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Cost Analysis of Different Digital Fir Filter Design Methods

Amninder Singh, Kulwinder Singh
M. Tech Department of Electronics & Communication Engineering, Punjabi University, Patiala
Associate Professor Department of Electronics & Communication Engineering, Punjabi University, Patiala

ABSTRACT
FIR digital filters are widely used in the communication world. The implementation cost of filter circuit is counted by the number of multipliers & adders used, that decides the chip area. In this paper, design techniques of low pass FIR filter using the different windows are presented. The simulation is done in MATLAB. It is shown that filter designed using Hamming and Blackman windows are better than rest of the windows used. Out of two, Hamming window is better as its transition width is narrow, 0.019 than Blackman, 0.034. Further the performance analysis of Kaiser Window, Equiripple and Minimum phase filters was obtained, for same 0.04 transition width. There is a disparity in implementation cost & area. The minimum phase filter can be implemented with lesser number of filter coefficients with tolerable pass-band, stop-band ripples specifications.
Keywords: FIR Filter, Windows Functions, IIR, Digital Filter, Equiripple Minimum Phase Filter.

I. INTRODUCTION

FIR (Finite impulse response) filters are most famous type filters that implemented in software. In a typical digital filtering application, software running on a DSP (Digital signal processor) reads samples from an analog to digital converter (A/D) , performs the mathematical manipulations and via digital to analog converter (D/A) [1]. Digital filters can be classified as FIR & IIR according to the filter length. The FIR filter is one of the most basic elements in a DSP system, and it can guarantee a strict linear phase frequency characteristics as they are non-recursive in nature. Where IIR filters are recursive with feed-back path that means they are not linear phase. As the FIR filters have finite length they are more economical than IIR. The number of non-zero coefficients required for FIR is less than IIR. The FIR filter can be divided into two main parts, one is the multiplier block and the second on is the delay block [8]. In the multiplier block output Y_i is obtained by multiplying all the filter coefficients with the input variable x(n). Then the outputs y_i are delayed and added in the delay blocks to produce y(n), as filter output as shown in Fig 1.

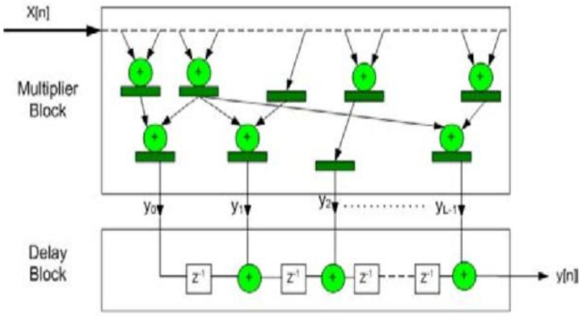

Fig1. FIR Filter structure

II. FIR FILTER DESIGN

The frequency response of Nth-order causal FIR filter is, [6]

$H(e^{j\omega}) = h(n)e^{-j\omega}$

And the design of an FIR filter involves finding the coefficients h(n) that in a frequency response that satisfies a given set of filter specification. FIR filters have two important advantages over IIR filters. First they are guaranteed to be stable, even after filter coefficients have been quantized. Second, they may be easily constrained to have linear phase. Because FIR filters are generally designed to have linear phase.

III. LINEAR PHASE FILTER DESIGN USING WINDOWS

Let $h_d(n)$ be the unit sample response of an ideal frequency selective filter with linear phase, [7]

$$H_d(e^{j\omega}) = A(e^{j\omega})e^{-j(\alpha\omega-\beta)}$$

Because $h_d(n)$ will generally be infinite in length, it necessary to find an FIR approximation to $H_d(e^{j\omega})$, with the window design method, the filter is designed by windowing the unit sample response,

$h(n) = h_d(n)w(n)$

Where w(n) is a finite-length window that is equal to zero outside the interval $0 \le n \le N$ and is symmetric about its midpoint:

$W(n) = W(N-n)$

The effect of the window on the frequency response may be seen from the complex convolution theorem,

$$H(e^{jw}) = \frac{1}{2\pi} H_d(e^{jw})+W(e^{jw}) = \frac{1}{2\pi} H_d(e^{jw})W^{(ej(w-\theta))}\, d\theta$$

Thus, the ideal frequency response is smoothed by the discrete-time Fourier transform of the window, $W(e^{jw})$

There are many different types of windows that may be used in the window design method. [2]

Rectangular:

$$w(n) = \begin{cases} 1 & 0 \le n \le N \\ 0 & else \end{cases}$$

Where N is the length of window

Hannin:

$$w(n) = \begin{cases} 0.5 - 0.5\cos\left(\frac{2\pi n}{N}\right) & 0 \le n \le N \\ 0 & else \end{cases}$$

Hamming:

$$w(n) = \begin{cases} 0.54 - 0.46\cos\left(\frac{2\pi n}{N}\right) & 0 \le n \le N \\ 0 & else \end{cases}$$

Blackman:

$$w(n) = \begin{cases} 0.42 - 0.5\cos\left(\frac{2\pi n}{N}\right) + 0.08\cos\left(\frac{4\pi n}{N}\right) & 0 \le n \le N \\ 0 & else \end{cases}$$

Bartlett:

$$w(n) = 1 - \left| \frac{n - \frac{N-1}{2}}{N - \frac{1}{2}} \right|$$

Kaiser:

$$w(n) = \frac{\left(Io\left(\pi\alpha \sqrt{1 - \left(\frac{2n}{N-1} - 1\right)\left(\frac{2n}{N-1} - 1\right)} \right) \right)}{Io\,(\pi\alpha)}$$

Here Io is the zero^th order modified Bessel function of the first kind, and α= 3, [1]

IV. MATLAB SIMULATION

We have designed FIR low pass filter using different windows methods for different filter lengths .The windows used were Blackman, Hamming, Rectangular, Kaiser, Hann , Bartlett, Gaussian window.

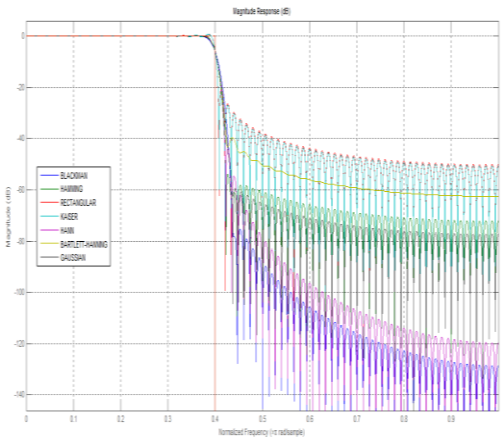

Fig2. Frequency Response of filter for N=150

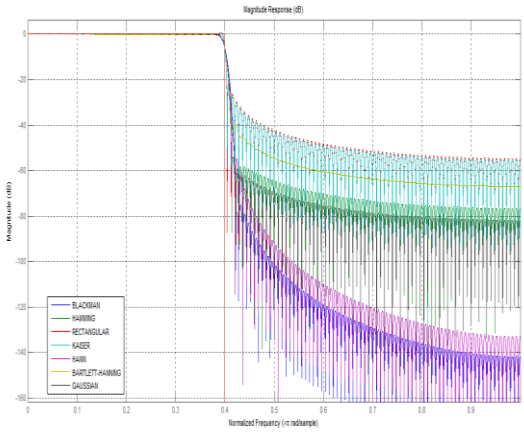

Fig3. Frequency Response of filter for N=250

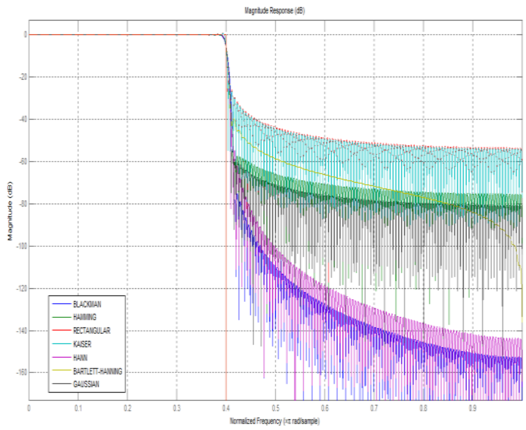

Fig4. Frequency Response of filter for N=351

V. RESULTS AND DISCUSSION

The stop-band attenuation can be increased by increasing filter length. But at the same time ROM (Read only memory) to store the filter coefficients also increases. That means cost and area of implementation also increased. There are also some other methods that can be used to minimize the non-zero coefficients to attain the tolerable pass-band & stop-band ripples. The pass-band & stop-band ripples for Kaiser, Equiripple, and Minimum phase filter are shown in Table 1. Table2. Shows the characteristics and cost analysis of FIR low pass filter design using different windows functions. All the windows have nearly same number of filter elements, but hamming window is best after weighting all the aspects.

Table 1. CHARACTERISTICS FILTER DESIGN METHODS

Method	Filter Length	Stop-band Attenuation	Pass-band Ripples
Kaiser Window	183	60.092	0.016058
Equiripple Window	146	60.1526	0.058484
Equripple Minimum Phase	117	59.75	0.064833

Table 2. CHARACTERISTICS & IMPLEMENTATION COST OF VARIOUS WINDOWS

Window Functions	Stop-Band Attenuation	Transition Width	No. of Multipliers	No. of Adders	Multiplication per input sample	Addition per input sample
Blackman	78.3	0.034	350	349	350	349
Hamming	54	0.019	352	351	352	351
Rectangular	21	0.005	352	351	352	351
Kaiser	21.59	0.006	352	351	352	351
Hanning	44	0.018	350	349	350	349
Bartlett	39.67	0.021	350	349	350	349
Gaussian	59.27	0.030	352	351	352	351

VI. CONCLUSION

The low pass FIR filter designed using different windows have been analyzed. The Blackman window provide maximum stop-band attenuation of 78.3 for N=351, but the transition width of 0.034.Thus it is not suitable for filter designing because of more transition width as compare to Hamming window with 0.019.That means Hamming window is best choice for designing filter with stop-band attenuation of 54 and narrowest main lobe out of Rectangular, Kaiser, Hanning, Bartlett, Gaussian windows. Now the main problem with these windows is high implementation cost. Thus further the performance analysis of Kaiser Window, Equiripple, and Minimum Phase filter was obtained with same transition width of 0.04.There is a small difference in pass-band, stop-band ripples, but from implementation cost point of view, there is a disparity in cost and area. As in case of Kaiser Window, at 183 filter length the stop-band attenuation is 60.092 & pass-band ripples are 0.0160.For equiripple these two specifications can be nearly obtained with filter length of 146. Filter length can be further reduced using Minimum phase filter to 117.As minimum phase filters have non-linear phase, but according to our application, like where small group delay is needed, gives better solution. This will fulfill our both of requirements, better performance & low implementation cost.

VII. ACKNOWLEDGMENTS

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