# RESPONSE ANALYSIS OF FIR HIGH PASS FILTER DESIGN USING WINDOW METHODS

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**Abstract: Filters are widely employed in signal processing and communication systems in applications such as channel equalization, noise reduction, radar, audio processing, video processing, biomedical signal processing, and analysis of economic and financial data. Window methods are prominently used in the design of digital FIR filter. The paper studies the comparative analysis of a proposed high pass FIR filter design using Kaiser, Rectangular and Tukey window methods with the aid of FDATOOL in MATLAB. From the comparative analysis Rectangular is found to be the best for the proposed filter design based on the magnitude responses of the three windows.**

*Keywords*: **MATLAB, DSP, Window Method, Magnitude response.**

## I. INTRODUCTION

In many applications of signal processing we want to change the relative amplitudes and frequency contents of a signal. This process is generally referred to as filtering. Since the Fourier transform of the output is product of input Fourier transform and frequency response of the system, we have to use appropriate frequency response. Digital signal processing techniques are used in a variety of areas which include set top box, spread spectrum, cable modems, video compression, robotic vision, speech processing, image processing, RADAR, SONAR, etc. These techniques are applied in spectral analysis, channel vocoders, homomorphic processing systems, speech synthesizers, linear prediction systems, analyzing the signal in radar tracking, etc.

The attraction of DSP comes from key advantages such as guaranteed accuracy, perfect reproducibility, greater flexibility and superior performance (Emmanuel *et al*., 2004). Digital filter is important class of Linear time invariant DSP systems designed to modify the frequency characteristics of the input signal x(n) to meet certain specific design requirements. Digital filters are widely used because of certain advantages over Analog filters. Digital filters have the potential to attain much better signal to noise ratios than Analog filters. Digital Filters have emerged as a strong option for removing noise, shaping spectrum and minimizing inter-symbol interference (ISI) in communication architectures (Marthy, 2008).

### A. FIR Filter

Finite impulse response (FIR) filter is a filter whose impulse response (or response to any finite length input) is of finite duration, because it settles to zero in finite time. A finite impulse response (FIR) filter is a filter structure that can be used to implement almost any sort of frequency response digitally. An FIR filter is usually implemented by using a series of delays, multipliers and adders to create the filter's output. FIR filters also known as feed forward or non-recursive, or transversal filters. The unit impulse response is finite; so FIR filters are stable system.

FIR filters are employed in filtering problems where linear phase characteristics within the passband of the filter is required. If this is not required, either an IIR or an FIR filter may be employed. An IIR filter has lesser number of side lobes in the stopband that than FIR filter with the same number of parameters. For this reason, if some phase distortion is tolerable, an IIR filter is preferable. Also, the implementation of an IIR involves fewer parameters, less memory requirements and lower computational complexity.

### B. FIR Filter Design Methods

FIR filter design consists of Approximation problem and Realization problem. The approximation stage gives transfer function. Realization part deals with choosing the structure to implement the transfer function which may be in the form of circuit diagram or in the form of a program. There are three common methods for filter design one is the window method

(Yan, 2010), it truncates the Fourier series. Second is the frequency sampling technique (Ammar *et al.,* 2013) by using this method set of samples can be obtained in frequency domain. In Second method Frequency response of the filter is same as obtained at the sampling instant (Spanias, 2004). Third method is the optimal filter design method (Ran *et al.,* 2014). Window method is used throughout this paper.

### C. Window Method

Window technique involves a function called window function or apodization function which states that if some interval is chosen, it returns with finite nonzero value inside that interval and zero value outside that interval. So, if the window with chosen interval is applied on a IIR system, it will obviously return with a finite non-zero value inside that interval producing a FIR system and all other value that are outside the interval will be zero. So, we can view the finite response inside some predefined interval (Sarita *et al.,* 2012) (Datar *et al.,* 2009) (Sonika *et al.,* 2012) (Shanoi, 2006) (Li, 2008) (Andreas, 2006).

There are many window techniques available for designing the FIR filter and they are (Bob, 2000) (Ramesh *et al.,* 2012) (Babu, 2008) (Andreas, 2006):
 a. Hanning Window
 b. Hamming Window
 c. Blackman Window
 d. Rectangular Window
 e. Bartlett Window
 f. Kaiser Window.

In this research paper, we compare and analyze Rectangular, Kaiser and Tukey window methods.

### D. Rectangular Window

Rectangular window is the simplest window function for FIR filter design. The function can be stated as follows:

$$w(n) = \begin{cases} 1, & n = 0, 1, 2....., M-1, \\ 0, & \text{otherwise} \end{cases}$$

(1)

The unit sample response of the FIR filter becomes:

$$h(n) = h_d(n)w(n)$$

(2)

Where $h_d(n)$ is the desired impulse response filter.

$$h(n) = \begin{cases} h_d(n), & n = 0, 1, 2....., M-1, \\ 0, & \text{otherwise} \end{cases}$$

(3)

The Fourier Transform of $w(n)$ gives the frequency domain representation of the window.

### E. Kaiser Window

The Kaiser Window function can be written as (Patel *et al.,* 2013):

$$W(n) = \begin{cases} Io(\beta\sqrt{1-(2(n+1)(N+1)}, & from = 0 \ to \ n-1 \\ 0, & elsewhere \end{cases}$$

(4)

### F. Tukey Window

The Tukey window is also called the tapered cosine Window. The Tukey Window is defined as (Goyal *et al.,* 2015):

$$W_r(n) = \begin{cases} \frac{1}{2}\left[1 + cos\left(\pi\left(\frac{2n}{\alpha(M-1)} - 1\right)\right)\right], \\ \qquad 0 \leq n \leq \frac{\alpha(M-1)}{2} \\ 1 \qquad , \frac{\alpha(M-1)}{2} \leq n \leq (M-1)(1-\frac{\alpha}{2}) \\ \frac{1}{2}\left[1 + cos\left(\pi\left(\frac{2n}{\alpha(M-1)} - \frac{2}{\alpha} + 1\right)\right)\right], \\ \qquad (M-1)\left(1-\frac{\alpha}{2}\right) \leq n \leq (M-1) \end{cases}$$

(5)

## II. METHODOLOGY

A proposed high pass FIR filter using Tukey, Kaiser and Rectangular window methods has been designed with the aid of FDATOOL in MATLAB. The table 1 below shows the parameter specifications used for the proposed design.

Table 1: Parameter Specifications

| Window | Sampling frequency, fs(MHz) | Cut-off frequency, fc(MHz) | Order (N) | Alpha($\alpha$) | Beta ($\beta$) |
|---|---|---|---|---|---|
| Rectangular | 48 | 10.8 | 50 | - | - |
| Kaiser | 48 | 10.8 | 50 | - | 0.5 |

| Tukey | 48 | 10.8 | 50 | 0.5 | |
|-------|----|------|----|----|--|

### III.    SIMULATION RESULTS AND DISCUSSION

Using the specified parameters from table 1 the proposed high pass FIR filter is designed with the aid of FDATOOL in MATLAB. The simulation results of the three windows are shown in figures 1 to 12.

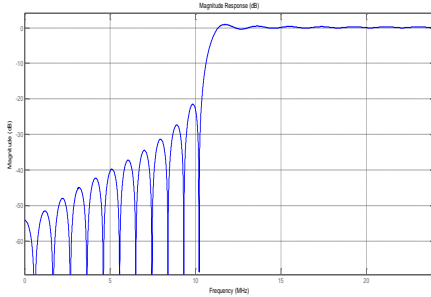#### A.    Rectangular Window Simulations



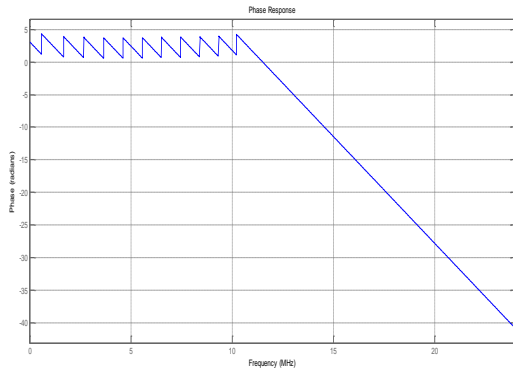Fig. 1: Magnitude response for Rectangular window.
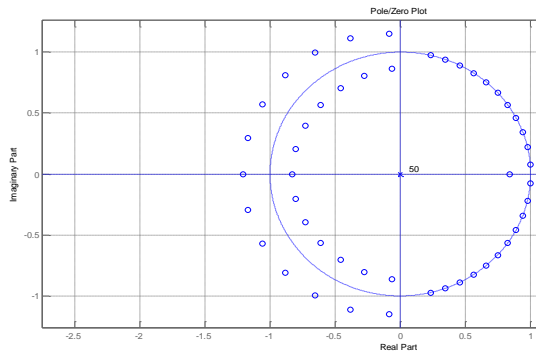


Fig. 2: Phase response for Rectangular window.



Fig. 3: Pole/Zero for Rectangular window.

Figures 1 to 3 above show the simulation results of Rectangular window. The magnitude response, phase response and the pole/zero are all plotted. The magnitude response cuts at exactly 10.22 MHz with gap of 0.58 MHz between the specified cut off frequency (10.8 MHz). The phase also changes at 10.22 MHz.

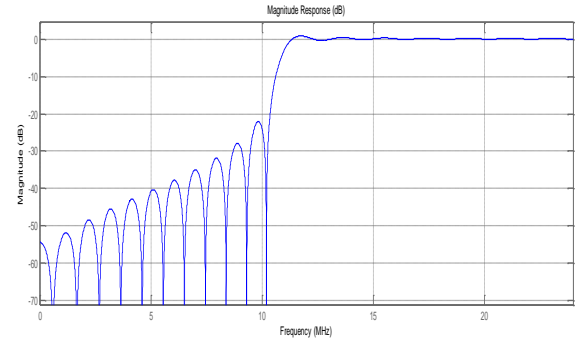#### B.    Kaiser Window Simulations



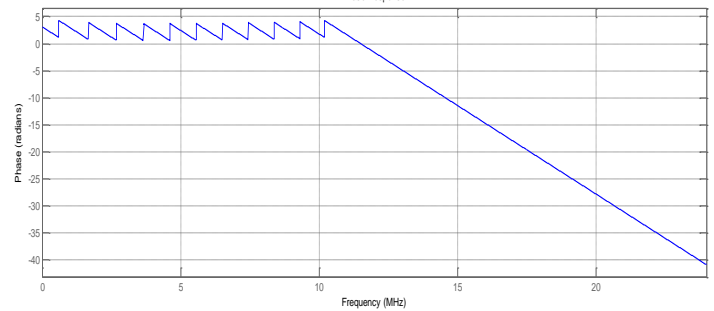Fig. 4: Magnitude response for Kaiser Window.



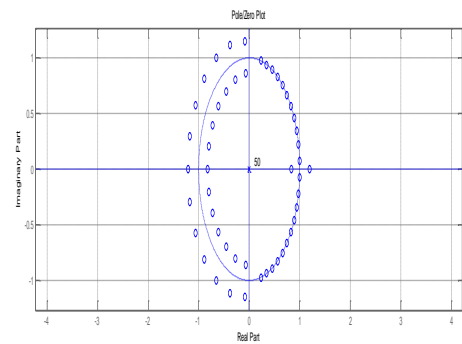Fig. 5: Phase response for Kaiser Window.



Fig.    6:    Pole/Zero    for    Kaiser Window.

Figures 4 to 6 above show the simulation results of Kaiser Window. The magnitude response, phase response and the pole/zero are all plotted. The magnitude response cuts at exactly 10.16 MHz with gap of 0.64 MHz between the specified cut off frequency (10.8 MHz). The phase changes at 10.20 MHz.
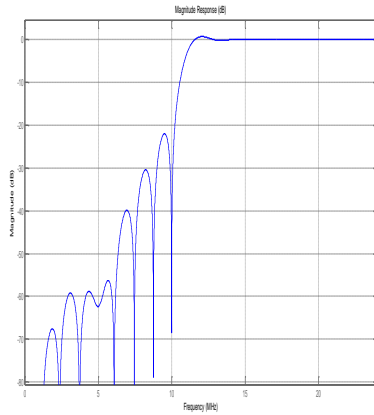
### C. **Tukey Window Simulations**
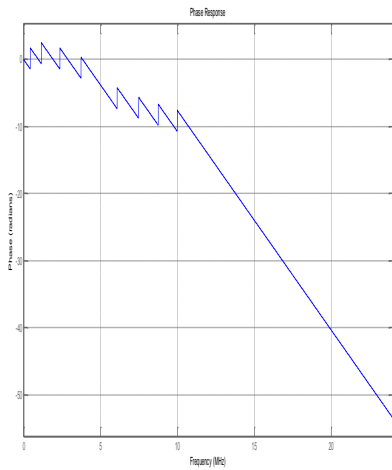


Fig. 7: Magnitude response for Tukey Window.
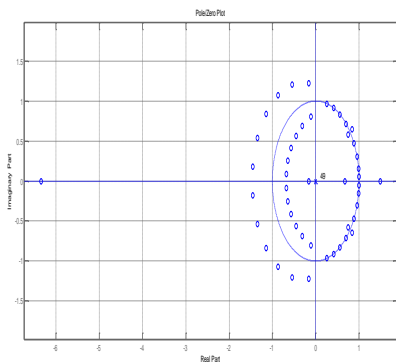


Fig. 8: Phase respose for Tukey Window.



Fig. 9: Pole/Zero for Tukey Window.

Figures 7 to 9 above show the simulation results of Tukey window. The magnitude response, phase response and the pole/zero are all plotted. The magnitude response cuts at exactly 10.00 MHz with gap of 0.8 MHz between the specified cut off frequency (10.8 MHz). The phase changes at 10.0 6 MHz.

### IV.     COMPARATIVE ANALYSIS

The magnitude responses, phase responses and pole/zero plots are combined in a single diagram for comparison as shown in the figures 10-12 below.
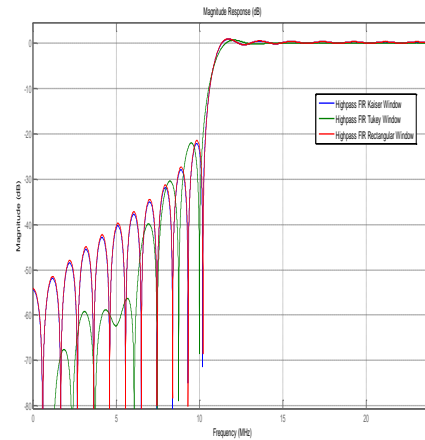


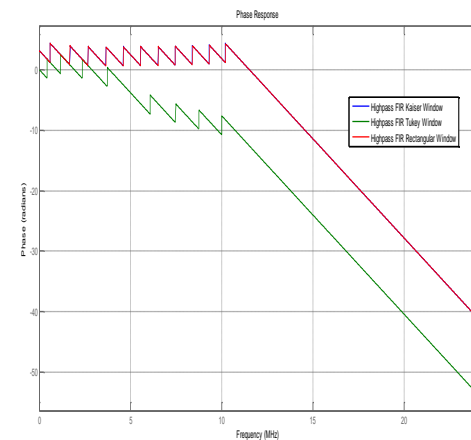Fig. 10: Comparison among magnitude responses.



Fig. 11: Comparison among phase responses.

In fig. 10 above, the magnitude responses of the Rectangular, Kaiser and Tukey windows are plotted together on a single figure for comparison. From the figure, it can be observed that Rectangular window cuts at 10.22 MHz, Kaiser window cuts at 10.16 MHz and Tukey cuts at 10.00 MHz. Based on the magnitude response comparison, Rectangular which cuts at 10.22 MHz is 0.58 below the exact specified cut off frequency (10.8 MHz), Kaiser which cuts at 10.16

MHz is 0.64 below the specified cut off frequency and Tukey which cuts at 10.00 MHz is 0.8 below the specified cut off frequency in the design.



Fig. 12: Comparison among pole/zero plots.

Table 2: Parameter comparison among the three windows.

| S/N | Parameter | Rectangular | Kaiser | Tukey |
|---|---|---|---|---|
| 1 | Magnitude response(MHz) | Cuts at 10.22 | Cuts at 10.16 | Cuts at 10.00 |
| 2 | Phase response(MHz) | Changes at 10.22 | Changes at 10.20 | Changes at 10.06 |
| 3 | Leakage factor | 9.25% | 8.4% | 3.61% |
| 4 | Relative Sideband Attenuation | -13.3dB | -13.6dB | -15.1Db |
| 5 | Stable | Yes | Yes | Yes |

There are various parameters upon which the comparative analysis can be made among the Rectangular, Kaiser and Tukey windows. Viewing closely figure 10 which compares the magnitude responses of the windows, it can be observed that Rectangular window cuts at 10.22168 MHz which is clearly closest to 10.8 MHz cut off frequency used for the proposed design. On the basis of magnitude responses, Rectangular windows appears to be the best for the proposed design.

## V.      CONCLUSION

This paper studies the comparative analysis of a proposed high pass FIR filter using Rectangular, Kaiser and Tukey window methods. The study shows that Rectangular window is the best for the proposed

filter design based on the magnitude responses of the three windows. This is because the magnitude response of the rectangular window is found to be the closest to the specified cut off frequency in the design.
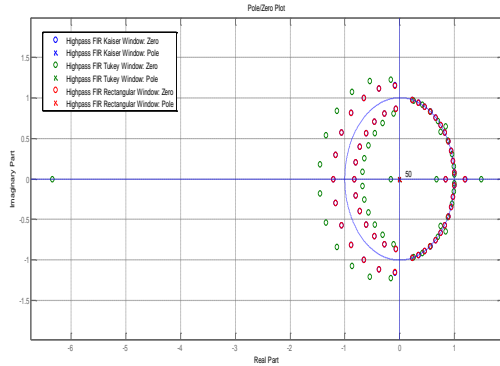
## VI.      ACKNOWLEDGEMENT

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