Performance Analysis and Behaviour of Cascaded Integrator Comb Filters

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***Abstract*— Cascaded Integrator Comb (CIC) filter is a class of linear phase FIR filter that does not require any multiplier. These filters are generally used in multirate systems with large sampling rate conversion factors. In this paper a multistage multirate CIC filter has been compared with a FIR Filter to show their performance analysis with different factors. The comb decimation filter at the first stage operates at the input sampling rate, sharpened second stage operates at lower sampling rate as compared to first stage and sharpened third stage operates at lower than the first and second stages. This process reduces the sampling rate at every stage of the three stage CIC decimation filter. This sharpened second stage produces narrow pass band droop and better stop band alias rejection. This narrow pass band droop can be remunerated with the help of third stage which is sharpened section FIR filters are widely used in implementation of Digital Filters, but with few of its disadvantages like higher number of computational coefficients requirement and less computational speed and further improvement can be made by cascading different stages of CIC Filters to reduce hardware complexity of the system.**

***Index Terms*— CIC Filters, Integrator, Comb Filter, Decimator, Interpolator, MATLAB.**

I. INTRODUCTION

Filters are systems that process signal in a desired fashion. It can be either signal separation or signal restoration. Digital filters are widely used in many applications like communication, medical, control systems, etc. They are categorized as Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters [1]. The most widely used digital filter in signal processing is FIR filter. This is due to their stability as compared to IIR filter. However, these filters require a higher order for the same specification compared with IIR filter. The order can be seen as required number of adders, multipliers and memory for the filter. During the last decade, Multirate filters have gradually more found applications in new and emerging areas of signal processing such as digital communications. The cascaded integrator-comb (CIC) [2] filter is a digital filter which is employed for multiplier-less realization of filters. This type of filter has extensive applications in low cost implementation of Interpolators and decimators. However, some disadvantage of CIC-filters like pass-band droop is there but this can be eliminated by using compensation techniques.

In 1981, Eugene Hogenauer [3] proposed a class of digital filter without multipliers for interpolation and decimation and which uses limited storage elements to have better economical hardware implementations. This filter was named as CIC filter, because it consists of an equal number of integrator sections operating at the high sampling rate and a comb section operating at the low sampling rate as compared to Integrator section.

II. CASCADED INTEGRATOR COMB (CIC) FILTERS

The cascaded integrator-comb (CIC) filter is a class of linear phase finite impulse response (FIR) digital filters. CIC-filters achieve sampling rate decrease (decimation) and sampling rate increase (interpolation) without using multipliers in the filters. A CIC filter consists of an equal number of stages of ideal integrator followed by comb filters. Its frequency response may be tuned by selecting the appropriate number of cascaded integrator and comb filter pairs. The disadvantage of a CIC -filter is that its pass-band is not maximally flat, which is undesirable in many applications [3]. This problem can be eliminated by using compensation filter. The integrator section of CIC filters consists of N digital integrator stages operating at the high sampling rate, f. Each stage is implemented as a one—poll filter with a unity feedback coefficient. The system function equation of single integrator is given by equation (1)

$$H(z) = \frac{1}{M}\left[\frac{1-z^{-M}}{1-z^{-1}}\right] \qquad (1)$$

Where, M is the decimation factor

In equation (1) the numerator $(1-z^{-M})$ represents the transfer function of comb and the denominator ($1/1-z^{-1}$) indicates the transfer function of integrator. Figure 1 shows the first order CIC filter; here the clock divider circuit divides the oversampling clock signal by the oversampling ratio, M after the integrator stage. The integrator operates at the input

ISSN: 2278 – 7798

Sampling frequency, while the differentiator operates at down sampled clock frequency fs/M[8]. By operating at differentiator at the lower sampling rate the power consumption is achieved.

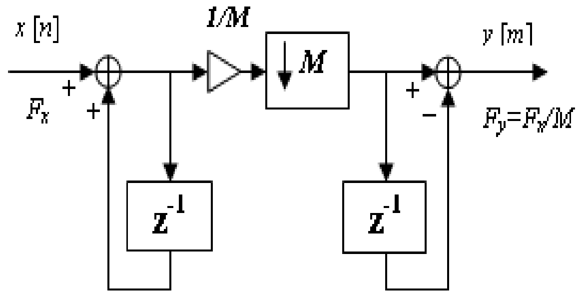

Fig.1 Structure of first order CIC filter.

A magnitude characteristic of the comb filter is improved by cascading [8] several identical comb filters which is shown in Figure 2. The transfer function of multistage comb filter composed of identical single stage comb filter is given by,

$$H(z) = \left(\frac{1}{M}\frac{1 - Z^{-M}}{1 - Z^{-1}}\right)^{K} \tag{2}$$

The magnitude response of this filter is given by equation (3)

$$H(z) = \left|\frac{\sin \omega M/2}{\sin \omega M/2}\right|^{K} \tag{3}$$

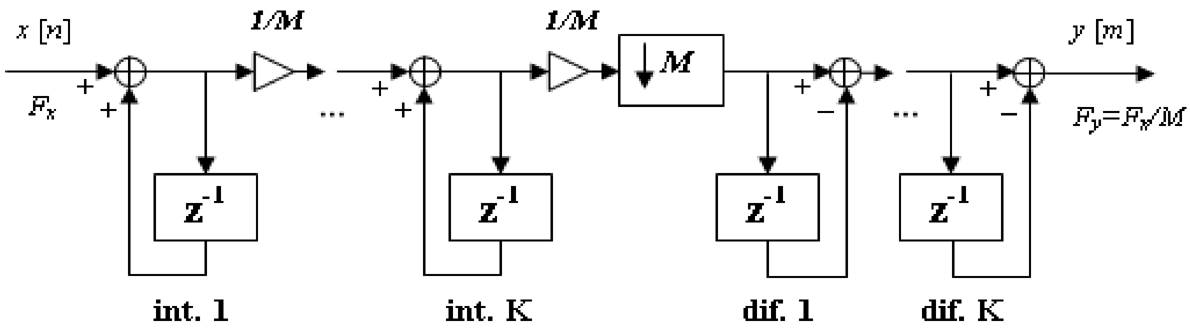

Fig.2 Structure of CIC filter with K stages

Based on the design of integrator and comb sections, CIC filters are two types: Interpolator and Decimator

a) CIC INTERPOLATOR: It consists of comb section followed by integrator section [6] as shown in the Figure 3. Data is feed to the filter at the rate fs/R where it is processed by the integrator section.

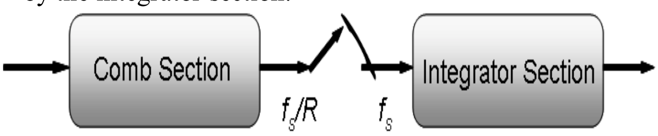

Fig.3. CIC Interpolator

b) CIC DECIMATOR: The decimator comprises of cascade of integrators followed by cascade of differentiator [6] as shown in Figure 4. The differential delay in the differentiator can be taken as either 1 or 2.

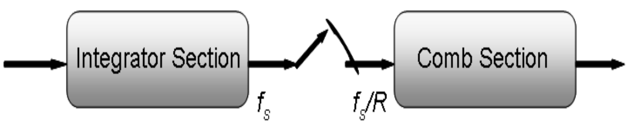

Fig.4. CIC Decimator

The economics of CIC filters derive from the following sources: (a) no multipliers are required; (b) no storage is required for filter coefficients[3] (c) intermediate storage is reduced by integrating at the high sampling rate and comb filtering at the low sampling rate, compared to the equivalent implementation using cascaded uniform FIR filters; (d) the same filter design can be used for a wide range of rate change factors, R, with the addition of a scaling circuit and minimal changes to the filter timing.

The application for CIC filters are to be in areas where high sampling rates make multipliers an uneconomical choice and areas where large rate change factors would require large amounts of coefficient storage or fast impulse response generation.

III. COMPENSATION OF CIC FILTERS

A CIC-filter can be used as a first stage in decimation when the overall conversion ratio M is factorable as

$$M = N \times R \tag{4}$$

ISSN: 2278 – 7798

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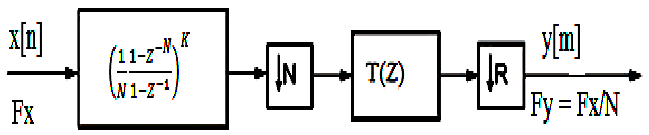
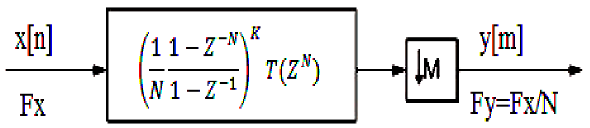


(a)



(b)

Fig.5. Two-stage decimator composed of a CIC filter and an FIR filter: (a) Cascade implementation (b) Single-stage equivalent.

The overall factor-of-M sampling rate conversion system can be implemented by cascading a factor of N CIC decimator [5] and a factor of R FIR as shown in Fig.5(a).The corresponding single-stage equivalent is given in Fig.5(b).In the two-stage solutions of Fig.5 the role of CIC decimator is to convert the sampling rate by the large conversion factor N, whereas the FIR filter T(z) provides the desired transition band of the overall decimator and compensates [6] the pass-band characteristic of the CIC filter.

IV. CIC FILTER GAIN RESPONSE AND PASS BAND DROOP

Fig.6. shows the Comb Filter gain response [7]

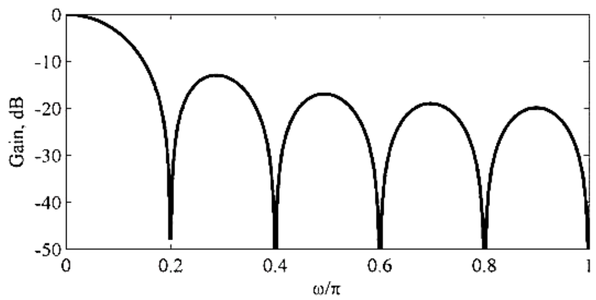


Fig.6. Gain response of the single comb filter for K = 10 and L=1

A very poor magnitude characteristic of the comb filter is improved by cascading several identical comb filters. The transfer function H (z) of the multistage comb filter composed of K identical single-stage comb filters is given by

$$H(z) = \left(\frac{1}{N}\frac{1-Z^{-N}}{1-Z^{-1}}\right)^{K} \quad (5)$$

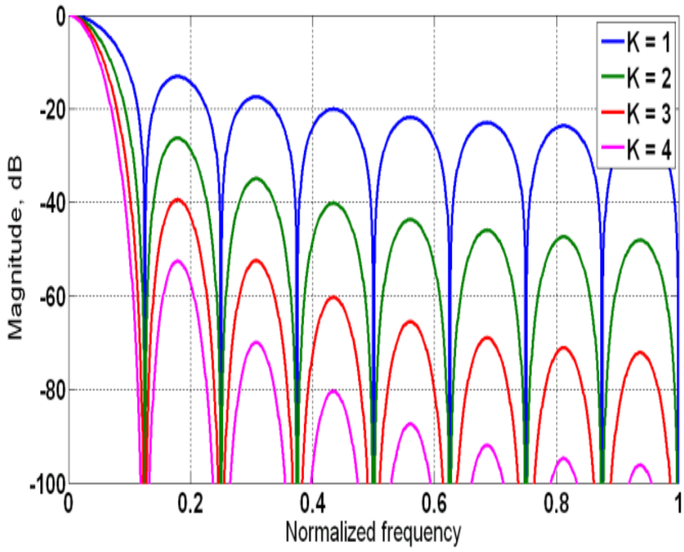


Fig.7. CIC-Filter Gain Responses: single-stage K = 1, two-stage K = 2, three-stage K = 3 and four-stage K = 4[8]

Fig.7. shows how the multistage realization improves the selectivity and the stop-band attenuation of the overall filter: the selectivity and the stop-band attenuation are augmented with the increase of the number of comb filter sections [7]. The filter has multiple nulls with multiplicity equal to the number of the comb sections (K). Consequently, the stop-band attenuation in the null intervals is very high, while increasing the K values pass band droop decreases and stop band attenuation increases.

Fig.8. shows a monotonic decrease of the magnitude response in the pass-band, called the pass-band droop [7]

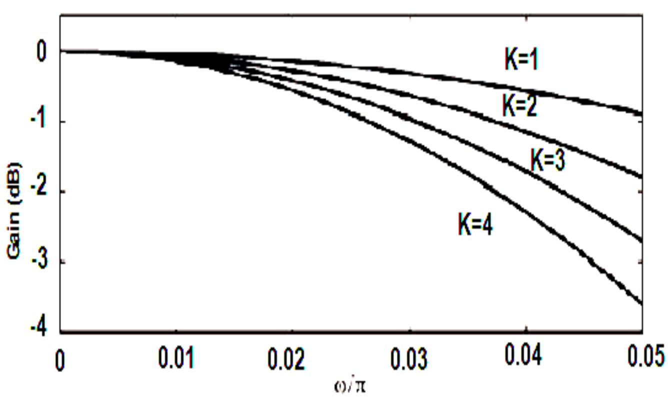


Fig.8. CIC-Filter Gain Response: Pass-band droop.

V. SIMULATION RESULTS

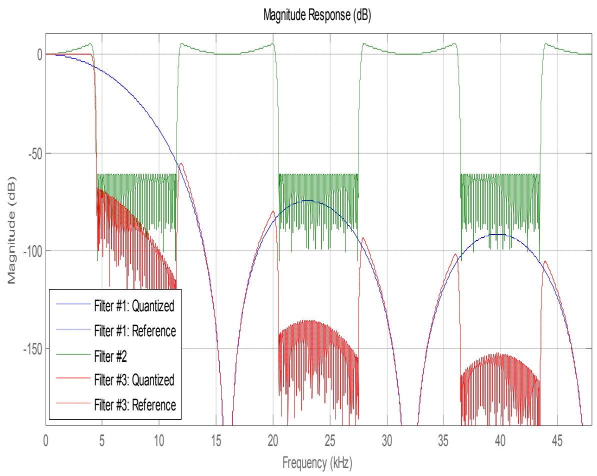


Fig.9.Gain Response of the Comb Filter and FIR Filter for K=3

Fig.9 shows the gain response of CIC filter and that of periodic FIR filter for K=3.If the value of K (K is the number of comb filter section) will be increased, so the gain response of the CIC –filter will also be improved and FIR filter gain response does not affected.

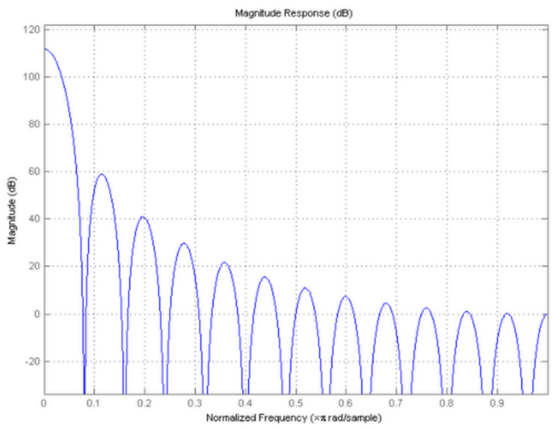


Fig.10. Magnitude response plot of Decimation Filter with M=25 and D=1.

Fig.10. shows the magnitude response plot of Decimation Filter to reduce the sampling rate with decimation factor M=25 and differential delay of D=1.

Fig.11. shows the decimation response of CIC filter for [R=8, M=1, N=4]

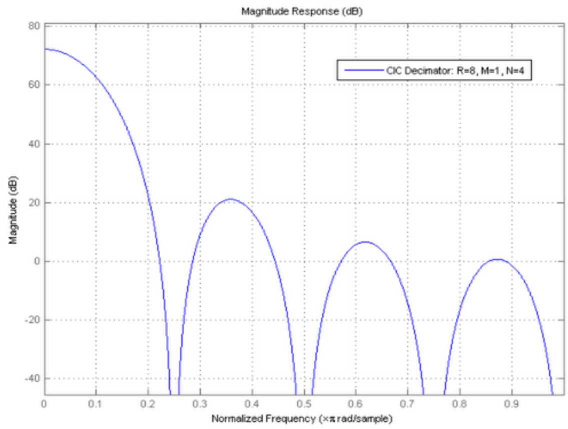


Fig.11. Decimation Response [R=8, M=1, N=4]

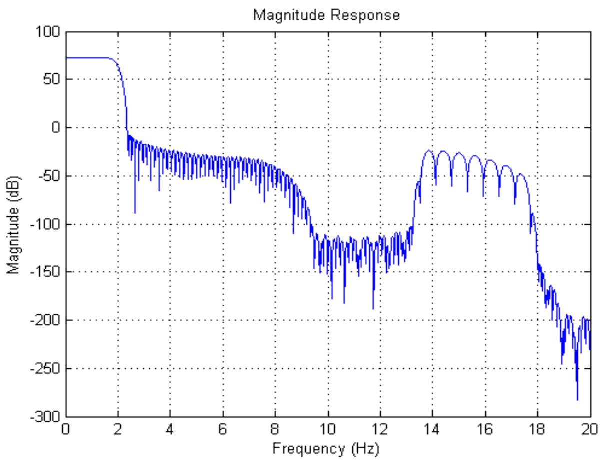


Fig.12.Cascade of four interpolators (I1=4, I2=2, I3=2, I4=16).

Fig.12. shows the cascade of four interpolators to form a four stage filter. In this case, the sampling frequency specified corresponds to the output of the four-stage interpolator because this is the rate at which the equivalent filter is operating with interpolation factors(I1=4, I2=2, I3=2, I4=16).

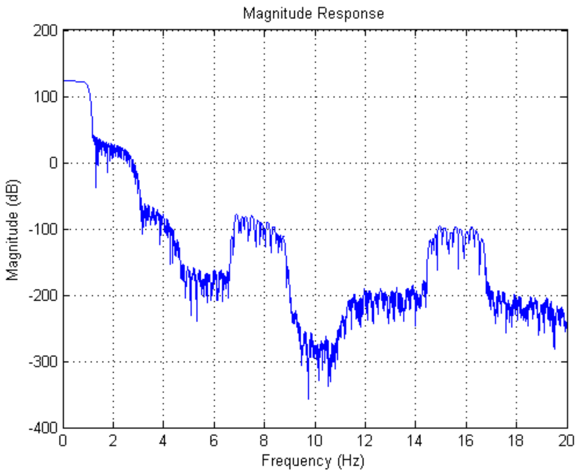


Fig.13.Magnitude Response of decimation Filter

Fig.13. shows the magnitude response of decimation stages to form a multistage sample-rate converter. The sampling frequency specified once again corresponds to the rate of the equivalent filter. This is the fastest rate in the entire system in this case.

VI. CONCLUSION

Performance analysis of CIC (cascaded integrator-comb) filters are studied in this paper. This type of filter has extensive applications in low-cost implementation of interpolators and decimators. With the new structures, the proposed filters can operate at much lower sampling rate as is used in cascaded form. They have advantages in high speed operation and low power consumption due to its structure. Simulation results show the gain responses of the CIC-filter and filter sharpening technique is used to improve the filter performances in terms of a smaller pass band error and greater stop band attenuation. Also designed for different factors to improve its characteristics.

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