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Article

Towards Investigating the Properties of some Finite Impulse Response Filter in Signal Processing

[1]*Ebenezer Olukunle Oyebode and [2]Adewale Olatunji

[1]Department of Computer Science, Faculty of Natural Sciences, Ajayi Crowther University, Oyo, Nigeria.
eo.oyebode@acu.edu.ng (E.O.O.)
[2]Department of Physics, Faculty of Natural Sciences, Ajayi Crowther University, Oyo, Nigeria,
a.olatunji@acu.edu.ng (A.O.)

* Correspondence: eo.oyebode@acu.edu.ng; Tel: +234 803 248 1502

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Abstract

In this study, the use of windowing technique has been used to design filters within a range of specify order 35-40 alongside with adjustable parameters for each function. Three functions have been considered and results were obtained under each. The functions considered are Taylor window, Hamming window and Kaiser window. The results obtained showed that Hamming window generated the least relative sidelobe attenuation of -42.1Db and Leakage Factor of 0.04% at order 40 followed by Taylor window with level of relative sidelobe attenuation of -30.3dB and Leakage Factor of 0.44%. Kaiser window has relative sidelobe attenuation of -14.5dB and Leakage Factor of 8.54% while maintaining constant mainlobe width and same number of sidelobes. The conclusion is that when considering leakage factor and mainlobe width in terms of usefulness, Kaiser window can be preferred first followed by Taylor and Hamming windows but in terms of side lobe attenuation Hamming window is preferable followed by Taylor window and Kaiser respectively.

Keywords: Signal, Filter, Window, Leakage factor, Side lobe.

1. Introduction

A filter is a network that permits signals within certain frequencies to pass while blocking any other signals outside the specified range [3]. The primary purpose of filtering is to decompose the complex structure contained in the input signal into smaller components so as to identify and remove unnecessary element that has no useful information. Digital filtering forms one of the primary focuses of digital signal processing. A digital filter can perform mathematical operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal. Digital filter can make use of mathematical steps or algorithms to process digital input signals so that digital outputs with desired criteria can be achieved.

Digital filters are usually used for two general purposes which are:
(i) for separation of signals that have been combined together
(ii) for restoration of distorted signals in some way.

Using the type of impulse response, a digital filter may be classified as either FIR or IIR. The impulse response in signal processing for a dynamic system refers to its output when presented with a brief input signal [2]. A Finite impulse response (FIR) filter exhibits impulse response for a finite duration as it settles to zero in finite time. This makes FIR filters to have linear phase and they are easy to control. FIR filters are stable. Meanwhile, the infinite impulse response (IIR) filters can generate internal feedback and its response can be indefinite or in decay form. Its impulse response does not settle to zero. This category of filter is referred to as non-recursive filters. Fig. 1 below shows sample FIR filter.

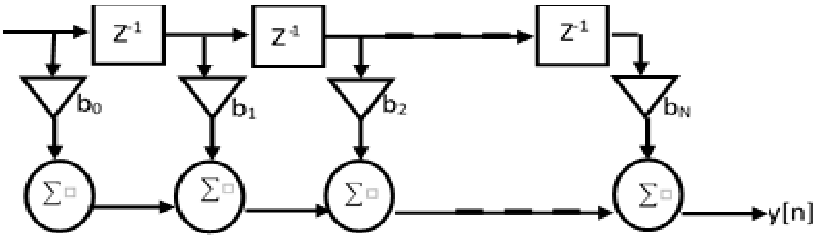


Figure 1: Sample FIR filter

The Z^{-1} represents the signal delay blocks for one sample and it can be implemented using buffers in practice. Whenever a signal arrives at the input of the Z^{-1} block, the signal $X_{(N-1)}$ will be generated at the output of this block. The output y of a linear time invariant system is determined by convolving its input signal with its impulse response b [4]. Its output sequence y[n] can be described in terms of its input sequence x[n].

$$y_{[n]} = b_0 x_{[n]} + b_1 x_{[n-1]} + \cdots + b_N x_{[n-N]} \qquad (1)$$

$$\sum_{i=0}^{N} b_i x_{[n-1]} \qquad (2)$$

Where

x[n] represents the input signal

y[n] represents the output signal

b_i represents coefficients or tap weights that make up the impulse response.

N represents the filter order.

FIR filter has a lot of applications in signal processing and can be implemented through the use of programmable digital processors. The FIR filter is capable of performing the weighted summations of input sequences with constant coefficients in most of the signal processing and multimedia applications. FIR filter is a digital filter that is useful in digital signal processing applications like imaging, instrumentation and communication, noise reduction, frequency boosting, digital audio equalizing, digital crossover etc. FIR filters are implementable in hardware since it does not allow division and feedback paths. Specific applications of filter in various areas include:

(i) Radar involves transmitting radio signals at distant and analyzing the reflections. It can involve positioning and movement of the object and can also be used to identify object via its "signature". Filter can be used to generate and shape the transmission pulses, control the antenna beam pattern, at the receiving end [8]. Its functions include space and time adaptive processing, removal of clutter and beamforming (electronic guidance of direction). Ground-based radar, Ship borne radar, Airborne radar and Space borne radar are examples of radar applications involving filters.

(ii) Sea wave do result in roll and pitch motions on ships. The ship rotational motion can cause error in measurement. To overcome this effect, there is need for antenna stabilization to achieve the beam pointing accuracy over a duration. Ship-borne phased array radar do engage filter meanifully to achieve this purpose. Adaptive filter for roll/pitch prediction, ship/earth coordinates conversion, ship motion compensation and target tracking accuracy etc are some of the stages involved [7].

(iii) Image processing and filtering: Most images have the tendency of some kind of unwanted noises that can have negative effect on the image quality. Such image then requires analysis and removal of noise from the image. It can further be used for image processing to achieve a better resolution or to emphasize the edges properly. Box filter, gaussian filter, bilateral filter etc are common types of filter used for image processing [11].

Echo cancellation is very useful in audio teleconferencing, especially in simultaneous communication of speech. Echo is the outcome of repetition of a waveform due to reflection from points where the characteristics from the medium over which the wave propagates changes. Echo cancellation system can be built using adaptive filters. It is also applicable in consumer electronics- Digital Audio/TV, electronic music synthesizer, educational toys, FM stereo application and sound recording applications [7].

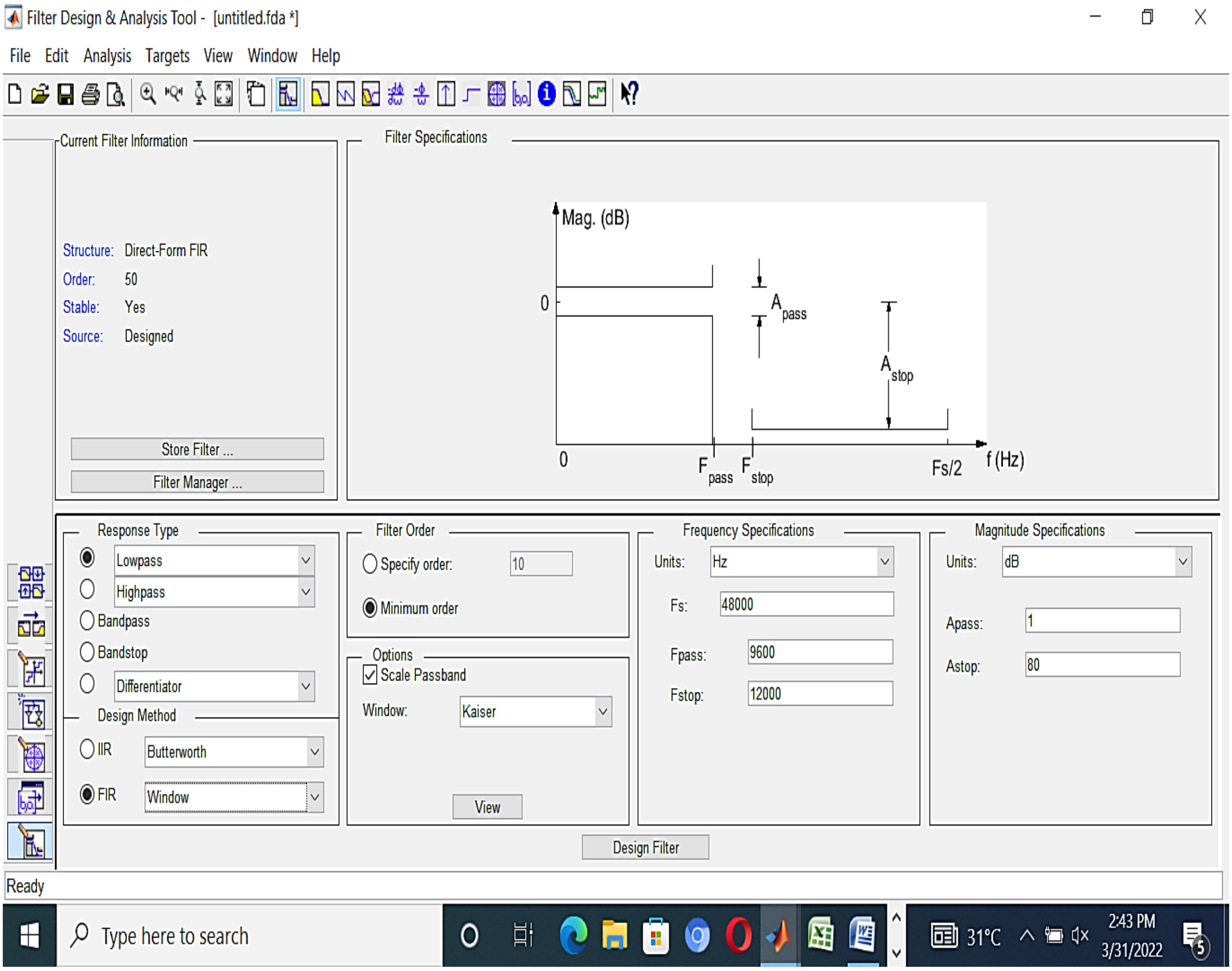
2. Methods

The design procedure in this study considered the technique of window functions for designing filter. The two basic factors that describe a window function are:

(a) the width of the main lobe which refers to frequency bin in which the power is half that of the maximum response).

(b) the attenuation of the side lobes which refers to how far away down are the side lobes from the main lobe). This explains the spectral leakage in the window.

The processing procedure was carried out using the FDA Tool of MATLAB for Kaiser, Hamming and Taylor windows. The interface for the design is shown in Fig. 2. The basic features of the windows that reflected in its performance for the selected functions were discussed below.



Filter Design & Analysis Tool - [untitled.fda *]

Structure: Direct-Form FIR
Order: 50
Stable: Yes
Source: Designed

● Lowpass
○ Highpass
○ Bandpass
○ Bandstop
○ Differentiator

○ IIR Butterworth
● FIR Window

○ Specify order: 10
● Minimum order

☑ Scale Passband
Window: Kaiser

Units: Hz
Fs: 48000
Fpass: 9600
Fstop: 12000

Units: dB
Apass: 1
Astop: 80

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Figure 2: Design interface for window functions.

(i) Kaiser window was based on discrete-time approximations of the prolate spheroidal wave functions. It has a flexible parameter β that can be chosen to meet a given stopband attenuation, also the window length N can be chosen to meet certain requirements. A window is essentially a time-limited function with a lowpass type transform. The Kaiser window is a discrete-time approximations of an optimal continuous time family of functions. It is defined using eq(3).

In Kaiser window, the width of the mainlobe is inversely proportional to the length of the filter. It has been established that the length of the filter needed to increase considerably in other to reduce the main lobe width and to achieve the desired transition band [9]. Kaiser window can be used to control the side lobes through the main lobes by varying the parameters. Kaiser windows can be applied to maximize the energy concentration at main lobes [6]. It can give information about the amount of ripple and the transition bandwidth than the filter length.

$$W_{(n)} = I_0 \left[\frac{\pi\alpha\sqrt{1-(\frac{2n}{N-1}-1)^2}}{I_0(\pi\alpha)} \right] \qquad (3)$$

Where I_0 = *the zero-order modified Bessel function of the* α *first kind*

N = *window length*

α = *non-negative real number that determines the shape of the window*

(ii) Hamming window is a modified extension of Hann window as it is a raised cosine window [5]. The spectral windows of both Hemming and Henn windows are additions of three-shifted kernels. The mathematical function for hamming window can be expressed using eq(4).

$$W_{(n)} = \alpha - \beta cos \left[\frac{2\pi n}{\mu-1}\right] \qquad (4)$$

$$where\ \beta = 1 - \alpha$$

(iii) The Taylor windows operate to allow tradeoffs between the mainlobe width and side lobe level. The Taylor window distribution seeks to avoid edge discontinuities which makes Taylor window side lobes to decrease monotonically [1]. The Taylor function can be obtained from a weighted cosine series plus a constant. The co-efficients of Taylor windows are not normalized. [10] described taylor window using eq

$$w(n) = (-1)^{n+1}\frac{1}{n}\exp\left(\frac{-n^2}{2r^2}\right) \qquad (5)$$

$$where, -\frac{(N-1)}{2} \le n \le \frac{(N-1)}{2} \qquad (6)$$

3. Results

Fig. 3.01 – 3.06 represents the performance of the Hamming windows at order 35-40. Fig. 3.07 – 3.12 represents the performance of the Taylor windows at order 35-40 while 3.13 – 3.18 represents the performance of the Taylor windows at order 35-40 respectively. The results obtained showed that Hamming window generated the least relative sidelobe attenuation of -42.1Db and Leakage Factor of 0.04% at order 40 followed by Taylor window with level of relative sidelobe attenuation of -30.3dB and Leakage Factor of 0.44%. While Kaiser window alongside with its beta parameter adjustment that enables it to further reduce relative sidelobe attenuation to -13.6dB and Leakage Factor of 8.52% while maintaining relatively close constant mainlobe width and same number of sidelobes.

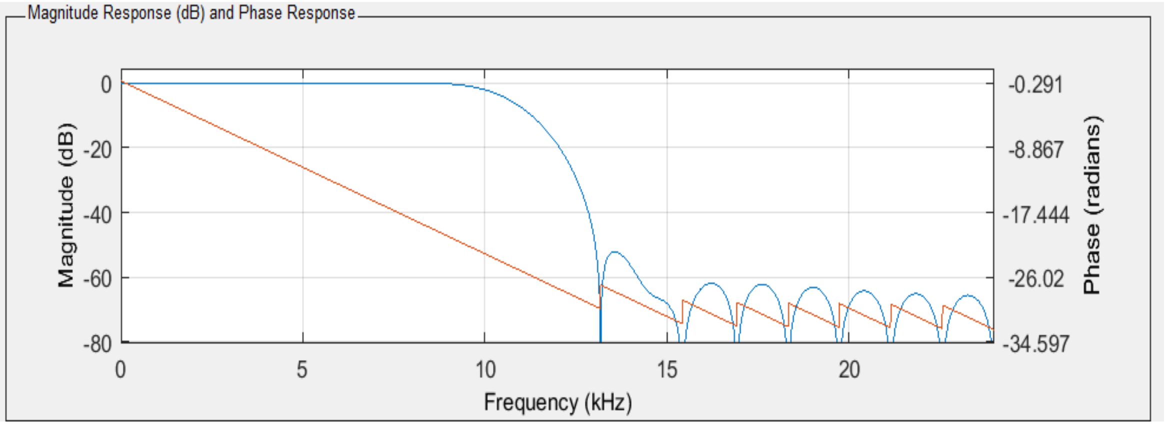

Figure 3.01: Low FIR with Hamming at order length 35

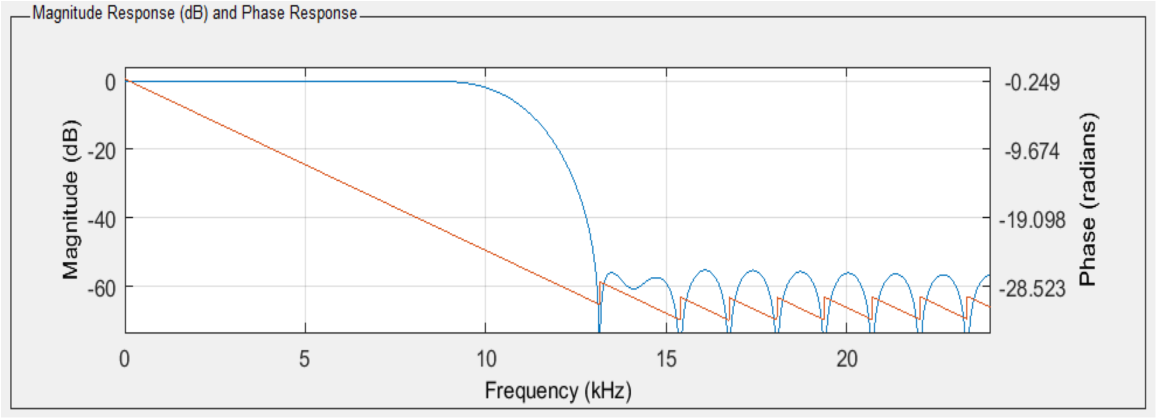

Figure 3.02: Low FIR with Hamming at order length 36

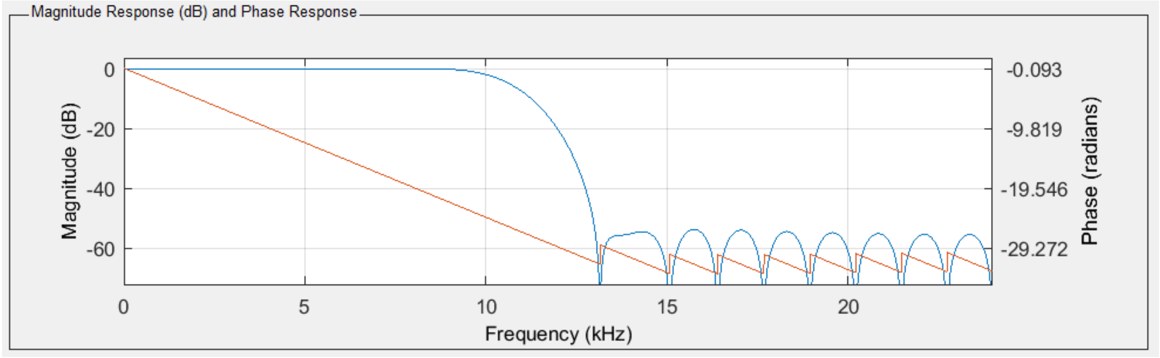

Figure 3.03: Low FIR with Hamming at order length 37

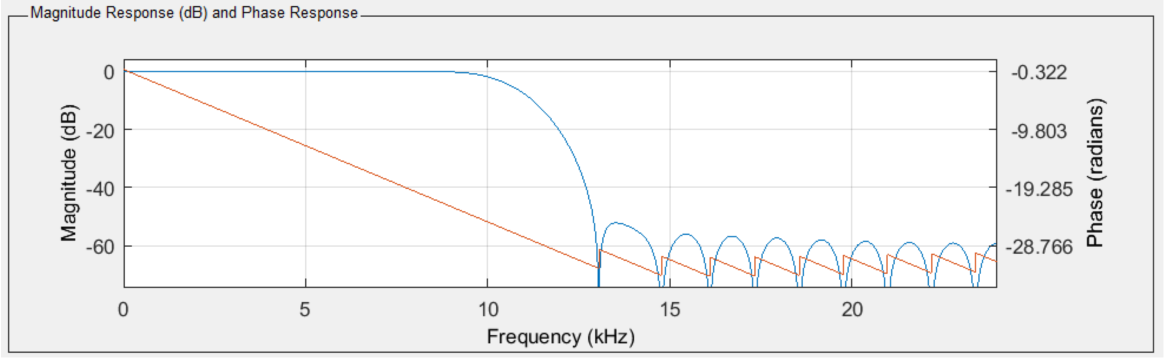

Figure 3.04.: Low FIR with Hamming at order length 38

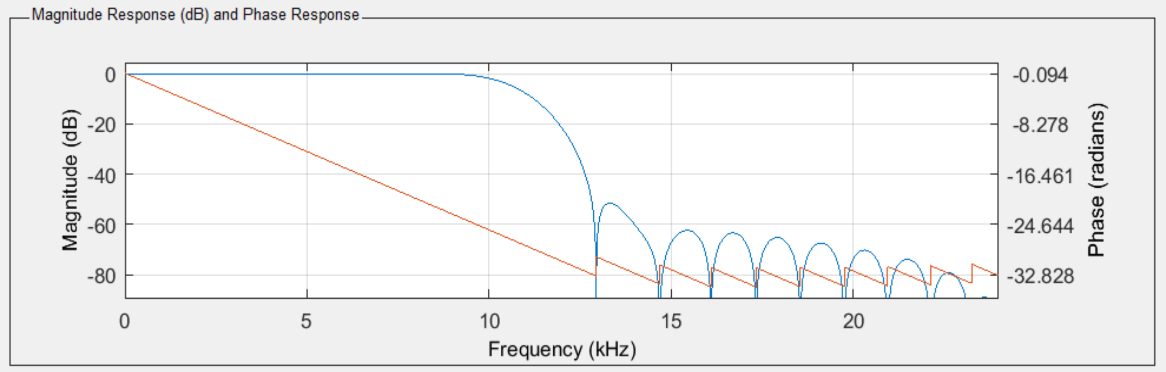

Figure 3.05: Low FIR with Hamming at order length 39

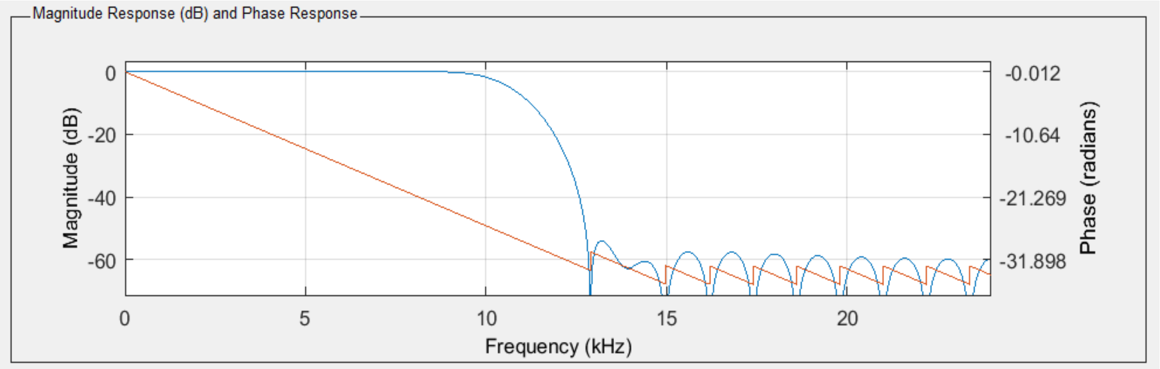

Figure 3.06: Low FIR with Hamming at order length 40

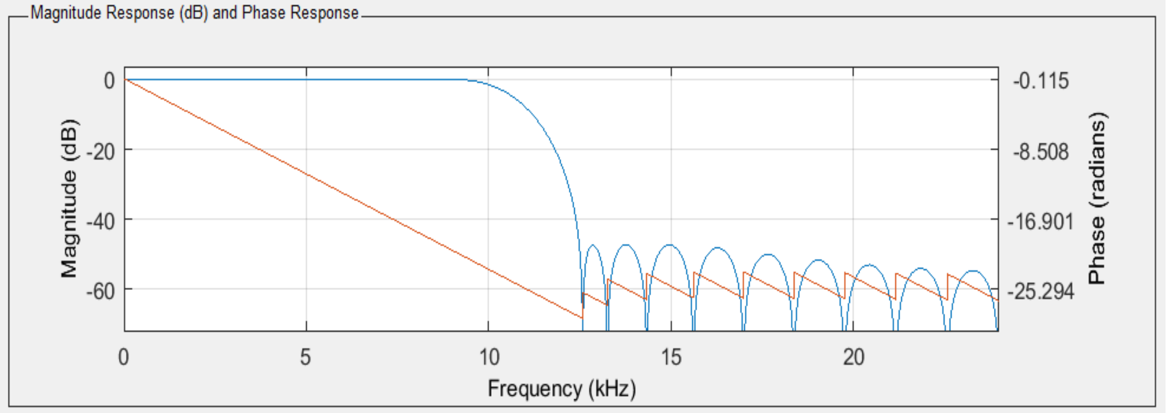

Figure 3.07: Low FIR with Taylor at order length 35

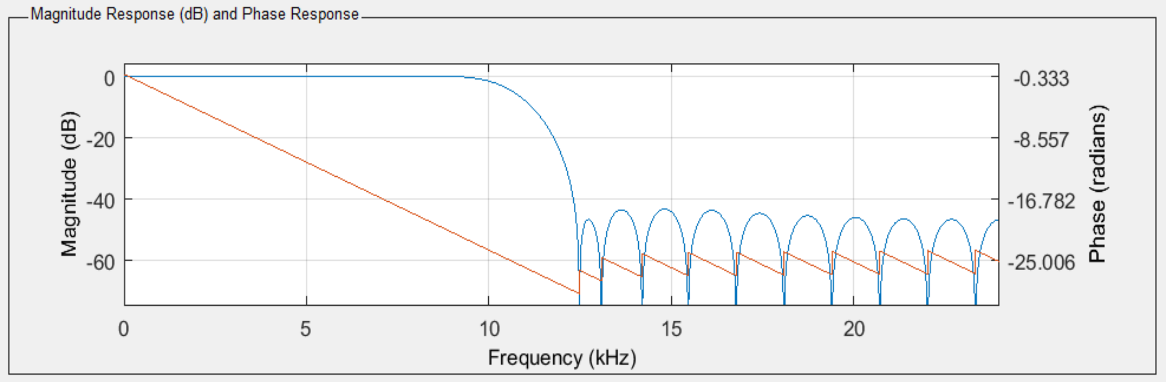

Figure 3.08: Low FIR with Taylor at order length 36

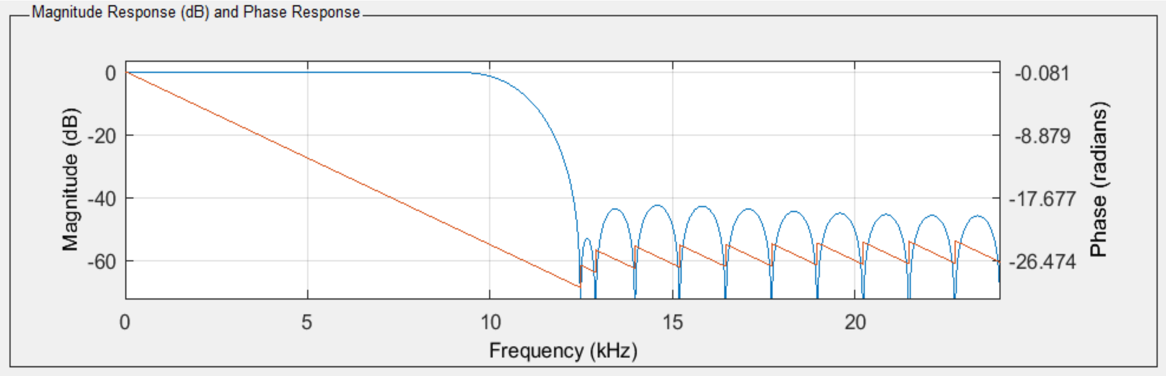

Figure 3.09: Low FIR with Taylor at order length 37

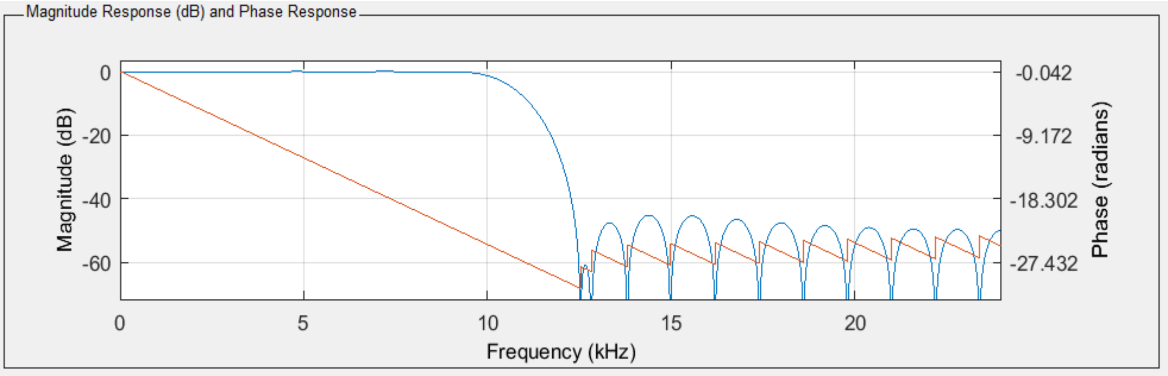

Figure 3.10: Low FIR with Taylor at order length 38

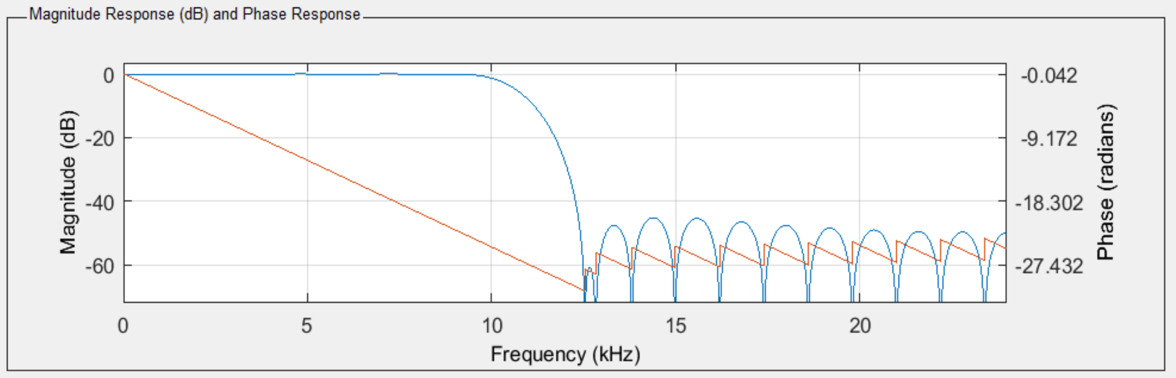

Figure 3.11: Low FIR with Taylor at order length 39

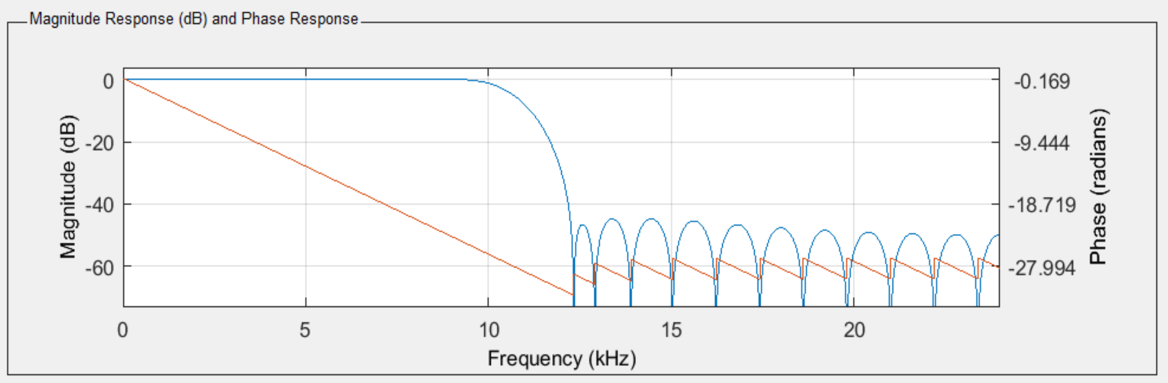

Figure 3.12: Low FIR with Taylor at order length 40

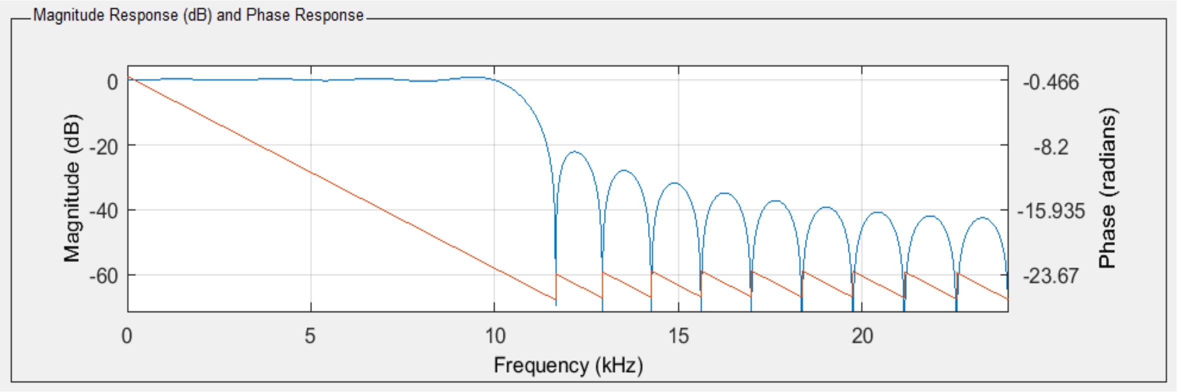

Figure 3.13: Low FIR with Kaiser at order length 35

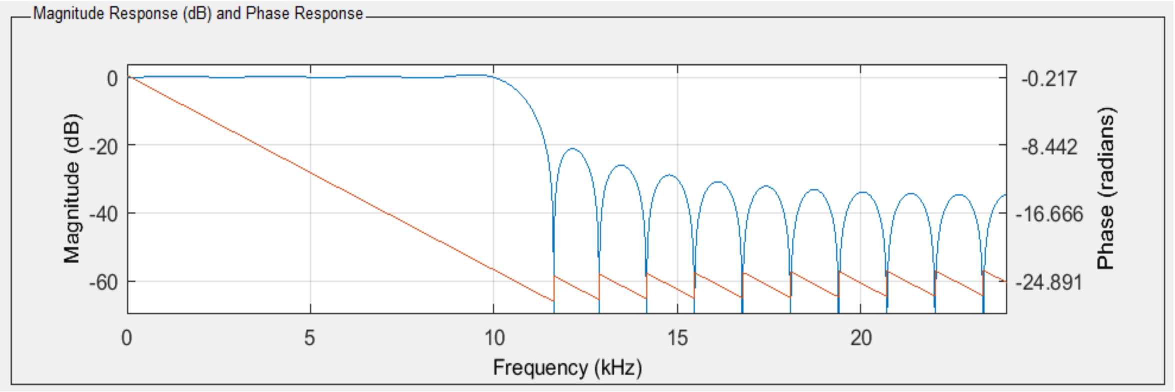

Figure 3.14: Low FIR with Kaiser at order length 36

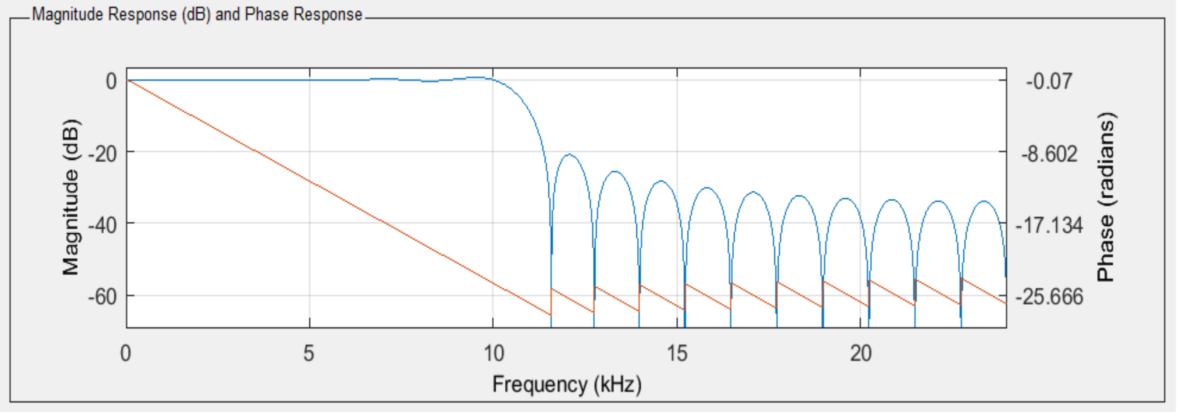

Figure 3.15: Low FIR with Kaiser at order length 37

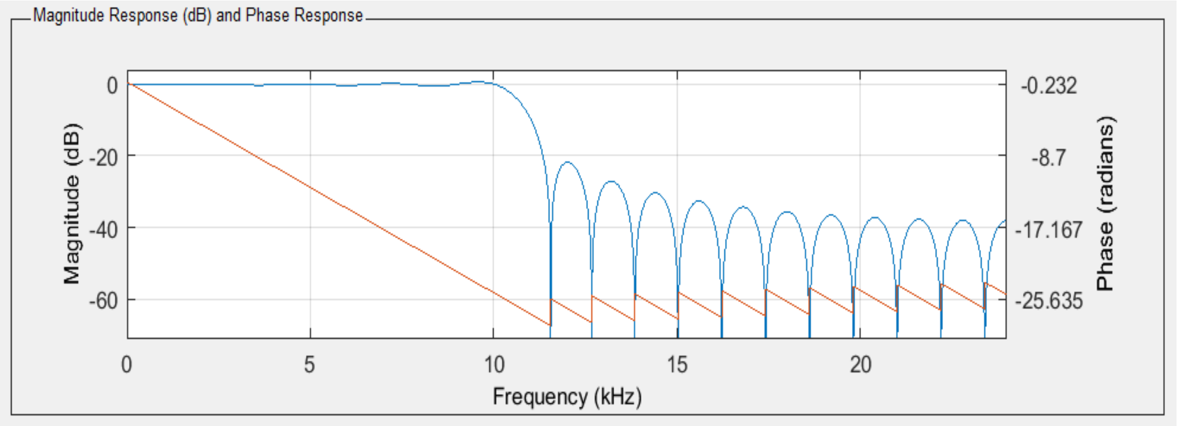

Figure 3.16: Low FIR with Kaiser at order length 38

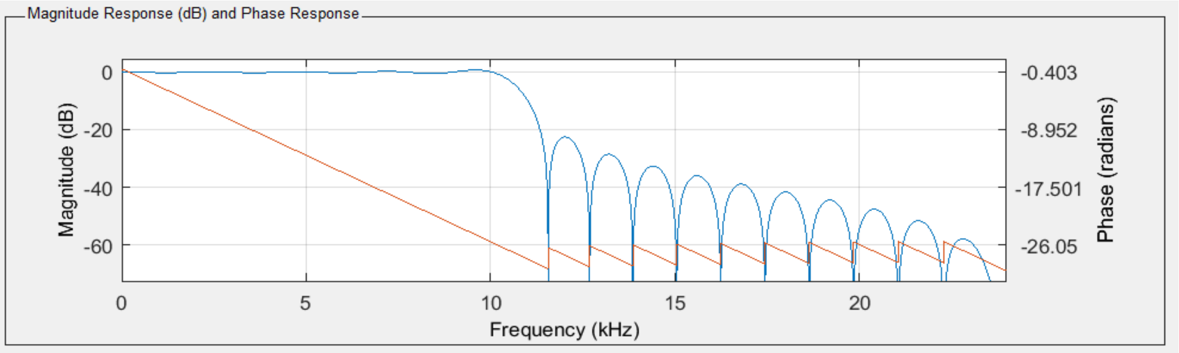

Figure 3.17: Low FIR with Kaiser at order length 39

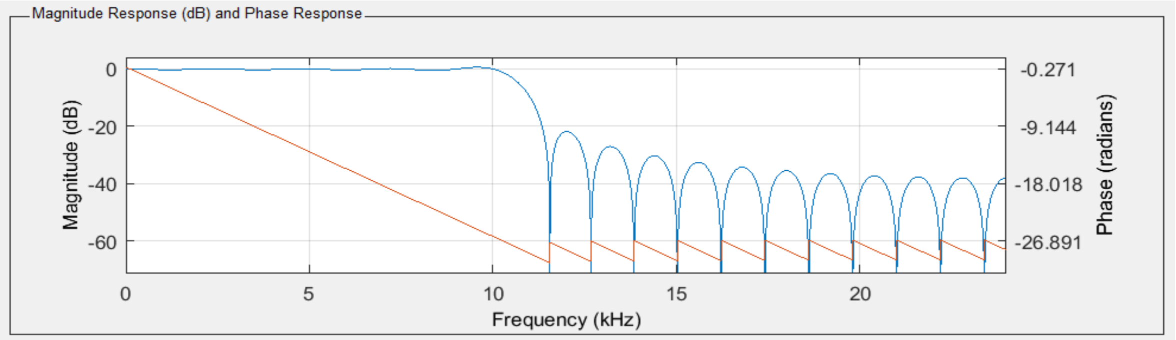

Figure 3.18: Low FIR with Kaiser at order length 40

Table 1 shows the results obtained for each window function at order 35-40 using Leakage factor, Relative sidelobe attenuation and Mainlobe width. Fig. 4 shows the comparism among the three window functions using the mainlobe width.

Table 1: Filter order 35-40 for Hamming, Taylor and Kaiser Windows.

	Filter order	Leakage factor	Relative sidelobe attenuation	Mainlobe width
Hamming				
	35	0.04%	-41.9	0.074219
	36	0.04%	-42	0.070313
	37	0.04%	-42	0.070313
	38	0.04%	-42	0.066406
	39	0.04%	-42.1	0.066406
	40	0.04%	-42.1	0.0625
Taylor				
	35	0.44%	-30.3	0.0626
	36	0.44%	-30.3	0.058594
	37	0.44%	-30.3	0.058594
	38	0.44%	-30.3	0.058594
	39	0.44%	-30.3	0.054688
	40	0.44%	-30.3	0.054688
Kaiser				
	35	8.54%	-13.6	0.050781
	36	8.54%	-13.6	0.046875
	37	8.54%	-13.6	0.046875
	38	8.53%	-13.6	0.046375
	39	8.52%	-13.6	0.042969
	40	8.52%	-13.6	0.042969

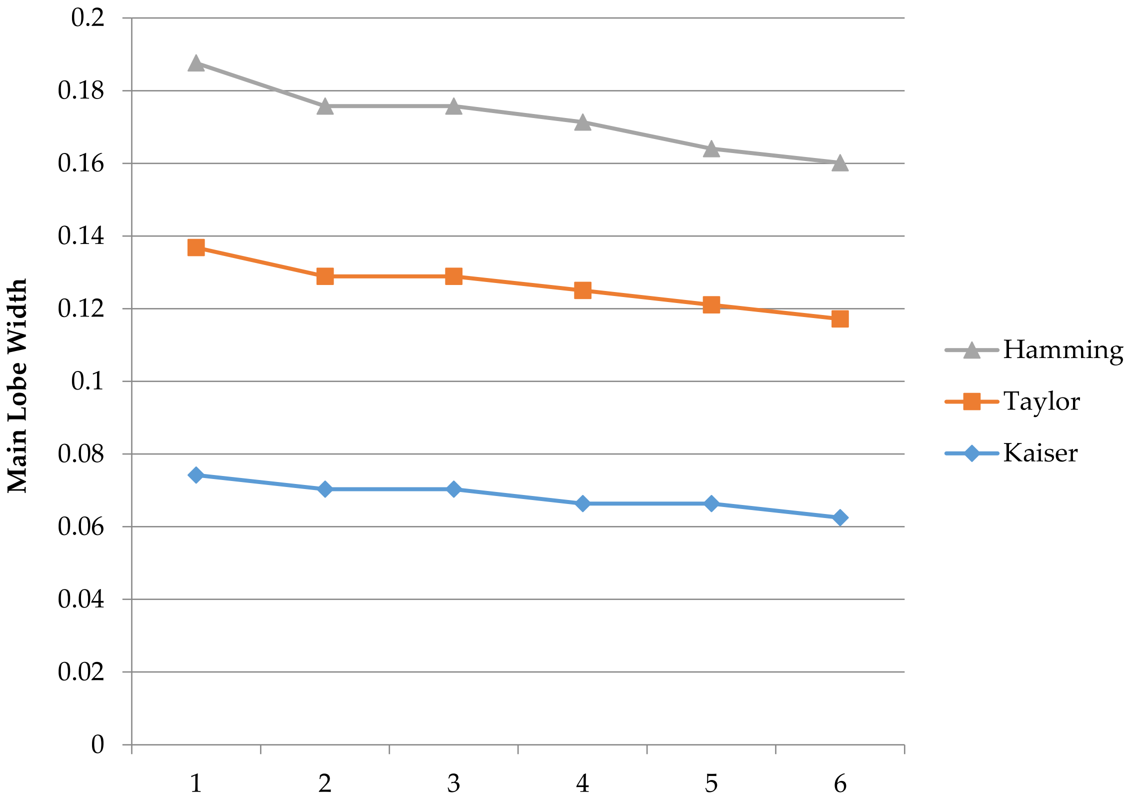

Figure 4: Comparism of the Mainlobe results for three window functions

4. Discussion

In this study, lowpass filter has been designed using three window functions (Hamming, Taylor and Kaiser). From the results obtained, the characteristics of the window functions under consideration can be known. The results show various usefulness or areas in signal processing where the functions may be further deployed. The Kaiser window with very high leakage can found usefulness in noise reduction systems and echo cancellation while its relatively low mainlobe width is added advantage over others as it can reduce signal distortion. It is followed by taylor function and Hamming window demonstrated the least. In terms of side lobe attenuation, Hamming window has the lowest relative sidelobe attenuation which can be useful followed by Taylor window and Kaiser maintains the highest.

5. Conclusions

Window functions use in signal processing do not exhibit the same characteristics. Using the features, the strength of each function can be known prior to further applications of such windows in signal processing as demonstrated in this study. Selecting window function with required features can improve results in signal processing.

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