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Multiplierless Wideband and Narrowband CIC Compensator for SDR Application

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Abstract

This paper presents multiplierless CIC compensator for software-defined radio (SDR) application. The compensator is composed of two simple filters with sinewave form of magnitude responses. The parameters of the design are the sinewave amplitudes expressed as powers-of-two and estimated in a way to fulfill the absolute value of the maximum passband deviation of 0.25 dB and 0.05 dB, for the wideband and narrowband compensations, respectively. The proposed compensator requires maximum nine adders. The comparisons with the methods proposed in literature show the benefits of the proposed compensator.

Keywords

Software Radio, Sampling Rate Conversion, Decimation, CIC Filter, Compensator

1. Introduction

Software-defined radio (SDR) has found important role in modern wireless communications. The main idea in SDR is to move the analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) as close as possible to the antenna and thus perform all signal processing in the digital form [1]. As a consequence, SDR is able to support different wireless standards using the same hardware. Knowing that different wireless standards require different sampling rate for baseband processing, the sampling-rate conversion (SRC) becomes a key operation in a SDR receiver [2].

SRC involves resampling in a digital domain thus causing aliasing and imaging which must be eliminated by filtering [3]. CIC (cascaded-integrator-comb) filter proposed in [4] is widely used as anti-aliasing and anti-imaging filter due to its simplicity: the filter requires no multiplication or coefficient storage. The transfer function of the CIC decimation filter in z-domain is given as:

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

where M is the decimation factor and K is the number of the cascaded filters.

However, its magnitude characteristic:

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

exhibits a low attenuation in the stopband of interest and a passband droop in the band of interest. As K increases, the stopband attenuation increases, resulting in an increased droop in the passband, which may deteriorate the decimated signal. The motivation of this work is to achieve good CIC wideband and narrowband compensation while keeping low rate of addition operations.

Different methods were proposed to compensate for the CIC passband droop. The compensators which need multipliers were proposed for example in [5] [6] [7]. However, due to lower power consumption, multiplierless compensators [8]-[13] are of more interest for SDR application. A two/stage CIC compensator with sinewave form of magnitude responses was recently proposed in [13]. The parameters of design are amplitudes of sinewaves expressed as sum-of-powers-of-two (SPT), and chosen in a way to provide better compensation than any other multiplierless compensator from literature. (The absolute value of the maximum passband deviation of the compensated comb is less than 0.1 dB). The compensator requires 11 adders for $K = 2$, 4, and 5, and 10 adders for $K = 3$, and 6. The goal here is to design a compensator requiring even fewer adders than the compensator in [13] while permitting a slight increase of the absolute value of the maximum passband deviation. The method is based on the sinewave magnitude responses multiplierless filters.

The paper is organized in the following way. Next section introduces transfer function of the proposed filter and describes the choice of the design parameters for wideband and narrowband compensation. Some comparisons are provided in Section 3.

2. Proposed Compensator

2.1. Transfer Function of Proposed Compensator

Like compensator in [13], the proposed compensator has magnitude response in the form:

$$\left|G_c(e^{j\omega M})\right|=\left|G_1(e^{j\omega M})\right|\times\left|G_2(e^{j\omega M})\right|, \tag{3}$$

$$\left|G_1(e^{j\omega M})\right|=1+B_1\sin^4(\omega M/2). \tag{4}$$

$$\left|G_2(e^{j\omega M})\right|=1+B_2\sin^2(\omega M/2). \tag{5}$$

In contrast to the method in [13], we express the parameters of sinusoidal functions as powers of two, in order to decrease the number of the required adders:

$$B_1 = 2^{-N_1}; B_2 = 2^{-N_2}. \tag{6}$$

where N_1 and N_2 are integers.

The corresponding transfer function at low rate becomes:

$$G_c(z) = G_1(z)G_2(z), \tag{7}$$

where

$$G_1(z) = 2^{-4}2^{-N_1} \times \left[1 + z^{-4} - 4(z^{-1} + z^{-3}) + (2^2 + 2)z^{-2}\right] + z^{-2}, \tag{8}$$

and

$$G_2(z) = 2^{-2}[(-1 + 2z^{-1} - z^{-2})2^{-N_2} + 2^2 z^{-1}]. \tag{9}$$

As a result, filters (8) and (9) require 6 and 3 adders, respectively, *i.e.* the compensator (7) requires total of 9 adders.

2.2. Wideband Compensation

We consider the passband edge $\omega_p = \pi/(2M)$, and impose the following condition:

$$\max_{N_1,N_2}\{20\log 10\left|H(e^{j\omega})G_1(e^{j\omega M})G_2(e^{j\omega M})\right|\} \le 0.25dB, \tag{10}$$

where:

$$0 \le \omega \le \pi/(2M), \tag{11a}$$

$$\left|G_1(e^{j\omega M})\right| = 1 + 2^{-N_1}\sin^4(\omega M/2), \tag{11b}$$

$$\left|G_2(e^{j\omega M})\right| = 1 + 2^{-N_2}\sin^2(\omega M/2). \tag{11c}$$

Considering $M > 10$ the compensator parameters do not depend on M, [13]. Using the MATLAB simulation, and taking the condition (10), we can easily find the parameters B_1 and B_2, for $K = 1, \cdots, 5$, shown in **Table 1**. The number of required adders is equal to 9, for $K = 2, \cdots, 5$, and 6 for $K = 1$. The maximum passband deviation is obtained for $K = 4$, (0.25 dB), while the smallest one is for $K = 1$, (0.14 dB).

Figure 1 illustrates the passband zooms for different values of K and $M = 15$.

The method is illustrated in the following example.

***Example* 1:** We consider the value of $M = 18$ and $K = 5$. According to **Table 1**, the values of B_1 and B_2 are equal to 1/2 and 1, respectively. **Figure 2** compares the magnitude responses of the compensated CIC and the corresponding CIC filter. The passband zooms show that the absolute value of the maximum passband

Table 1. Parameters B_1 and B_2 for wideband compensation.

K	B_1	B_2
5	1/2	1
4	1	1/2
3	1	1/4
2	1/2	1/4
1	1/2	0

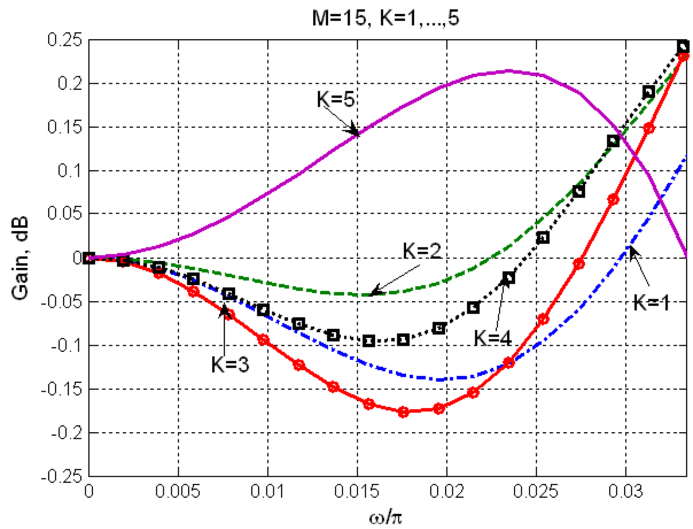

Figure 1. Passband zooms for compensated comb for $M = 15$ and $K = 1, \cdots, 5$.

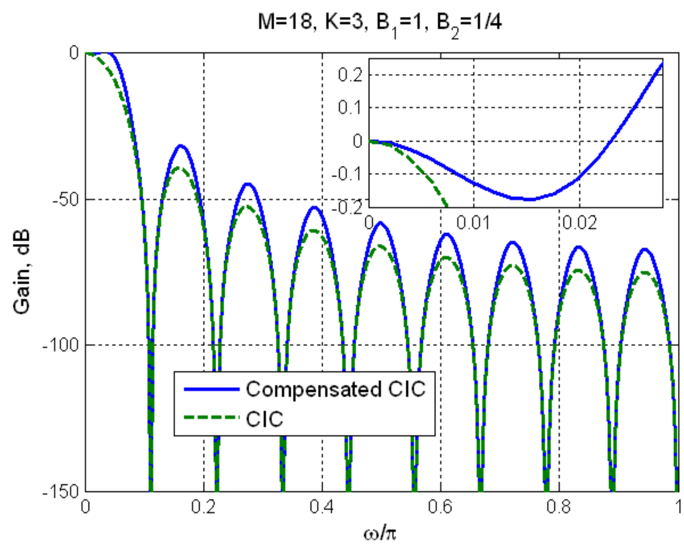

Figure 2. Magnitude responses of CIC and compensated CIC filters.

deviation is lesser than 0.23 dB. The proposed compensator requires 9 adders.

The overall magnitude responses in **Figure 2** confirm that the proposed compensator, despite the slight increase in the magnitudes of side lobes, does not deteriorate the attenuations in the folding bands.

2.3. Narrowband Compensation

We consider the passband edge $\omega_p = \pi/(8M)$ for narrowband compensation and the following condition:

$$\max_{N_1,N_2}\{20\log 10\left|H(e^{j\omega})G_1(e^{j\omega M})G_2(e^{j\omega M})\right|\} \le 0.1dB, \tag{12}$$

where:

$$0 \le \omega \le \pi/(8M), \tag{13}$$

and $G_1(e^{jwM})$ and $G_2(e^{jwM})$ are given in (11b) and (11c), respectively.

Applying the MATLAB simulation we got the values of parameters B_1 and B_2, shown in **Table 2**. The method is illustrated in Example 2.

Example **2**: We consider values of $M = 21$ and $K = 5$ and the passband edge of $\omega_p = \pi/(8M)$. **Figure 3** shows the overall magnitude responses and the passband zooms for the compensated CIC and CIC filters. The absolute value of the passband deviation of the compensated CIC is lesser than 0.05 dB. The compensator requires only three adders.

In next section are given some comparisons with the recently proposed compensators.

3. Some Comparisons

3.1. Comparison with Method in [13]

Consider $M = 20$ and $K = 5$. **Figure 4** compares the passband zooms of the proposed compensator and compensator in [13]. The parameters in the proposed method are: $B_1 = 1/2$, $B_2 = 1$. The parameters of the compensator in [13] are: $B_1 = 1$ and, $B_2 = 2^0 - 2^{-2} - 2^{-5}$, thus requiring total of 11 adders.

3.2. Comparison with Method in [12]

The compensator in [12] has two second order sections both with sine-squared

Table 2. Parameters B_1 and B_2 for narrowband compensation.

K	B_1	B_2
5	0	1
4	0	1/2
3	1	1/2
2	1	1/4
1	1	1/8

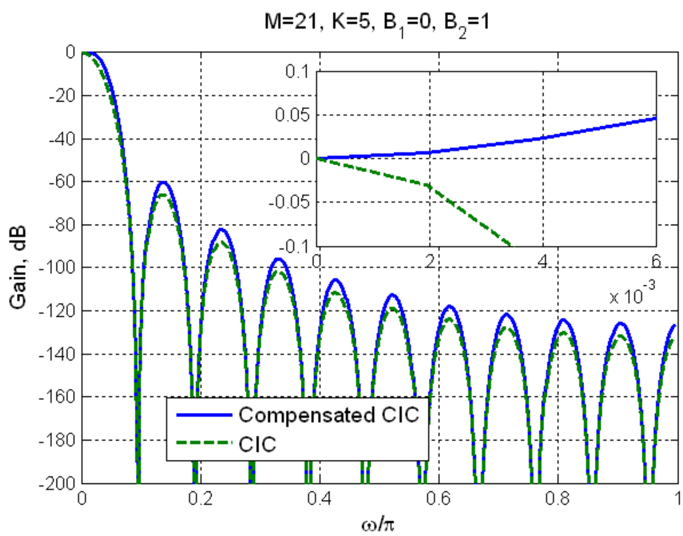

Figure 3. Magnitude responses of CIC and compensated CIC filters.

magnitude responses with amplitudes of sine squared functions B_1 and B_2. The value of B_1 is equal to 2^{-3} for all values of K, while $B_2 = (1 + 4(K - 1))/16$. For the sake of comparison we consider $M = 16$ and $K = 5$. The compensator in [12] requires 7 adders. The passband zoom is shown in **Figure 5**.

3.3. Comparison with Method in [9]

The proposed compensator is compared with that in [9], taking $M = 32$ and $K = 5$. The result is shown in **Figure 6**. The compensator in [9] has 5 coefficients and requires 14 adders.

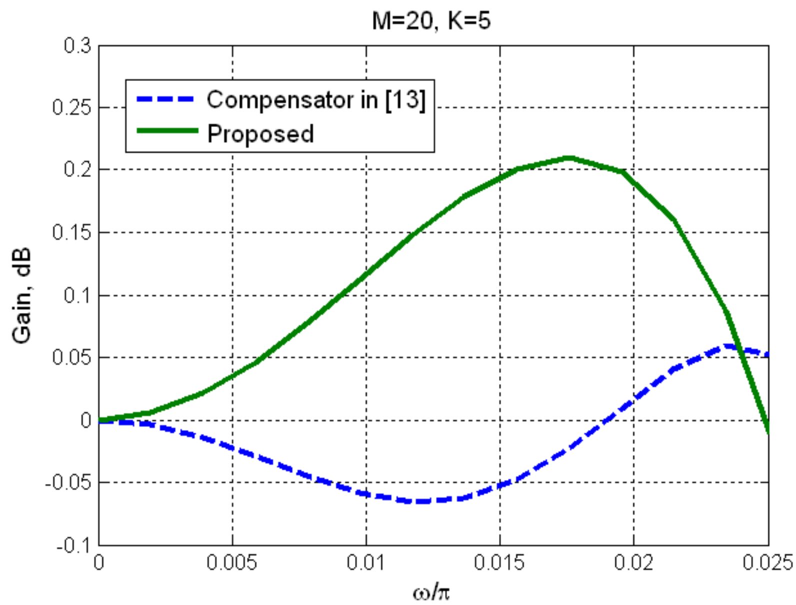

Figure 4. Comparison with method in [13].

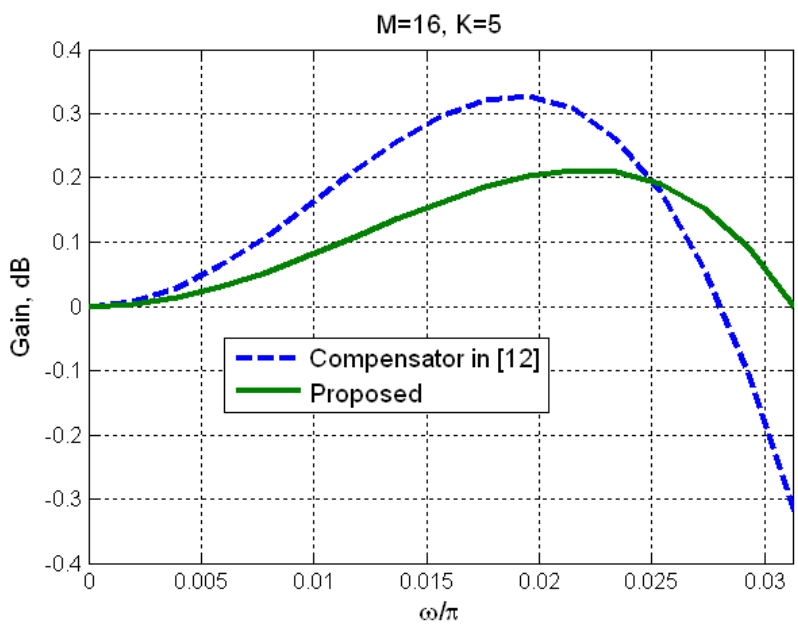

Figure 5. Comparison with method in [12].

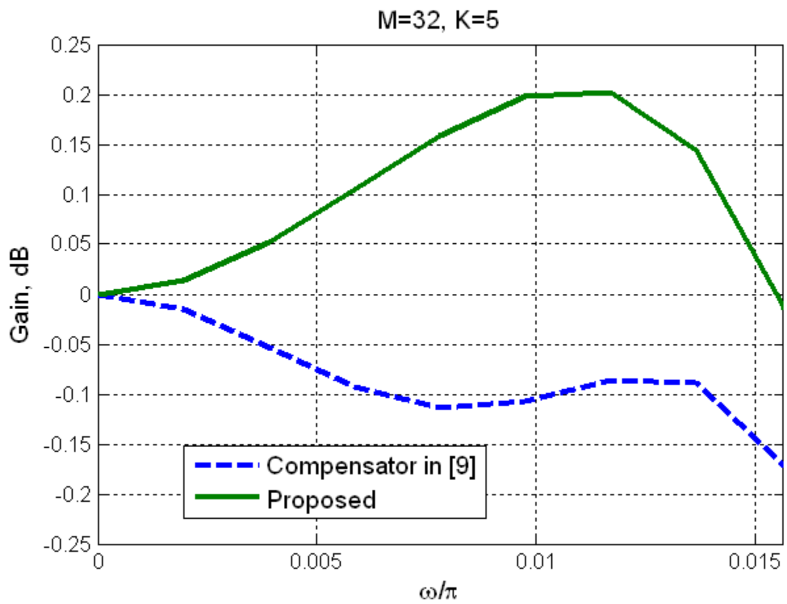

Figure 6. Comparison with method in [9].

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