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Efficient Technique for Improving the Frequency Response of CIC Compensation Filter

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Abstract

This paper presents a new method to improve the frequency response of CIC compensation filter. After the CIC filter cascaded the fir filter which has inversed magnitude response to CIC compensation filter was proposed, which improved the pass band and the transition band features of the CIC filter and improved the performance of CIC compensation filter. The decimation factor of the CIC filter is M and stage of it is N. The new parameter Fo was introduced. It presents new CIC compensation filter to compensate for CIC filter that pass band flatness is improve .Here we used three coefficients so less computation is required .The resulting structure is multiplier less and exhibits small passband droop in comparison to CIC filter. To overcome the magnitude droop.One benefit of the running the compensation filter at the low rate is achieve more efficient hardware solution that is more timing sharing in the compensation filter. This filter is design using FDA tools.

Keyword: CIC filter, Fir filter, Compensation filter

Introduction

Multirate digital signal processing hardware is an important sub-category of the DSP hardware .It deals with the sampling rate conversion of a digital signal including interpolation and decimation .There are basically two methods accomplish This one method converts a digital signal to analog through a D/A converter, and then resample's the analog signal using a different sampling rate with an A/D converter, a process that requires analog filter. Multirate systems have different applications, such as efficient filtering, subband coding, audio and video signals, analog/digital conversion, software defined radio and communications, The other method operates totally in the digital domain which has a great advantage over the first method as only digital filter are needed. David B. Chester from Harris Semiconductor has given a comparison between Analog filters and digital filters. It is reported that digital filters are more Size and power efficient than analog filters in application requiring an extremely linear phase very high stop band attenuation or very low pass band ripple. As well if the filter's response must be programmable or adaptive, digital filter are more appropriate

In multistandard radio receivers, the hardware should be programmable for the reception of different types of signals having different symbol rates. Overall implementation should be simple in order to have economic implementation and low power consumption, because the decimation filter is used in the digital front-end of mobile receivers where the sampling rate is high [1].The cascaded integrated comb decimation filters are a class of hardware efficient linear phase finite impulse response (FIR) digital filters. CIC filters achieve sampling rate decrease (decimation) without using multipliers. The CIC decimation filter is used as an anti aliasing filter when the data rate is high since the operation in the CIC filter only consists of addition operation. Cascaded integrator-comb (CIC) decimation digital filters are efficient implementations of narrowband lowpass filters and are often embedded in hardware implementations of decimation in modern communications systems. The Cascaded Integrator Comb (CIC) filter is a digital filter which is employed for multiplier-less realization. This type of filter has extensive applications in low-cost implementation of interpolators and decimators.

The CIC filter is used as an anti aliasing filter when the data rate is high since the operation in the CIC filter only consists of addition operation. The CIC filter can handle large rate changes. It was proposed by Eugene Hogenauer in 1981 [1]. It is formed by integrating basic 1-bit integrators and 1-bit differentiators. It uses limited storage as it can be constructed using just adders and delay elements. That's why it is also well suited for FPGA and ASIC implementation. The CIC filter can also be implemented very efficiently in hardware due to its symmetric structure.The CIC filter can perform the operation of digital low pass filtering and decimation

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at the same time. Comb filters are commonly used for decimation by an integer factor providing efficient anti-imaging and anti-alas filtering [2]-[5]. The CIC filter has a simple structure without multipliers.
However, when the decimation factor is a non-integer number, CIC filter cannot be directly used. One solution is to use CIC filters in a implement with an interpolation filter [3], [4]. The role of the interpolation filter is to perform fine tuning of sampling rate and to provide better attenuation and less power consumption for aliasing bands. The decimator filter structure presented in [4] consists of CIC filter having an interpolation filter between integrator and comb stages.

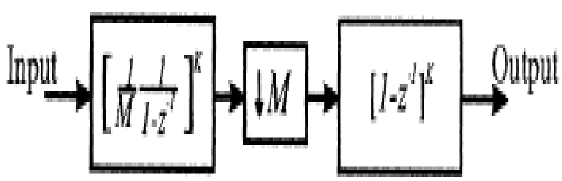

Fig.1 CIC filter

A very poor magnitude characteristic of the comb filter is improved by cascading several identical comb filters. The transfer function of CIC filter (recursive form) also known as a comb filter. The transfer function H (z) of the multistage comb filter composed of K identical single stage comb filters is given by

$$H(z) = \left(\frac{1}{N}\frac{1-z^{-N}}{1-z^{-1}}\right)^{k} \qquad (1)$$

CIC Compensation Filter

The Magnitude Response of CIC Filter

Figure 2 shows that magnitude response of a CIC filter with N=9, R=8, and M=1. From the figure 1 showing, the CIC filter frequency response did not have a wide, flat pass band.

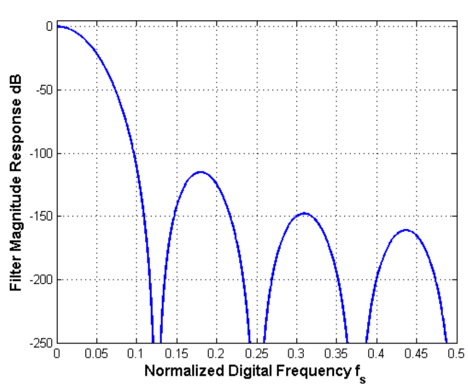

Figure .2 Magnitude Response of a CIC Filter with N = 9, R = 8, and M = 1

Compensation Filter

CIC Compensation filter Design ,When the number of stages is large, the CIC filter frequency response does not have a wide flat pass band .To overcome the magnitude droop. A FIR filter that has a magnitude response inverse of the CIC filter can be applied to achieve frequency response correction. Implementation structure of the two-stage factor of 10 decimator consisting of the cascade of factor of 5 CIC decimator and factor of 2 FIR decimator. The comb decimators and interpolators are extremely efficient due to their inherent multiplierless implementations. A simple compensation filter based on the CIC filter and a cos compensator is presented. The proposed filter performs decimation efficiently using only additions/subtractions making it attractive for software radio (SWR) applications The Compensation filter is required in a bandwidth requirements system. A number of different methods which have been proposed can only compensate a narrow pass band segment of CIC filter. CIC filter, for its simple structure without using multipliers is widely used in digital down converter to achieve efficient digital filtering. However, it has an inherent pass band magnitude droop. Compensation filter is required in a bandwidth requirement system.

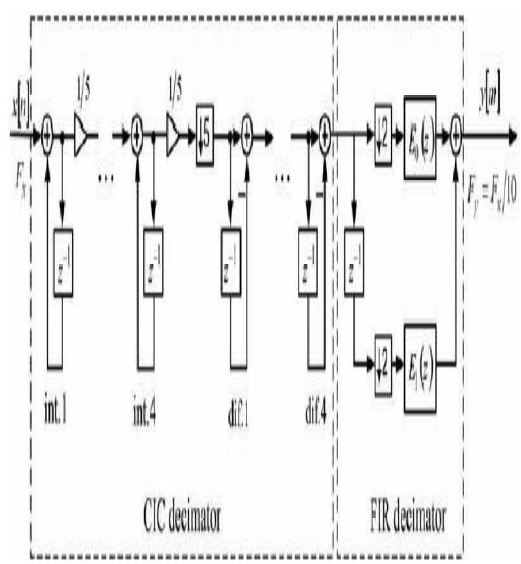

Fig-3 compensation filter

Compensation filter always operates at the lower rate in a rate conversion design. One benefit of running the compensation filter at the low rate is to achieve a more efficient hardware result, that is, more time sharing in the compensation FIR filter. compensation filters are also multirate filters. They can implement additional decimation or interpolation as necessary, but usually by a factor of 2 or less. To meet the request for fast attenuation in stop-band of a digital filter, the usual practice is to cascade several CIC filters.However, the attenuation in pass-band also becomes fast. So amplitude must be compensated. And there are many methods to compensate CIC filter, i.e. based on sharpening technique , the interpolation binomial compensation method , and inverse sinc function compensation. But these methods cannot guarantee the flatness of pass band when the bandwidth is wide. Because of advantages of FIR filters, i.e. adaptability, flexibility, easily adjusted coefficients and structure of polyphase filters can be used to FIR filters, most of digital commercial down-conversion chip still use the FIR filters to compensate CIC filters and also do signal extraction. A basic knowledge of DSP and digital filter design will helpful to understand the trade-off between various CIC compensation filter design methods.

Compensated CIC-Cosine decimation filter

Transfer function of compensation filter is given as

$$H_{COMP}(Z^m) = a + bz^{-M} + az^{-2M} \qquad (2)$$

Where a & b are real valued constant, and M is decimation factor.

Magnitude response is :-

$$\left|H_{comp}(e^{jM\omega})\right| = |2\,a\cos(M\omega) + b| \qquad (3)$$

*W*orst pass band distortion occurs at $\omega = 0$ & $\omega = \omega_C$

Where $\omega_C = \frac{\pi}{MR}$, R is the decimation factor of next decimation stage.

$$\text{At } \omega = 0 \quad 2a+b=1 \qquad (4)$$

In order to compensate the pass band droop δc at the frequency ω_c

$$2\cos(M\omega_C) + b = \frac{1}{\delta_c} \qquad (5)$$

$$\delta_{comp=\frac{1}{\delta_z}} \qquad (6)$$

$$\begin{bmatrix} 2 & 1 \\ 2\cos\,(M(\omega_C) & 1 \end{bmatrix} = \begin{bmatrix} 1 \\ \delta_{comp} \end{bmatrix} \qquad (7)$$

$$\begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \frac{-1}{2(\cos(M\omega_C)-1)} & \frac{1}{2\cos(M\omega_C)-1)} \\ \frac{\cos\,(M\omega_C)}{(\cos(M)\omega_C)-1)} & \frac{-1}{(\cos(M\omega_C)-1)} \end{bmatrix} \qquad (8)$$

$$a = \frac{-1+\delta_{comp}}{2(cos(M\omega_C)-1)} \qquad (9)$$

$$b = \frac{cos(M\omega_C)-\delta_{comp}}{cos\,(M\omega_{C}-1)} \qquad (10)$$

The respective values of M, K, R are 4, 4, 8

$$\omega_{c=\frac{\pi}{MR}=\frac{\pi}{4\times 8}} = 0.9817477$$

$$\delta_{comp} = \frac{1}{\delta_c} \;\&\; \delta_c < 0.01dB$$

There is a tradeoff between the desired compensation of the pass band droop. Filter coefficient can control the desired passband droop of the overall decimation filter.

Proposed compensation filter

The transfer function of the proposed compensation filter is given b

$$H_{comp}(z^M) = a + bz^{-M} + az^{-2M}$$

Where a and b are real valued constants and M is a decimation filter. Using multirate identity, this filter can be moved to a low rate which is a M times less than high input rate becoming a second order filter .The magnitude response of (3) is expressed as :-

$$\left|H_{comp}(e^{jM\omega})\right| = |2\,cos(M\omega) + b| \qquad (11)$$

*I*n order to compensate the passband droop δ_c at the frequency ω_c

$$\delta_c = \left|\frac{\sin M\pi fn}{M\sin(\pi fn)}\right|^k$$

$$\delta_c = \frac{1}{\delta_c} = \left|\frac{M\sin\pi fn}{\sin(\pi fn)}\right| \qquad (12)$$

The compensation pass band droop is compared with the generalized magnitude of the CIC filter.

Here, function is used as a normalise frequency term

$$fn = \left(\frac{2fn}{fx}\right) \qquad (13)$$

By putting value of δ comp.15 in eq.3

$$2a[\cos(M2\pi fm) - 1] = \delta_{comp} - \qquad (14)$$

$$a = \frac{\delta_{comp-1}}{2[\cos 2\pi Mfm-1]} \qquad (15)$$

$$b=1-2a \qquad (16)$$

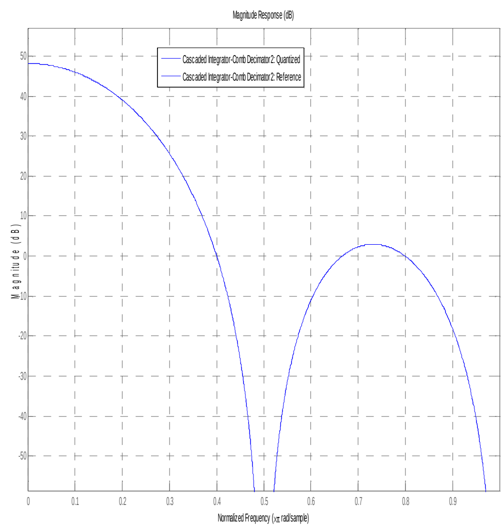

Fig 4.Proposed compensation filter

Design of Compensation Filter

We design a compensation filter for R=4. Choosing N=4,M=2.

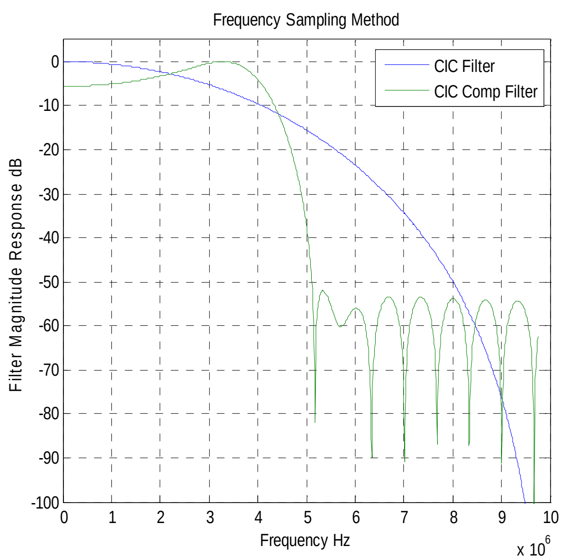

Fig 5- Response of CIC compensation filter

Where F_0 is normalized cutoff frequency, it must be meet condition: 0<<F_0=0.5/M. So, when R is large enough, that it can not meet above conditions. The design will to be wrong. The solution for this problem is to change the value of the $F_0$to meet the above conditions. In the figure 5, we choose

F_0=R*c/Fs.

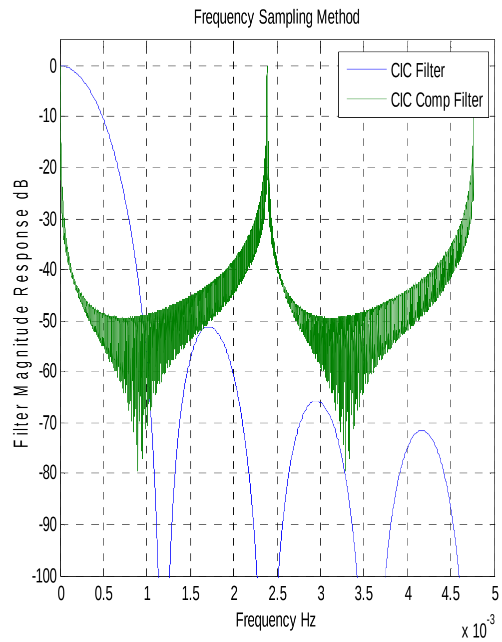

Fig 6. Final response of Compensation filter

From figure 5, It can be seen, the new design of filter spectral characteristics has been significantly improved, increasing the stop band attenuation, and transition zone is more sharp, better able to reject the image aliasing. In addition, from Figures 5 and 6 can also be seen through the sidelobe suppression also of compensated CIC filter meet.

Conclusion

The performance of the compensation filter depends on the value of a which is obtained by minimizing corresponding error function. Filter coefficient can control the desired pass band droop of the overall decimation filter. The resulting structure is multiplier less and exhibits small pass and droop in comparison to CIC filter. The Cascaded integrator comb filters do not require any multiplier circuits and hence are very economical for implementation in hardware and the problems with cascading faced by the accumulate .A functional model of the CIC compensation filter is developed using the MATLAB program. The paper will describe a mode composed of integrator comb pairs, and it is based on a floating point mathematical algorithm. A series of tests are carried out on this model. Final results show that the CIC compensation filter is a low-pass filter, and its frequency response depends on the number of integrator-comb stages N . As N increases , the CIC compensator has greater stop band attenuation but a less flat pass band. They are normally more costly because of a number of manufacturing problems in such component. CIC (cascaded-integrator-comb) filter is widely used as the compensation filter. we have prensented a new compensation filter to compensate for CIC filter that pass band is not flat and the transition zone is not steep. This paper introduces a new filter called compensation to compensate for CIC filter pass band which is not flat and the transition zone is not sharp. Pass band of CIC has been improved and became flat, transition zone of it became sharp, as a result the performance of the filter has been improved. The design parameters include R, M, N and Fo. We need to pay attention to the design parameters--Fo, it needs to meet the conditions $0<Fo<=0.5/M$. In future work, we will experiment more appropriate design parameters to improve the performance of the CIC compensation filter.

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