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Efficient Design of Low Pass Fir Filter by Rectangular, Taylor and Kaiser Window Techniques

Pramod Yadav[1], Shankarlal Sahu[2], Pranay Kumar Rahi[3]

B.E. Scholar, Department of Electrical and Electronics Engg, Institute of Technology, Korba Chhattisgarh, India[1,2]

Assistant Professor, Department of Electrical and Electronics Engg, Institute of Technology, Korba Chhattisgarh, India[3]

Abstract: The aim of this paper is to design FIR filter of the order "30" using various window function methods. Digital filter are widely used in the world of communication and computation. On the other hand to design a Digital Finite Impulse Response (FIR) Filter that satisfies. This paper presents the importance of filter in signal processing. Digital filter are two type 1. FIR and 2. IIR. These are various methods for filter designing. This paper discuss the window method low pass fir filter designing rectangular, taylor and Kaiser window function methods are presented. Design of FIR filter is done in MATLAB by FDATOOL low pass filter is designed with sampling frequency 48000Hz and cut-off frequency 10000Hz magnitude, phase impulse, step response and pole, zero plot. We found that filter designing by window method is easy and fast.

Index Terms: FIR Digital filter, DSP, low pass filter, window function, MATLAB, FDATOOL in MATLAB, rectangular window, taylor window, and Kaiser window techniques.

1. INTRODUCTION

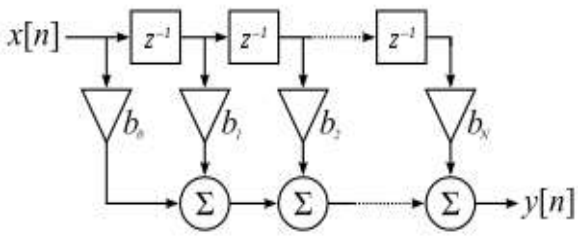
Digital Signal Processing is the technique employed for the mathematical manipulation of an information signal so as to modify or improve it. For this purpose filters are mainly used. The filter is used to describe a linear time invariant system used to performing spectral shaping or frequency selective filtering[1]. It is the network which changes the amplitude, frequency, phase frequency characteristics of the signal in desired manner. Digital filters have characteristics such as linear phase response. If we compare digital filter with analog. Filter they are preferred in number of application like speech processing, image processing and data compression[2].

1.1 BASIC PRINCIPLE OF FIR WINDOW TECHNIQUE

The most straightforward to FIR filter design is to obtain a finite length impulse response by truncating an infinite duration impulse response sequence. If we suppose that $H_d(e^{j\omega})$ is an ideal desired frequency response, then

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

Where $h_d(n)$ is the corresponding impulse response[3].



Figure–1. Block Diagram of an FIR Filter.

In the window design method, first the desired filter impulse response $h_d(n)$ is evaluated from the given desired frequency response $H_d(\omega)$, and then an appropriate window is applied that satisfies pass band or attenuation specification. Finally filter coefficient are derived for the given filter. When $H(\omega)$ is simulated on a computer using MATLAB software with N in the hundreds then it is seen that there is non-zero transition width, overshoots and ripples due to the gibbs phenomenon[4].

$h[n] = h[N-1-n]$, $n=0,1,2,\ldots.(N-1)$

$H(e^{j\omega}) = \sum_{n=0}^{N-1} h[n]e^{-j\omega n}$

$= \sum_{n=0}^{\frac{N}{2}-1} h[n]e^{-j\omega n} + \sum_{n=\frac{N}{2}}^{N-1} h[n]e^{-j\omega n}$

$= \sum_{n=0}^{\frac{N}{2}-1} h[n]e^{-j\omega n} + \sum_{m=0}^{\frac{N}{2}-1} h[m]e^{-j\omega(N-1-m)}$ [5]

2. WINDOWS AND THEIR EQUATIONS

Several window function have been proposed. Listed below are some of the most common.

- Rectangular window
- Taylor window
- Kaiser window

To reduce the oscillation in fourier series method, the fourier coefficient are modified by multiplying the infinite impulse response by a finite weighing sequence $\omega(n)$ called a window. Windows are characterize by the main lobe width which is the bandwidth between first negative and first positive zero crossing and by their ripple ratio.

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The main lobe far as possible in the main lobe and the energy in the side lobe should be as low as possible[6].
The Kaiser window is a kind of two parameter window function. In a Kaiser window width of main lobe can be controlled by adjusting the length of the filter and side lobe level can be controlled bby varying the order parameter. But the Kaiser window has the disadvantage of higher computational complexity due to the use of vessel function in the calculation of the window coefficient.

However the amplitude of the side lobe and ripples in pass band is also increased. The function is

$$\omega(n) = \begin{cases} a - (1-a)\cos\left(\frac{2\pi}{M-1}\right), 0 \le n \\ \le M-1 \end{cases}$$

otherwise the value of ω(n) is zero[6].

2.1 RECTANGULAR WINDOW

The rectangular window is what you would obtain if you were to simply segment a finite portion of the impulse response without any shapping in the time domain .

$$\omega(n) = \begin{cases} 1, 0 \le n \le M \\ 0, \text{otherwise} \end{cases}$$

we have studied this function extensively in class and known it's DTFT to be

$$\omega(e^{j\omega}) = \frac{\sin\left(\frac{M\omega}{2}\right)}{\sin\left(\frac{\omega}{2}\right)} e^{\frac{-j\omega M}{2}}$$

compare the plots of the original sinc function above and its magnitude plotted in dB.
$20\log_{10}(I\omega(e^{j\omega})I)$. [7].

2.2 TAYLOR WINDOW

Taylor function are obtained from a weighted – cosine series added to a constant, or a pedestal. A similar form of these function can be obtained by dropping from of some of the higher – order terms. If all, except the first term, are dropped, a taylor function is obtained which can be expressed as

$$f(x) = \begin{cases} \frac{(1+K)}{2} + \left(\frac{1-K}{2}\right)\cos\frac{\pi t}{\tau}, ItI < \tau \\ 0, \quad \text{otherwise} \end{cases} \quad [8].$$

2.3 KAISER WINDOW

The width of the main lobe is inversely proportional to the length of the filter. The attenuation in the side lobe is, however, independent of the length and is function of the type of the window.

Therefore the length of the filter must be increased considerably to reduce the main lobe width and to achieve the desired transition band.

Kaiser has chosen a class of window having properties closely approximating those of the prolate spheroidal wave functions. This family of window, known as the Kaiser window is defined by

$$W_k(\beta,n) = \frac{I_s\left\{\beta\sqrt{\left[1-\left(\frac{2n}{N-1}\right)^2\right]}\right\}}{I_s(\beta)}, -\frac{N-1}{2} \le InI \le \frac{N-1}{2}$$
$$0 \quad , \text{otherwise. [9].}$$

2.4 WINDOW FUNCTION METHOD FOR FIR FILTER DESIGN

Window function can be divided into two parts: fixed window function and adjustable window function. Rectangular, taylor and Kaiser window are type of adjustable window function. Adjustable window function is best because it has control parameter[2].
Parameters used for FIR low-pass Filter to obtain magnitude, phase step response and pole, zero plot

3. SIMULATION AND RESULT

Table – 1. Parameter specification

PARAMETER	VALUE
Sampling frequency(f_s)	48000Hz
Cut-off frequency(f_c)	10000Hz
Order(N)	30

Table – 2. Frequency and magnitude

frequency	Window technique		
	rectangular	taylor	kaiser
0.1π	0.222	0.025	0.182
0.2 π	0.581	-1.296	0.657
0.3 π	-1.725	-3.177	-2.738
0.4 π	-3.610	-4.670	-4.529
0.5 π	-4.851	-6.366	-6.213
0.6 π	-5.944	-7.095	-7.789
0.7 π	-7.277	-9.623	-9..440
0.8 π	-8.876	-11.713	-10.757
0.9 π	-10.773	-13.095	-12.077
π	-12.434	-14.489	-14.398

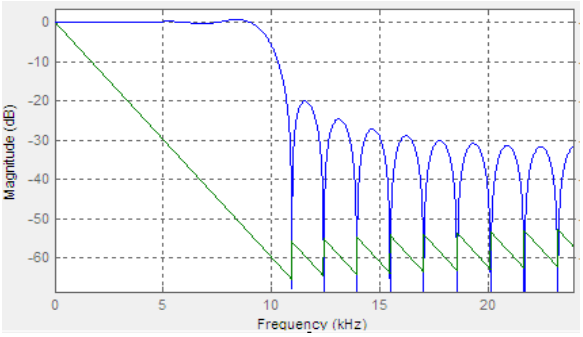

Figure-2. Rectangular Magnitude and Phase response

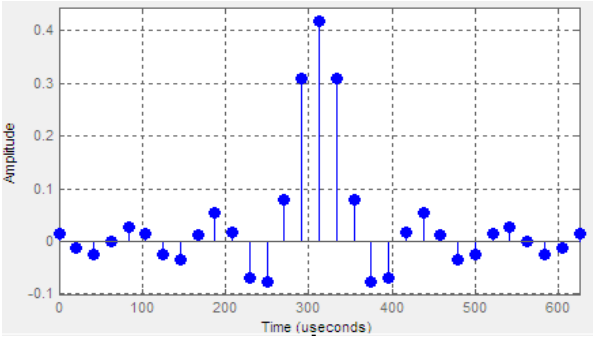

Figure-3. Rectangular Impulse Response.

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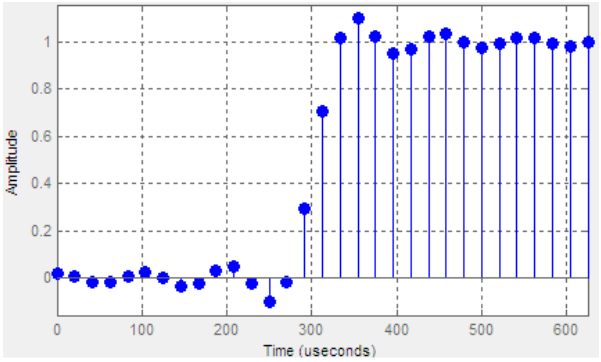

Figure-4. Rectangular Step Response.

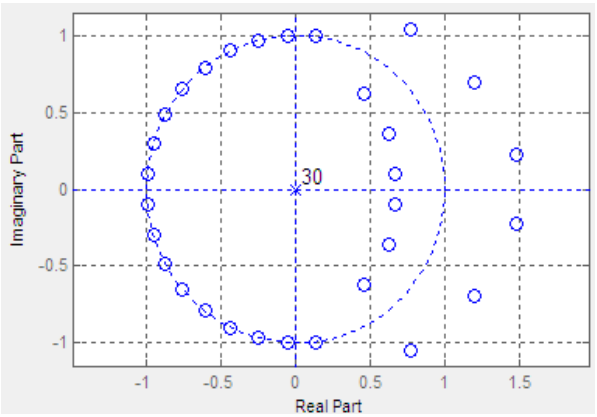

Figure-5. Rectangular Poles and Zeros.

```
 0.015092330660604244
-0.011434167165024546
-0.023788277405423278
 0.00000000000000001633661892282358 8
 0.028113418751863867
 0.016007834031034378
-0.025153884434340443
-0.034657977326102027
 0.011837520908776999
 0.053359446770114533
 0.016572529272287813
-0.06931595465220404
-0.075461653303021223
 0.080039170155171785
 0.30924760627050263
 0.41908411493151859
```

Figure-6. Rectangular Filter Coefficient.

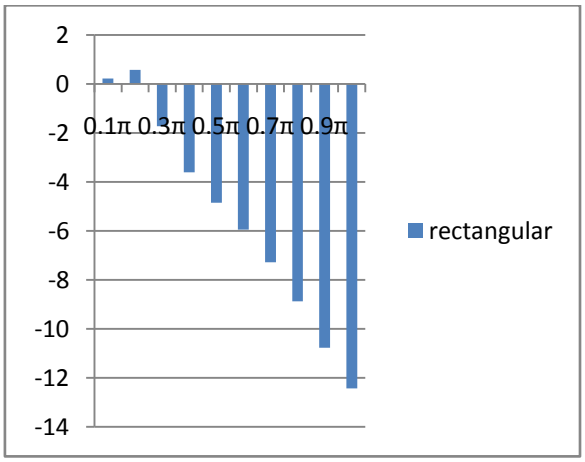

Figure-7. Magnitude and frequency plot of rectangular window.

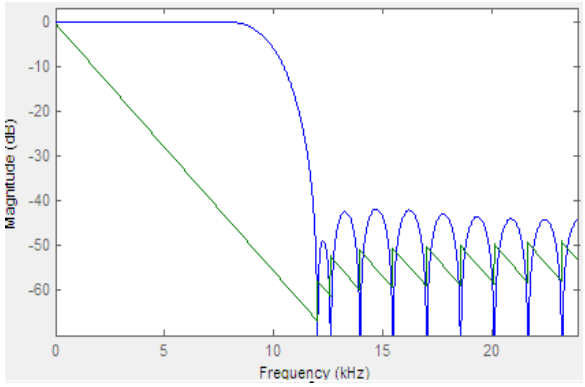

Figure-8. Taylor magnitude and phase response.

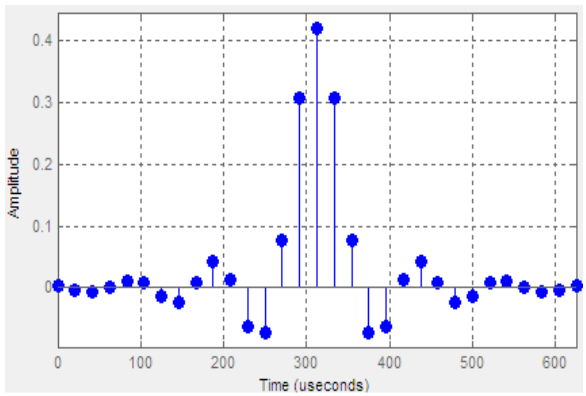

Figure-9. Taylor impulse response.

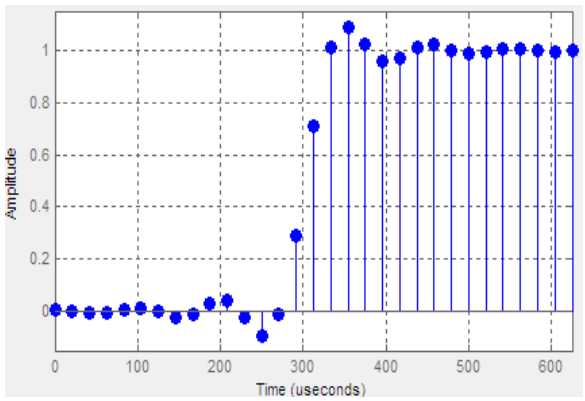

Figure-10. Taylor step response.

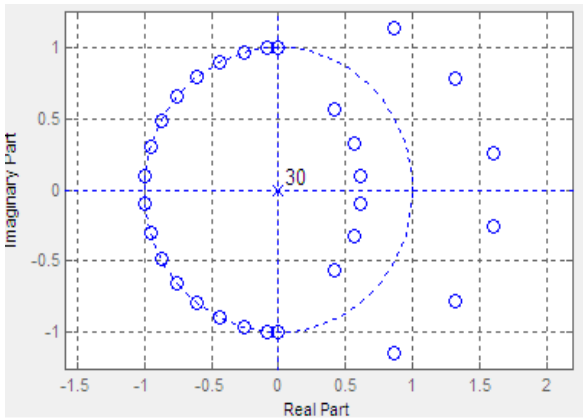

Figure-11. Taylor poles and zeros plot.

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```
 0.0036894761726505181
-0.0030168804875024824
-0.0071635672756452965
 0.00000000000000000577656063787658 8
 0.011741196181644304
 0.0078328212548579162
-0.014205649758825951
-0.022197694545313538
 0.0084470104697375436
 0.04171013849238462
 0.013968338408209539
-0.062072099195072367
-0.070796105853692531
 0.077611652729174738
 0.30584714613118191
 0.41720843455242196
```

Figure-12. Taylor filter coefficient.

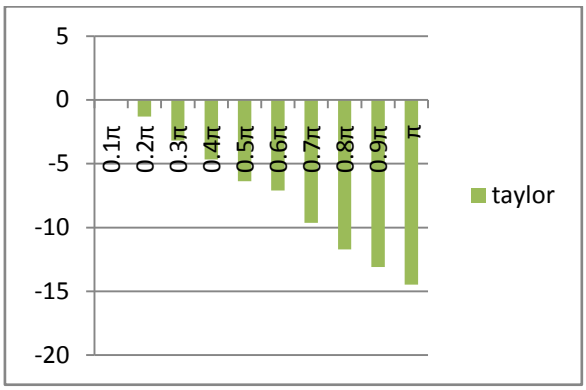

Figure-13. Magnitude and frequency plot of taylor window.

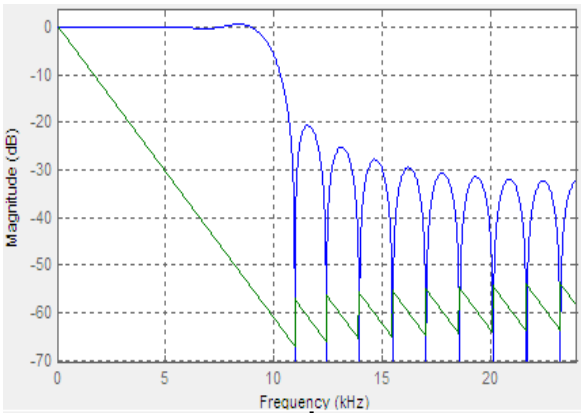

Figure-14. Kaiser magnitude and phase response.

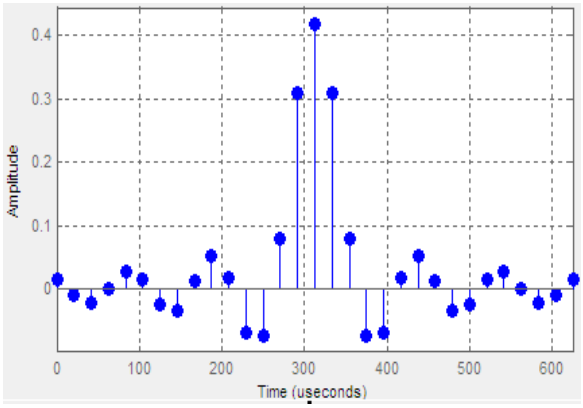

Figure-15. Kaiser impulse response.

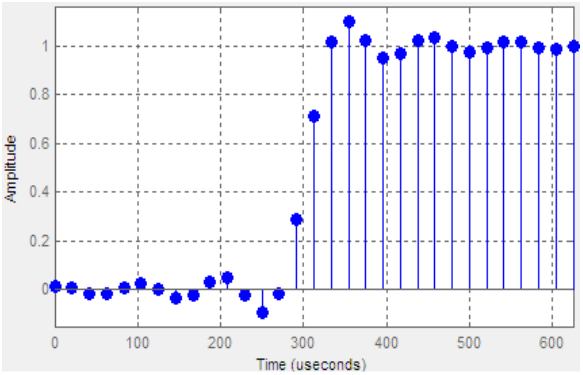

Figure-16. Kaiser step response.

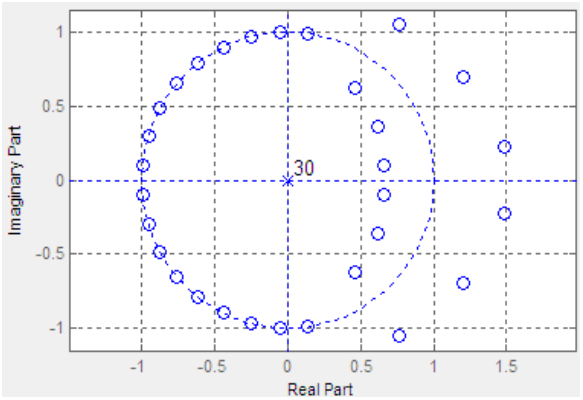

Figure-17. Kaiser poles and zeros plot.

```
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-0.022713142557357544
 0.00000000000000001570594291947082 1
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-0.024603153780010763
-0.034056304756821497
 0.011679481471003504
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 0.016457878007063019
-0.069004001408071294
-0.075264098346048608
 0.079937344538486318
 0.3091040224421096
 0.41900242388911402
```

Figure-18. Kaiser filter coefficient.

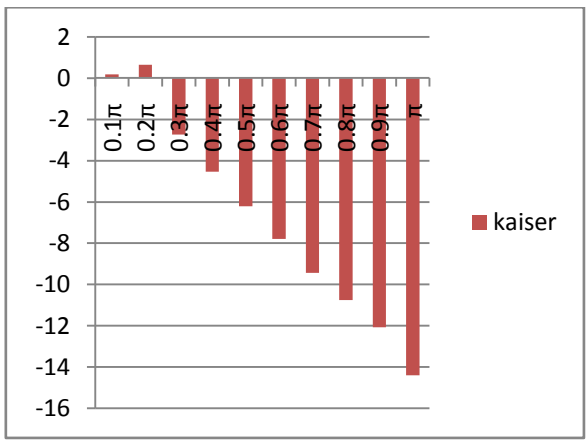

Figure-19. Magnitude and phase plot of Kaiser window.

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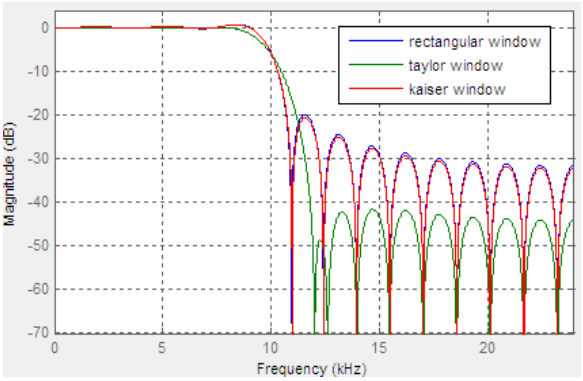

Figure-20. Magnitude response comparison of rectangular, taylor and Kaiser window.

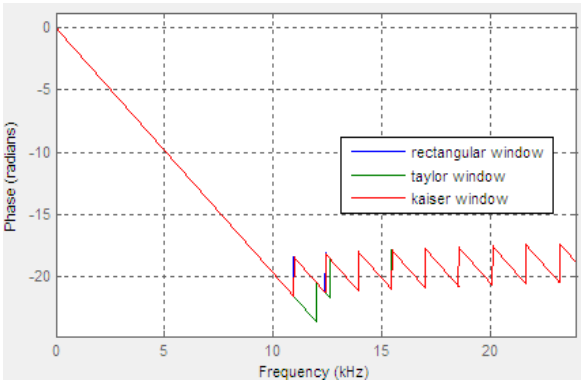

Figure-21. Phase response comparison of rectangular, taylor and Kaiser window.

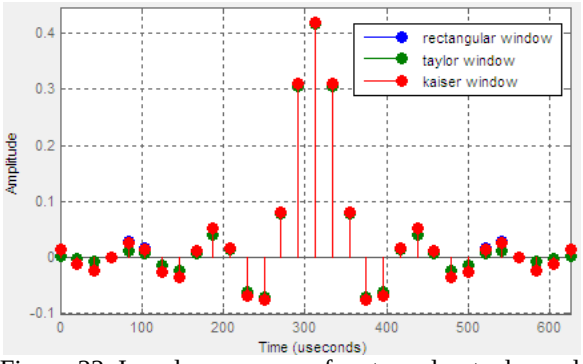

Figure-22. Impulse response of rectangular, taylor and Kaiser window.

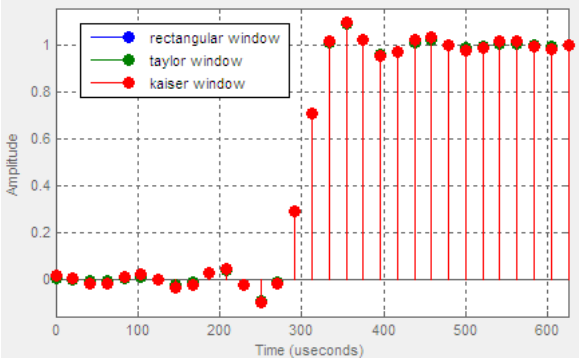

Figure-23. Step response comparison of rectangular,taylor and Kaiser window.

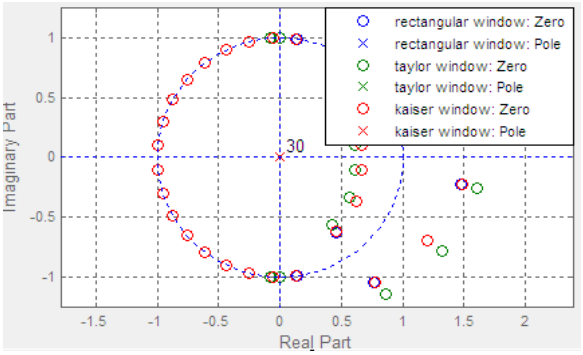

Figure-24. Pole and zero comparison of rectangular, taylor and Kaiser window.

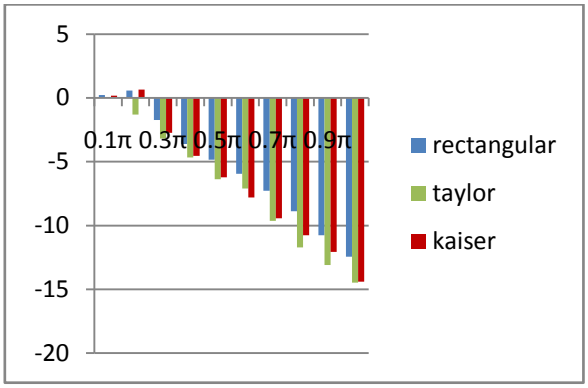

Figure-25. Magnitude and frequency plot of rectangular, taylor and Kaiser window.

4. CONCLUSION

This paper discuss FIR low pass filter hs been designed and simulated using rectangular, taylor and Kaiser window technique. Taylor window main lobe width is increase and decrease the amplitude of side lobes that is increase the attenuation. Taylor window has greater main lobe width and less leakage factor in comparison of rectangular and taylor window. The result show that the filter design using modified window function has a small main lobe width and sharp transition band compared to rectangular, taylor and Kaiser window function. The major advantages of window technique is its simplicity and easy to understand using FDATOOL in MATLAB, we can design Digital filter very easily.

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BIOGRAPHIES

Pramod yadav persuing bachelor of engineering in electrical and electronics engineering in 6th semester from institute of technology korba,Chhattisgarh Swami Vivekanand Technical University, India.

Shankarlal sahu persuing bachelor of engineering in electrical and electronics engineering in 6th semester from institute of technology korba, Chhattisgarh swami Vivekananda technical university Chhattisgarh, india.

Pranay Kumar Rahireceived the bachelor of technology degree in Electronics and Telecommunication engineering collage, guru ghashidas university, bilaspur Chhattisgarh, india in 2004, and persuing master of engineering in electronics and communication engineering from national institute of technical teacher's training & research, Punjab university, Chandigarh, india. Presently working as assistant professor in department of electrical and electronics engineering, institute of technology, korba Ch.hattisgarh since 2008. He has authored more than 40 research publications and published journal paper and research papers in the leading international and national journal. This primary research interest includes digital signal processing, VLSI design, control systems and digital electronics and logic design.