The Improvement of Design for CIC Compensation Filter

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***Abstract*—This paper presents a new design method to improve the performance of CIC filter. After the CIC filter cascaded the compensation filter which has inversed magnitude response to CIC filter was proposed, which improved the pass band and the transition band features of the CIC filter and improved the performance of CIC filter. The decimation factor of the CIC filter is M and stage of it is N. The new parameter Fo was introduced. The parameters was design the compensation filter. Weighing the choice of above parameters can improve the performance of the filter.**

Keywords- CIC; compensation; decimation; inverse; magnitude

I. INTRODUCTION

The concept of digital down-conversion is the signal from the higher sampling rate converting to a lower sampling rate. In the digital down-conversion system, CIC filters play an important role. The filters require no multipliers and use limited storage thereby leading to more economical hardware implementations. They are designated to cascade integrator-comb (CIC) filters because their structure consists of an integrator section operating at the high sampling rate and a comb section operating at the low sampling rate.[1] The structure of CIC filter determines its use in the forefront of decimation filter .

An integrator filter is a single pole accumulator with a transfer function is given by

$$H_I(z) = \frac{1}{1-z^{-1}} \quad (1)$$

A comb filter is a differentiator with a transfer function, as in

$$H_C(z) = 1 - z^{-M} \quad (2)$$

In this equation, M is the differential delay, and is usually limited to 1 or 2.

The transfer function of N-stage CIC decimation filter is given by

$$H(z) = H_I^{\,N}(z) H_C^{\,N}(z^R) = \left(\frac{1-z^{-RM}}{1-z^{-1}}\right)^N \quad (3)$$

In this equation, N is the number of integrator-comb filter pairs, and R is the rate change factor.

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$$|H(f)| = \left|\frac{\sin(\pi M f)}{\sin(\pi f / R)}\right|^N \quad (4)$$

Equation 4 is the magnitude response of an N-stage CIC filter at high frequency, see the figure 1.

Essentially, CIC filter is equivalent to a number of rectangular windows cascade recursive filter form, and therefore has a more significant performance limitations. From above equations we can deduce that CIC filter has low attenuation and a droop in the desired pass band that is dependent upon the decimation factor R and the number N of section in cascade. [2]-[4]

Some designs of CIC filters have been proposed to improve magnitude response required for software radio applications, see the references. [5]-[14] In this paper, the magnitude response of CIC filter has been improved by introducing a compensation filter. The rest of the paper introduced the design of the CIC compensation filter.

II. CIC COMPENSATION FILTER

A. The Magnitude Response of CIC Filter

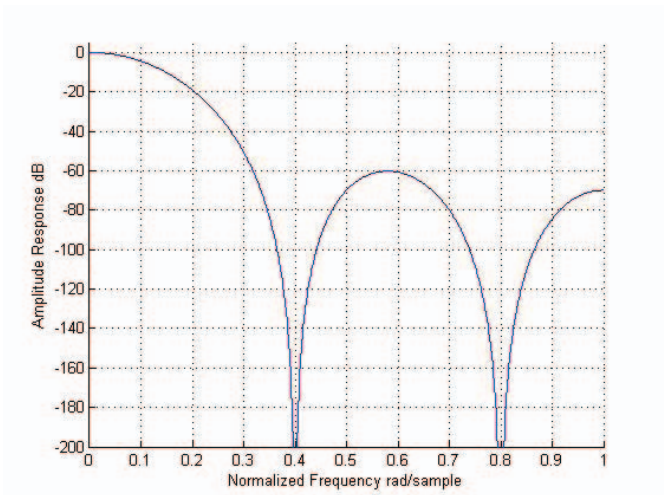

Figure 1. CIC filters. N=5, R=8 and M=1.

Figure 1 shows that magnitude response of a CIC filter with N=5, R=8, and M=1. From the figure 1 showing, the CIC filter frequency response did not have a wide, flat pass band.

B. Compensation Filter

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To improve the magnitude droop, some compensation filters that has a magnitude response such as the sine compensator and cosine filters have been proposed, see for example [2]-[4].

The magnitude characteristic compensates the pass band droop of the CIC filter. The transfer function of the proposed filter is given as

$$H_{\sin}(e^{j\omega}) = e^{-j\omega M/2}(1+\sin^2(M\omega/4)) \quad (5)$$

The corresponding magnitude characteristic is of the form

$$\left|H_{\sin}(e^{j\omega})\right| = \left|1+\sin^2(M\omega/4)\right| \quad (6)$$

The reference [2] propose to use the following cosine filter

$$H_{\cos}(z) = (1+z^{-L})/2 \quad (7)$$

It has the magnitude characteristic in cosine form

$$\left|H_{\cos}(e^{j\omega})\right| = \cos(L\omega/2) \quad (8)$$

In the reference [2], how its filter's compensates the pass band droop of the CIC filter is showed in next.

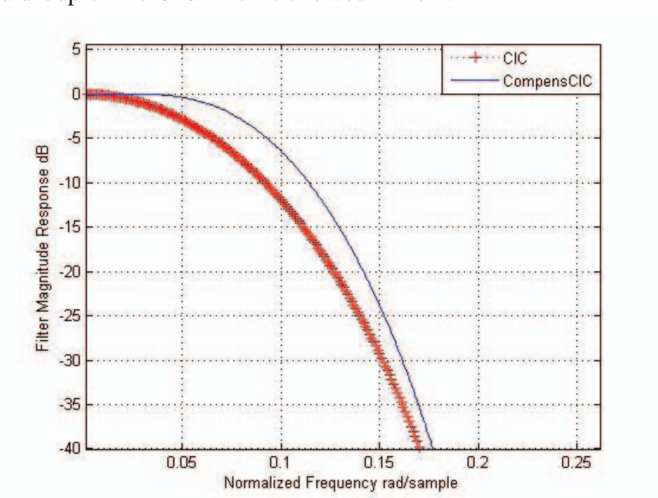

Figure 2. Pass band details, sine compensator, R=5

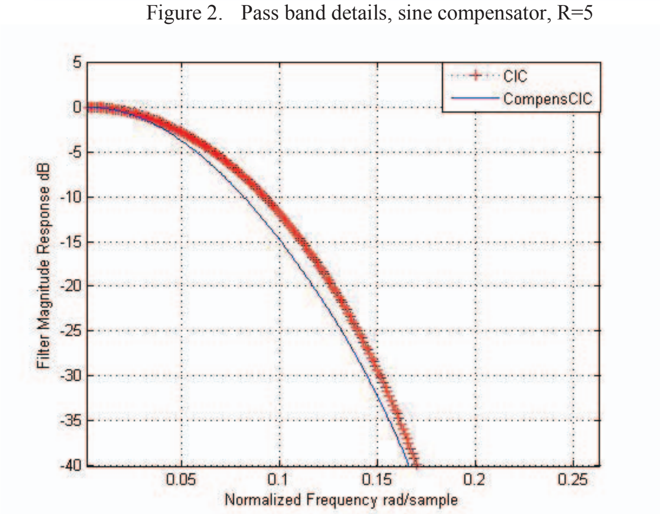

Figure 3. Pass band details, cosine compensator, L=2

From figure 2 and figure 3, we can see that pass band details have been improved. However, this improvement is not satisfactory. The rest paper, we propose the more efficient compensation filters.

C. *Proposed Filter*

In the following, we proposed the new compensation filters. This is the inverse of the CIC filter, which can be efficient to improve the magnitude response of the CIC filter.

Equation 3 gives the magnitude response of a CIC filter. To achieve a flat pass band, the compensation FIR filter should have a magnitude response that is the inverse of equation 3 was proposed, as show following

$$\left|H_{comp}(f)\right| = \left|\frac{MR\sin(\pi f_p / R)}{\sin(\pi M f_p)}\right|^N \quad (9)$$

In equation 9, f_p is bandwidth of the pass band of the single. It determines the compensation bandwidth. In there, if R is large, the response of the compensation is approximated by the inverse sinc function, so this filter is named "inverse sinc compensation filter."

The magnitude response of the compensation filter has been proposed, so, make use of the cascade of these filters, as show

$$H(z) = H_{CIC}(z)H_{comp}(z) \quad (10)$$

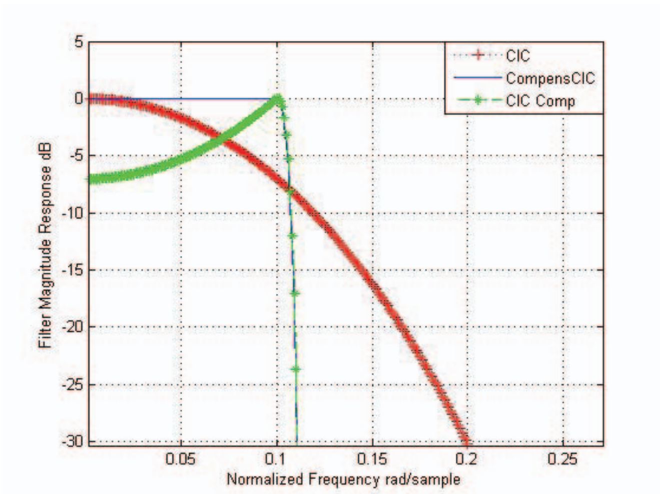

Figure 4. Inverse Sinc Compensation Filter, R=5, M=1, N=8 and L=110

In the figure 4, L is order of the compensation FIR filter. In the figure 4, the green dashed curve is the magnitude response of the inverse sinc compensation filter, and the blue dashed curve is the total magnitude response after cascaded the CIC filter and the inverse sinc compensation filter. The red dashed curve is the magnitude response of the CIC filter. As the figure 4 shows, at the pass band, its magnitude response is contrary to the CIC filter. Obviously, through the compensated of the inverse sinc compensation filter, the total filter pass band magnitude response has been improved becomes flat. Transition zone is improved to be very sharp and stop band improved to very good stop-band rejection.

III. DESIGN EXAMPLE

We design a decimation filter for R=6. Choosing N=5, M=1and Fo=R*Fc/Fs. The magnitude response has shown as figure 5.

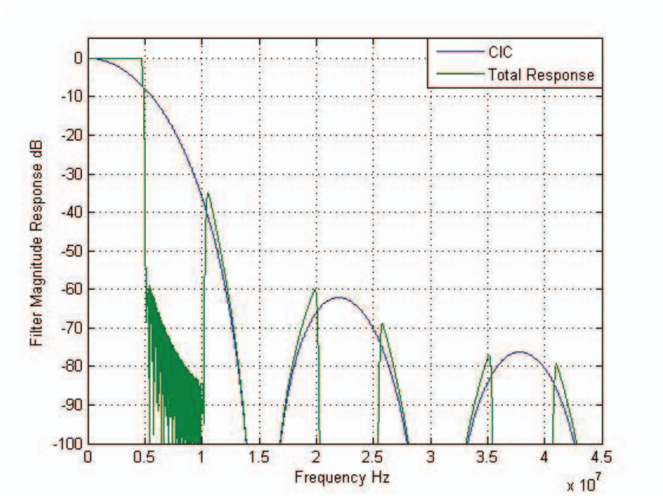

Figure 5. R=6, N=5, M=1

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

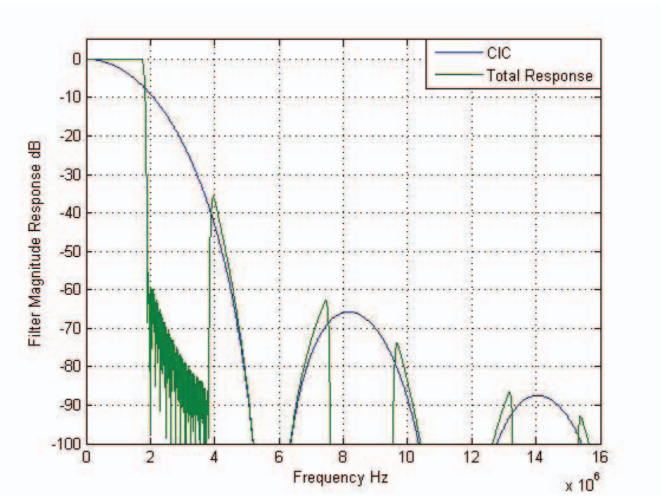

Figure 6. R=16, N=5, M=1

In the figure 6, when R=16 design will be error, so we change the value of the Fo=(R-10)*Fc/Fs.

We can notice that the choice of value of Fo is according to the design requirements.

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 the design requirements. In the design, we must considering the side lobe suppression.

IV. CONCLUDING REMARKS

we have prensented a new inverse sinc 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 k compensation to compensate for CIC filter pass band which is not flat and the transition zone is not sharp. Compared with the reference [4], 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 CIC filter.

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