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MULTISTAGE CIC FILTERS FOR SUBBAND TUNING

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ABSTRACT
This paper introduces a new multistage CIC decimation filter based on non recursive and modified recursive structure of CIC filter. The resulting decimation filter has an improved magnitude response compared with that of a corresponding conventional CIC filter. Additionally the filter is a multiplier-free and has no filtering at high input rate. The sharpening technique is used to further improve the magnitude characteristic of the proposed structure.
Keywords: subband tuning, CIC filter, sharpening.

1. INTRODUCTION
In many communication and signal processing systems it is necessary to isolate a very narrowband signal from a very wideband signal, referred to as sub-band tuning. Recent advances in digital technology are making efficient all-digital solutions for sub-band tuners possible. The decimation filter is the key component required to provide an efficient solution for the overall system. A commonly used decimation filter is the cascaded integrator comb (CIC) filter, consisting of an integrator section and a differentiator section separated by a down-sampler with a down-sampling factor M, [1]. Each of the main sections is a cascade of K identical filters as shown in Figure 1.

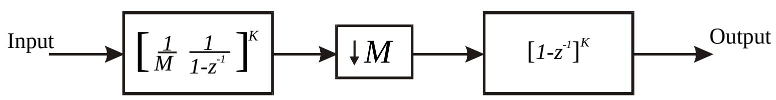

Figure 1. CIC decimation filter

The transfer function of the resulting decimation filter is given by

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

where M is the decimation ratio.
The relation (1) is also known as recursive form. The comb section operates at the lower data rate, while the integrator section works at the higher input data rate thereby resulting in higher chip area and higher power dissipation for this section. In order to resolve this problem the non-recursive form of (1) can be used [2]-[3].

The above decimation filter is attractive in many applications because of its very low complexity. The magnitude response of the filter can be expressed as

$$\left| H(e^{j\omega}) \right| = \left| \left[\frac{1}{M} \frac{\sin(\omega M / 2}{\sin(\omega / 2)} \right]^K \right| . \qquad (2)$$

The characteristic has a low attenuation and a droop in the desired passband that is dependent upon the decimation factor *M* and the cascade size *K*. Dufferent method have been proposed to improve the magnitude characteristic of Eq.(2), [4]-[9]. In this paper we present a new decimation filter based on LTCIC (linearly tapered CIC) filter introduced in [10].

The paper is organized as follows. Next section describes the linearly tapered CIC filter, while Section 3 presents how to express the LTCIC filter as the cascade of the corresponding expanded filters. The sharpening technique and the proposed efficient structure are introduced in Section 4.

2. LT CIC FILTER

Let $h_M[n]$ and $h_R[n]$ denote the impulse responses of two CIC filters of length *M* and *R*, respectively

$$h_M[n] = \begin{cases} 1/M & 0 \le n \le M-1 \\ 0 & otherwise, \end{cases}$$
$$h_R[n] = \begin{cases} 1/R & 0 \le n \le R-1 \\ 0 & otherwise \end{cases} . \qquad (3)$$

The general form of the impulse response of the LTCIC filter is given by the convolution of $h_M[n]$ and $h_R[n]$, [10]

$$h_{LT,R}[n] = h_M[n] * h_R[n], \qquad , \qquad (4)$$

where * indicates the convolution.

The corresponding transfer function is

$$H_{LT,R}(z) = \frac{1}{M} \frac{1-z^{-M}}{1-z^{-1}} \times \frac{1}{R} \frac{1-z^{-R}}{1-z^{-1}} . \qquad (5)$$

It can be seen that one can control the stopband attenuation by changing the values of *R*, [10]. Additionally, LTCIC filters (5) have the same zeros as the corresponding CIC filter (3), and they are also multiplier-free. In the following we use the general factorization method [9], to express the transfer function of the LTCIC filter (5) as the product of expanded subfilters.

3. GENERAL FACTORISATION METHOD

Using the general factorisation method form [9] for *R*< *M*, and

$$R = R_1 R_2 R_3 \cdots R_L , \qquad (6)$$

we have

$$H_{LT,R}(z) = \left[\prod_{i=1}^{N} H_{Mi}\left(z^{\prod_{j=0}^{i-1} M_j}\right) \right]^K \left[\prod_{i=1}^{L} H_{Ri}\left(z^{\prod_{j=0}^{i-1} R_j}\right) \right]^K . \qquad (7)$$

We choose *R* as follows

$$R = \begin{cases} \prod_{j=1}^{L} M_j, & for \quad L = 1 \\ \prod_{j=1}^{L-1} M_j R_L, & for \quad L > 1, \end{cases} , \qquad (8)$$

where

$R_L \ne M_j, \ j = 1, ..., N.$

Example 1:

Let M=9 and M_1=M_2=3. We choose R=6, R_1=3=M_1, R_2=2, and L=2, yielding

$$H_{LT,6} = H_9(z) \times H_6(z) =$$
$$\frac{1}{9}\frac{1-z^{-9}}{1-z^{-3}}\frac{1-z^{-3}}{1-z^{-1}} \times \frac{1}{6}\frac{1-z^{-6}}{1-z^{-3}}\frac{1-z^{-3}}{1-z^{-1}}$$
$$H_{M1}(z) = H_{R1}(z) = \frac{1-z^{-3}}{1-z^{-1}}$$
$$H_{M2}(z^3) = \frac{1-z^{-9}}{1-z^{-3}}; H_{R2}(z^3) = \frac{1-z^{-6}}{1-z^{-3}}$$

resulting in

$$H_{LT,6}(z) = \frac{1}{54}[H_{M1}(z)]^2 H_{M2}(z^3) H_{R2}(z^3)$$

4. PROPOSED METHOD

According to the factorization given in Section 3 we arrive at the general expression of the form

$$\begin{aligned} &H_{LT,R}(z) = A \times [H_{M1}(z)]^{k1}[H_{R1}(z)]^{s1} \times \\ &[H_{M2}(z^{M1})]^{k2}[H_{R2}(z^{M1})]^{s2} \times \\ &\ldots \times [H_{MN}(z^{\prod_{j=1}^{N-1} M_j})]^{kN} \end{aligned}, \tag{9}$$

where A is the scaling factor and k_i and s_i are corresponding cascaded sizes.

We next apply the sharpening technique [11] to improve the magnitude response of the general LTCIC structure (9). We apply the sharpening technique to all stages except the first . The sharpening polynomials can be different for different stages and for different subfilters in the same stage.

From (9) the proposed decimator filter based on sharpened LTCIC filter is characterized by

$$\begin{aligned} &Sh\{H_{LT,R}(z)\} = A \times [H_{M1}(z)]^{k1}[H_{R1}(z)]^{s1} \times \\ &Sh\{[H_{M2}(z^{M1})]^{k2}\} \times Sh\{[H_{R2}(z^{M1})]^{s2}\} \times \\ &\ldots \times Sh\{[H_{MN}(z^{\prod_{j=1}^{N-1} M_j})]^{kN}\} \end{aligned}, \tag{10}$$

where Sh{.} indicates sharpening.

The corresponding proposed structure is given in Fig.2.

Example 2:

In this example we have M=16 and M_1=M_2=4. We choose R=12 and R_1=M_1=4, R_2=3; k_1=s_1=2, k_2=2, s_2=1. The sharpening polynomial with parameters n=m=1 is used for the original RRS filter and for the filter $H_2(z)$ while the polynomial m=n=2, ($6H^5$-$15H^4$+$10H^3$) [11] is used for the filter R_2(z).

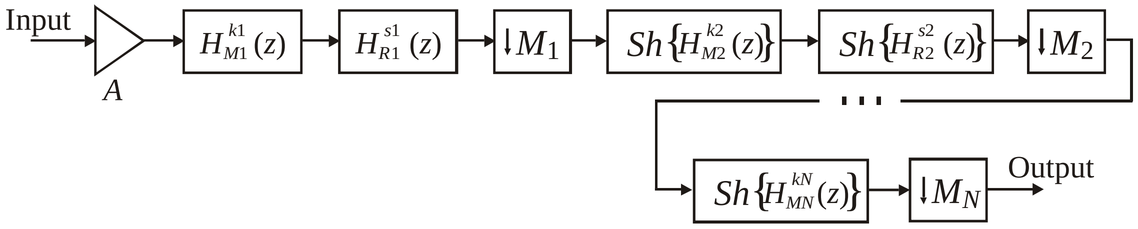

Figure 2. Proposed sharpened LTCIC structure

The corresponding gain responses are shown in Fig.3.

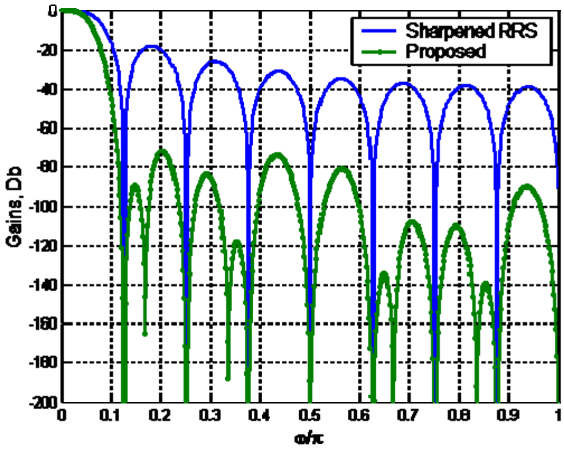

Figure 3. Gain responses

5. CONCLUSIONS

A new decimation filter based on the linearly tapered CIC (RRS) structure is proposed here. For this structure it is assumed that the decimation factor can be expressed as a product of integer-valued subfactors. We have shown how to choose the number of the tapered elements so that by applying the decomposition method the corresponding expanded CIC subfilters can be moved to the lower rates. In that way each section is composed of simpler CIC filters. The sharpening technique is used to all stages except the first to improve the overall magnitude characteristic of the proposed filter. Consequently, we can apply the polyphase decomposition at the first stage and move the polyphase filters to the lower rate. In that way there is no filtering at the high input rate.

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