Simple method for compensation of CIC decimation filter

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A simple second-order sine-based CIC (cascaded-integrator-comb) compensator is presented. The design parameter is the integer b, which depends on the number K of the cascaded CIC filters. The proposed filter performs compensation efficiently using only three additions/subtractions.

Introduction: A commonly used decimation filter is the cascaded-integrator-comb (CIC) filter, which consists of two main sections: an integrator and a comb, separated by a down-sampler [1]. The transfer function of the CIC filter is given by

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

where M is the decimation ratio, and K is the number of the stages. Magnitude response of the filter exhibits a linear-phase, lowpass characteristic given by

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

The above characteristic has a high droop in the desired passband that is dependent upon the decimation factor M and the cascade size K.

Several schemes have been proposed to design the compensation of the CIC filter's passband droop, mainly in the narrow passband [2–5]. The motivation behind the compensation methods is to appropriately modify the original CIC characteristic in the passband such that the compensator filter has as low complexity as possible. This Letter presents one simple compensator with only one parameter, which depends on the number of cascade size K. Consider the normalised passband frequency $\omega_p/\pi = c/M$, where c is the fraction of the total band after decimation by M. The choice of the b for a given K depends on if the compensation is in the narrow (tentative $c < 1/2$) or the wideband (tentative $1/2 \le c < 3/5$).

Sine-based compensator: Consider the filter with the magnitude response

$$|G(e^{j\omega})| = |1 + 2^{-b}\sin^2(\omega M/2)| \tag{3}$$

Using the well known relation

$$\sin^2\alpha = (1-\cos 2\alpha)/2 \tag{4}$$

the corresponding transfer function is given as

$$G(z^M) = -2^{-(b+2)}[1 - (2^{b+2}+2)z^{-M} + z^{-2M}] \tag{5}$$

or

$$G(z^M) = A[1 + Bz^{-M} + z^{-2M}] \tag{6}$$

where

$$A = -2^{-(b+2)}; \quad B = -(2^{b+2}+2) \tag{7}$$

The compensator filter has the scaling factor A and one coefficient B, which requires only one adder. Additionally, the compensator can be implemented at a lower rate after the downsampling by M by making use of the multirate identity. A simple MATLAB program is used to obtain the corresponding value of b for given M, K and c. Table 1 shows typical values of the compensation filter parameters for $M = 16$ for narrow ($c = 1/8$), as well as for wide passband ($c = 3/5$).

Table 1: Typical values of compensation filter parameters for $M = 16$

Parameter K	Narrowband parameter b, $c = 1/8$	Wideband parameter b, $c = 3/5$
2	2	1
3	2	0
4	1	0
5	0	−1
6	0	−1

Fig. 1*a* shows the magnitude responses of the proposed compensated CIC filters along with that of the CIC filter for several different values of b and $M = 16$, $K = 4$, and $c = 1/8$. Note that best compensation in the narrow passband is obtained for $b = 1$ (Fig. 1*a*). Fig. 1*b* shows the compensation in the wideband for $c = 3/5$, confirming that the best compensation is obtained for $b = 0$.

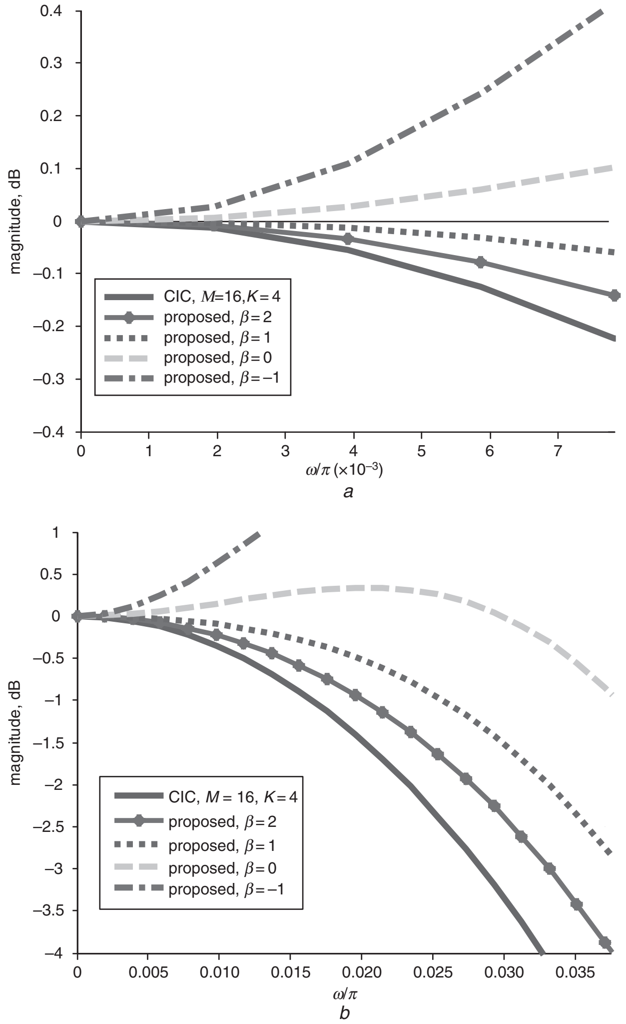

Fig. 1 *CIC and Compensated CIC filters*

a $c = 1/8$
b $c = 3/5$

Results: We now compare the performance of the proposed compensation filter with that recently reported in literature. Kim *et al.* [4] proposed the use of a CIC roll-off compensation filter in a W-CDMA digital IF receiver. The coefficients of the compensation filter are given by

$$[-a/(1-2a),\ 1/(1-2a),\ -a/(1-2a)] \tag{8}$$

The performance of the compensation filter depends on the value of a, which is obtained by minimising the corresponding error function. We compare the performance of our proposed filter with that of a decimation filter designed using a CIC roll-off compensation filter when the decimation rate is 11 and $K = 4$ (Fig. 3 in [4]). The corresponding value of a is 0.1799 [4]. The results are shown in Figs 2*a* and 2*b* for narrowband ($c = 1/3$) and wideband, respectively.

The proposed filter exhibits better compensation in narrowband and has less computational load. However, method [4] has better compensation in the wideband ($c \ge 3/5$). Additionally the compensator of [4] has two multipliers and the proposed compensator is multiplier-less requiring only three adders.

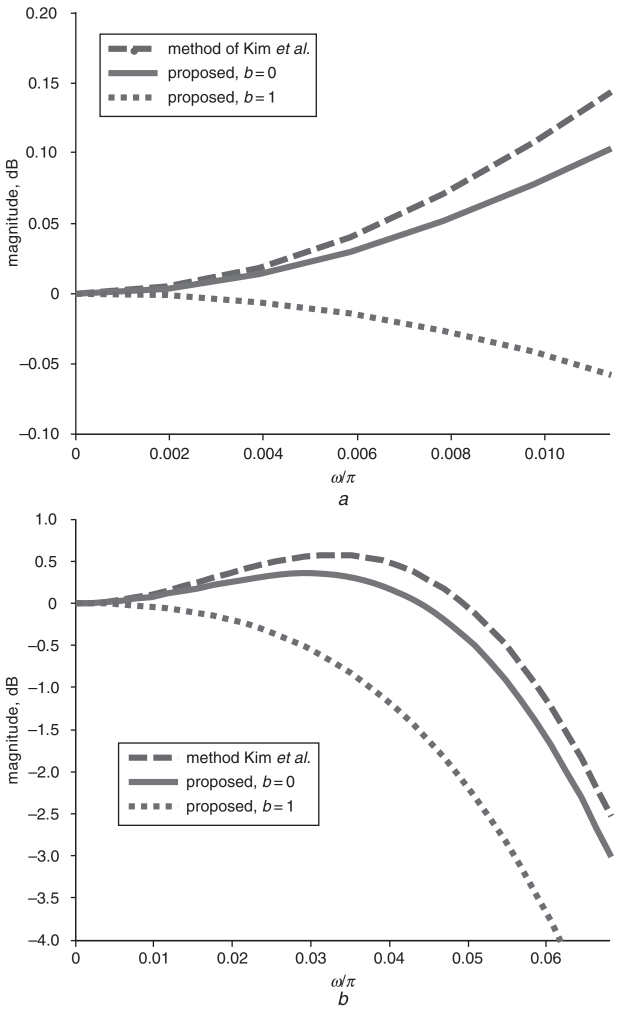

Fig. 2 *Comparisons with method [4]*

a In narrowband, $c = 1/3$
b In wideband

Conclusions: A simple multiplier free sine-based compensator with only two adders is proposed. The number K of the cascaded CIC filters defines the parameter b depending on whether the compensation is in the narrowband or wideband. The proposed filter is convenient to the passband CIC compensation in the band less than $3/5$ of the total band after decimation. Comparison with some known methods show that the proposed method requires less computational efforts and is generally less complex.

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