

Design and Performance Analysis of Low Pass Fir Filter Using Different Windows Techniques

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ABSTRACT

In communication system digital filters plays a significant role as it provides high attenuation to the unwanted signals and at same time offers very low attenuation to the desired signals. In this paper, Low pass filter is designed using different window techniques namely Parzen, Nuttall and Rectangular. Here the Magnitude and phase response in time and frequency domain of these window techniques have been compared using MATLAB simulation. From the simulation result of different window, we found Nuttall window gives better magnitude and phase response as compared to other two techniques.

Keywords: - FIR, DSP, Digital filter, Low pass filter, Nuttall Window, Parzen Window, Rectangular Window

1. INTRODUCTION

A fundamental aspect of signal processing is filtering. In signal processing, there are many instances in which an input signal to a system contains extra unnecessary content or additional noise which can degrade the quality of the desired portion [2]. Digital filters play an important role in digital signal processing applications. A digital filter is a mathematical algorithm implemented in hardware / software that operates on a digital input to produce a digital output [1]. In signal processing, a filter is a device or process that removes from the unwanted component of the signal. Digital filter are classified into two categories and they are the Finite Impulse Response (FIR) filter and Infinite Impulse Response (IIR) filter [3]. In the FIR system, the impulse response is of finite duration, and has finite number of nonzero terms. On the other hand, the IIR system has an infinite number of nonzero terms [4]. FIR filters are one of the primary types of filters used in

DSP.

For the design of low pass FIR filters complex calculations are required. Mathematically, by substituting the values of the pass band, transition width, pass band ripple, stop band attenuation, sampling frequency in any of the methods from window method we can get the values of filter coefficients $h(n)$ [2].

2. SYSTEM DESIGN AND ANALYSIS

A finite Impulse Response (FIR) filter are type of digital filters and consists of weighting sequence (impulse response) among non-recursive digital filters which is finite in length. The simple form of FIR filters is coming through the windowing method. So, in this section, we have described mathematical model equation for various window functions. The Window functions are widely used for different applications of digital signal processing such as signal analysis, signal estimation, digital filter design and speech processing. Fourier series method with windowing is the most straight forward technique to design FIR filters[2]. The desired frequency response of any digital filter is periodic in frequency and can be expanded in Fourier series ,i.e.,

$$H_d(e^{j\omega}) = \sum_{n=-\infty}^{\infty} h_d(n)e^{-j\omega n} \dots\dots\dots(1)$$

$$\text{Where, } h_d(n) = \frac{1}{2\pi} \int_0^{2\pi} H(e^{j\omega}) e^{j\omega n} d\omega \dots(2)$$

The coefficients of the series $h_d(n)$ are identical to the impulse response of a digital filter[1]. The impulse response of the ideal low pass filter can easily be found as follows:

$$h_{LP}[n] = \frac{\sin \omega_c n}{\pi n}, \quad -\infty < n < \infty \dots\dots (3)$$

There are essentially three well-known methods for FIR filter design:

- 1) FIR filters design using windows.

- 2) FIR filter design using frequency sampling method.
- 3) Optimal or Minimax FIR filter design [4].

But throughout this paper we have discussed the window method for designing the low pass FIR filter. Some of the windows commonly used are as follows:

2.1 NUTTALL WINDOW

The Nuttall window has the widest main lobe and lowest maximum side lobe level among the Blackman, Exact Blackman, and the Blackman-Harris window. The equation for the Nuttall window is [5]

$$\omega(n) = a_0 - a_1 \cos\left(2\pi \frac{n}{N-1}\right) + a_2 \cos\left(4\pi \frac{n}{N-1}\right) - a_3 \cos\left(6\pi \frac{n}{N-1}\right) \quad (4)$$

Where $n=0,1,2, \dots N-1$

The equation for the periodic Nuttall

$$\omega(n) = a_0 - a_1 \cos\left(2\pi \frac{n}{N}\right) + a_2 \cos\left(4\pi \frac{n}{N}\right) - a_3 \cos\left(6\pi \frac{n}{N}\right) \quad (5)$$

where $n= 0,1,2, \dots N-1$. The periodic window is N-periodic. The coefficients for this window are given in table

Table 1. Coefficient of Nuttall window

a_0	0.3635819
a_1	0.4891775
a_2	0.1365995
a_3	0.0106411

2.2 PARZEN WINDOW

The following equations defines the N- point Parzen window [6] over the interval $-\frac{(N-1)}{2} \leq n \leq \frac{(N-1)}{2}$

$$\omega(n) = \begin{cases} 1 - 6\left(\frac{|n|}{N/2}\right)^2 + 6\left(\frac{|n|}{N/2}\right)^3 & 0 \leq |n| \leq (N-1)/4 \\ 2\left(1 - \frac{|n|}{N/2}\right)^3 & \frac{N-1}{4} \leq |n| \leq \frac{N-1}{2} \end{cases} \quad (6)$$

2.3 RECTANGULAR WINDOW

The Rectangular Window has the highest amount of spectral leakage. The rectangular function truncates the signal to within a finite time interval. The weighting function for the Rectangular window is to be defined [1] by

$$\omega_R(n) = \begin{cases} 1, & \text{for } |n| \leq \frac{M-1}{2} \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

3. DESIGN SIMULATION

To design the low pass FIR filter using MATLAB Nuttall Parzen and Rectangular Window the parameter specifications are given in table 2. as

Table 2: Parameter Specification

PARAMETER	VALUES
Sampling Frequency(F_s)	48000 Hz
Cut off Frequency(F_c)	10800 Hz
Order(N)	20

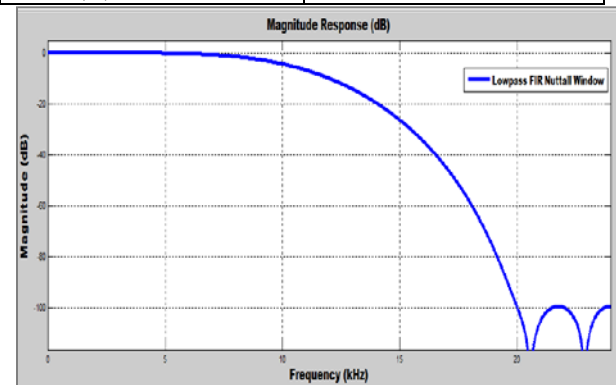


Fig.1 Magnitude Response of Nuttall Window Technique

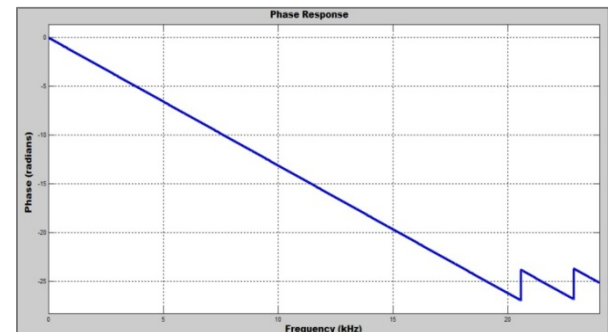


Fig.2 Phase Response of Nuttall Window Technique

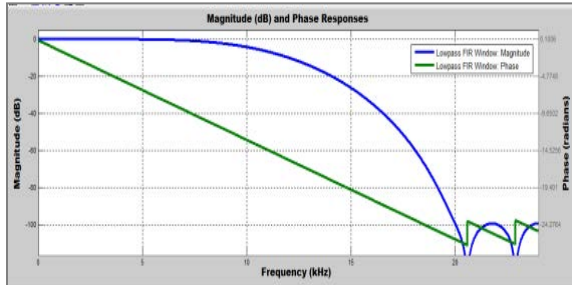


Fig.3 Magnitude [dB] and Phase [rad] of Nuttall Window Technique

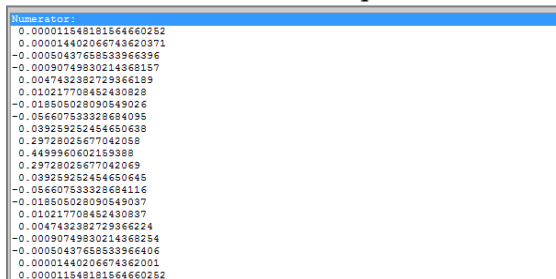


Fig. 4 Filter coefficient on Nuttall Window Technique

Fig. 1 shows the magnitude response of Nuttall window and Fig. 2 shows phase response of Nuttall window. The magnitude response contains ripples in stop band and good pass band response.

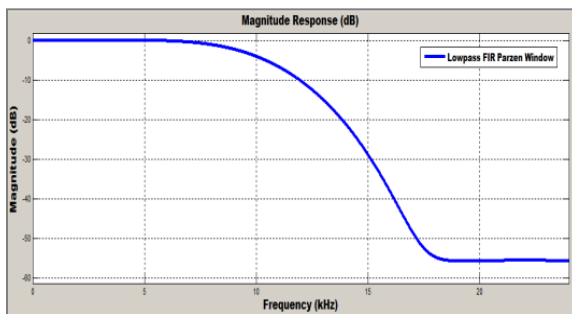


Fig.5 Magnitude Response of Parzen Window Technique

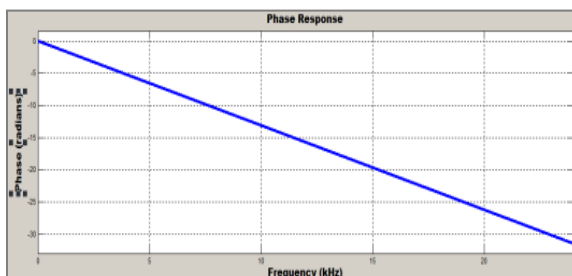


Fig.6 Phase Response of Parzen Window Technique

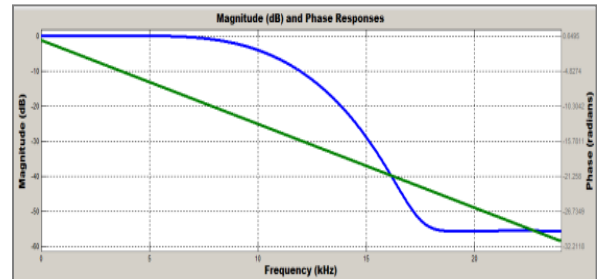


Fig.7 Magnitude [dB] and Phase [rad] of Parzen Window Technique

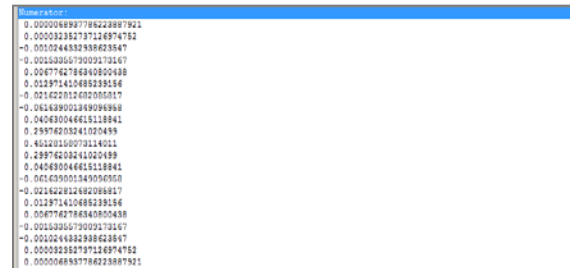


Fig. 8 Filter coefficient on Parzen Window Technique

Magnitude and phase response of Parzen window is shown in Fig. 5 and 6. In this method magnitude response contains negligible ripples in stop band and it is also having good pass band response.

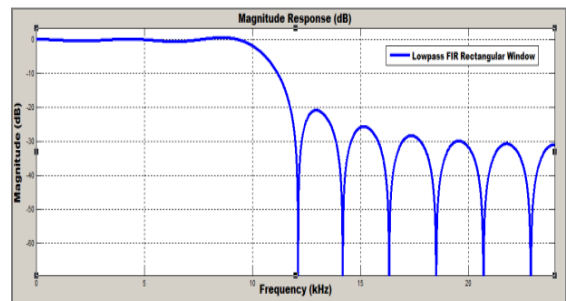


Fig.9 Magnitude Response of Rectangular Window Technique

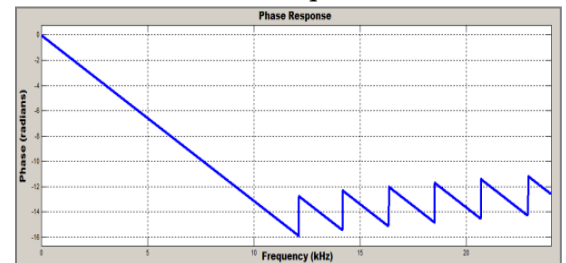


Fig.10 Phase Response of Rectangular Window Technique

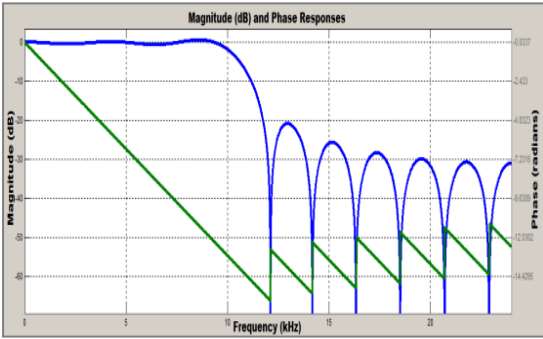


Fig.11 Magnitude [dB] and Phase [rad] of Rectangular Window Technique

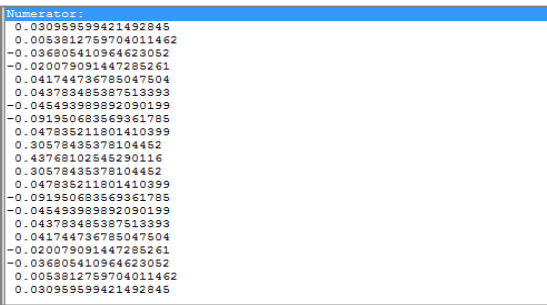


Fig. 12 Filter coefficient on Rectangular Window Technique

Fig. 9 and 10 shows the magnitude and phase response of Rectangular window. The magnitude response shows very good pass band response but stop band contains very large amount of ripples.

4. COMPATIVE ANALYSIS

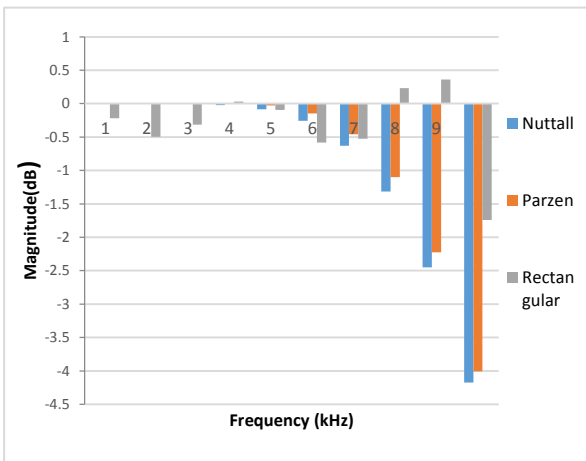


Fig.13 Magnitude [dB] Vs Frequency [kHz] Plot of Nuttall, Parzen and Rectangular Window

5. RESULT

Table 3: Magnitude and Frequency Result of Nuttall, Parzen & Rectangular window

Frequency (in kHz)	Magnitude (in dB)		
	Nuttall window	Parzen Window	Rectangular Window
1	0	0	-0.219
2	0	0	-0.497
3	0	0	-0.313
4	-0.021	0	0.033
5	-0.084	-0.028	-0.095
6	-0.258	-0.147	-0.584
7	-0.631	-0.458	-0.527
8	-1.315	-1.098	0.230
9	-2.449	-2.226	0.361
10	-4.175	-4.007	-1.740

From the Matlab simulation result of Nuttall, Parzen and Rectangular window at sampling frequency 48000Hz, cut off frequency 10800 Hz and order 20, table 4 shows that Nuttall window has higher gain than Parzen and rectangular window.

6. CONCLUSIONS

In this research paper, Low pass filter has been designed and simulated using three different Window Techniques namely Nuttall, Parzen and Rectangular. After analysing the performance of proposed FIR filter by their magnitude and phase response using MATLAB simulation at same values of sampling frequency 48kHz, cut off frequency 10.8kHz and order of 20, we conclude that Rectangular window has better pass band response as compared to Nuttall and Parzen Window but it contains more ripples in stop band, whereas Parzen window shows minimum ripples in stop band and Nuttall Window has good magnitude response.

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