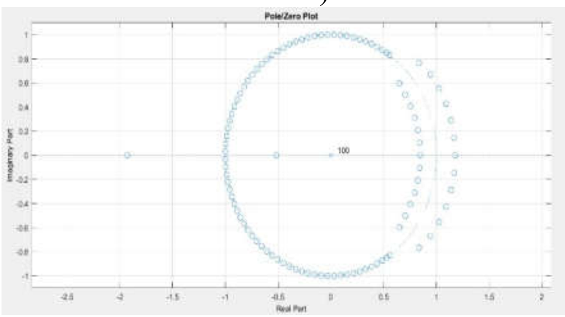

Fig 10: Pole-Zero plot of Kaiser window(β = 5)

Window function	Coherent gain	Equivalent noise bandwidth	Signal-to-noise ratio	Mean square error	Processing gain	Leakage factor %	Relative side lobe attenuation (dB)	Main lobe width (-3dB)
Kaiser window	-5.3653	1.1549	34.8422	0.4474	-0.6253	9.17	-13.3	0.000489
Hanning window	-5.3661	1.1548	34.0753	0.4460	-0.6254	9.16	-13.3	0.000488

Table 1: Window measurements

CONCLUSION

For ECG signals, which are typically low-frequency signals with some noise and artifacts, a low-pass filter can help remove high-frequency noise and smooth out the signal. The performance of the filter can be evaluated based on various parameters such as Signal-to-Noise Ratio(SNR), Mean Square Error(MSE), Processing Gain, Coherent Gain, and Equivalent Noise Bandwidth(ENBW).

Regarding the comparison of parameters such as signal-to-noise ratio, mean square error, processing gain, coherent gain, and equivalent noise bandwidth, the choice of the window will depend on the specific application and requirements. However, in this, the kaiser window provided better performancein terms of processing gain and coherent gain due to its sharper cut-off, while the hanning window has a lower equivalent noise bandwidth due to its smoother transition between passband and stopband. Ultimately, the choice between the two windows will depend on the specific requirements and constraints of the application.

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