

A review on the design and improvement techniques of comb filters

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ABSTRACT

Comb filters are basically the decimation filters and used for sigma delta modulator. Comb filters are multiplier less decimation filters. Comb filters introduces stop-band attenuation and pass- band droop. For achieving better performance attenuation around the folding bands in stop-band must be high while that of pass- band droop must be reduced to an acceptable limit. The paper presents a review of some techniques used in some standard papers to improve stop-band attenuation and decrease droop in pass-band and comparison by taking decimation factor 16 & various values of order of filter 3, 4, 5.

Keywords:- CIC, $\Sigma\Delta$ ADC, FIR, IFIR, PCM

1. INTRODUCTION

The decimation filter widely used in sigma delta ADC is comb filter because of their multiplierless structure. The comb filter introduces droop in pass-band and low attenuation in stop-band. Compensation filter [1] is signed to compensate for roll-off of cascaded comb filters in a Wideband-CDMA receiver. The FIR Interpolated (cascade of comb & wideband filter) filter is constituted [3], and coefficients of response are rounded to next integer value. The decimation filter [4] is designed to eliminate fake signal around the folding bands. The paper knocks out the problem of sharpening technique while the design itself suffers from the problem of pole zero cancellation.

1.1 Comb filters

Comb filters were first introduced by Hogenauer two decennium ago and can be used for both decimation and interpolation. Comb filters are affiliated for the process of decimation in sigma delta modulator. The assets of employing comb filters for decimation are i) Simple implementation using only addition and subtraction. ii) Comb filters don't require any multiplier iii) The structure requires only two elementary building blocks. Comb filters implants attenuation in stop-band and pass-band droop in frequency response. During the usual design procedure of decimation filters stop-band attenuation must be high while the pass-band droop must be tolerable because droop causes distortion in the signal. Droop and attenuation produced respectively in pass-band and stop-band depends on both the decimation value R and number of cascaded comb filters K. To improve attenuation in stop-band and decrease droop various techniques have been designed.

1.1.1 Cascaded Comb Filter

Cascaded integrated comb filters are basically comb filters formed by cascading integrators with that of comb filters separated by down sampler. Sometimes it is simply known as comb filters. The fig.1 shows CIC by cascading three integrators and comb filters. The transfer function of Cascaded Comb filters is given as follows:

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

Where, R is the decimation factor

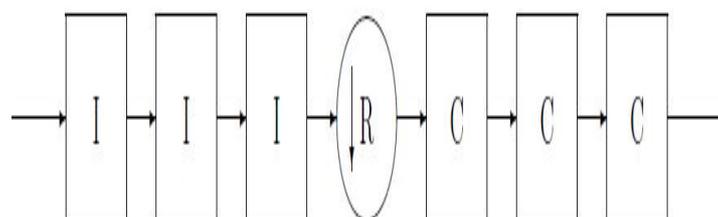


Figure 1 N=3 stage decimation

1.2 Decimation

The process used for sample rate conversion used in multirate signal processing is decimation. Fundamentally the mechanism of decimation is related to reduce the sample rate down to the Nyquist rate. The Sigma delta modulator sets up an output in the form of oversampled signal. The mechanism of sample rate decrement is then applied to this oversampled output. The assets of the decimation task can be defined in terms of reduction in number of delay elements in differentiator of decimation filters which reduces cost and complexity of designing circuit. Decimation process operating on an oversampled signal eliminates the need of antialiasing filter is reduced.

1.3 Sigma Delta ADC

ADC's are basically of two types depending upon sampling rate. First one samples the output at Nyquist rate. The second type is recognized as oversampling ADC and Sigma Delta ADC is a type of oversampling ADC's. The oversampled ratio is given by: $K = \frac{f_s}{f_B} / 2$. Where, K is oversampling ratio, f_s is frequency required for sampling, B is the desired bandwidth. As shown in fig.2 the sigma delta modulator samples the input signal at an oversampling ratio into bit stream instead of pulse stream as in case PCM. The output is comprised of required signal and noise. The decimation filter which is succeeded by the modulator consists of low pass filter which removes the noise along with the operation of sample reduction.



Figure 2 Sigma Delta ADC with 16-bit output

2. TECHNIQUES OWNED FOR RECTIFICATION IN STOP-BAND AND PASS-BAND DROOP AS IN THE FOLLOWING PAPERS

Gordana Jovanovic Dolecek: The paper uses the compensated CIC filter based on order $2 * R$ where R is the decimation factor and sharpening techniques. A simple polynomial is used to improve frequency characteristics. The parameter b alternates only when the K no. of cascaded stages are alternated and alteration in decimation factor R doesn't have any impact on b. The frequency response of filter used is approximate to that of sinc filters ($\frac{\sin(Rx)}{\sin(x)}$). The desired magnitude response of filter is calculated by substituting $z = e^{-j\theta}$.

$$|H(e^{-j\theta})| = \left| \frac{\sin(\frac{R\theta}{2})}{\sin(\frac{\theta}{2})} \right| \tag{1}$$

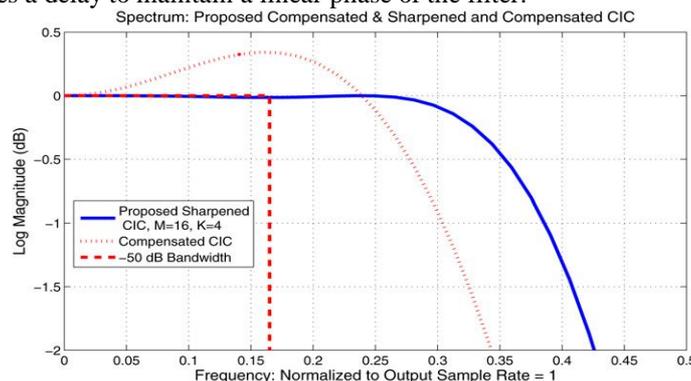
Compensator filter revealed in the paper can be represented with frequency response as shown:

$$G(e^{-j\theta R}) = 1 + \epsilon * \sin^2(R\theta/2) \tag{2}$$

using relation $\sin^2(\theta) = (1/2)[1 - \cos(2\theta)]$ and Taylor series is used to expand the series as:

$$1 + \frac{\epsilon}{2}[1 - \cos(R\theta)] = 1 + \frac{\epsilon}{4}(R\theta)^2 + \dots \tag{3}$$

Where, ϵ can be expressed in two's power i.e. 2^{-b} and will be converted to an increased compensation by using sharpening technique. The approach is employed to embellish the frequency response of compensated filter as well as that of FIR decimator filter by using amplitude change function developed by Kaiser-Hamming. The revealed compensated filter originates a delay to maintain a linear phase of the filter.



a) Particulars of main lobe

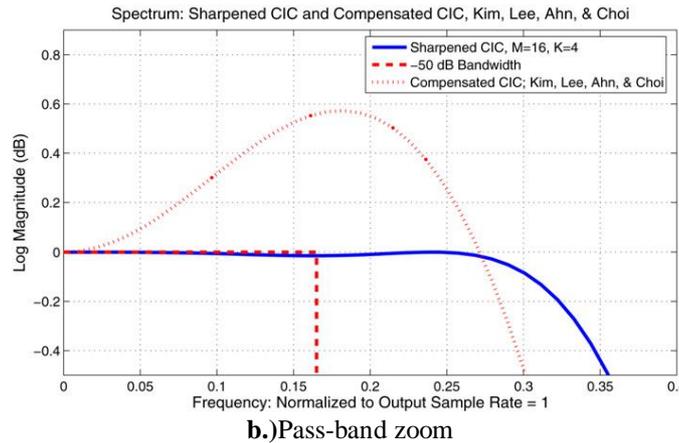


Figure 3 Comparison of compensated CIC with sharpened filters for R=16 & K=4

G.J.Dolecek, Alfonso Fernandez-Vazquez: A multiplier-less narrowband FIR is designed using the method known as Interpolated FIR structure. Interpolated filter is designed by cascading multiplierless wideband compensators and comb filters. The filter constructed using IFIR method is then rounded off to next nearest integer and can be implemented without using a multiplier.

1. The model filter has specification as shown below: $a_{mr}(n) = \text{round}(a_m(n)/k)$

Where k is a constant used for rounding $k=2^{-6}$, a_{mr} is the impulse response of rounded filter

2. The second step used is expanding the model filter by R.

3. Comb filters with length R & R_1 are designed where $R_1 = \text{round}(2\pi/w_p)$

4. The no. of comb filters cascaded K & K_1 are calculated on the basis of specifications needed for stop-band.

5. Then for given K & K_1 wideband compensators are designed.

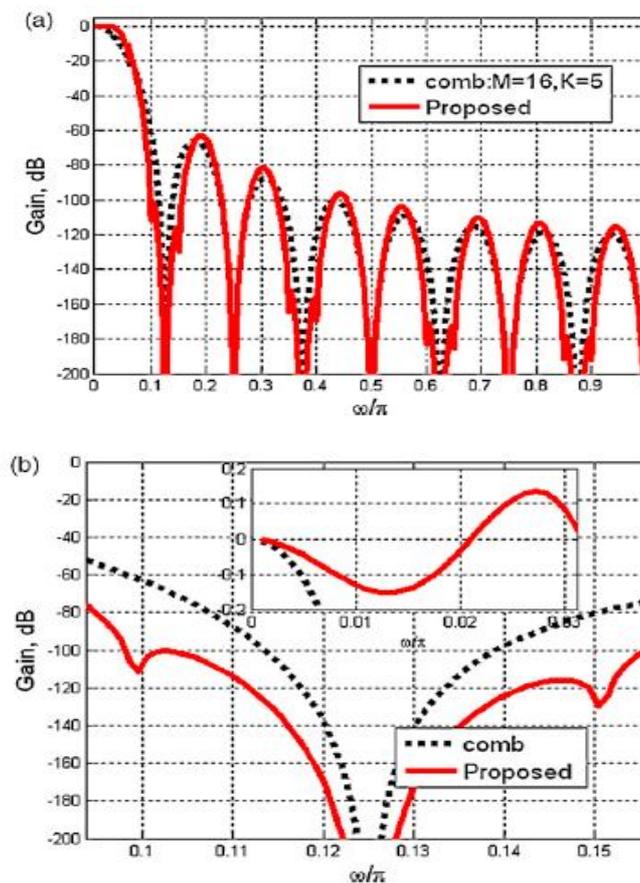


Figure 4 Comparison of proposed method and comb filters (R=16 & K=5) (a) Total gain (dB) (b) Pass-band zoom

M. Laddomada, G. Jovanovic Dolecek: The paper presents a multiplier less decimation filters and improves frequency characteristics by adding more attenuation around so called folding bands as well as reduces droop in pass-band by using an extra block of droop compensator. The proposed filter is slightly composite, achieved by addition and subtraction. The architecture known as non-recursive is used to design the proposed filters. The proposed decimation filters are able to enhance the response of classical comb filters while other parameters are kept retained. A comparison of proposed decimation filter introducing a droop of 0.9 dB is made with that of fifth order comb filter which introduces a droop of roughly equal to 5 dB depending upon distinct parameters. Non-recursive architecture is resolved using polyphase decomposition.

The composite filter employs transfer function as follows:

$$H(z) = H_c(z) H_s(z) G(z^R) \tag{4}$$

Where, $G(z^R)$ is the droop compensator filter

$H_s(z)$ is the filter employed for the intention of rising attenuation in stop-band

$H_c(z)$ is the K^{th} order comb filter

The magnitude response of compensator is given by

$$|G(e^{j\omega R})| = |1 + 2^{-b} \sin^2(\omega R/2)| \tag{5}$$

The stop-band correction filter has magnitude response as

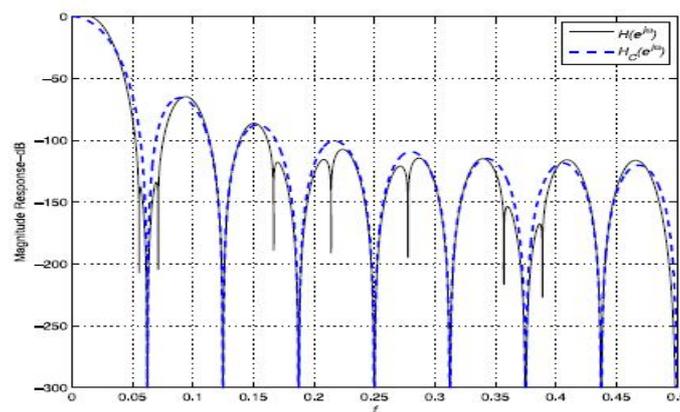
$$|H_s(e^{j\omega})| = |\cos(\omega N_1/2) \cos(\omega N_2/2)| \tag{6}$$

The design parameter N_1, N_2 & K is as given by equation:

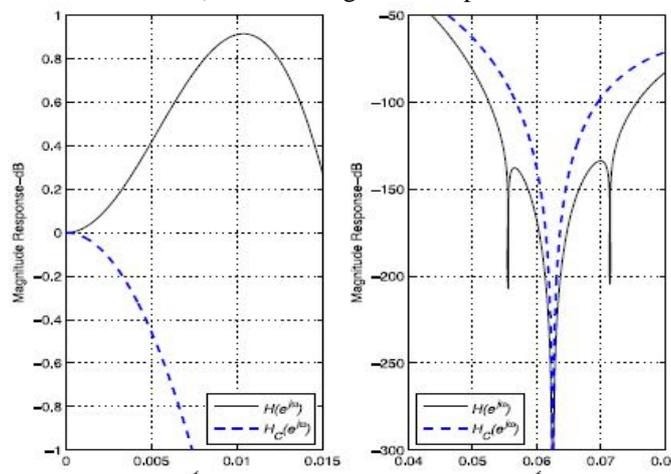
$$R \text{ even: } N_1 = R/2 - 1; N_2 = R/2 + 1; \tag{7}$$

$$R \text{ odd: } N_1 = R/2; N_2 = N_1 + 1; \tag{8}$$

b depends upon both the number of cascaded stages (K) as well as decimation factor v that follows first stage of decimation factor R and values are noted down by using Matlab



a) Overall Magnitude response



b) Pass-band & first folding band

Figure 5 Proposed filter comparison with classical comb filters ($R=16, K=5, v=2$)

G.J.Dolecek, Massimiliano Laddomada The two stage decimation filters are designed to improve elimination capability around the folding bands by placing the zeroes of classical comb filters. A comparison of classical & generalized comb filters is made with that of frequency response of proposed decimation filters. To take satisfy filter droop a compensator

named as a droop compensator is described. Number one stage employed for decimation is invoked by using a comb filter which acts as an anti-aliasing filter will help to attenuate noise and undesired signal, second stage employs a FIR filter. The two stages can be handled for overall decimation using $R=2R_1$ by reducing transfer function as follows:

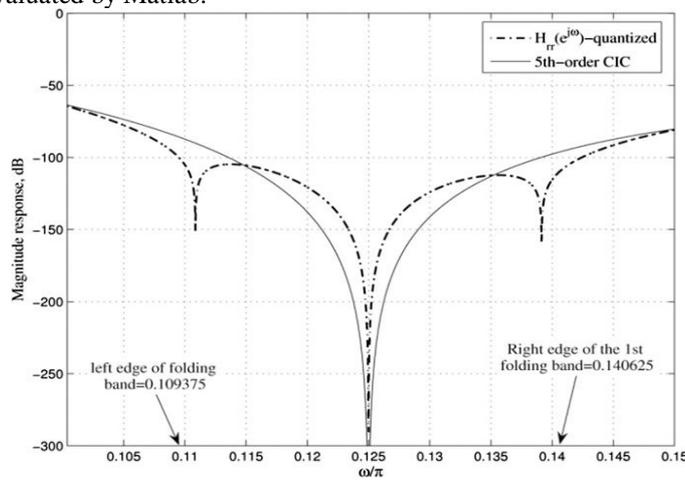
$$H(z) = H_1(z)H_2(z^{R_1}) \tag{9}$$

Thus zero rotation can be applied to only second stage. The first stage is designed by using the technique known as polyphase decomposition. A theoretical proof is used to optimize zero-location in proposed filters to increase signal rejection around folding bands. The compensation employs a droop compensator.

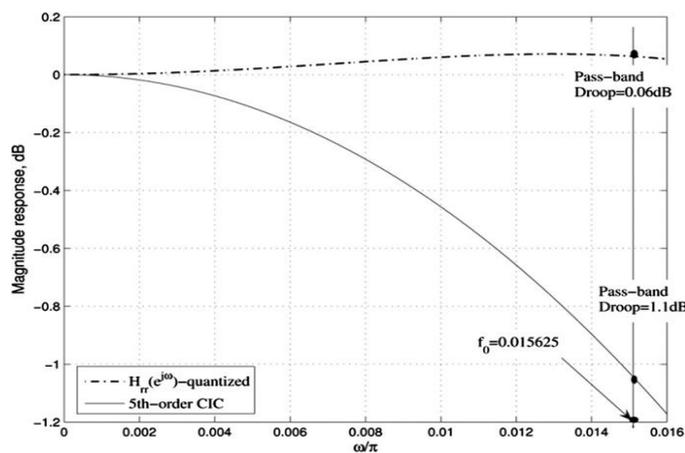
$$H_c(z^R) = A [1 + Bz^{-R} + z^{-2R}] \tag{10}$$

Where $A = -2^{(b+2)}$, $B = (-2^{b+2} + 2)$

$H_c(z^R)$ symbolize the transfer function of droop compensator. The parameters used for oversampling ratios are 8, 16, 32, 64, 128 and order used for the proposed designed filter is 3. The runner-up stage of decimation introduces decimation factor of 2 while first stage have decimation (R) factor as 2, 4, 8, 16, 32. The constant b of droop compensated filter can be evaluated by Matlab.



a) Discrimination between first folding band of revealed filter with that of fifth order comb filter



b) Discrimination of revealed filter pass-band with 5th order comb filter

Figure 6 Design parameters used are $R=16$, p (oversampling factor)=64. Decimation factor in first stage =8 & in second stage =2

3. CONCLUSION

The various techniques for compensation of droop and improving attenuation have been discussed. The sharpened compensated filter allows better droop as compared to compensated filter but requires more number of memory elements. The corrector filter designed by frequency sampling method and IFIR method compensates droop in wideband region while attenuation in the folding bands is increased. The filter developed is obstructed for even decimation values & attenuation is improved only in odd folding bands. The improvement in even folding bands

increases complexity of circuit. The droop compensator outlined in the paper makes a comparison with sharpening method to show better alias rejection around folding bands while more complex because of high input rate for filtering.

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