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FIR FILTER DESIGN USING A NOVEL WINDOW FUNCTION

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ABSTRACT

The FIR filters are designed efficiently and accurately using the Windowing method. The logic is to use a window function in a way to have low sidelobe peaks to avoid the noise. The communication filters should have the higher attenuation for the stop band. The latest research conducted in this regard shows the common trends of using Rectangular Window, Blackman Window, Hanning window, Gaussian Window, and Kaiser Window. The attempt was to have the low side lobes and high main lobe. In this design, we have proposed a novel window function. The new function is based on the product of classical Blackman and Gaussian window.

KEYWORDS: *FIR filter, Blackman window, Gaussian window, Hanning window, Kaiser window, side lobe,*

I. INTRODUCTION

In the recent past, India has seen the revolution in the Digital Industry. The FIR filters are the important part of Digital Signal Processing domain The most common use is of FIR (Finite Impulse Response) and IIR (Infinite Impulse Response) filters. Based on passband characteristics there is four type of filters namely, Low-Pass, High-pass and Band- Pass and Band-Stop filters. The design procedure to get the desired response is based on the selection of the desired frequency. The second step to compute the filter coefficients.

The basic difference between the FIR and IIR filters is due to the source. The approximation is followed by the .realization in the filter design. The approximation helps to set ideal response then the class of the filter is identified. The next step is to check the performance of the filter and finally, the algorithm is deployed which yields the response close to the ideal characteristics.

The realization helps to select the filter structure. The FIR filters can be designed in three ways. The most common method is the Windowing technique. The second method is frequency sampling-based and third is optimization methodology. [2]

The specific filter is designed as per the requirement. The desired response is controlled by the filter coefficients. The most popular, fast and reliable method of designing is called Window method. The classical Inverse Fourier transform is used to get the unit impulse response on an ideal filter. The frequency domain characteristics are the basis of fixing the design The unit sample response must show the cut-off. The methodology is to find the product of a fixed length window function. This is called truncation and windowing. Further, Fast Fourier Transform (FFT) is applied. Thus, we get the frequency response of the FIR filter being designed. This result can also be modified by selecting other window functions. In fact, the window is a string of coefficients which results in the desired results. The filter order of the FIR filter depends on the selectivity, stopband, and passband. It is also necessary to select the appropriate window function. There is a trade between the side lobe attenuation peaks and faithful passage of pass-band with minimum ripples. As the selectivity increases the transition band reduces but the stop band attenuation increases and thus the noise decreases.[1]

Mitun Shil et. al In this design the authors have proposed a novel function. The FIR filter has been designed with specific features. The window has the variables which can be modified to get the optimum desired results. On the basis of the observation of the results the lobe attenuation is better than that for the Hamming and the Kaiser Window The proposed window is compared with classical Kaiser window. Abdullah A.Aljuffri et. al work is based on Wallace Tree and Vedic multipliers for The ripple ratio for Hamming window is higher, which is -55.7 dB and the values for the Kaiser it is -29 dB while that for the designed window it is -63. dB. This shows the improvement over the stated two windows. In the base work, the design results are 24. 78 dB attenuation of the noise , the values for roll-off ratio for hamming & Kaiser windows have 5.71 dB & 18.76 dB respectively [2] Implementation of 8-tap and 16-tap sequential and parallel micro programmed FIR filters 8-tap FIR filter using Wallace Tree have minimum period 11.448 ns and maximum operating frequency 87.4 MHz and for 16-tap FIR filter using Wallace [3].

II. FIR FILTER

The FIR filters are commonly designed filters using different software tools like MATLAB. The filter is the signal processing component of most of the circuits. The objective of the FIR filter is signal conditioning. The filter has a specific role to perform it has a pass band, and stopband based on the frequency range. It allows the range to pass and attenuates any signal outside the passband.

The Finite Impulse Response Filters (FIR) are better defined by:

$$y[n] = a_0 + \sum_{l=0}^{M} b_1 x[n-1]$$
(1)

By the transfer function,

$$H(e^{jw}) = \frac{Y(e^{jw})}{X(e^{jw})} = \sum_{l=0}^{M} b_l e^{-jwl}$$
(2)

The entire technical exercise of designing the FIR filter is to set the parameters such that there is a minimum difference between the ideal behavior and the realized practical filter with a specified frequency band and other essential features. The window design method is a bit different in the sense that the filters designed are not based on optimization. The method is quite cost effective, fast and easy to implement in the real world. The filters designed this way are of good quality when compared with the other common design techniques. The method is pretty easy and therefore, very popular. The Window method can be described as the multiplication of the ideal filter with the finite duration window function. The result is the desired linear phase casual filter. The ideal filter is, in fact, the IIR filter, which has an infinite impulse response.

$$h(n) = h_d[n]w[n] \quad (3)$$

In the equation above the realized filter is given by $h(n)im, while\ h_d[n]$ is Infinite Impulse response filter., while W[n] is the window function.

FIR FILTER FUNCTION.:

$$H(e^{jw}) = \frac{1}{2\pi_{2\pi}} \oint H_d(e^{j\theta}) w(e^{j(\omega-\theta)}) d\theta$$
(4)

The response of the FIR filter remains zero when the values for n are less than 0. This mandatory for the casual filter. The linear phase results are based on HS(Hermitian Symmetry)

III. THE PROPOSED WORK

The finite impulse response is achieved by applying window technique on IIR filter there are many Window techniques are -1. Hamming, 2. Blackman, 3 Gaussian, 4. Kaiser, 5 Blackman. In this work, we have simulated base work, which describes all techniques as mentioned above, and the combination of Gaussian and Hamming as the main method. But, our proposed work uses the combination of Gaussian and Blackman techniques for the improvement. The product of Blackman window and the Gaussian window is as under:

$$W\,(n) = \sum_{k=0}^{M/2} (-1)^k a^k cos\left(\frac{2\pi nk}{M}\right) \qquad (5)$$

The Blackman Window function parameters over frequency domain are : K = 2, a_0 = 0.42, a_1 = 0.50, a_2 = 0.08 [3]

$$wW(\omega) = \sum_{k=0}^{M/2} (-1)^k \left(\frac{a_k}{2}\right)\left[D\left(\omega - \frac{2\pi}{M}k\right) + D\left(\omega + \frac{2\pi}{M}\,k\right)\right] \qquad (6)$$

We have shown the comparison between the basic and the advanced technique graphically as shown below:

It is clear from the user-interface, length, alpha can be inputted, and all options are shown to run any of the window methods individually or show them all are compared in one graph rather than the combination of two of them like in the basic and improved methods. For every run, you can get the output graphs and results and there is an option to get a comparison between the basic and advanced method graphically to study the improvement.

Fig. 1 Graphical Interface of the simulation

(a) Three popular windows are described as under: **The Blackman Window:** It is the family of cosine series window. In the time domain, it is defined by equation [12].From the fig. 2 we observe that for M=64 the main lobe width (2x The Blackman Window function is a cosine series over the time domain. In the fig. 2, the length of the filter is 64.

This window is the set of cosine series. This is given in the equation. 0.089843pi) and side lobe peak is -58.1dB. Blackman Window is mathematically described by the formula below:

$$W(n) = \exp\left[-\frac{1}{2}\left(\frac{\propto n}{M/2}\right)^2\right] \quad 0 \le |n| \le |M/2 \quad (7)$$

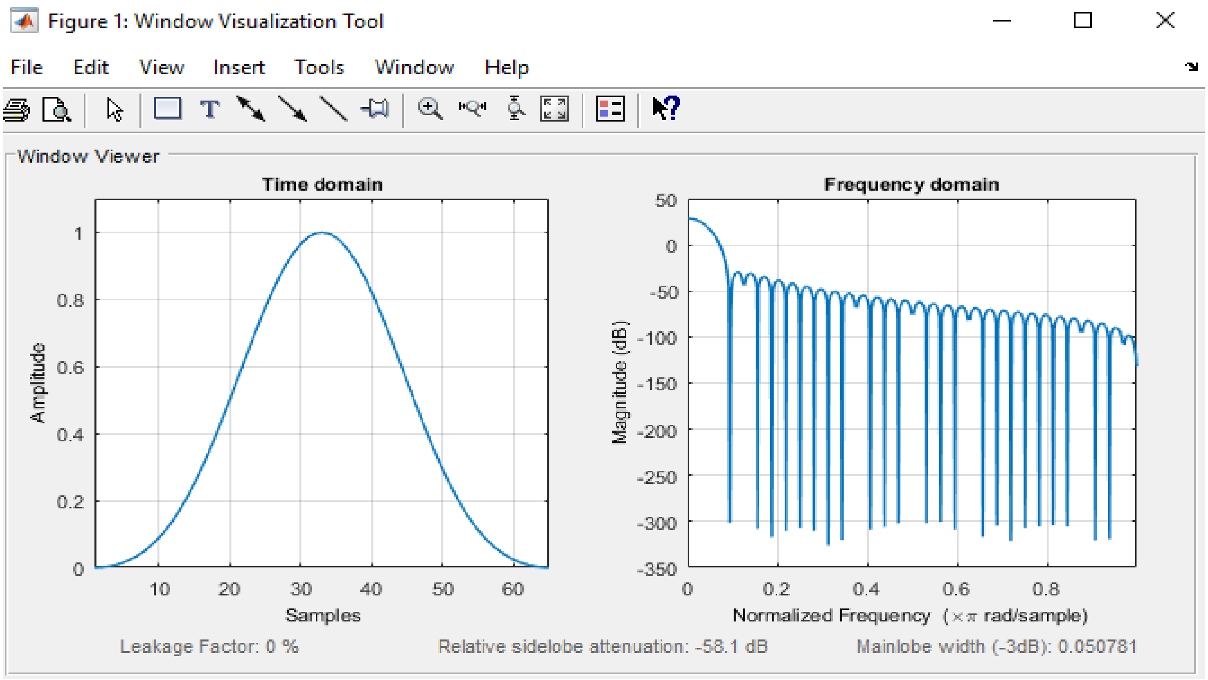

Fig. 2 Blackman window

1. **The Gaussian Window** In the time domain graph with the time on the x-axis. There is a trade-off between alpha the window width reduces. The continuity at the boundary increases. But the main lobe width and there is lower side-lobe attenuation. The window is tuned using the value of α.have the desired "main lobe width - sidelobe peak" trade-off. is defined as:

$$w(n) = \exp\left[-\frac{1}{2}\left(\frac{\alpha n}{\frac{M}{2}}\right)^2\right] 0 \le |n| \le M/2 \quad (8)$$

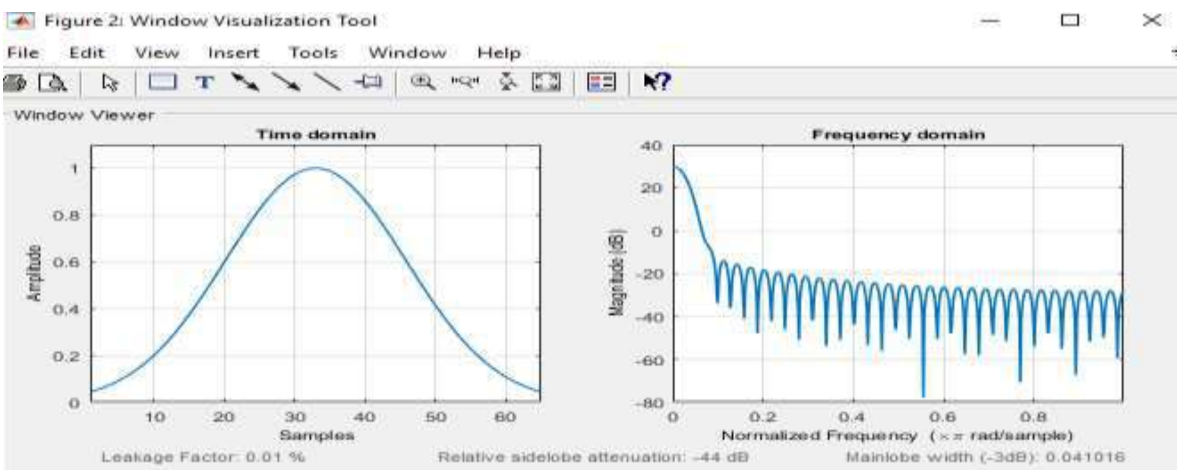

Fig. 3 Gaussian Window

2. KW (Kaiser Window): The CW has the option to keep main lobe width and the side lobe peaks can also be modified. The Bessel Function 10 is for the zero order. The frequency tuning is done by manipulating "alpha". The length of the filter, M is set to 64, alpha is 8 and the main lobe width is 2x 0.1054685n the peak sidelobe rejection is -89.2 for our proposed design. The Kaiser Window allows -69.4 dB attenuation of the noise.

$$W(n) = \frac{I_o\left[\alpha\pi\sqrt{1-\left(\frac{n}{M/2}\right)^2}\right]}{I_{o[\pi\alpha]}} \quad 0 \le |n| \le |M/2 \quad (9)$$

Where, $I_o(x) = \sum_{k=0}^{\infty}\left[\frac{\left(\frac{x}{2}\right)^k}{k!}\right]^2$

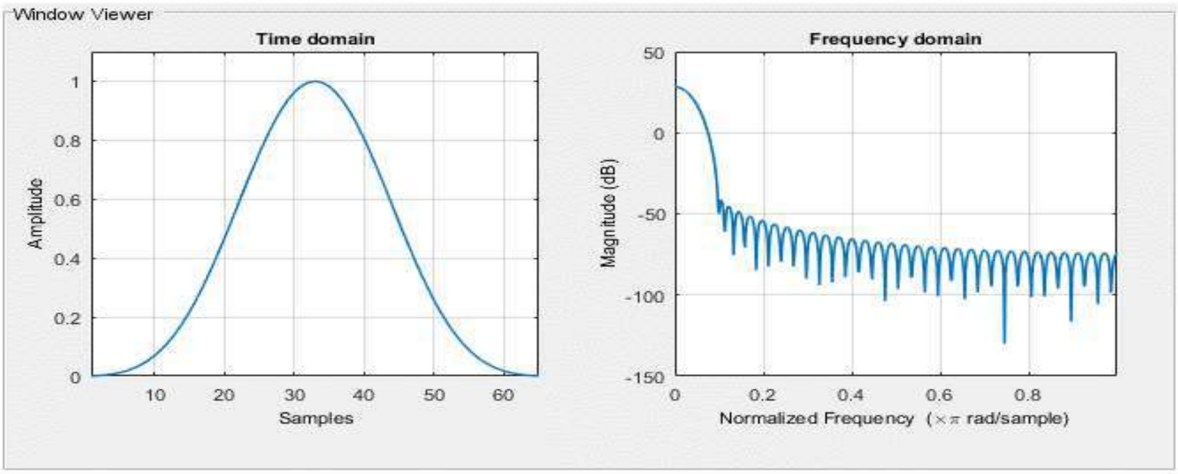

Fig. 4 Kaiser Window

3. The proposed window:

Gaussian window is as under:

$$W(n) = \sum_{k=0}^{M/2}(-1)^k a^k \cos\left(\frac{2\pi nk}{M}\right) \qquad (10)$$

For Blackman window,

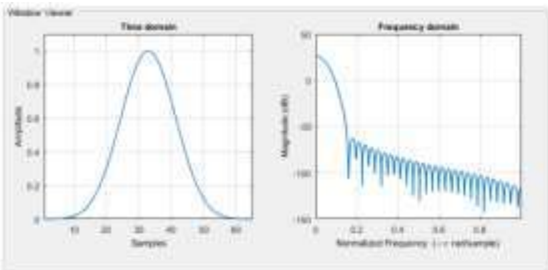

Fig. 5 Proposed window

IV. RESULTS AND DISCUSSION

K = 2, a_0 = 0.42, a_1 = 0.50, a_2 = 0.08

In frequency domain [3]

$$W(\omega) = \sum_{k=0}^{M/2}(-1)^k\left(\frac{a_k}{2}\right)\left[D\left(\omega - \frac{2\pi}{M}k\right) + D\left(\omega + \frac{2\pi}{M}k\right)\right] \qquad (11)$$

The Blackman Window v/s The proposed

.

This window belongs to the cosine series. The time domain equation is as stated in [3]. The simulation of this window is given in fig. 5. The rest of the of the parameters M, alpha and main lobe width are kept as 64, 8 and 2x O.1054685n), respectively. The proposed results are -89.2 and for Blackman, the side lobe attenuation peaks are -58.1 dB.

$$W(n) = \exp\left[-\frac{1}{2}\left(\frac{\propto n}{M/2}\right)^2\right] \quad 0\le|n|\le M/2 \qquad (12)$$

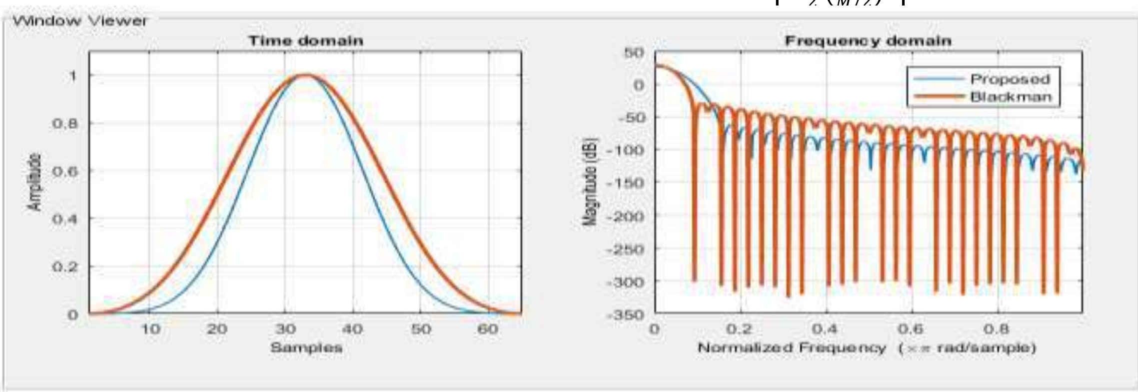

Fig. 6 The Blackman Window v/s The proposed Window

1. The Gaussian Window v/s The proposed Window

The alpha is directly proportional to the width. The continuity increases at edges. There is a trade-off between the main lobe width and the side lobe attenuation. The selection is based on the application of the filter. The fig. 7 shows the results. The tuning is controlled by alpha values. The alpha is 8 in this case and the main lobe width is 0.0410. The proposed side-lobe attenuation is -89.2 dB and for the Gaussian window, it is -44 dB.

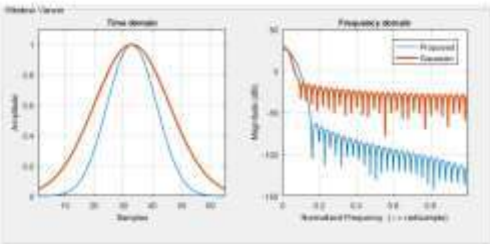

Fig.7 The Gaussian Window v/s The proposed Window

2. The Kaiser Window v/s The proposed Window

$$W(n) = \frac{I_o\left[\propto\pi\sqrt{1-\left(\frac{n}{M/2}\right)^2}\right]}{I_{o[\pi\propto]}} \qquad 0 \le |n| \le |M/2 \qquad (13)$$

Where $I_o(x) = \sum_{k=0}^{\infty}\left[\frac{\left(\frac{x}{2}\right)^k}{k!}\right]^2$

Kaiser window has very attractive features. It has well defined main lobe and good sidelobe rejection. It has the zero-order modified Bessel function of the first kind alpha =Tuning parameter, M=length of window From the fig.8. we observe that for M=64, a=8.0, and for same main lobe width (2x 0.1054685n), so the proposed window offer - the 89.2db peak of a side lobe, while the Kaiser window shows -69.4 DB peak of side lobe i.e. Proposed window has -18.8 dB smaller peak of side lobe.

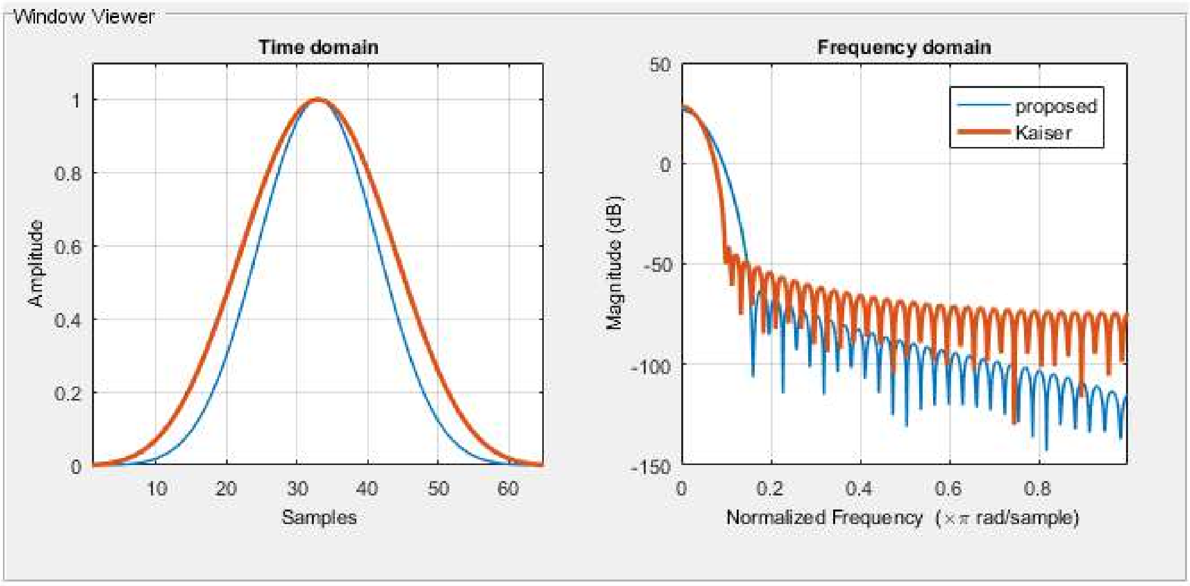

Fig. 8 **The Kaiser Window v/s The proposed Window**

V. THE COMPARISON OF BASE WORK WITH THE PROPOSED

The base work is based on z the product of Gaussian and Hamming - Window [3]. The family is defined by [3.]

$$w(n) = 0.5\left[1+\cos\left(\frac{\pi n}{m/2}\right)\right]e^{\left(\frac{-\alpha|n|}{\frac{m}{2}}\right)} \quad 0 \le |n| \le M/2 \qquad (14)$$

The following window is the product of Hamming and Gaussian window. The mathematical expression for the novel window is as under:

$$w(n) = \left[0.54 + 0.46\cos\left(\frac{\pi n}{\frac{M}{2}}\right)\right]e^{\left[-1/2\left(\frac{\alpha n}{\frac{M}{2}}\right)^2\right]} \quad 0 \le |n| \le M/2 \qquad (15)$$

If $\alpha = 2.3$ then w(n)= Hanning (M) X Gaussian (M,2.3)

The reference work is based on the s quasi-tuneable window. It is derived from the product of

Hanning and Gaussian window. The peak side lobe rejection is -65.1 dB. The main lobe width is (2x 0.1054685n).

W (n) = 0.54-0.46cos 2πn/M n = zero,1,2……..M-1

In frequency domain,

$$W(\omega) = 0.54\,(\omega) + 0.46\left[D\left(\omega - \frac{2\pi}{M}\right) + D\left(\omega + \frac{2\pi}{M}\right)\right] \quad (16)$$

$$D(\omega) = e^{jw/2\frac{\sin M\omega/2}{\sin\omega/2}} =$$ Drichlet kernel

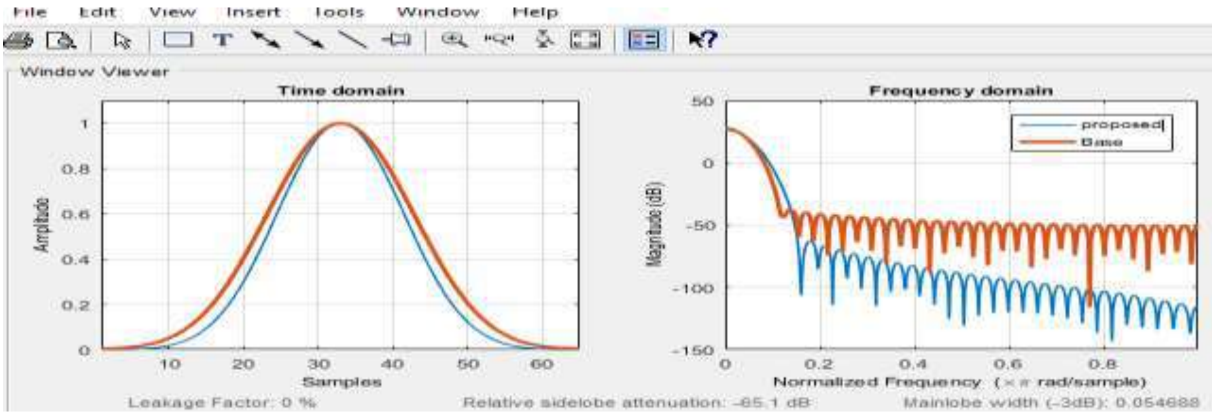

Fig. 9. The Proposed Vs the Base work.

V. CONCLUSION AND THE FUTURE WORK

The FIR filters are popularly used as a communication filter. The design depends on the application. The user actually decides the main-lobe width and side-lobe attenuation. There is a trade-off between the main lobe width and side-lobe peaks. The parameter M decides the main-lobe width, and alpha controls the side-lobe peaks. The window functions can be used to get the desired characteristics. The continuity increases towards zero ends. We simulated both the base work and the proposed design. We have also compared the proposed with the standard windows like Blackman, Gaussian, Kaiser, and Hamming windows. The proposed design seems to be better as compared with the base work. The base work is the window derived by the vector product of Gaussian and Hamming Window. The proposed design has better side lobe attenuation and it is a suitable feature for any communication filter attenuation. On the basis of the simulation results of the reference work[1], it is found that the relative sidelobe attenuation is -65.1 dB and main lobe width (-3db)= 0.054688. Our proposed work shows, the relative sidelobe attenuation is -89.2 DB and main lobe width (-3db) = 0.0625. The simulation results are inspiring. The better performance proves that the proposed design is more useful. The careful study shows that the proposed window which is based on the product of Gaussian and Blackman provides better linear phase characteristics. The desired response can be achieved by manipulating the design parameters. The future work should be that the researchers must find better windowing function. The new research must be directed towards efficient filter design with good main-lobe features and still higher side-lobe attenuation.

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