International Journal of Engineering Research and Development
e-ISSN : 2278-067X, p-ISSN : 2278-800X, www.ijerd.com
Volume 2, Issue 6 (August 2012), PP. 78-84

Design of Cost Effective Custom Filter

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Abstract—Polyphase filters are becoming a very important component in the design of various filter structures due to the fact that it reduces the cost and complexity of the filter by doing the process of decimation prior to filtering which reduces the multiplications per input sample. In this paper, a review of the basic polyphase filter has been done along with calculation and comparison cost of various filters with same parameters.

Keywords—Polyphase, Complexity, Sampling rate, MPIS

I. INTRODUCTION

The world of science and engineering is filled with signals such as images from the remote space probes, voltages generated by the heart and brain and countess other applications. Digital signal processing is used in a wide variety of applications. Digital refers to operating by the use of discrete signals to represent data in the form of numbers. Signal refers to a variable parameter by which information is conveyed through an electronic circuit. Processing means to perform operations on data according to programmed instructions. So, DSP is defined as changing or analysing information which is measured as discrete sequences of numbers In digital signal processing, many application areas require sampling rate alteration. The processes involved in the alteration of the sampling rate are interpolation and decimation. One of the most efficient structures to implement interpolation and decimation operations is the polyphase structure. Decimation is the process of reducing the sample rate Fs in a signal processing system, and interpolation is the opposite, increasing the sample rate Fs in a signal processing system. These processes are very common in signal processing systems and are nearly always performed using an FIR filter. First, why are sampling rates changed? The most common reason is to ease the interface of the digital signals to the outside environment. Signals have a frequency representation, and this frequency representation must be less than the Nyquist frequency, which is defined as Fs/2.This sets a lower bound on Fs. The amount of hardware or software processing resources is normally proportional to Fs, so we usually want to keep Fs as small as practical. So while there is no upper bound on Fs, it is usually less than 10Â the frequency representation of the signal. A minimum Fs is needed to ensure the highest frequency portion of the signal does not approach the F Nyquist frequency.

II. DECIMATION AND INTERPOLATION

The idea of decimation polyphase filters is developed as follows. First, the idea of filter-then-decimate is introduced. Namely, the signal to be decimated, $x[n]$, is first filtered by a filter with impulse response $h[n]$ to give the intermediate signal $v[n]$ given by

$$v(n) \quad = \sum_{i} x(i)h(n-i), \qquad (1)$$

and then that filtered signal is decimated by an integer factor M to give the lower rate signal $y[n]$ as

$$y(n) = v(nM) = \sum_{i} x(i)h(nM-i), \qquad (2)$$

which is simply (1) with n replaced by nM, to enact the decimation. In such developments it is then pointed out that although this structure accomplishes the desired goal it is computationally inefficient.

Up to here the development is intuitive and instructive. However, at this point the polyphase structure is then developed one of two ways, neither of which provides much
insight or understanding – even when fully understood. The first way is a time-domain development that uses a non obvious re-indexing of the summation in (2) given by

$$i = i'M + m \ \ with\, i' \in Z,$$

$$m = 0,1,2,\dots,M-1 \qquad (3)$$

which, after some mathematical manipulation of double summations, leads to the desired polyphase filter structure.
The second way is a z-domain development that starts by first demonstrating that the filter transfer function can be reorganized into a sum of the polyphase component transfer
functions, as given by

$$H(z) = \sum_{m=0}^{M-1} z^{-m} \; P_m(z^m) \qquad (4)$$

with

$$P_m(z) = \sum_n h[nM + m]z^{-n}$$

The development is then completed by multiplying this form of $H(z)$by $X(z)$, applying the z-domain result for decimation, and finally exploiting the noble identities (also called the multirate identities) to move the decimation to the front of the resulting system[1].

III. ACTIVE AND PASSIVE POLYPHASE FILTERS

Typical modern radio transceiver architectures require circuits for generation of high frequency local oscillator quadrature signals. There are several well-known methods to implementing the quadrature generation for the local oscillator signal on chip. These include e.g. divider, quadrature VCO and RC-CR based circuits. Passive polyphase filter implementation is known to require good quality passives, which is no longer self-evident with deep-submicron CMOS processes. Additionally, the tuning of the passive polyphase filters is difficult. Therefore, with the high-speed transistors available, active polyphase filters (APPF) have been proposed to overcome these limitations [2].

The active polyphase filters provide important advantages over their passive counterparts. With APPFs signal amplification, filter response calibration and tuning are possible. Contrary to PPFs, the most critical design parameters of APPFs are determined by the active elements [3]. Compared to passive polyphase filter implementation, benefits of the APPF include the possibility for filter calibration, tuning and signal amplification. Although practical APPF implementations have been presented, this is the first time APFFs have been analyzed in terms of gain and stability. Stability analysis is crucial for APPFs because due to the nature of the APPFs, they have a tendency to oscillate easily.

Quadrature signal generation is an essential part of modern telecommunication RF front-end signal processing. Nowadays, commonly used direct-conversion and low-IF receivers, see, e.g., [4]–[6], require two local oscillator (LO) signals in quadrature. Three commonly applied methods for in-phase (I) and quadrature-phase (Q) signal generation are the use of phase shifter, divide-by-two circuit, and coupled oscillator, see, e.g., [7].

IV. RESULTS AND COMPARISON

The complexity of a filter is very much dependent on the number of multiplications per sample (MPIS). So, for different types of filters the MPIS is calculated and the magnitude responses are plotted. The magnitude response is a very important characteristic of a filter. It shows how the signal will be processed by the filter. It is basically a graph that is plotted between the magnitude and the normalized frequency. It decides the output of the filter. The application to which a particular filter is put is decided by the magnitude response of that filter.

CASE I

For the first case, the following sets of parameters are considered. For these parameters, six different types of filters are designed. The parameters are as below:
Cut-off frequency: 0.0625*pi rad/sample, Transition width: 0.002*pi rad/sample
Maximum passband ripple: 0.003 dB
Minimum stopband attenuation: 80 dB

4.1 FILTER 1 (IIR Low pass Filter):- In the first step, the IIR Low pass filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.1 below:

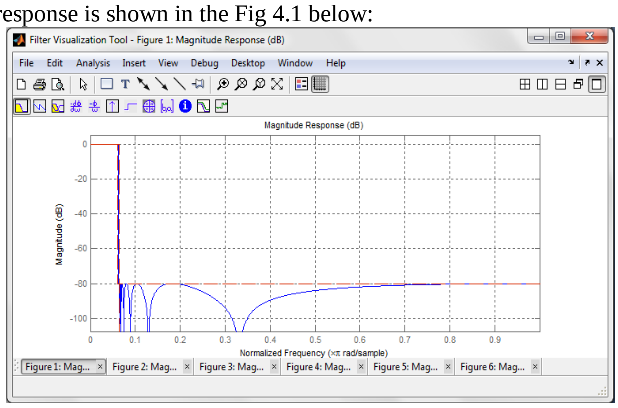

Fig.4.1Magnitude Response of Filter 1

If the required magnitude response is as shown above then with the given set of parameters the IIR Low pass filter will have MPIS of 32.

4.2 FILTER 2 (Multistage FIR Polyphase Filter): - In the second step, the multistage FIR Polyphase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.2 below:

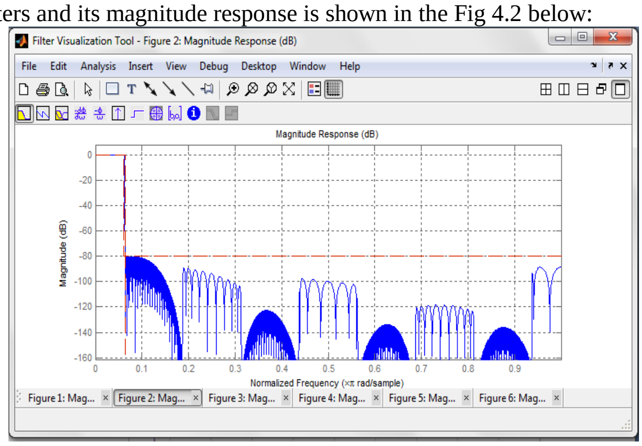

Fig. 4.2 Magnitude Response of Filter 2

If the required magnitude response is as shown above then with the given set of parameters the Multistage FIR Polyphase Filter will have MPIS of 23.8125.

4.3 FILTER 3 (IIR Polyphase Filter): -In the third step, the IIR Polyphase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.3 below:

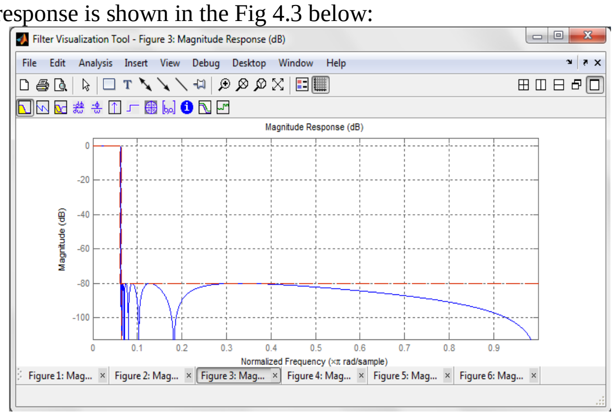

Fig.4.3 Magnitude Response of Filter 3

If the required magnitude response is as shown above then with the given set of parameters the IIR Polyphase Filter will have MPIS of 18.

4.4 FILTER 4 (Multistage IIR Polyphase Filter): - In the fourth step, the Multistage IIR Polyphase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.4 below:

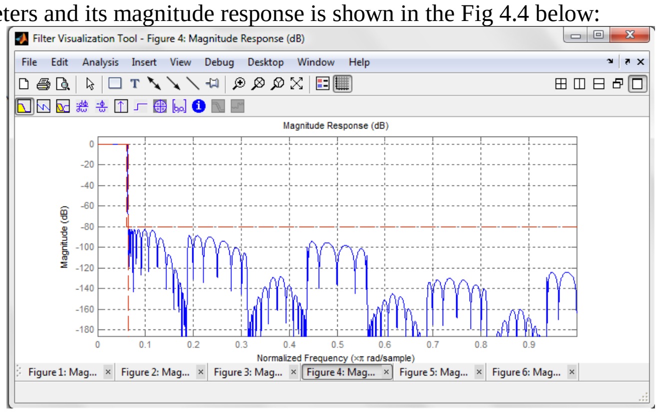

Fig. 4.4 Magnitude Response of Filter 4

If the required magnitude response is as shown above then with the given set of parameters the Multistage IIR Polyphase Filter will have MPIS of 2.5.

4.5 FILTER 5 (Multistage FIR Linear Phase Filter): - In the fifth step, the Multistage FIR Linear Phase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.5 below:

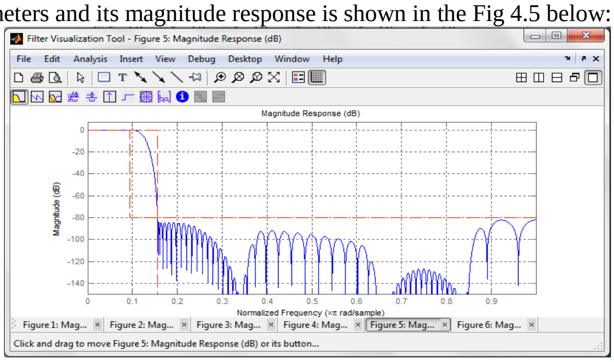

Fig. 4.5 Magnitude Response of Filter 5

If the required magnitude response is as shown above then with the given set of parameters the Multistage FIR Linear Phase filter will have MPIS of 9.875.

4.6 FILTER 6 (Multistage IIR Linear Phase Filter): - In the sixth step, the Multistage IIR Linear Phase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.6 below:

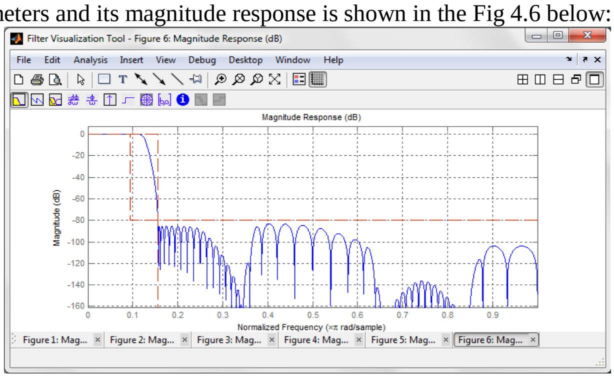

Fig. 4.6 Magnitude Response of Filter 6

If the required magnitude response is as shown above then with the given set of parameters the Multistage IIR Linear Phase filter will have MPIS of 3.75. Along with all these different magnitude responses, the cost of the filter is also calculated. Out of the five different parameters, the MPIS (multiplications per input sample) is preferred as it very much decides the cost of the filter.

Table 4.1 Comparison of the parameters of different filters for Case I

PARAMETERS	FILTER 1	FILTER 2	FILTER 3	FILTER 4	FILTER 5	FILTER 6
NUMBER OF MULTIPLIERS	32	314	18	17	43	16
NUMBER OF ADDERS	32	310	35	34	40	32
NUMBER OF STATES	16	612	21	25	74	38
MULTIPLICATIONS PER INPUT SAMPLE	32	23.8125	18	2.5	9.875	3.75
ADDITIONS PER INPUT SAMPLE	32	22.875	35	5	9	7.5

CASE II

For the second case, the following changed set of parameters is considered. For these parameters, the Magnitude response of six different types of filters has been plotted again. The changed set of parameters is as below:
Cut-off frequency: 0.125*pi rad/sample
Transition width: 0.006*pi rad/sample
Maximum passband ripple: 0.00003 dB
Minimum stopband attenuation: 120 dB

4.7 FILTER 1 (IIR Low pass Filter): - In the seventh step, the IIR Low pass filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.7 below:

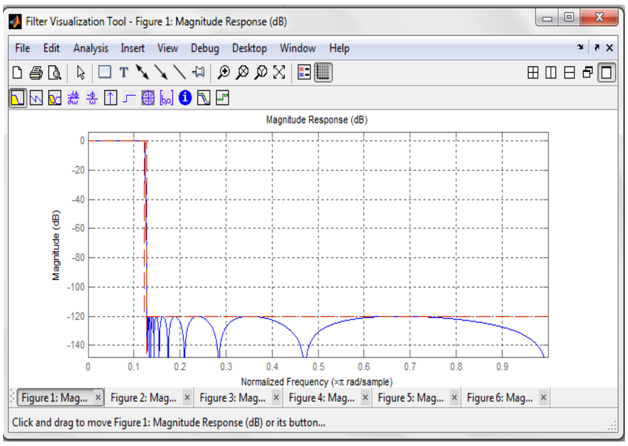

Fig. 4.7 Magnitude Response of Filter 1

If the required magnitude response is as shown above then with the given set of parameters the IIR Low pass filter will have MPIS of 46.

4.8 FILTER 2 (Multistage FIR Polyphase Filter): - In the eighth step, the multistage FIR Polyphase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.8 below:

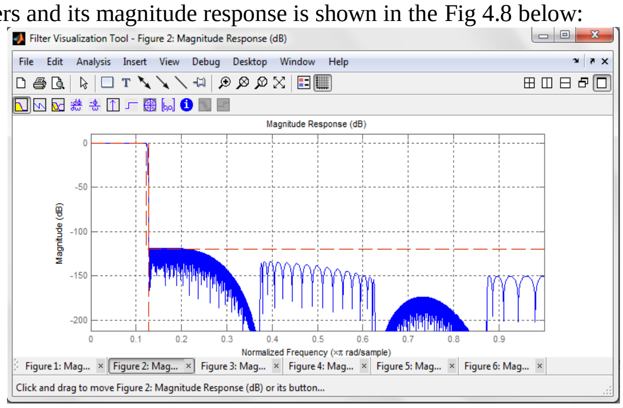

Fig. 4.8 Magnitude Response of Filter 2

If the required magnitude response is as shown above then with the given set of parameters the Multistage FIR Polyphase Filter will have MPIS of 48.125.

4.9 FILTER 3 (IIR Polyphase Filter): -In the ninth step, the IIR Polyphase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.9 below:

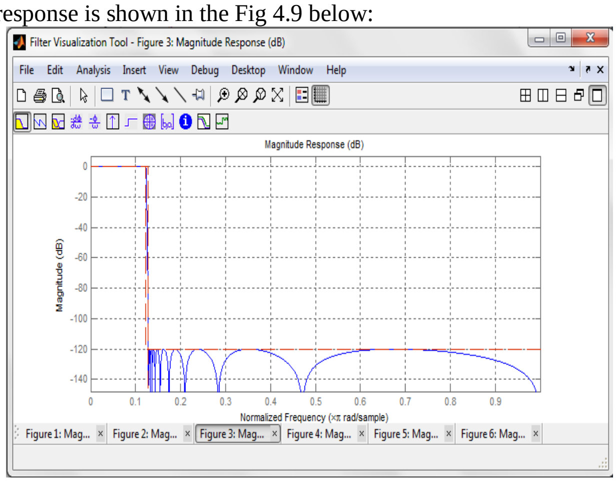

Fig. 4.9 Magnitude Response of Filter 3

If the required magnitude response is as shown above then with the given set of parameters the IIR Polyphase Filter will have MPIS of 24.

4.10 FILTER 4 (Multistage IIR Polyphase Filter): - In the tenth step, the Multistage IIR Polyphase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.10 below:

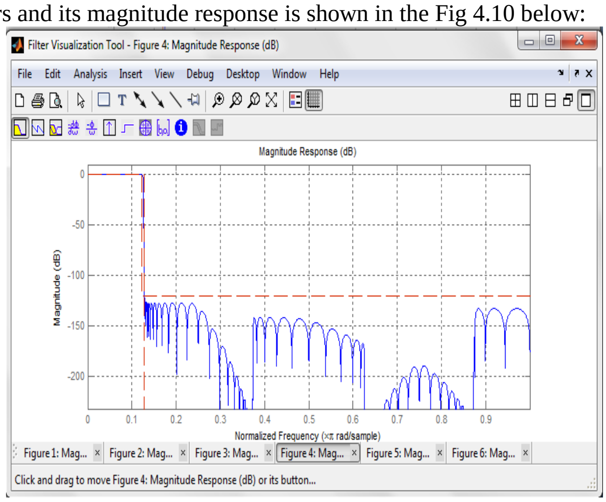

Fig. 4.10 Magnitude Response of Filter 4

If the required magnitude response is as shown above then with the given set of parameters, the Multistage IIR Polyphase Filter will have MPIS of 4.5.

4.11 FILTER 5 (Multistage FIR Linear Phase Filter): - In the eleventh step, the Multistage FIR Linear Phase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.11 below:

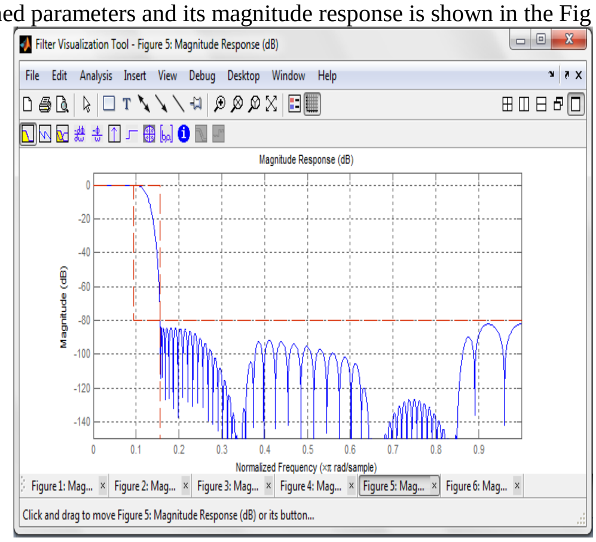

Fig. 4.11 Magnitude Response of Filter 5

If the required magnitude response is as shown above then with the given set of parameters the Multistage FIR Linear Phase filter will have MPIS of 9.875.

4.12 FILTER 6 (Multistage IIR Linear Phase Filter): - In the twelfth step, the Multistage IIR Linear Phase Filter is designed for the above mentioned parameters and its magnitude response is shown in the Fig 4.12 below:

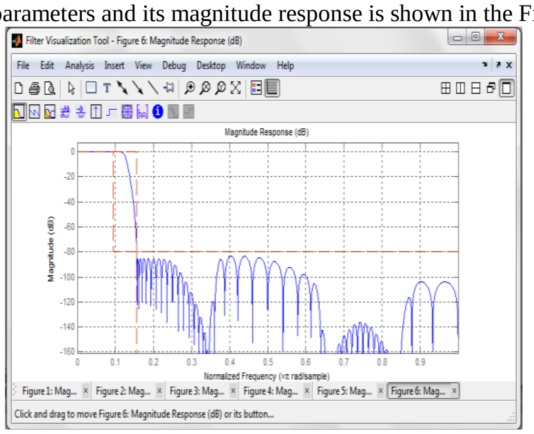

Fig. 4.12 Magnitude Response of Filter 6

If the required magnitude response is as shown above then with the given set of parameters the Multistage IIR Linear Phase filter will have MPIS of 3.75.

Along with all these different magnitude responses, the cost of the filter is also calculated. Out of the five different parameters, the MPIS (multiplications per input sample) is preferred as it very much decides the cost of the filter.

The results obtained are summarized in the table below:

Table 4.2 Comparison of the parameter of different filters for Case II

PARAMETERS	FILTER 1	FILTER 2	FILTER 3	FILTER 4	FILTER 5	FILTER 6
NUMBER OF MULTIPLIERS	46	335	24	22	43	16
NUMBER OF ADDERS	46	332	47	44	40	32
NUMBER OF STATES	23	658	27	28	74	38
MULTIPLICATIONS PER INPUT SAMPLE	46	48.125	24	4.5	9.875	3.75
ADDITIONS PER INPUT SAMPLE	46	47.25	47	9	9	7.5

From the above results it is seen that the multiplications per input sample (MPIS) is reduced significantly when polyphase filters are used in place of the FIR or IIR filters. IIR polyphase filters enjoy most of the advantages that FIR filters have and require a very small number of multipliers to implement.

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