A Survey of the Implementation techniques of Quantized Coefficient F.I.R. Filter for the Design of Filter Bank

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Abstract-**In this paper we have performed the study of different approaches and ideas associated with the implementation of quantized coefficient F.I.R. filter using for the design of the F.I.R. filter bank. These techniques involve approximation of a quantized coefficient FIR filter by rounding operation to design a filter bank. The prototype filter is designed using rounding technique to provide quantized coefficient FIR filter. Our purpose is to see the different methods in the comparative expect, so as to find an appropriate and suitable method for our future work.**

I. INTRODUCTION

In many applications it is often advantageous to employ finite impulse response (FIR) filters, since they can be designed with exact linear phase and exhibit no stability problems (Mitra, 2006)[1-2]. MultiMate filter banks find wide applications in many areas of digital signal processing such as sub-band coding, transmultiplexer, image, video and audio compression, adaptive signal processing. Multi rate filter bank implementation preferably done with the FIR filters.[1-4] However FIR filters have a computationally more intensive complexity compared to infinite impulse response (IIR) filters with equivalent magnitude responses. During the past several years, many design methods have been proposed to reduce the complexity of the FIR filters.[4-8]

In most applications, the required number of multipliers is excessively large compared to an equivalent IIR filter. An approach to the reduction of computational complexity is to reduce the number of non-zero bits in every multiplier coefficient to a very small number so that the multiplication can be implemented by a few shifts and add operations. However, their application generally requires more computation.[6-9]

On the basis of time-frequency resolution, filter bank can be classified in two categories, which include, uniform and non-uniform filter bank.[1-4,7-10] The uniform filter bank (UFB) provides fixed and uniform time frequency decomposition e.g. ECG and image decomposition, whereas, in some applications like audio analysis and coding, broadband array signal processing non-uniform and variable time-frequency resolution may lead to better performance and reduced arithmetic complexity, which is provided by non-uniform filter bank (NUFB).Thus both UFB and NUFB are have importance depends upon the application. Our work will mainly concern with the UFB only

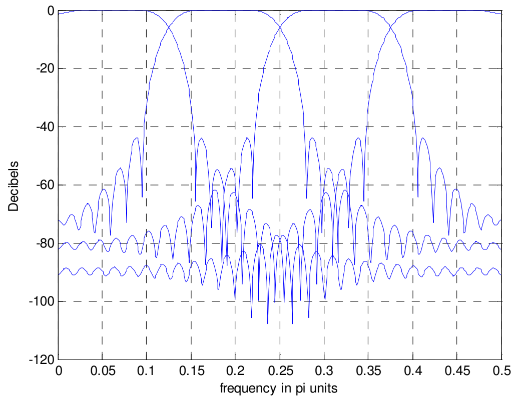

Fig1. 4 channel uniform filter bank

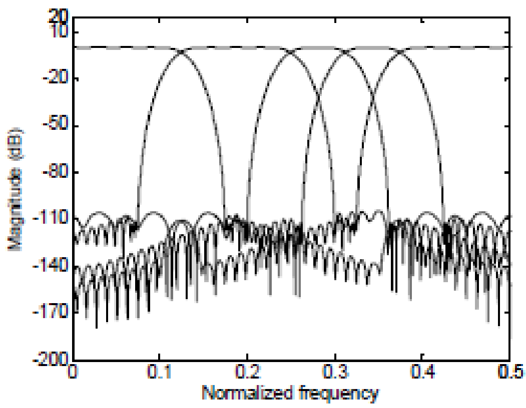

Fig2. 5 channel non-uniform filter bank

Several techniques have been developed to improve FIR filter efficiency in terms of computational requirements. As suggested by A. Mehrnia and A. Willson, IFIR technique reduces number of multipliers and adders at the cost of increased system delay known as cascaded structure design and its generalization is FRM technique. Recently Gordana et al. has suggested a technique to design a computationally efficient multiplier free FIR filter based on rounding operation. By FIR filter coefficient rounding, we may design multiplier-less filters which can be utilized in many signal processing applications in the field of uniform and non-uniform filter bank.[3-7]

Among the different classes of multichannel filter banks, cosine-modulated filter banks are the most frequently used filter banks due to simpler design, where analysis and synthesis filter banks are derived by cosine modulating a low-pass prototype filter. The design of whole filter bank thus reduces to that of a single lowpass prototype filter.[8-11] Cosine modulated filter bank (CMFB) finds wide application in different areas of digital signal processing such as equalization of wireless communication channel, sub band coding, spectral analysis, adaptive signal processing, denoising, feature detection and extraction. Several design techniques have been developed for these filter banks in the past. In CMFB, analysis and synthesis filters are cosine modulated versions of low pass prototype filter. Thus, the design of whole filter bank reduces to that of the prototype filter and the cost of overall filter bank is almost equal to the cost of one filter with modulation overheads.

II. DESIGN OF PROTOTYPE FILTER USING WINDOW FUNCTION

For this work, Blackman window is used for the Design of the prototype filter for CM filter bank.[1-5,11] The impulse response coefficients of a causal *N*th-order linear phase FIR filter *h*(*n*) using window technique is given by

$$h(n) = h_i(n).w(n)|$$

Where

$$h_i(n) = \frac{\sin(w_c(n-N/2)}{\pi(n-N/2)}$$

is an ideal impulse response filter with cut-off frequency w_c while *w*(*n*) is a window function of order *N*. The filter order *N* and transition width $\Delta\omega$ is estimated as

$$N = 5.5/\Delta w$$

$$\Delta w = (w_s - w_p)/2\pi$$

For a given value of pass band (w_p) and stop band (w_s), the required number of adders and multipliers are equal to (*N*) and (*N*+1)/2, respectively. In case of FIR filters the filter order is inversely proportional to the transition bandwidth. Thus, for narrow transition bandwidth, filter order becomes very high, and hence number of adders and multipliers are also high. Therefore, researchers are putting efforts on developing computationally efficient design techniques. In this proposed work, computationally efficient and multiplier-less design technique of FIR filters is used to design the prototype low pass filter.

For improving the performance of filter designed with window function, a function called spline, and is defined in transition region to shape it such that it allows an explicit control on transition bandwidth. In addition, it also eliminates the Gibbs' phenomenon even more.

An example of proto type filter is given below:

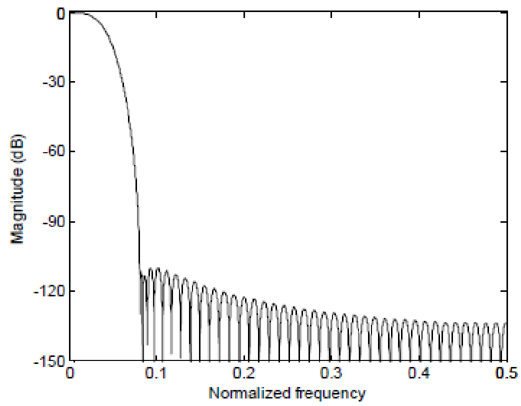

Fig. 3 Frequency response of the prototype filter

III. WINDOW FUNCTIONS USED FOR THE PROTO TYPE FILTER FOR QMF CONSTRUCTION

The use of the Kaiser window is very common for the prototype implementation in the QMF construction. The Kaiser window is a variable window provides us the options regarding the window shape.[1,4-7,9-10]

The Kaiser window is given by:

$$w(n) = \begin{cases} \frac{I_0(\alpha)}{I_0(\beta)} & for -\frac{N}{2} \le n \le \frac{N}{2} \\ 0 & otherwise \end{cases}$$

where I_0 is the Bessel's function of first order and $\beta = \alpha\sqrt{1-\left(\frac{2n}{N}\right)^2}$

Yet we have freedom to adjust the window shape with the variable window but still it is difficult to get the optimal prototype filter, which can provide the prototype filter of required features. Thus we may look towards the fixed windows for the same purpose. The Blackman window and the other windows of its family have been utilized for the same purpose.

The Blackman window can be given by:

$$w(n) = \begin{cases} 0.42 + 0.50\cos\left(\frac{2\pi n}{N}\right) + 0.08\cos\left(\frac{4\pi n}{N}\right); & for -\frac{N}{2} \le n \le \frac{N}{2} \\ 0 & otherwise \end{cases}$$

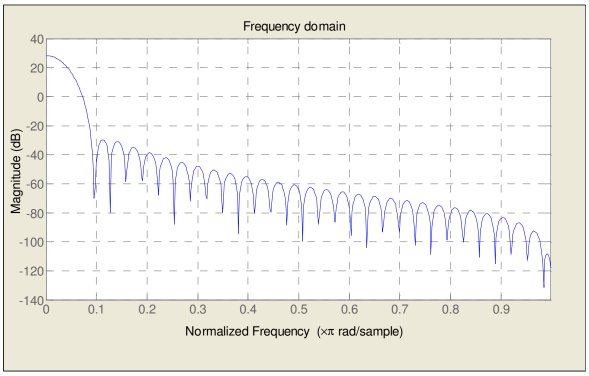

Fig.4 Freq response of Blackman window

Blackman-Harris window is the window of Blackman family, which is given by:

$$w(n+1) = \begin{cases} a0 - a1.\cos\left(\frac{2\pi n}{N-1}\right) + a2.\cos\left(\frac{4\pi n}{N-1}\right) - a3.\cos\left(\frac{6\pi n}{N-1}\right); & for\ 0 \le n \le N-1 \\ 0 & otherwise \end{cases}$$

where: $a0 = 0.35875$; $a1 = 0.48829$; $a2 = 0.14128$; $a3 = 0.01168$;

IV. ROUNDING TECHNIQUE

The rounding technique is applied on window based FIR filter to satisfy the given specifications.[3] The technique is briefly described in this section. The impulse response rounding is given by

$$h(n) = \alpha \times g_i(n) = \alpha \times round\ (h(n)/\alpha)$$

Where, $h(n)$ is an impulse response of the FIR filter which satisfies the given specifications, *round* (.) means the rounding operation, $g_i(n)$ is the new impulse response derived by rounding all the coefficients of $h(n)$ to the nearest integer. The rounded impulse response $g_i(n)$ is scaled by a factor α which determines the precision of the approximation of $g(n)$ to $h(n)$. The rounding constant is chosen in the form of $\alpha = 2^{-N}$. where N is an integer. The process of rounding introduces some null coefficients in the rounded impulse response. The number of nonzero integer coefficients corresponds to the number of the sums and the number of integer multiplications corresponds to the number of a different positive integer coefficients. Computational complexity is expressed in terms of number of integer multiplications, which itself depends on rounding constant.

V. COSINE MODULATED FILTER BANK

Cosine modulation is the cost effective technique for M-band filter bank.[1-7,9] Cosine Modulated Filter banks (CMFB) are widely used in different multi-rate applications. The main advantages of the Cosine Modulated filter banks are that, they have computationally efficient design and all the coefficients are real. It is sufficient to design only the prototype filter. All the analysis and synthesis filters are derived from this filter by cosine modulation. Since all the analysis and synthesis filters are modulated versions of the prototype filter, the shapes of their amplitude responses are the same as those of the prototype filter. Let $H(z)$ denote the transfer function of the prototype filter, then

$$H(z) = \sum_{n=0}^{N-1} h(n).z^{-n} \quad \text{With } h(n)=h(n\text{-N})$$

Where, N is order of the prototype filter for the analysis and synthesis sections. The analysis and synthesis filters are determined by

$$H_k(n) = 2h(n)\cos(\frac{\pi}{M}(k+0.5)\left(n-\frac{N}{2}\right) + (-1)^k\frac{\pi}{4})$$

$$F_k(n) = 2h(n)\cos(\frac{\pi}{M}(k+0.5)\left(n-\frac{N}{2}\right) - \left(-1\right)^k\frac{\pi}{4})$$

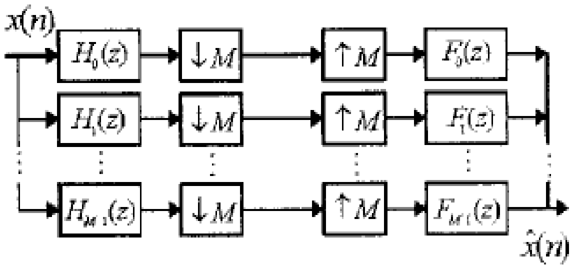

Fig 5. M channel uniform filter bank

$$Y(z) = T_O(z)X(z) + \sum_{l=0}^{M-1} T_l(z)X(ze^{-j2\pi l/M})$$

Where,

$$T_O(z) = \frac{1}{M}\sum_{k=0}^{M-1} F_k(z)H_k(z)$$

And

$$T_l(z) = \frac{1}{M}\sum_{k=0}^{M-1} F_k(z)H_k(ze^{-j2\pi l/M})$$

for $l = 0,1,2 \ldots\ldots\ldots\ldots\ldots (M-1)$

Here, $T_O(z)$ is the distortion transfer function and determine the distortion caused by the overall system for the unaliased component $X(z)$ of the input signal. $T_l(z)$ for $l = 1, 2, \ldots (M-1)$ are called the alias transfer function, whichdetermine how well the aliased components $X\left(ze^{\frac{j2\pi l}{M}}\right)$ of the input signal are attenuated.

VI. PERFORMANCE PARAMETERS

A. Amplitude distortion

Amplitude distortion error is given by[1-3,7-11]:

$$E_r = max|[|MT_0(e^{jw})| - 1]|$$

B. Aliasing distortion

The worst case aliasing distortion is given by[1-3,7-11]:

$$E_a = max(T_{alias}(w))$$

Where

$$T_{alias}(w) = \frac{1}{M}\left[\sum_{l=1}^{M-1}|T_l(e^{jw})|^2\right]^{\frac{1}{2}}$$

Whereas, total aliasing distortion is given by

$$e_{ta} = \left[\sum_{l=1}^{M-1}\left|T_l\left(e^{j\omega}\right)\right|^2\right]^{1/2}$$

C. Computational complexity

It is measured by No. of integer sums, N1 and No. of integer multiplications, N2. N1 is measured by the evaluating the non zero coefficients and N2 is measured by evaluating the different positive integer coefficients excluding 1, corresponding negative values are not counted[5-11].

The Amplitude distortion error and Aliasing distortion increases when we increase the rounding coefficient α and Computational complexity decreases with the increment in the value of rounding coefficient α.

VII. CONCLUSION AND FUTURE WORK

In our study we have seen the multiple types for the multi rate filter bank that can be uniform or non uniform. The both UFB and NUFB are utilized in the different applications as per the requirements. We have chosen the UFB for our further works. The Cosine modulated filter bank provides a easy and correct approach for the design of the UFB. The prototype filter is only the one requirement for the CMFB implementation. The windowed filter provides much better response as compare to the filter implemented without it. The kaise and Blackman family windows are mainly used for the CMFB.

We may utilize the Nuttall window for our future work and the results can be analyzed. The Nuttall window is a good window, which might provides the much better results.

The expression for Nuttall window can be given as:

$$w(n) = \begin{cases} a0 - a1.\cos\left(\frac{2\pi n}{N}\right) + a2.\cos\left(\frac{4\pi n}{N}\right) - a3.\cos\left(\frac{6\pi n}{N}\right) & for -\frac{N}{2} \le n \le \frac{N}{2} \\ 0 & otherwise \end{cases}$$

where: $a0 = 0.40243;\ a1 = 0.49804;\ a2 = 0.09831;\ a3 = 0.00122$

Further, we may also try to use some other implementation approach for the UFB via which we might get some improvisation.

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