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A Two-Variable Window Function FIR Filter with Modifiable Spectral Properties

Dr. N.V.Subba Rao

Professor, Department of EEE

Anu Bose Institute of Technology for Women's, Paloncha, Telangana, India

Email: nvsubbaraonv@gmail.com

ABSTRACT: The authors of this work provide a novel dynamic window function that can have its spectral properties changed or adjusted. This research proposes a novel dynamic window function that combines the hamming, Blackman-Harris, chebwin, and Kaiser window functions. The proposed window function, which is a hybrid of the hamming, Blackman-Harris, chebwin, and Kaiser window functions, has been compared with the existing Blackman-Harris, chebwin, and Kaiser window functions. A MATLAB simulation was used to do the comparison observation. From what we can tell from the simulations, the proposed window function outperforms the Blackman-Harris, chebwin, and Kaiser-window functions in terms of ripple-ratio, main lobe width, and side lobe roll-off ratio. With just a little compromise in one spectral property, the suggested window function outperforms the Blackman-Harris, chebwin, and Kaiser Window functions in terms of spectral performance.

Keywords: FIR Filter, Window Function, Ripple-Ratio, Side-lobe Roll-Off Ratio, Main–lobe Width.

1. INTRODUCTION

For an input sequence x(n) with discrete-time, discrete-time filter generated an output sequence y(n) with discrete-time. As know that filter has a device which gives us desirable outcomes in term of frequency and these discrete-time filters have been shown a lot of application like signal processing, suppression of noise and also an enhancement in images [1-2].

Filters may be designed to mimic analogue systems, respond to impulses, steps, or ramps, or have a specified frequency response. Based on the system's unit pulse response, digital filters are classified as either FIR or IIR. There is a limited amount of non-zero terms in a digital FIR filter, which indicates that the impulse response is finite in time.

Assume that a system has an equation (difference) with input and output sequence x(n)and y(n) respectively define as follows;

$$\sum_{k=0}^{N} a_k y(n-1) - \sum_{k=0}^{M} b_k x(n-k)$$

M-length FIR filter is described as follows by the difference equation

$$y(n) = b_0 x(n) + b_1 x(n-1) + b_2 x(n-2) + \cdots$$
$$\ldots \ldots + b_{M-1} x(n-M+1) = \sum_{k=0}^{M-1} b_k x(n-k)$$

Where $\{h_k\}$ is the set of filter coefficient. So it is very clear from the above equation, the output response of the FIR filter depends upon only on the present and past input sample sequence.

There is a limited period to the filter start-up transients, the design approaches are typically linear, the FIR filters are always stable, and they are realised in hardware so efficiently. If you don't need any phase distortion, FIR filters are great because of these benefits. The number of methods offered by the scientists that study FIR filters have developed methods that provide us with closed solutions [10].

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The impulse response of an infinite impulse response filter is reduced by the windowing process. The product of and w[n] is the truncation of the impulse response from an infinite impulse response filter. This is why the window method is superior for designing digital finite impulse response filters. You can change the value of an adjustable window by adjusting one or more of its variable parameters; typically, window functions allow us to set zero outside of certain intervals. [2] [6]. Compared to standard windows, the spectral responses of the windows shown in this work are much superior.

To begin with, every window function should have a narrow main lobe, a high ripple ratio (negatively), and a high side-lobe roll-off ratio [8]. In some cases, however, these features work against one another and reveal limitations; for example, a window with a larger side lobe will have a narrower main lobe [3-5].

There are three desired specifications for a window function which are defined as:

Main-lobe width (W_B) $\stackrel{\text{def}}{=}$ Width of the main-lobe x 2π

Ripple-Ratio (R) $\stackrel{\text{def}}{=}$ Maximum side-lobe amplitude (in dB) - Main-lobe amplitude (in dB) = S_1

Side-lobe roll-off ratio (S) $\stackrel{\text{def}}{=}$ Maximum side-lobe amplitude (in dB) - Minimum side-lobe amplitude (in dB) = S_1- S_L

A new dynamic window function proposed in this paper is a combination of hamming, Blackman-Harris, chebwin, and Kaiser Window function. Blackman-Harris, chebwin, and Kaiser Window functions have been used to compare with the suggested proposed window function i.e. a combination of hamming, Blackman-Harris, chebwin, and Kaiser Window function. Compare observation has been done with the help of MATLAB simulation.

This section of paper discusses the introductory part of FIR filter and their advantage and also discusses the window design approach, rest of the paper describe as follows, section II discusses the suggested proposed window function to design FIR filter and comparison discusses in the section 3 of this paper and last but not the least conclusion discusses in section 4.

2. SUGGESTED WINDOW FUNCTION

A new dynamic window function proposed in this paper is a combination of Blackman-Harris, hamming, Kaiser and chebwin-window function provided in equation respectively;

The function of the Blackman-Harris window given as;

$$w_1[n] = 0.35875 - 0.48829\cos\left(\frac{2\pi n}{N-1}\right) + 0.14128\cos\left(\frac{4\pi n}{N-1}\right) - 0.01168\cos\left(\frac{6\pi n}{N-1}\right)$$

The function of the hamming window given as;

$$w_2[n] = 0.54 - 0.46\cos\left(\frac{2\pi n}{N-1}\right)$$

The function of Kaiser Window given as;

$$w_3[n] = \frac{I_0\left(\pi\alpha\sqrt{1-\left(\frac{2n}{N-1}\right)^2}\right)}{I_0(\pi\alpha)} \quad for\ 0 \le n \le N-1$$

Where N is the length of FIR filter require and I_0 is the zeroth-order modified Bessel function of the first kind and α is inverse of the standard deviation of Kaiser Window function.

The function of Chebwin Window given as;

$$w_4[n] = w_0\left(n - \frac{N-1}{2}\right) for\ 0 \le n \le N-1$$

A new dynamic window function proposed is a combination of hamming, Blackman-Harris, chebwin, and Kaiser Window function. The suggested window functions are given by the equation below;

$$w[n] = \begin{cases} \left[w_2 w_1 - w_1\left\{\left(\frac{1}{a}\right)(\cosh(w_3))^{0.1} w_4\right\} w_4\right]^r & 0 \le n \le N-1 \\ 0 & otherwise \end{cases}$$

Where 'a' setup the gain of the window and 'r' is the spectral control parameter.

3. RESULTS & DISCUSSION

A new dynamic window function proposed in this paper is a combination of Blackman-Harris, hamming, Kaiser and chebwin Window function provided in the equation as follows;

$$w[n] = \begin{cases} \left[w_2 w_1 - w_1\left\{\left(\frac{1}{a}\right)(\cosh(w_3))^{0.1} w_4\right\} w_4\right]^r & 0 < n < N-1 \\ 0 & otherwise \end{cases}$$

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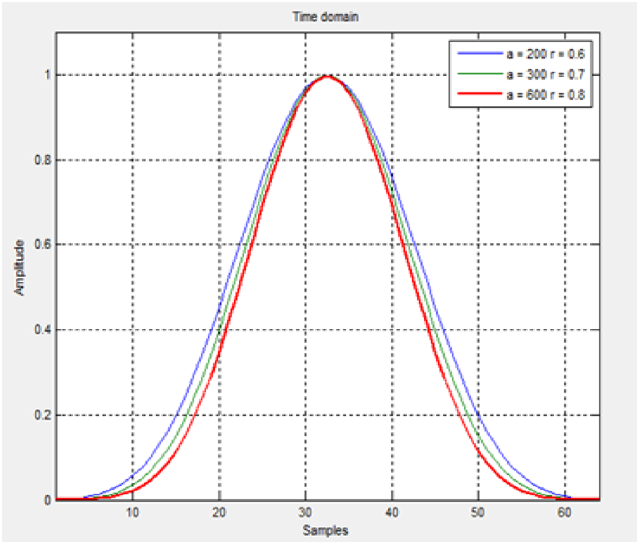

Figure 1: Time Domain Characteristic of suggested proposed window for the specific value of ‘a’ and ‘r’

Figure 1 illustrates the time domain and frequency domain properties of the proposed window for a given value of 'a' and 'r,' as shown above.

Figure 1 displays the time domain characteristics of the proposed window for 'a' = 200, 300, and 600, as well as values of 'r' = 0.6, 0.7, and 0.8, respectively. By reducing the window width in the time domain characteristics, the main lobe width in the frequency domain characteristics is increased, as shown in the graph of the time domain characteristics.

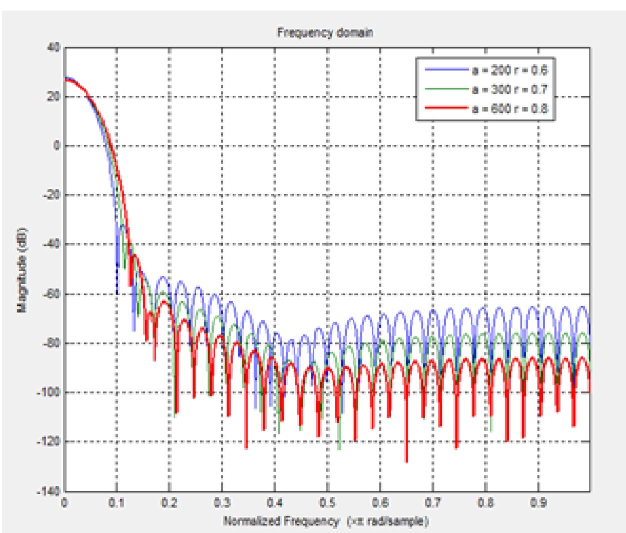

Figure 2: Frequency Domain Characteristic of the suggested window for the specific value of ‘a’ and ‘r’.

As above depicted figure 2 shows that the frequency domain characteristics of the suggested window for the different specific value of ‘a’ and ‘r’. The figure shows the frequency domain characteristics of proposed window for ‘a’ = 200, 300, 600 and value of ‘r’ = 0.6, 0.7, 0.8 respectively, from the frequency domain characteristics graph shows that the proposed window achieved better performance for ‘a’ = 600 and ‘r’ = 0.8.

Table 1: Frequency Domain Characteristics of Suggested window for Specific ‘a’ and ‘r’

Adjustable Parameter ‘a’ and ‘r’	**Main Lobe Width (MLW)**	**Ripple Ratio (RR in dB)**	**Side-lobe Roll-off Ratio (SLRR in dB)**
a = 200, r = 0.6	0.1015× 2π	-59.50	46.062
a = 300, r = 0.7	0.1152 × 2π	-64.09	49.777
a = 600, r = 0.8	0.1250 × 2π	-71.00	45.878

Figure 1 shows that the while increasing ‘a’ and ‘r’ the reduction of window width achieved in the time domain but the reduction of window width in time domain cause higher main-lobe in the frequency domain as shown in figure 2. It is also clear from table 1 and figure 2, increases the ‘a’ and ‘r’ increase the value of RR in the negative sense but SLRR increases up-to some extent than decreases.

This section of the paper presents a comparative analysis of suggested proposed window with black-man Harris, Kaiser and Chebwin window function.

3.1 Black-man Harris Window:

The Black-man Harris window function is defined as the equation below;

$$w_1[n] = 0.35875 - 0.48829\cos\left(\frac{2\pi n}{N-1}\right) + 0.14128 \cos\left(\frac{4\pi n}{N-1}\right) - 0.01168\cos\left(\frac{6\pi n}{N-1}\right)$$

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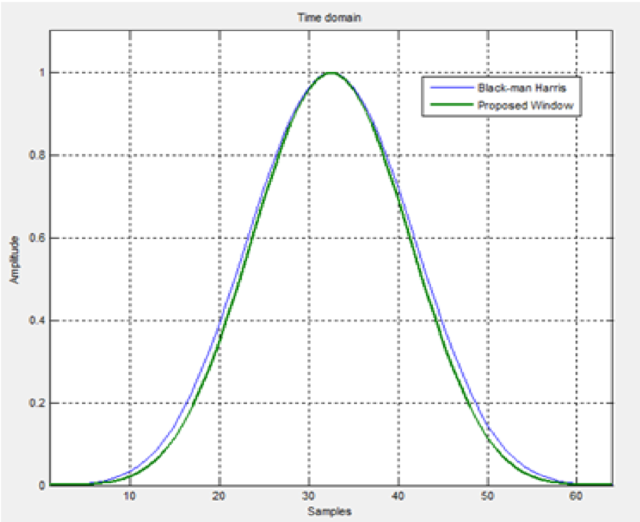

Figure 3: Time Domain Comparative Analysis of Proposed Window with Black-man Harris

As above depicted figure 3 shows that the time domain characteristics for Black-man Harris and Proposed suggested window technique and the proposed window technique provide less window width as compared to Black-man Harris window in the time domain but it causes higher MLW in frequency domain characteristics.

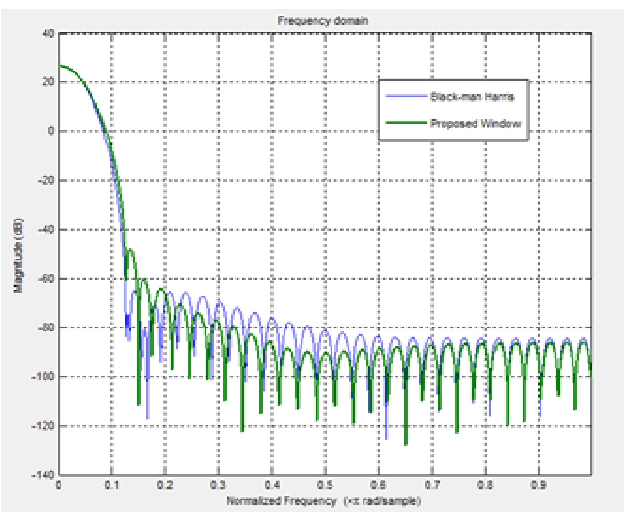

Figure 4: Frequency Domain Comparative Analysis of Proposed Window with Black-man Harris

Figure 4 below displays the frequency domain features of the Black-man Harris Window and the proposed window for various particular values of 'a' = 600 and 'r' = 0.8. You can see that the suggested window performed better in terms of SLRR and MLW with a value of 'r' = 0.8, as shown in the frequency domain characteristics figure, although there is a compromise of around 18 dB in RR.

Table 2: Frequency Domain Characteristics comparison of Proposed Window with Black-man Harris

Window Function	Main Lobe Width (ML)	Ripple Ratio (RR in dB)	Side-lobe Roll-off Ratio (SLRR in dB)
Black-man Harris Window Function	0.1296 × 2π	-93.48	30.771
Proposed Window Function a = 600, r = 0.8	0.1250 × 2π	-75.11	45.878

As above depicted table 2 shows that suggested window (a=600, r=0.8) gives smaller main-lobe width, smaller and higher side-lobe roll-off ratio as compared to Black-man Harris window as desired. But there is compromisation of 18 dB in RR in negative-sense.

3.2 Kaiser Window Function

Kaiser window function is defined as:

$$w_3[n] = \frac{I_0\left(\pi\alpha\sqrt{1-\left(\frac{2n}{N-1}\right)^2}\right)}{I_0(\pi\alpha)} \quad for\ 0 \le n \le N-1$$

Where the zero-order is modified Bessel function of the first kind.

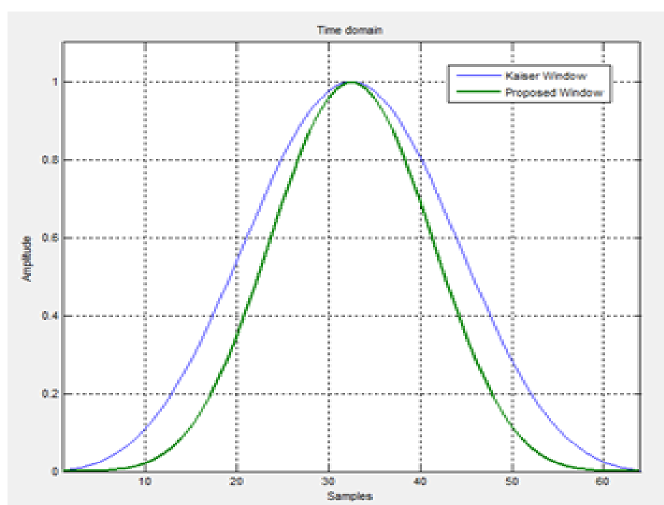

Figure 5: Time Domain Comparative Analysis of Proposed Window with Kaiser Window Function.

As above depicted figure 5 shows that the time domain characteristics for Kaiser and Proposed suggested window technique and the proposed window technique provide less window width as compared to Kaiser Window in the time domain but it causes higher MLW in frequency domain characteristics.

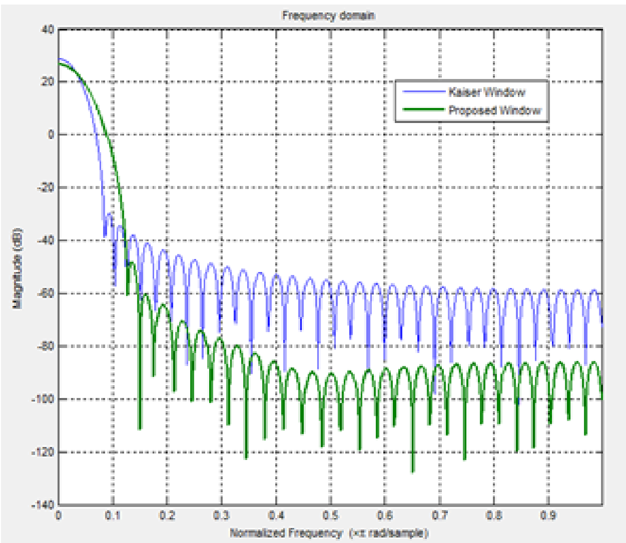

Figure 6: Frequency Domain Comparative Analysis of Proposed Window with Kaiser Window Function

As above depicted figure 6 shows that the frequency domain characteristics of the suggested window for the different specific value of ‘a’ = 600 and ‘r’ = 0.8 and Kaiser Window. The figure shows the frequency domain characteristics of the proposed window for ‘a’ = 600 and value of ‘r’ = 0.8 achieved better performance in term of SLRR and RR.

Table 3: Frequency Domain Characteristics comparison of Proposed Window with Kaiser Harris

Window Function	Main Lobe Width (MLW)	Ripple Ratio (RR in dB)	Side-lobe Roll-off Ratio (SLRR in dB)
Kaiser Window Function	0.08593 × 2π	-58.30	27.467
Proposed Window Function a = 600, r = 0.8	0.1250 × 2π	-77.31	45.878

As above depicted table 3 shows that suggested window (a=600, r=0.8) gives smaller ripple-ratio and higher side-lobe roll-off ratio compared to Kaiser Window as desired.

3.3 Chebwin Window Function

Chebwin window function is defined as:

$$w_4[n] = w_0(n - \frac{N-1}{2})\ for\ 0 \le n \le N-1$$

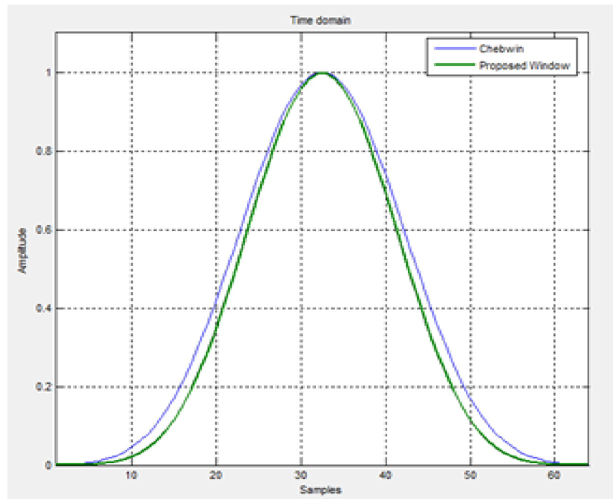

Figure 7: Time Domain Comparative Analysis of Proposed Window with Chebwin Window Function

As above depicted figure 7 shows that the time domain characteristics for Chebwin and Proposed suggested window technique and the proposed window technique provide less window width as compared to Chebwin Window in the time domain but it causes higher MLW in frequency domain characteristics

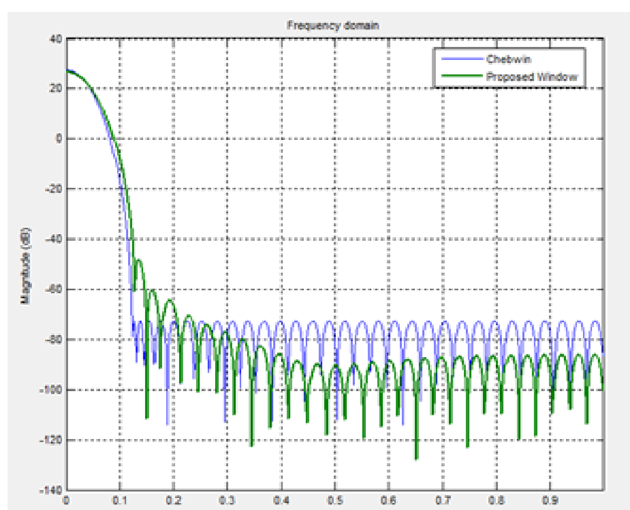

Figure 8: Frequency Domain Comparative Analysis of Proposed Window with Chebwin Window Function

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As above depicted figure 8 shows that the frequency domain characteristics of the suggested window for the different specific value of ‘a’ = 600 and ‘r’ = 0.8 and Chebwin Window. The figure shows the frequency domain characteristics of the proposed window for ‘a’ = 600 and value of ‘r’ = 0.8 achieved better performance in term of SLRR and MLW but there is 25 dB in RR compromisation in the negative sense.

Table 4: Frequency Domain Characteristics comparison of Proposed Window with Chebwin Window Function

Window Function	Main Lobe Width (MLW)	Ripple Ratio (RR in dB)	Side-lobe Roll-off Ratio (SLRR in dB)
Chebwin Window Function	0.1230 × 2π	-99.45	38.780
Proposed Window Function a = 600, r = 0.8	0.1250 × 2π	-74.67	45.878

As above depicted table 4 shows that suggested window (a=600, r=0.8) gives smaller main-lobe width and higher side-lobe roll-off ratio compared to Chebwin window as desired. But there is a compromisation of 25 dB in RR.

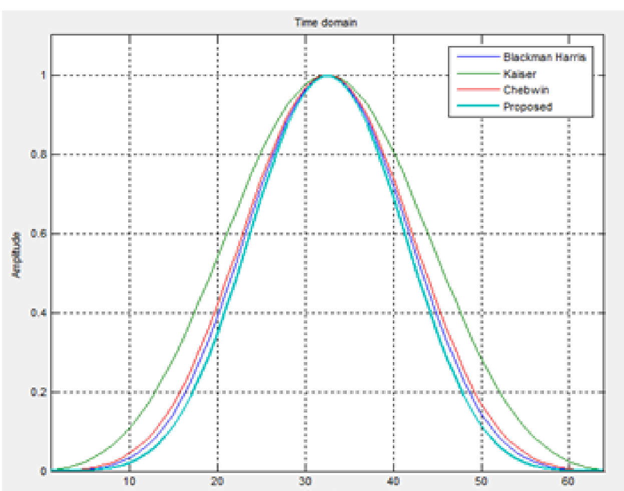

Figure 9: Time Domain Comparative Analysis of Proposed Window with Blackman Harris, Kaiser and Chebwin Window Function

As above depicted figure 9 shows that the Time Domain Comparative Analysis of Proposed Window with Blackman Harris, Kaiser and Chebwin Window Function and the proposed window technique provide less window width as compared to Black-man Harris, Kaiser and Chebwin Window in the time domain but it causes higher MLW in frequency domain characteristics.

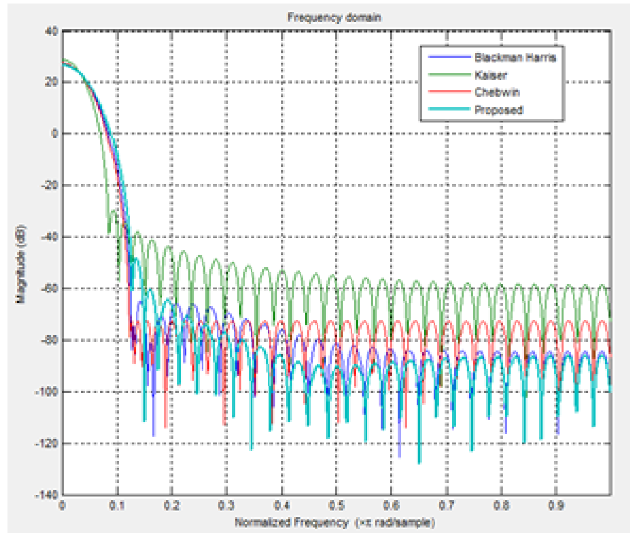

Figure 10: Frequency Domain Comparative Analysis of Proposed Window with Blackman Harris, Kaiser and Chebwin Window Function

Table 5: Frequency Domain Characteristics comparison of Proposed Window with Black-man Harris, Kaiser and Chebwin Window

Window Function	Main Lobe Width (MLW)	Ripple Ratio (RR in dB)	Side-lobe Roll-off Ratio(SLRR in dB)
Black-man Harris Window Function	0.1296 × 2π	-93.48	30.771
Chebwin Window Function	0.1280 × 2π	-99.45	38.780
Kaiser Window Function	0.08593 × 2π	-58.30	27.467
Proposed Window Function = 600, r = 0.8	0.1250 × 2π	-77.31	45.878

Figure 10 and table 5 illustrate the results of comparing the frequency-domain features of the recommended window with those of the Black-man Harris, Kaiser, and Chebwin Window techniques for various particular values of 'a' = 600 and 'r' = 0.8. The proposed window has a

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narrower pane than the Black-man Harris and Chebwin varieties, but a wider pane than the Kaiser variety. While the proposed window outperforms the competition in terms of SLRR, it falls short of the RR of Black-man Harris by about 18 dB and Chebwin by about 25 dB. However, it still outperforms Kaiser Window and other window function techniques in terms of SLRR.

4. CONCLUSION

Using two adjustable parameters 'a' and 'r,' the suggested window function may vary the spectral properties, i.e. ripple-ratio main-lobe width and side-lobe roll-off. With respect to SLRR and RR, it outperforms Kaiser Window. Although the suggested window compromises on ripple ratio (around 18 dB), it outperforms the Blackman Harris Window in main-lobe width and SLRR. After comparing the suggested window to the Chebwin window, we found that it improves main-lobe width and SLRR, but compromises RR by around 25 dB.

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