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Design of FIR Filter using Rife-Vincent Window Using FFD Algorithm

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***Abstract:** In Digital Signal Processing, The window techniques are used to design the FIR filter. Actually the window techniques can be applied on the IIR filter response to make it finite and so the FIR filter can be designed. Rife-Vincent window technique is one of the useful one to realize the FIR filter. The algorithm and the design method of Rife-Vincent window are shown in this paper with the realization and the simulation results where the advantage of the window is shown which is actually the minimization of the sidelobes. The simulation is done in Matlab 7 and it can be observed that the minimization of the sidelobes increase the efficiency of the filtering process as well as decreasing the power consumption. The other well known window functions such as the Blackman window, kaiser window, Hamming window, Hanning window etc. generates the sidelobes that are of higher Decibels compared to the Rife-Vincent window.*

***Keywords:** FIR Filter, Window technique, Rife-Vincent Window, FFD Algorithm, Window function, Realization, Magnitude response*

I. INTRODUCTION

In Digital Signal Processing, Filters are employed to filter out the required signal or a band of required signals which are essential in performing some specific operations. The types of filter are mainly determined by its impulse response and depending upon it, filter are categorised into two types, one is the Infinite Impulse Response Filter or IIR Filter and another is Finite Impulse Response Filter or FIR filter[1][2][3][4]. The impulse response generated by the IIR Filter is of infinite duration whereas the impulse response of the FIR filter is of finite duration. There are many differences in between IIR Filter and the FIR Filter and one of the most notable difference is the recursion path i.e. IIR Filter requires a feedback or recursion path for which it is known to as the Recursive filter whereas FIR Filter requires no feedback path and so it is known to as the Non-Recursive filter[2][3][4][5][7].

There are various methods available to design the FIR filter. Window technique is one the best known and widely used method among the all other methods. There are a numbers of windows are available for designing the FIR Filter[2][4][7][15]. The main objective of the window technique is to make the impulse response to finite duration. The widely used window techniques are the Kaiser window, Blackman window, Hamming window, Hanning window, Blackman-Harris window, Flat top window etc[2][3][6][12]. The difference comes to their sidelobes. The sidelobe peak value is lesser in case of Rife-Vincent window than any other well known window technique. So, it is obvious that the Rife-Vincent consumes less power than other window functions mentioned earlier. Rife-Vincent window is not widely used window technique as the function that will be needed in the simulation are not available in Matlab environment. This will require additional function for the simulation. However, the simulation with the additional and new function is done in Matlab 7 using the FIR Filter Design(FFD) algorithm which produce the satisfactory output result with the respective coefficient calculation with the window function. So, if the window function will be used in the design of FIR Filter, the output ripple or the noise will be minimised and hence increase the speed of operation by increasing efficiency.

II. FIR FILTER DESIGN

The FIR filter have some advantages over IIR filter which makes an interest for designing the FIR filter and they are stated below[2][3][20][22][27][28][29]:

1. FIR filters are stable.
2. FIR filters can be easily designed as for it's linear phase.
3. FIR filters, when implemented on a finite word length digital system, are free of limit cycle oscillations.
4. There are various methods are available for designing the FIR filter.
5. FIR filter require no feedback i.e any rounding error are not compounded by summed iteration and for that it is inherently stable.
6. Impulse response is finite.

In FIR filter the impulse response will be zero after a finite time duration and so for this reason the realization and the respective calculations are much more easier than that of the IIR filter[3][5][15][21][25].

A. FFD Algorithm

The algorithm for designing the FIR filter is described here. This algorithm is helpful for the design of FIR filter. The steps and the flow chart of the FFD (FIR Filter Design) algorithm is described below:

Steps:
1. Construct the Analog filter by selecting proper parameter.
2. Select proper input signal or band of signals.
3. Design the IIR filter and check the infinite response.
4. Select the tapering function or window function to make the response finite.
5. Calculate the Tap weight b_i.
6. Calculate the window coefficients.
7. Design the FIR filter by the selected window function.
8. Observe the responses.
9. Calculate the desired response $h_d(n)$.
10. Check the symmetry of desired response $h_d(-n)$.
11. View the magnitude response.

This steps of the FFD algorithm is necessary to design and construction of the FIR filter. When all the parameters are specified, the analog filter can be constructed and from that the IIR filter can be designed. Then the suitable tapering function or window function will have to be selected to design the FIR filter. The filter coefficient is called the tap weight of the function. The tap weight is one of the most important parameter because the response of the FIR filter is totally dependent on the tap weight. So, after selecting the tap weight and calculating the window coefficients, the FIR filter can be designed and the desired response can be obtained. An FIR filter with lesser noise and ripples can be designed by using the FFD algorithm. The flow chart is shown below:

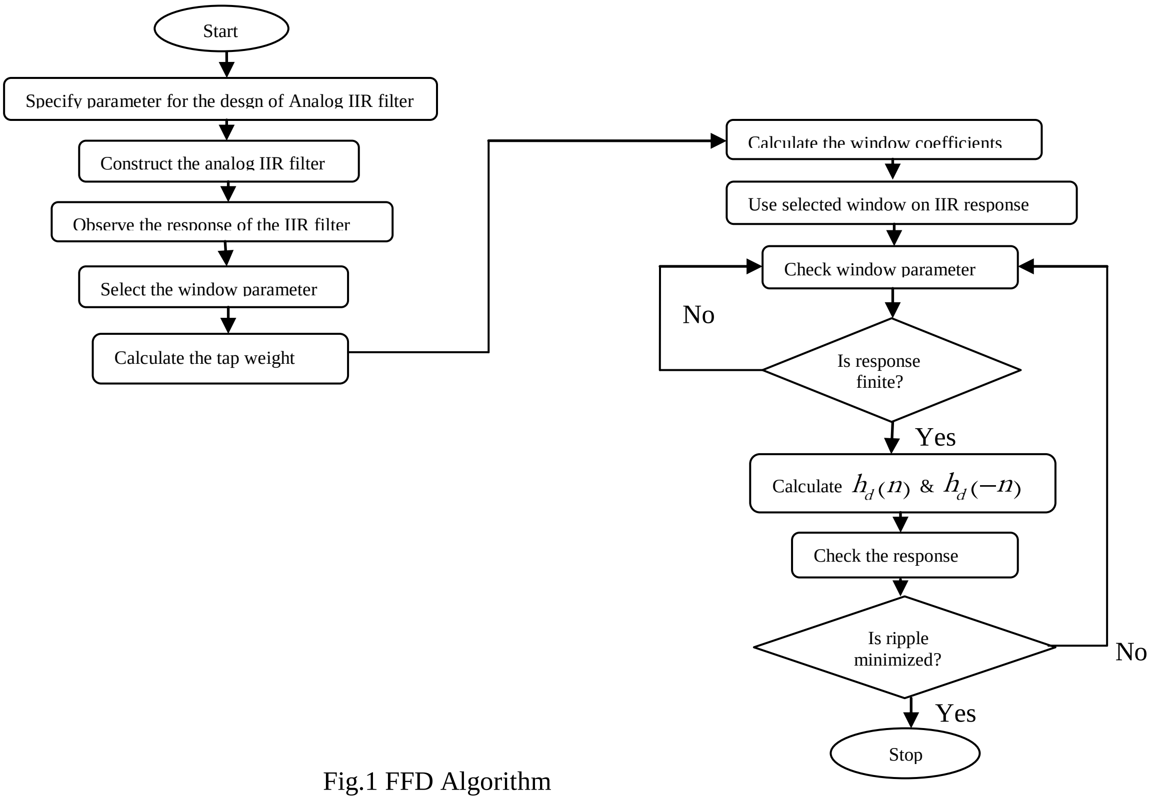

Fig.1 FFD Algorithm

B. Design of FIR Filter

Design of FIR filter meaning that to realize the FIR filter and finding the coefficients. Coefficient will have to be selected in such a way that the system will accure some specific characteristics[3][5][8][12][16] .Actually coefficients of the filter is the most important parameter to specify and design the realizable FIR filter. The realizable filter concept comes to the formulae given below:

$$h(n) = 0 \quad \text{for} \quad n \leq 0 \qquad ....(1.1)$$

where, h(n) = impulse response of the filter

$$\sum_{n=0}^{\infty} | h(n) | < \infty \qquad ....(1.2)$$

The eq.(1.1) and eq.(1.2) gives the stability condition of a realizable filter. So, after selecting a realizable filter with proper stability, the FIR filter can be designed and realized according with the coefficients can be determined with a various way. The different way of determining the coefficients are[1][4][18][23][26]:

1. Window design method
2. Frequency sampling method
3. Weighted least square design
4. Parks-McClellan method
5. FFT method.

The widely used method for designing the FIR filter is the window design method discussed in the next section.

III. WINDOW DESIGN METHOD

In window technique, the waveform or the data sequence is multiplied by the window function and returns a non-zero value inside the interval and produce the zero value outside the given interval and forming a finite region of impulse response which produce the finite impulse response. Actually the non-zero value is highest at the angular frequency and decreased toward the interval. Practically, the value decreased rapidly towards zero outside the interval[2][5][8][10][19][28].

There are various window technique are available for the FIR filter design and they are[2][3][4][5][7][14][15]:

1. Hamming window
2. Rectangular window
3. Triangular window or Bartlett window
4. Hanning window
5. B-Spline window
6. Welch window
7. Parzen window
8. Raised cosine window
9.Kaiser window
10.Dolph-Chebyshev window

There is another type of window available known to as the Rife-Vincent window. This window performs better compared to other windows from lower order to higher. In this paper the coefficients are determined and the simulation is shown with comparison of some of the other effective windows.

A. Rife-Vincent Window

The Rife-Vincent window can be represented as the modified version of the Hanning window. It is one of the efficient window technique among all the other conventional window techniques. It overperforms than any other window function that are generally used in some specific applications. The main advantages of theRife-Vincent window is the high decay at the stop band and the low attenuation at the stopband[4][5][9][11][13].

The Rife-Vincent window function can be representated as follows[19][23][27][28][29]:

$$\omega_d(n) = \sum_{i=0}^{d} C_i \cos\left(\frac{2n\pi i}{N}\right)$$

....(1.3)

Where,

N=order

i = natural number

d = grade

C_i = coefficient

$\omega_d(n)$ = window function

Form eq.(1.3) it is clear that the window function can be evaluated with calculation of the cosine series and the coefficient can be calculated with respect to the value of the natural nimber i.

There are some interconnection in between Rife-Vincent window and some other window. The lower order Rife-Vincent window (for example, order=1) resembles with the characteristics of the Hanning window[2][4][7][14][17]. So,from Rife-Vincent window, the Hanning window and the Blackman window can be designed and vice-versa. That means, at any time the conevntional window can be designed from the Rife-Vincent window and if any problem occured regarding to the conventional window, i.e. if higher resolution is needed or if peak sidelobe is needed to be minimized, the Rife-Vincent window can also constructed from the conventional window. This is one of the advantages of the Rife-Vincent window.

For higher order of Rife-Vincent window, it resembles with the Blackmann window. There are a wide variety of the Rife-Vincent window.The Rife-Vincent window produces higher numbers of sidelobes with minimized peak sidelobe attenuation and thus it produces high resolution at the output.

IV. REALIZATION OF FIR FILTER

Realization of the FIR filter means a graphical or pictorial representation of the filter which inchudes the signal flow path and the feedback. In FIR filter, the feedback is excluded as it is the nonrecursive filter. There are various methods are available to realize the FIR filter. To realize the filter structure, the transfer function must be first understood. With help of the transfer function, the realization structure can be constructed. Generally the transfer function can be described by[2][3][5][15][16][18][28][29],

$$H(z)=\sum_{n=0}^{\infty}h(n)z^{-n}$$
$$=h(0)+h(1)z^{-1}+h(2)z^{-2}+....+h(N-1)z^{-(N-1)}$$

....(1.4)

As we know $H(z)$ is equal to the ratio of output and input i.e,

$$H(z)=\frac{Y(z)}{X(z)}$$
$$=\sum_{n=0}^{\infty}h(n)z^{-n}$$
$$=h(0)X(z)+h(1)z^{-1}X(z)+h(2)z^{-2}X(z)+....+h(N-1)z^{-(N-1)}X(z)$$

....(1.5)

A. Direct Form Realization

Direct Form structure can be used to realize the FIR filter using the eqn (1.5). The structure for this realization is as follows [4][5][27][28][29],

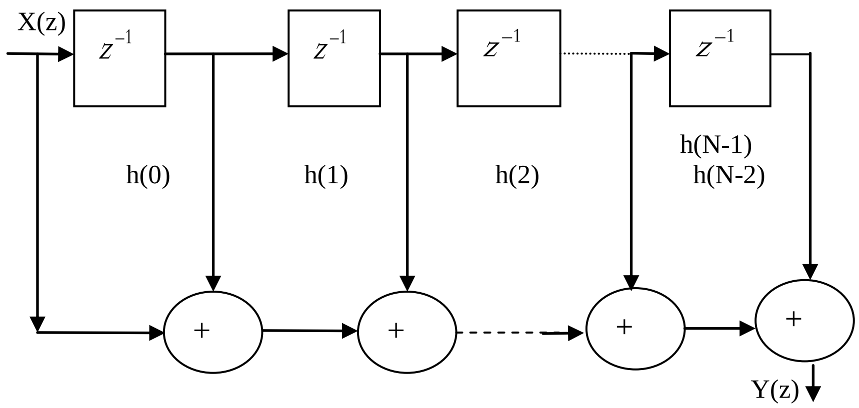

Fig.2 Direct Form Realization

The direct form realization shows the generalized structure for the FIR filter. Even or Odd ordered FIR filter cannot be seperated but can be realized in this common and more generalized structure. From the above structure of realization, it is clear that Direct form structure requires N multipliers, N-1 adders and N-1 delay elements[4][5][15][27][28][29].

B. Cascade Form Realization

A more compact structure from which the Even or Odd ordered FIR filter can be designed seperately and implemented on Rife-Vincent window structure is the cascade form realization. The Cascade form realization is discussed below seperately for Even ordered FIR filter and the Odd ordered FIR filter[22][24][25][28][29].

Order = Odd :

For Odd ordered filter, the transfer function H(z) can be factored as follows[20][23][27][28]

$$H(z)=\prod_{k=1}^{\frac{N-1}{2}}\left(b_{k0}+b_{k1}z^{-1}+b_{k2}z^{-2}+\ldots+b_{k(N-1)}z^{-(N-1)}\right)$$
$$=\left(b_{10}+b_{11}z^{-1}+b_{12}z^{-2}+\ldots+b_{1(N-1)}z^{-(N-1)}\right)\times\left(b_{20}+b_{21}z^{-1}+b_{22}z^{-2}+\ldots+b_{2(N-1)}z^{-(N-1)}\right)$$
$$\ldots\left(b_{\left(\frac{N-1}{2}\right)0}+b_{\left(\frac{N-1}{2}\right)1}z^{-1}+b_{\left(\frac{N-1}{2}\right)2}z^{-2}+\ldots+b_{\left(\frac{N-1}{2}\right)(N-1)}z^{-(N-1)}\right)\quad ....(1.6)$$

For odd order (N=Odd), N-1 value will be even, and H(z) will have $\frac{N-1}{2}$ ordered factors. The realization structure is shown in Fig.2[21][22][23][28][29],

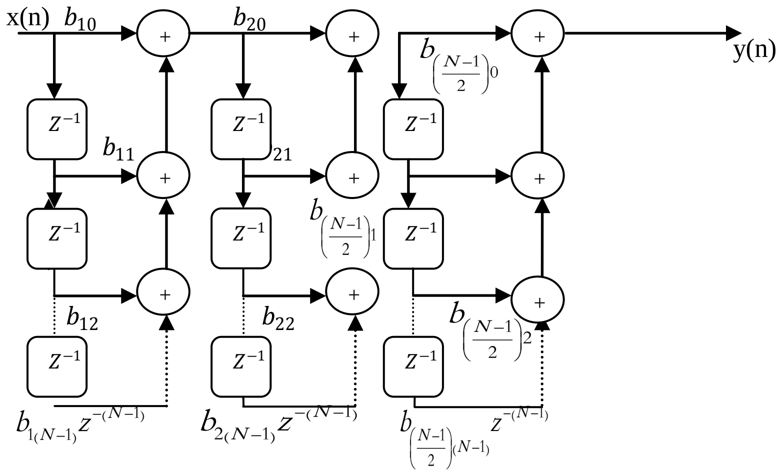

Fig.3 Cascade Form Realization (N=Odd)

<u>Order = Even:</u>

For Even ordered filter, the transfer function H(z) can be factored as follows[22][27][28][29],

$$H(z) = \left(b_{10} + b_{11}z^{-1}\right)\prod_{k=2}^{N/2}\left(b_{k0} + b_{k1}z^{-1} + b_{k2}z^{-2} + \ldots + b_{k\left(\frac{N-2}{2}\right)}z^{-\left(\frac{N-2}{2}\right)}\right) \quad ....(1.7)$$

The realization structure for the N=Even , for example N=2 is shown in Fig.4[21][23][25][28][29],

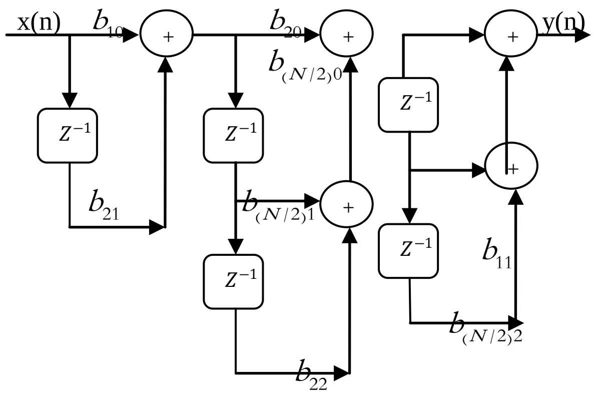

Fig.4 Cascade Form Realization (N- Even)

V. DETERMINATION OF WINDOW FUNCTION AND COEFFICIENT

The window function and the value of the coefficients can be determined from the Rife-Vincent function given in eq.(1.3). The value of coefficient of Rife-Vincent window of grade 4 are till tabulated[4][5][13][15].

A. Coefficients

Table-1 shows the values of the coefficients upto grade 4 and after that the transformed equation of the window function are shown.

Table-1

d	***i=0***	***i=1***	***i=2***	***i=3***	***i=4***
1	1/2	-1/2			
2	3/8	-4/8	1/8		
3	10/32	-15/32	6/32	-1/32	
4	35/128	-56/128	28/128	-8/128	1/128

B. Window Function

The window functions, depending upon the values of the coefficients shown in the table-1, can be shown for different grade i.e. the values of *"d"*.

Grade-1:

The window function for d=1, is given in the following equation w.r.t table-1.

$$\omega_1(n) = \frac{1}{2} - \frac{1}{2}\cos\left(\frac{2\pi n}{N}\right)$$

....(1.8)

Grade-2:

The window function for d=2, is given in the following equation w.r.t table-1.

$$\omega_2(n) = \frac{3}{8} - \frac{4}{8}\cos\left(\frac{2\pi n}{N}\right) + \frac{1}{8}\cos\left(\frac{4\pi n}{N}\right)$$

....(1.9)

Grade-3:

The window function for d=3, is given in the following equation w.r.t table-1.

$$\omega_3(n) = \frac{10}{32} - \frac{15}{32}\cos\left(\frac{2\pi n}{N}\right) + \frac{6}{32}\cos\left(\frac{4\pi n}{N}\right) - \frac{1}{32}\cos\left(\frac{6\pi n}{N}\right)$$

....(1.10)

Grade-4:

The window function for d=4, is given in the following equation w.r.t table-1.

$$\omega_4(n) = \frac{35}{128} - \frac{56}{128}\cos\left(\frac{2\pi n}{N}\right) + \frac{28}{128}\cos\left(\frac{4\pi n}{N}\right) - \frac{8}{128}\cos\left(\frac{6\pi n}{N}\right) + \frac{1}{128}\cos\left(\frac{8\pi n}{N}\right)$$

....(1.11)

VI. SIMULATION RESULT

The Simulation for the response of Rife-Vincent window is simulated in Matlab 7. Basically the functions for the generally used windows such as the Kaisar window, Blackman window, rectangular window etc are readily available in the Matlab environment but the function that will directly simulate and produce the output response for the Rife-Vincent window is not readily available in Matlab. So, for this reason, some external function must be added with the existing window function like Hanning or Blackman window to simulate the Rife-Vincent function as mentioned earlier. The simulation results of Rife-Vincent window are shown below.

A. Rife-Vincent Window (Order=4)

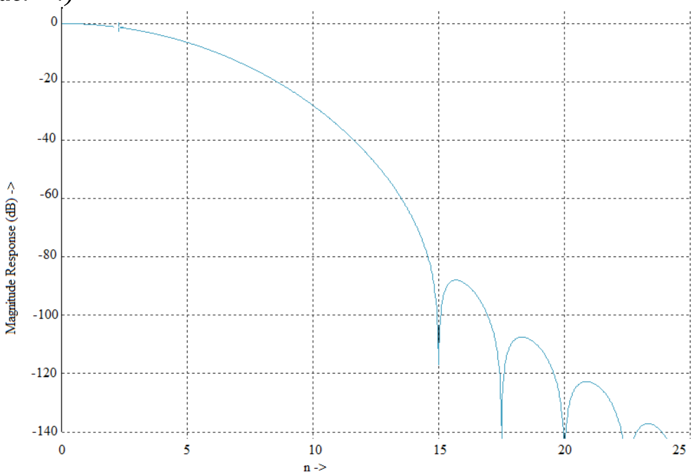

Fig.5 Rife-Vincent Window Order=4

B. Rife-Vincent Window (Order=5)

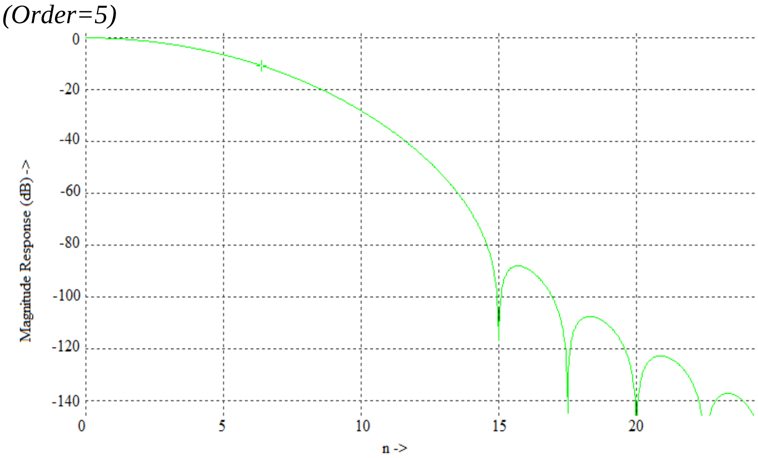

Fig.6 Rife-Vincent Window Order=5

C. Rife-Vincent Window (Order=6)

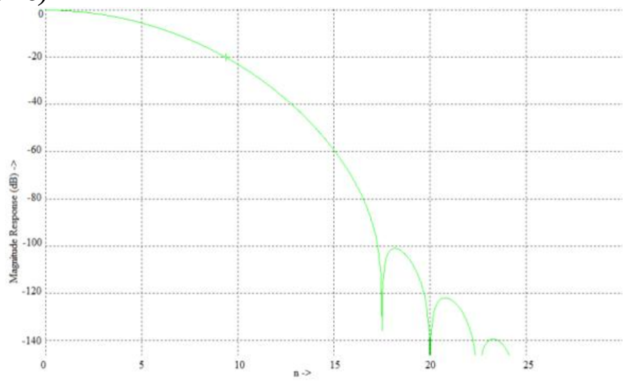

Fig.7 Rife-Vincent Window Order=6

D. Rife-Vincent Window (Order=7)

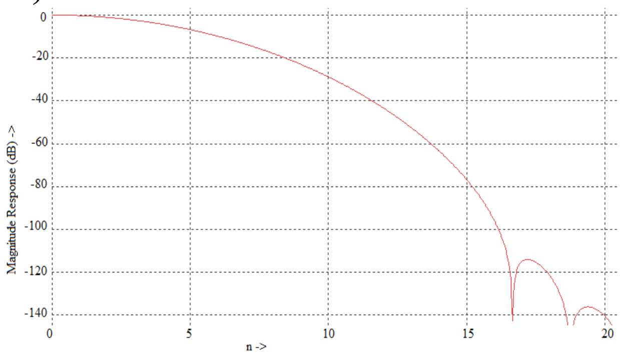

Fig.8 Rife-Vincent Window Order=7

From above four Fig., we can see that the magnitude of peak sidelobs are -84dB, -86dB, -100dB and -116dB for the order of FIR filter with Rife-Vincent window of 4,5,6 and 7 respectively.

There are several windows are available for the design of FIR filter. Some of the widely used windows are shown in FIR design of higher order and then comparison can be drawn to realize that the Rife-Vincent window technique can be used to efficient design of the FIR filter.

E. FIR Filter with Rectangular Window

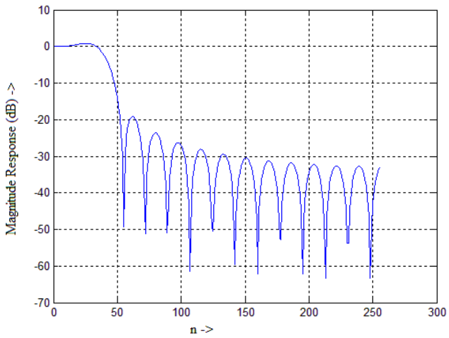

Fig.9 FIR Filter with Rectangular window (Order=15)

F. FIR Filter with Kaisar Window

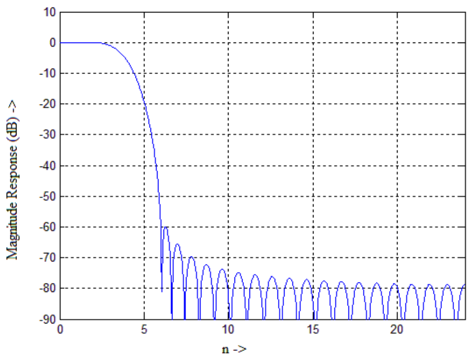

Fig.10 FIR Filter with Kaisar window (Order=15)

G. FIR Filter with Hamming Window

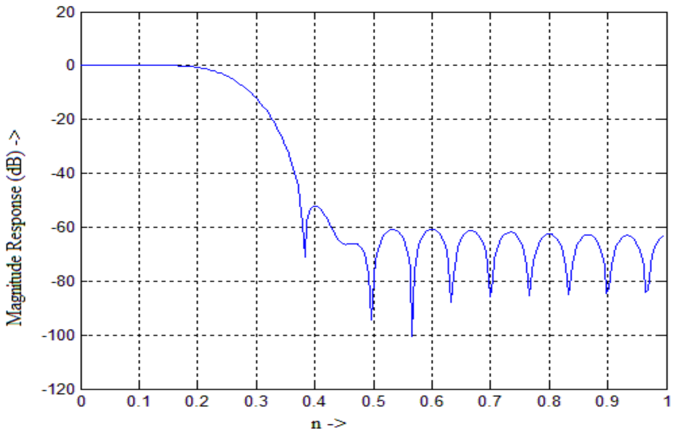

Fig.11 FIR Filter with Hamming window (Order=15)

H. FIR Filter with Bartlett Window

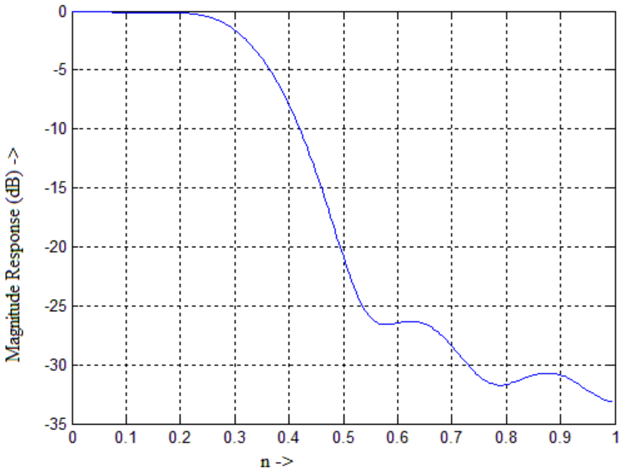

Fig.12 FIR Filter with Bartlett window (Order=15)

From the above Fig.9 to Fig.12, it can be seen that the magnitude for the peak sidelobes are -18dB, -60dB, -52dB and -27dB for Rectangular window, Kaisar window, Hamming window and the Bartlett window of order 15 each.

VII. CONCLUSION

The simulations of the Rife-Vincent window function for the design of the FIR Filter of different order are shown in this paper. From the comaprison of the magnitude response of Rife-Vincent window function and the other window functions, shown in this paper, it can be concluded that the magnitude of the peak sidelobe of Rife-Vincent window function is much more lower than the others. So, it can be said that there is an improvement of the reponse of the Rife-Vinecent window function than the other conventional and widely used general purpose window functions. It can also be observed that, for the lower order Rife-Vincent window function, it can generate the lower magnitude of the peak sidelobe compared to other where the other conventional window responds to higher magnitude response of peak sidelobe in much higher order. So, Rife-Vincent window can be used to generate an efficient response with lesser ripple in passband and stopband in lesser order and so the FIR filter can be designed in lesser complexity.

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