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Optimized Design of IIR Poly-phase Multirate Filter for Wireless Communication System

Er. Kamaldeep Vyas and Mrs. Neetu

[1] *M. Tech. (E.C.E), Beant College of Engineering, Gurdaspur*

[2] *(Astt. Prof.), Faculty Member of Bant college of Engineering. (Punjab)*

***ABSTRACT* — In this paper, IIR polyphase filters present several interesting properties: they require a very small number of multipliers to implement, they are inherently stable and have low round off noise sensitivity and no limit cycles. Furthermore, it is possible to achieve almost linear phase designs. Pulse shaping filters have been designed and implemented by using Raised cosine filter, Nyquist filter and optimized half band filters for software defined radio (SWDR) based wireless applications.**

However, IIR polyphase filters enjoy most of the advantages that FIR filters have and require a very small number of multipliers to implement. Multirate IIR halfband Filter with proposed Filters to provide cost effective solution for wireless communication applications. Cost effective techniques for design of Pulse Shaping Filter have been presented to improve the computational and implementation complexity.

***Keywords*—RRC, CDMA, ISI, GSM, HDTV**

[A] INTRODUCTION

The widespread use of digital representation of signals for transmission and storage has created challenges in the area of digital signal processing. The applications of digital FIR filter and up/down sampling techniques are found everywhere in modem electronic products. For every electronic product, lower circuit complexity is always an important design target since it reduces the cost. There are many applications where the sampling rate must be changed. Interpolators and decimators have been utilized to increase or decrease the sampling rate. Up sampler and down sampler are used to change the sampling rate of digital signal in multi rate DSP systems. His rate conversion requirement leads to production of undesired signals associated with aliasing and imaging errors. So some kind of filter should be placed to attenuate these errors [1]. Recently, there is increasingly strong interest on implementing multi-mode terminals, which are able to process different types of signals, i.e. WCDMA, GPRS, WLAN and Bluetooth. These versatile mobile terminals favor simple receiver architectures because otherwise they'd be too costly and bulky for wireless practical applications.

1. Root Raised cosine (RRC) filter

A root raised cosine filter is typically used to shape and oversample a symbol stream before modulation/transmission. The roll off factor (R) determines the width of the transition band. Practical digital communication systems use a **roll off factor** between 0.1 and 0.5. A minimum **stop band attenuation** of 60 to 80 dB is also desirable to suppress inter channel interference. The optimum pulse design this paper work uses a roll off factor 0.22 and show to give encouraging results. The raised-cosine filter designed a filter order as high as 240 are necessary to attain a minimum stop band attenuation of 60 dB [2].

2. FIR nyquist filter or FIR Kaiser Window filter

Nyquist filter can replace raised cosine filters for a fraction of the cost because they have an optimal equiripple response. The same stop band attenuation and transition width can be obtained with a much lower order. The transition width requirement can be deduced from the roll-off and interpolation factors. The magnitude response of this filter and the raised cosine filter above have the same transition width and minimum stop band attenuation but the filter order of the equiripple nyquist design [3]. Kaiser filters can replace raised cosine filters for a fraction of the cost because they have lower filter order as compare to RRC filter with same stop band attenuation and transition width.

3. Multistage half band filter

An even more efficient design is obtained by cascading 3 half band filters. The main advantage of multistage over single stage designs is that longer (i.e. more expensive) filters can be operated at lower sample rates while shorter filters are operated at higher sample rates. Half band filters can be designed using FIR and IIR design techniques [4]. FIR designs have an additional advantage in that every other coefficient is equal to zero. IIR designs can achieve quasi-linear phase and they offer a greater cost savings while achieving extremely low pass band ripples. Halfband filters are widely used in multirate signal processing applications when interpolating/decimating by a factor of two. Halfband filters are implemented efficiently in polyphase form, because approximately half of its coefficients are equal to zero.

4. Need of Pulse Shaping Design

Pulse shaping filters are used at the heart of many modern data transmission systems (i.e. mobile phones, HDTV) to keep a signal in an allotted bandwidth, maximize its data transmission rate and minimize transmission errors. Raised cosine filters form a well established solution to this filter design problem [8].

The 3GPP standard proposes $1/T = 3.84e\text{-}6s^{-1}$ and roll off factor = 0.22. In this case, the bandwidth occupied by the modulated raised cosine with these parameters is 1.22 × 3.84 = 4.68 MHz which is less than 5MHz separation between adjacent channels of W-CDMA. Therefore the value of roll off factor used in designing the raised cosine pulse shaping filter in this paper is 0.22 and shown hardware requirement [6].

5. Polyphase Pulse Shaping Filter Design

To implement a filter with a fractional multirate factor of L/M, the data is first upsampled by L and then a filter is applied to both interpolate between the data points as well as provide anti-alias protection, and then finally downsampled by M. These three designs are diagrammed below.

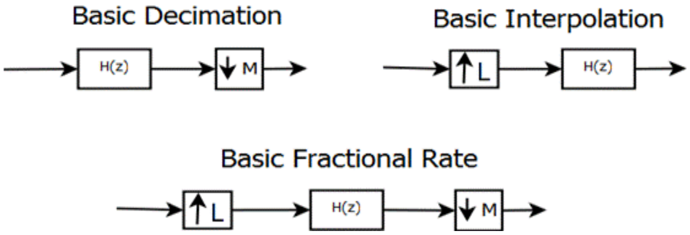


Fig. 1 polyphase filter structure

The basic decimating filter will calculate many outputs that will eventually be thrown away by the downsampler, while the basic interpolating filter has to process through not only the data but the zeroes from the upsampler as well. However, by using a polyphase filter structure, a decimating filter can be run at the decimated rate and an interpolating filter can be run at the input data rate and not at an upsampled rate. The two principles at work in a polyphase filter are noble identities and polyphase decomposition [5].The noble identity for decimation shows equivalence between a system with a filter before a downsampler and a system with a filter after the downsampler. The noble identity for interpolation does the same, only with an upsampler instead of a downsampler. If we define H (z) as the z transform of a filter, then we can represent the noble identities using the shown in figure 2.

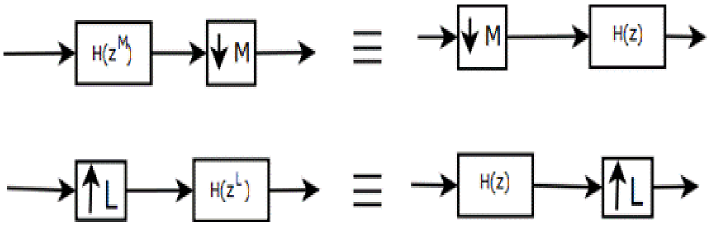


Fig. 2 upsampler & downsampler

For a basic filter that decimates by M, the filter must be in the form of H (z^M) to move it to the other side of the downsampler. Similarly, for a basic filter that interpolates by L, the filter must be in the form of H (z^L) to move it to the other side of the upsampler. In both cases, we need to take the filter and put it in terms of $H(z^N)$ for some integer N to move it to the other side of the multirate component in question. For most filters, and all FIR filters, one can perform the method known as polyphase decomposition and find N sub filters $H_0(z)$-$H_{N-1}(z)$ such that

$$H(z) = \sum_{i=0}^{N-1} Z^{-i} * H_i\,(z^N)$$

For example, for a FIR filter and N = 2, H_0 (z) will represent the even coefficients of H (z) and H_1 (z) will represent the odd coefficients. This equation allows us to describe a single filter as the sum of multiple sub filters in the form of H (z^N) for any N, which in turn allows us to use the noble identities to change the rate at which the filtering must run [5].

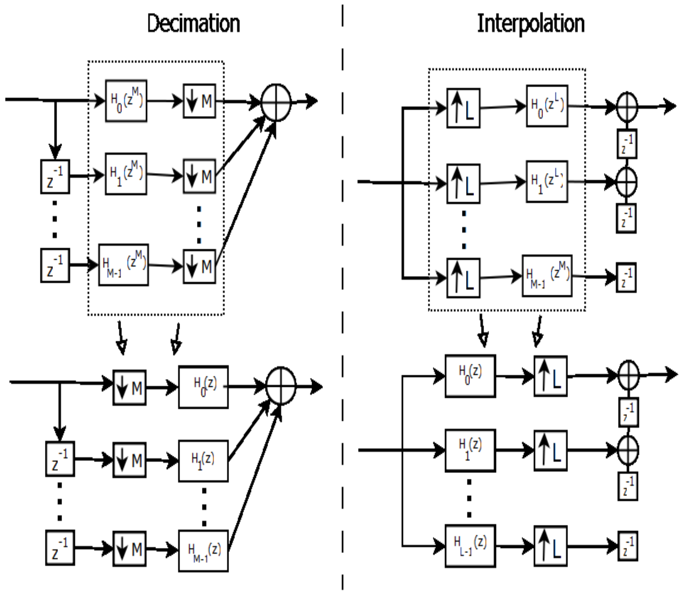


Fig. 3 Pulse shape filter design

A signal processing system that filters the data and has an output data rate that is different that the input data rate is known as multirate filter. The ratio of the output data rate to the input data rate is known as the multirate factor [8].

[B] PROPOSED FILTER DESIGN

A raised cosine filter is typically used to shape and oversample a symbol stream before modulation/transmission as well as after reception and demodulation. It is used to reduce the bandwidth of the oversampled symbol stream without introducing inter symbol interference.

In this proposed work first Raised cosine filter has been designed using filter order 240, roll off factor 0.22 and stop band attenuation of 60 dB with MATLAB. Kaiser window filter contain lower order 132 as compared to Raised cosine filter. So the proposed design is based on Park-McClellan algorithm technique which provides same stop band attenuation and transition width with much lower order. The comparison of Raised cosine filter and Kaiser Window filter is shown in Figure 4.

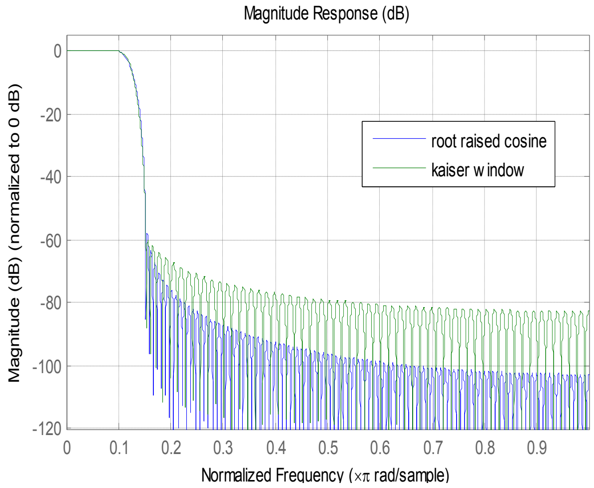


Fig. 4 Root raised Cosine and Kaiser Window Filter

An even more efficient design in terms of implementation complexity may be obtained by cascading three (3) half band filters. The main advantage of multistage over single stage designs is that longer filters are costly and can be operated at lower sample rates while shorter filters are operated at higher sample rates. An L^{th}-band filter for $L = 2$ is called a half-band filter. Halfband filters are commonly used when interpolating (or decimating) by a factor of 2.

$$H(z) = \alpha + z^{-1} E_1(z^2) \qquad (1)$$

With its impulse response satisfying [7]

$$h[2n] = \begin{cases} \alpha & n = 0 \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

The performance comparison of all the three designs is shown in Figure 5.

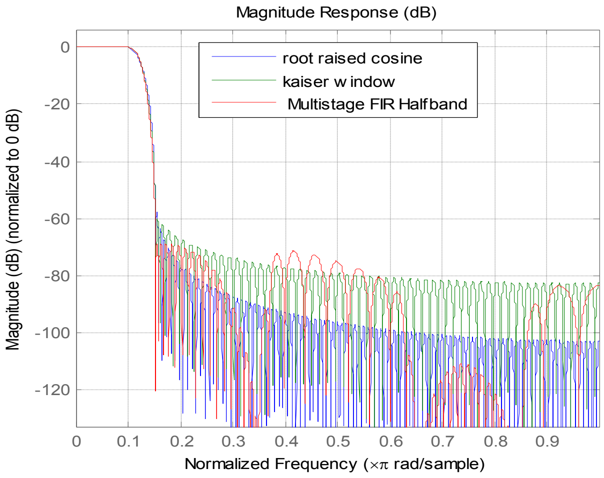


Fig. 5 Raised Cosine & Kaiser and Multistage FIR Halfband Filter

The performance comparison of the four designs is shown in Figure 6.

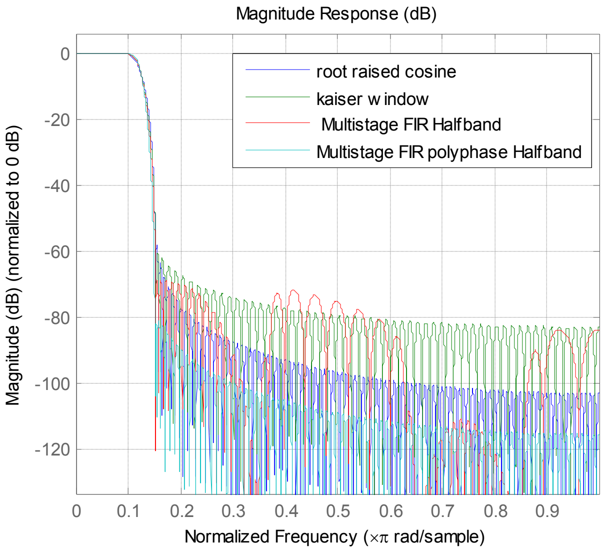


Fig. 6 Performance of cosine, Kaiser, FIR linear and FIR polyphase

The performance comparison of the five designs is shown in Figure 7.

All given filters (cosine, Kaiser, FIR) are compare with IIR Filters performance shown in figure 7.

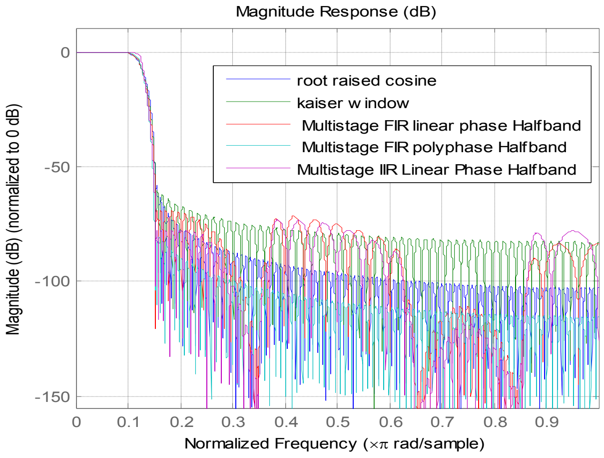


Fig. 7 Performance of cosine, Kaiser, FIR linear and polyphase and IIR linear

The performance comparison of the six designs is shown in Figure 8.

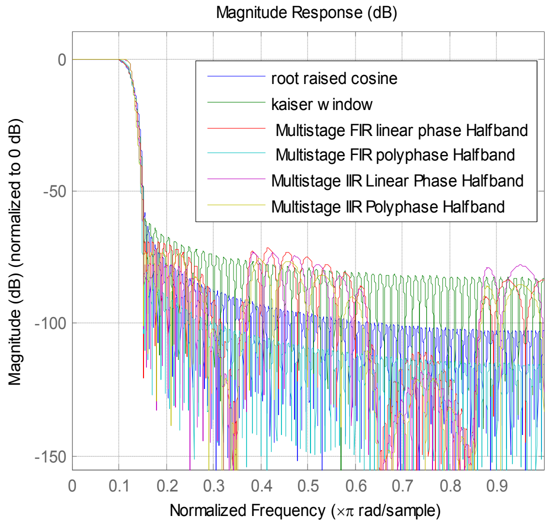
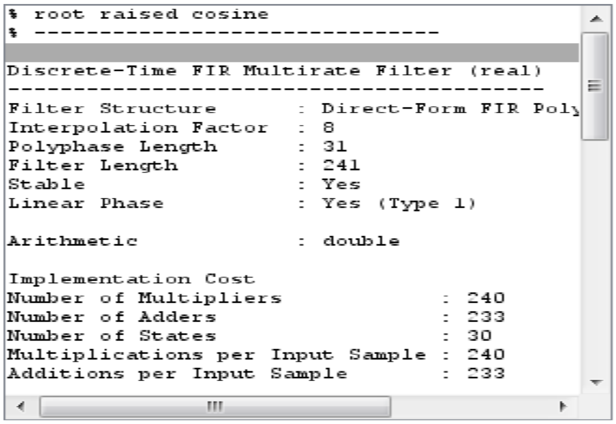


Fig. 8 Performance comparisons of all design

Now we are calculated no of Multipliers, Adders and MPIS if the value of this item is less, then this type of performance is called optimum filter design. Shown in Fig.(9),(10),(11),(12),(13) but Fig.(14) indicate optimum best design.



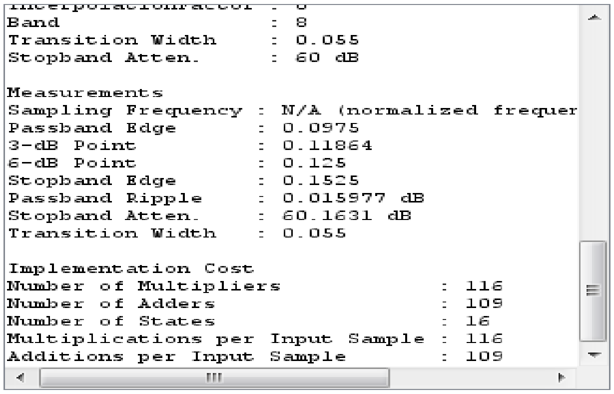
```
% root raised cosine
% -------------------------------

Discrete-Time FIR Multirate Filter (real)
-----------------------------------------
Filter Structure       : Direct-Form FIR Poly
Interpolation Factor   : 8
Polyphase Length       : 31
Filter Length          : 241
Stable                 : Yes
Linear Phase           : Yes (Type 1)

Arithmetic             : double

Implementation Cost
Number of Multipliers            : 240
Number of Adders                 : 233
Number of States                 : 30
Multiplications per Input Sample : 240
Additions per Input Sample       : 233
```

Fig. 9 Cost of Root raised Cosine

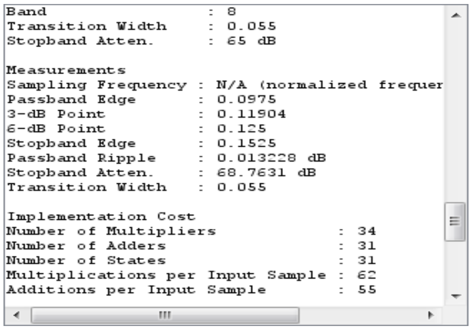


```
Band                 : 8
Transition Width     : 0.055
Stopband Atten.      : 60 dB

Measurements
Sampling Frequency : N/A (normalized frequer
Passband Edge      : 0.0975
3-dB Point         : 0.11864
6-dB Point         : 0.125
Stopband Edge      : 0.1525
Passband Ripple    : 0.015977 dB
Stopband Atten.    : 60.1631 dB
Transition Width   : 0.055

Implementation Cost
Number of Multipliers            : 116
Number of Adders                 : 109
Number of States                 : 16
Multiplications per Input Sample : 116
Additions per Input Sample       : 109
```

Fig. 10 Cost of Kaiser window Filter

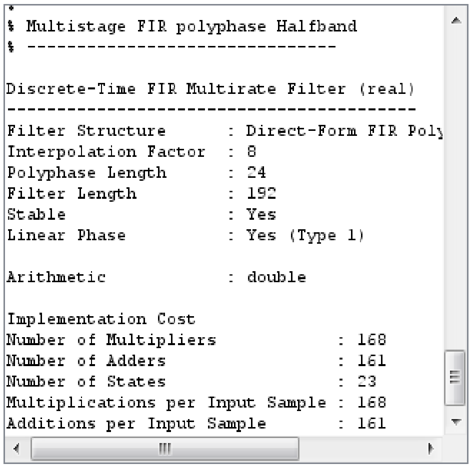


```
Band                 : 8
Transition Width     : 0.055
Stopband Atten.      : 65 dB

Measurements
Sampling Frequency : N/A (normalized frequer
Passband Edge      : 0.0975
3-dB Point         : 0.11904
6-dB Point         : 0.125
Stopband Edge      : 0.1525
Passband Ripple    : 0.013228 dB
Stopband Atten.    : 68.7631 dB
Transition Width   : 0.055

Implementation Cost
Number of Multipliers            : 34
Number of Adders                 : 31
Number of States                 : 31
Multiplications per Input Sample : 62
Additions per Input Sample       : 55
```

Fig. 11 Cost of Multistage FIR half band



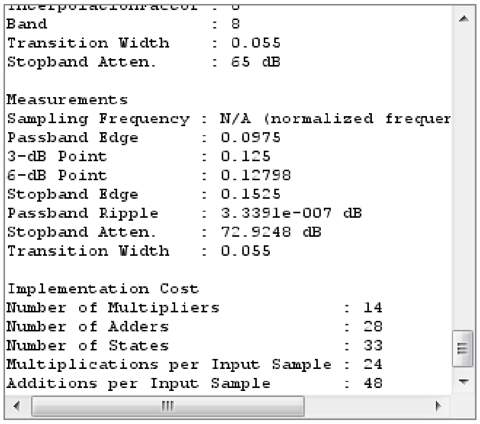
```
%
% Multistage FIR polyphase Halfband
% ------------------------------

Discrete-Time FIR Multirate Filter (real)
-----------------------------------------
Filter Structure      : Direct-Form FIR Poly
Interpolation Factor  : 8
Polyphase Length      : 24
Filter Length         : 192
Stable                : Yes
Linear Phase          : Yes (Type 1)

Arithmetic            : double

Implementation Cost
Number of Multipliers            : 168
Number of Adders                 : 161
Number of States                 : 23
Multiplications per Input Sample : 168
Additions per Input Sample       : 161
```

Fig. 12 cost of Multi-stage FIR polyphase half band

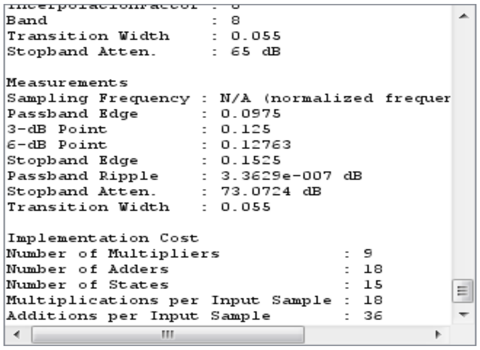


```
Band                 : 8
Transition Width     : 0.055
Stopband Atten.      : 65 dB

Measurements
Sampling Frequency : N/A (normalized frequer
Passband Edge      : 0.0975
3-dB Point         : 0.125
6-dB Point         : 0.12798
Stopband Edge      : 0.1525
Passband Ripple    : 3.3391e-007 dB
Stopband Atten.    : 72.9248 dB
Transition Width   : 0.055

Implementation Cost
Number of Multipliers            : 14
Number of Adders                 : 28
Number of States                 : 33
Multiplications per Input Sample : 24
Additions per Input Sample       : 48
```

Fig.13 Multi-stage IIR linear phase halfband



```
Band                 : 8
Transition Width     : 0.055
Stopband Atten.      : 65 dB

Measurements
Sampling Frequency : N/A (normalized frequer
Passband Edge      : 0.0975
3-dB Point         : 0.125
6-dB Point         : 0.12763
Stopband Edge      : 0.1525
Passband Ripple    : 3.3629e-007 dB
Stopband Atten.    : 73.0724 dB
Transition Width   : 0.055

Implementation Cost
Number of Multipliers            : 9
Number of Adders                 : 18
Number of States                 : 15
Multiplications per Input Sample : 18
Additions per Input Sample       : 36
```

Fig.14 Multi-stage IIR Poly phase half band

Root raised cosine filter functions delay the input signal before producing an output is called Group Delay. The actual group-delay depends on the filter order (the higher the order, the more the delay).

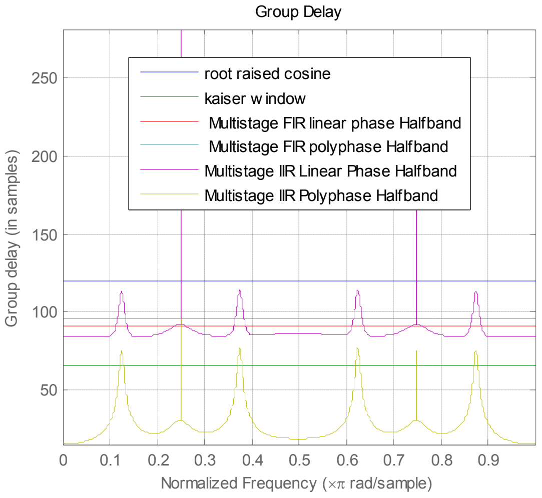


Fig. 15 IIR phase characteristics

By modifying the structure used to implement each IIR halfband filter, it is possible to achieve almost Poly-phase designs using IIR filters. This comes at the expense of a slight increase in computational cost due to the constrain on the phase (reduction in the degrees of freedom in the design) are shown in Figure 15. Nevertheless, these designs achieve very good phase characteristics and are still more efficient than comparable truly linear phase IIR or FIR halfband designs.

[C] **RSEULTS & DISCUSSION**

The performance and cost of all the all designs have been analyzed and compared with constant Transition width = 0.055

TABLE1: performance comparisons of all the Six (6) designs

Technique	Passband Edge	3-dB Point	6-dB Point	Stop band Edge	Pass band Ripple	Stop band Atten.
Root raised Cosine (RRC)	0.09	0.11	0.12	0.15	0.015	60 -dB
Kaiser window FIR	0.09	0.11	0.12	0.15	0.015	60.16-dB
Linear FIR Half Band	0.09	0.11	0.12	0.15	0.013	68.73-dB
Polyphase FIR Half Band	0.09	0.11	0.12	0.15	0.013	65-dB
Linear IIR Half Band	0.09	0.12	0.12	0.15	0.000	72.92-dB
Polyphase IIR Half Band	0.09	0.12	0.12	0.15	0.000	73.07-dB

TABLE 2: cost comparisons of all the four designs

Technique	Number of Multipliers MULTI	Number of Adders ADD	Number of States	Mult Per Input Sample (MPIS)	Add Per Input Sample
Root raised Cosine (RRC)	240	233	30	240	233
Kaiser window FIR	116	109	16	116	109
Linear FIR Half Band	34	31	31	62	55
Polyphase FIR Half Band	168	161	23	168	161
Linear IIR Half Band	14	28	33	24	48
Polyphase IIR Half Band	09	18	15	18	36

This method achieves computational costs lower than that of Cascade IIR Polyphase filter since it requires only 18 MPIS on average compared to 24 MPIS for the Cascade Direct-Form IIR Linear Phase Filter.

[D] CONCLUSION

In this paper, three optimized alternatives to Raised cosine filter are presented. The performance of the four designs (RRC, Kaiser, FIR, IIR) is almost identical in terms of IIR filters have traditionally been considered much more efficient than their FIR. The Kaiser window, FIR Half Band and IIR Halfband results in 75 to 95% saving in terms of hardware requirement.

So proposed alternative designs Multirate IIR Poly phase filter may be used to provide cost effective solution for (W-CDMA) wideband code division multiple access applications with roll off factor 0.22.

REFERENCES

[1]. Valenzuela et al. (1983) , "Digital signal processing schemes for efficient interpolation and decimation" *Proc. IEEE,* vol. 130, no. 6, pp. 225-235.

[2]. P.P. Vaidyanathan (Jan. 1990), "Multirate digital filters, filter banks, polyphase networks, and applications: A tutorial" *Proc. IEEE,* vol. 78, no. 1, pp. 56-97.

[3]. Adel Ghazel et al. (Oct. 2002)," On design and Implementation of a decimation filter for multi standard wireless transceivers" *IEEE Trans. on wireless Commun.,* vol. 1, no. 4, pp.558-562.

[4]. M. Rice et al (Oct. 2002),"Polyphase Filter Banks for Symbol Synchronization in Sampled Data Receivers", *Proc. IEEE military Commun. Conf.,* Anaheim, CA, 7-10, pp. 986-98

[5]. Fredric J. Harris et al (Apr. 2003)., "Digital Receivers and Transmitters Using Polyphase Filter Banks for Wireless Commun." *IEEE Trans. on Microw. theory and techniques,* vol. 51, no. 4. pp. 01-20.

[6]. Almadhdi Eshtawie Mohamed et al. (Dec. 2006),"FPGAImplementation of an Optimized Coefficients Pulse ShapingFIR Filters", *Proc. IEEE Int. Conf. on Semicon. Electron*.,Kuala Lumpur, Malaysia, , pp. 454-458.

[7]. Rajesh Mehra and Swapna Devi (Sept. 2010), "Area Efficient & Cost Effective Pulse Shaping Filter for Software Radios", *Int. J. of Ad hoc, Sensor & Ubiquitous Computing* (*IJASUC*) vol.1, no. 03, pp.85-91.

[8]. Mandeep Singh Saini and Kuldeep Kaur (Jun. 2012),"Optimized FIR Pulse Shaped Filter for Wireless Communication ", *Int. J. of Wireless Comm. and Networking*., *I J W C N*, 04**,** Issue No. 01, pp. 01-05

Mrs. Neetu is working as assistant professor (ECE) in BCET Gurdaspur, Punjab and has 16 years of teaching experience. She completed her M.Tech and publishes a Paper in PCET Journal on Rural networking.

Er. Kamaldeep Vyas received his B.Tech. (ECE) from GGSCMT Kharar, Mohali 2007 and M.Tech. from Beant College of Engineering and Technology, Gurdaspur Punjab, India. His field of interest includes Digital signal process