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Current mode all-pass filter using a single CDBA and its application

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Abstract

A current-mode all-pass filter configuration is proposed in this paper. The proposed circuit consists of a current differencing buffered amplifier (CDBA), one resistor and capacitor. Since the output of the filter exhibits low output impedance, the synthesized filter can be cascaded without additional buffers. Moreover, the proposed circuit is insensitive to parasitic input capacitances and resistances due to internally grounded input terminals of CDBA. Furthermore, it does not impose any component matching constraint in analog signal processing circuits. To explore the performance of the proposed filter structure, a new current-mode quadrature oscillator which has minimum number of passive components is implemented. The performances of the proposed all-pass filter as well as the quadrature oscillator are also investigated by applying sensitivity analysis to the both proposed circuits. Finally the theoretical results are verified with PSPICE simulations using a CMOS realization of CDBA.

Keywords: *Current mode filters, All-pass filter, integrator, CDBA, Quadrature oscillator, Sensitivity analysis.*

Tek CDBA kullanarak gerçeklenen akım modu tüm geçiren süzgeç ve uygulaması

Özet

Bu makalede, akım modunda tüm geçiren bir süzgeç yapısı önerilmiştir.Önerilen devre bir tampon akım farkı kuvvetlendirici (CDBA), bir direnç ve kapasiteden oluşmaktadır.Süzgeç çıkışının küçük çıkış empedansı olduğundan, tasarlanan süzgeç, ek tampon devre kullanılmadan doğrudan kaskat bağlanabilmektedir.Bundan başka önerilen devre, CDBA'nın giriş uçlarının içten topraklı olması nedeniyle, parazitik kapasite ve dirençlerine duyarsızdır.Ayrıca önerilen devre, herhangibir eleman denkleştirme koşuluna gerek duyulmadan analog işleme devrelerinde kullanılabilir.Önerilen süzgeç devresinin başarımını incelemek amacıyla, minimum sayıda pasif eleman kullanan yeni bir çeyrek faz kaymalı osilatör tasarlanmıştır.Keza önerilen tüm geçiren süzgeç ve çeyrek faz kaymalı ösilatörün başarımları, önerilen her iki devre için duyarlık analizleri yapılarak araştırılmıştır.En son olarak, kuramsal sonuçlar CDBA'nın CMOS gerçeklemesi kullanılarak SPICE benzetimleriyle doğrulanmıştır.

Anahtar kelimeler: *Akım modu süzgeçler, tüm geçiren süzgeç, integrator, CDBA, çeyrek faz kaymalı oscillator, duyarlık analizi.*

1.Introduction

All-pass filters are one of the most important building blocks of many analog signal-processing applications and therefore have received much attention. They are generally used for introducing a frequency dependent delay while keeping the amplitude of the input signal constant over the desired frequency range. Other types of active circuits such as oscillators and high-Q band-pass filters are also realized by using all-pass filters [1]. The active devices that have been used for the realizations of the first order all-pass circuits include operational amplifiers (OP-AMP), second generation current conveyor (CCII), current feedback op-amps (CFOA), operational trans-conductance amplifier (OTA) and four terminal floating nullor (FTFN). Current-mode filters reported in literature, either do not offer all-pass configurations at all, or are excess in the number of components and require component matching constraints [2-6]. Recently, a current differencing buffered amplifier (CDBA)-based first order current-mode all-pass filter configuration is proposed [7]. The circuit uses single CDBA, a resistor and a capacitor, which are of minimum number. However, the transfer function of the circuit is sensitive to current tracking error of the CDBA and the accuracy of CMOS CDBA depends on matching of CMOS transistors. It is a well-known fact that open-loop circuits are less accurate compared to their high-gain counterparts. In this paper, CDBA-based voltage-mode first order all-pass filter configuration is proposed. The proposed circuit uses a single CDBA, two resistors and two capacitors. Also a sinusoidal quadrature oscillator is implemented to show usefulness of the proposed configuration as an illustrating example. Moreover performances of the proposed all-pass filter and quadrate oscillator are investigated by applying sensitivity analysis to the both circuits. PSPICE simulations are given which confirms the theoretical analysis.

2.The Proposed Circuits

The circuit symbol of the CDBA is shown in Figure.1 An ideal CDBA is characterized by the following equations [2]:

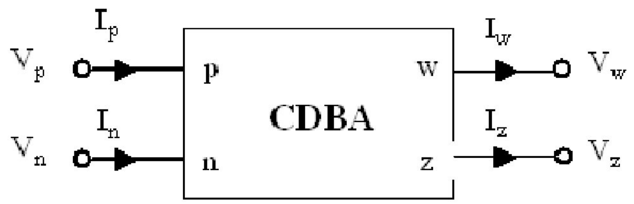

Figure.1. Symbol of the CDBA

$$V_P = V_N = 0,\ I_Z = I_P - I_N,\ V_W = V_Z \quad (1)$$

Fig.2 shows the proposed first order all-pass filter circuit. Routine analysis yields the current transfer function as follows:

$$\frac{I_{out}}{I_{in}} = \frac{1 - sCR}{1 + sCR} \quad (2)$$

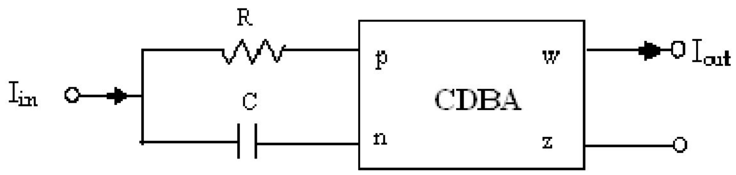

Figure.2. The proposed current-mode first order all-pass filter configuration

This transfer function allows the designer to obtain both inverting and non-inverting types of first order current-mode all-pass filters by simply exchanging C and R.

3. Quadrature Oscillator As An All-Pass Filter Application

It is a well-known fact that a sinusoidal quadrature oscillator can be realized using an all-pass section and an integrator [9]. CDBA-based current-mode quadrature oscillator can be implemented using this structure. In this circuit, the proposed all-pass filter and a current-mode integrator employing a CDBA with two matched resistors and capacitors are employed as shown in Figure.3. For providing a sinusoidal oscillation, the loop gain of the circuit is set to unity at $s = j\omega$, i.e.

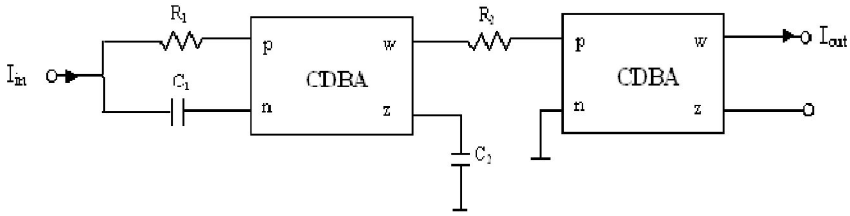

Figure.3. CDBA- based quadrature oscillator circuit

$$\left(\frac{1-R_1C_1}{1+R_1C_1}\right)\left(\frac{1}{sR_2C_2}\right)_{s=jw} = -1 \tag{3}$$

From Equation (3) oscillation condition and frequency can be found respectively as

$$R_2C_2 = R_1C_1 \tag{4}$$

$$w = \frac{1}{R_1C_1} \tag{5}$$

4. Sensitivity Analysis For Non-Ideal Case

In non-ideal case, the CDBA can be characterized by

$$V_P = V_N = 0,\ I_Z = \alpha_p I_P - \alpha_n I_N,\ V_W = \gamma V_Z \tag{6}$$

where α_p, α_n and γ are current and voltage gains, respectively, and $\alpha_p = 1 - t_p$, $\alpha_n = 1 - t_n$, $\gamma = 1 - t_v$. Here, t_p ,t_n are current tracking errors and t_v is the voltage tracking error, absolute values of all last three terms being much less than unit value. Taking the effect of these tracking errors into account, the expression for transfer function of all-pass filter shown in Figure-2 becomes:

$$H(s) = \frac{\alpha_p - \alpha_n RCs}{1 + RCs} \tag{7}$$

Note that pole frequency of all-pass filter is not influenced by tracking errors of CDBA, but gain and zero frequency of all-pass filter are affected by the tracking errors. From (7) all-pass filter condition is obtained as

$$\frac{\alpha_n}{\alpha_p} = 1 \tag{8}$$

After Equation (8) is substituted in Equation (7) transfer function is calculated as

$$H(s)=\frac{\alpha_p(1-RCs)}{(1+RCs)} \tag{9}$$

Thus amplitude of the all-pass filter becomes

$$\left|H(jw)\right|=\alpha_p \tag{10}$$

Notice that filter gain is influenced by tracking errors of CDBA. Sensitivity analysis of filter gain with respect to passive elements and tracking error parameters yields

$$S^{|H|}{}_{\alpha_p}=1,\ \ S_{R,C}{}^{|H|}=0 \tag{11}$$

It is evident that from eq. (11) $|H|$ sensitivities equal to unity and zero in magnitude. It should be noted that the condition for all-pass filter and filter gain depends on obtaining (9). Inaccurate component values due to manufacturing tolerances don't reduce the gain but tracking error parameters affect the filter gain..

Taking the effect of the tracking errors into account and assuming that both CDBA have same tracking error parameters the expression for open loop transfer function of the quadrature oscillator shown in Figure.3 becomes:

$$G(s)=\frac{\gamma\alpha_p(\alpha_p-\alpha_n R_1C_1s)}{(1+R_1C_1s)R_2C_2s} \tag{12}$$

For providing a sinusoidal oscillation the loop gain of the circuit is set to unity at $s=j\omega$.

From Equation (12) oscillation condition and frequency can be found respectively as

$$R_2C_2=\gamma\alpha_n\alpha_pR_1C_1 \tag{13}$$

$$w^2=\frac{\gamma\alpha_p{}^2}{R_1R_2C_1C_2} \tag{14}$$

If Eq.(13) is substituted in Eq.(14), oscillation frequency is

$$w = \frac{\sqrt{\alpha_p / \alpha_n}}{R_1 C_1} \tag{15}$$

It is remarked that oscillation frequency is affected by tracking error parameters and passive components of the all-pass filter. Sensitivity analysis of the oscillation frequency with respect to tracking error parameters and passive element yields:

$$S_{R_1,C_1}{}^{w} = -1 \tag{16a}$$

$$S_{\alpha_p}{}^{w} = 1/2, S_{\alpha_n}{}^{w} = -1/2 \tag{16b}$$

It is clearly observed from Eq.(16a-16b) with respect to passive and tracking errors sensitivities are equal or lower than unity in magnitude. It should be noted that oscillation frequency depends on obtaining eq. (15). Inaccurate component values due to manufacturing tolerances and tracking error parameters of CDBA reduce the oscillation frequency w..

5. Simulation Results

In order to demonstrate the applicability of the proposed all-pass filter, SPICE circuit simulations were performed using a CMOS CDBA realization [7]. The supply voltages were taken as $V_{DD} = 5V$ and $V_{SS} = -5V$. To verify the theoretical results, the first order all-pass filter was constructed and simulated with PSPICE program. For this purpose, passive components were chosen as R=1kΩ and C=100pF which results in a 1.59 MHz center frequency. MOS transistor aspect ratios and parameters were taken as in [7]. Simulation results of the filter response given in Fig.4. which follows theoretical results. The deviations in the frequency response of the filter from theoretical values are caused by nonzero parasitic input resistances at p and n terminals. Actually, the parasitic resistances and capacitances and tracking error parameters of the CMOS- CDBA, that is not mentioned in the limited space available here, causes the deviations in the frequency and phase response of the filter from theoretical values. Fig.5 shows the time-domain response of the filter. A sinusoidal input at the frequency of 1.59MHz was applied to the all-pass network constructed with above mentioned passive element values. Quadrature oscillator employing the proposed all-pass filter has also been simulated using PSPICE. In this simulation all resistances and capacitances were taken as $R_1 = R_2 = 1$ kΩ, $C_1 = C_2 = 100$ pF, $R_3 = 5$ kΩ, and $C_3 = 2$ pF respectively which results in a 1.59 MHz oscillation frequency. The output waveforms of the oscillators shown in Fig.6, which is in good agreement with the predicted theory. Actually, the parasitic resistances and capacitances and tracking error parameters of the CMOS- CDBA cause the deviations in the output waveforms of the filter and oscillator.

6. Conclusion

A current-mode first order all-pass filter configuration is presented. The proposed circuit uses only a single CDBA, a resistor and a capacitors. The output of the filter exhibits low impedance so that the synthesized voltage-mode filters can be cascaded without additional buffers. Most of the effects of parasitic input impedances disappear for the proposed all-pass filter due internally grounded input terminals of CDBA. As an application of the filter, a new current-mode quadrature oscillator was also realized. In non-ideal case, furthermore the effects of tracking errors parameters of CDBA and passive elements on all-pass filter gain and oscillation frequency are investigated by applying sensitivity analysis for both the proposed all-pass filter and oscillator circuits. PSPICE simulations were performed by using CMOS CDBA. PSPICE simulation results of the filter and quadrature oscillator responses are in good agreement with the predicted theory.

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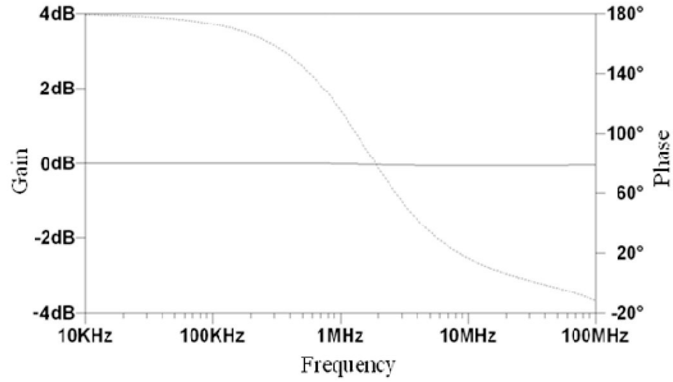

Figure.4. PSPICE simulation results of the proposed all-pass filter

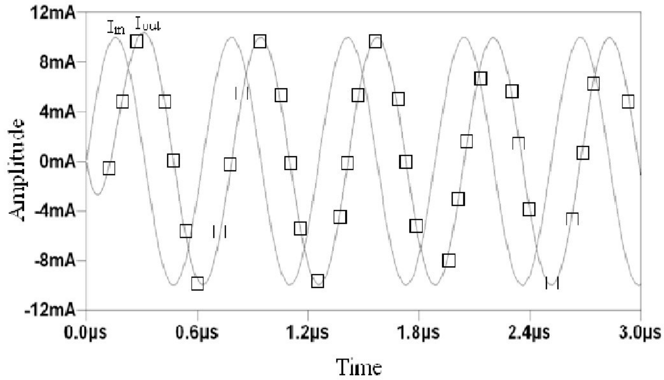

Figure.5. Simulated time-domain response of the proposed all-pass filter

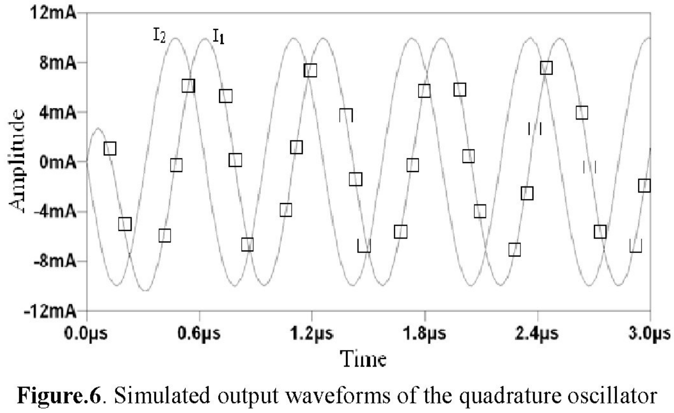

Figure.6. Simulated output waveforms of the quadrature oscillator