Realization of a CMOS Current Differencing Buffer Amplifier and Its Filter Application

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Abstract

In this paper, a CMOS realization of the current differencing buffer amplifier (CDBA) in the low voltage is presented. The circuit is suited for CMOS implementation. A first order all-pass filter circuit was chosen as an application example in order to demonstrate the performance of the CDBA. The SPICE simulation results for frequency response as well as transient response are incorporated to verify the theory. The feasibility of the proposed first-order all-pass filter is illustrated on the design of a quadrature oscillator.

1. Introduction

As an active building block, operational amplifier played a predominant role in the last two decades and an enormous number of publications exist in the literature on various circuit examples so that the design engineer can choose one of them. However, opamp-based circuits exhibit several drawbacks in their performance arising from the limited bandwidth and slew-rate of these active elements. Therefore, current-mode approach has been increasingly recognized as a way to overcome the opamp drawbacks and to realize high speed systems. In the last two decades new current-mode active building blocks like second generation current conveyors (CCII+ and CCII−), current-feedback opamps (CFOA) received considerable attention due to their larger dynamic range and wider bandwidth [1, 2]. In addition, different types of active elements like electronically controlled current-conveyor (ECCII), differential voltage current conveyor (DVCC), differential difference current conveyor (DDCC), third generation current conveyor(CCIII), dual output operational transconductance amplifier (DO-OTA) and four terminal floating nullor (FTFN) are presented in the literature [3–8].

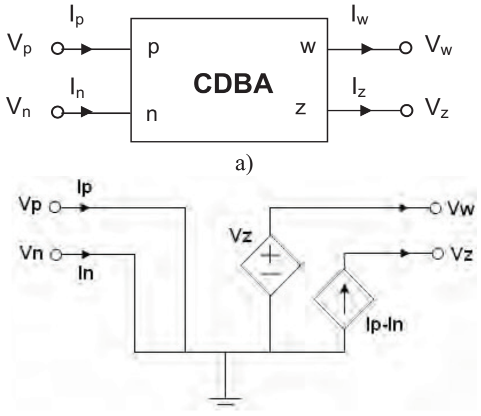
In recent years, a new active building block, current differencing buffered amplifier (CDBA), is introduced by Acar and Ozoguz to provide further possibilities in the circuit synthesis and to simplify the implementation [9]. The CDBA can offer such as high-slew rate, wide bandwidth and simple implementation [10]. Many applications based on CDBA were reported in the literature. Some of them are fully integrated signal process circuits [11], current-mode filters [10-15], voltage-mode filters [16, 17], resistance controlled sinusoidal oscillators [18], fully integrated gyrator circuits [19]. They have been demonstrated that the CDBA is a versatile active building block for voltage-mode and current-mode signal processing applications.

All-pass filters are widely used for phase shifting while keeping the amplitude of input signal constant over the frequency range of interest [10-12, 20-22]. They can be used to equalize the undesired phase change as a result of the band-pass analog filter operation. Another application of all-pass filters is the synthesis of multiphase oscillators.

In this paper, a new improved CMOS configuration of CDBA is presented providing low input impedances at ports p and n, very high output impedance at port z, a good linearity and high input/output gain ratio for current transfer. The offered CDBA contains only MOS transistors and is designed to be implemented in CMOS technology. To demonstrate the performance of the CDBA circuit, a first order all-pass filter was chosen. The next sections include the PSPICE simulations filter characteristics and the oscillator characteristic. The simulations show that the proposed CDBA circuit exhibits a very good performance and the results obtained for the filter are in good agreement with theory.

2. Circuit Description of CDBA

The circuit symbol of the current differencing buffered amplifier (CDBA) is shown in Fig. 1a, where p and n are input, w and z are output terminals. The equivalent circuit of the CDBA is given in Fig. 1b.



a)

b)

Fig. 1. a) Symbol of the CDBA b) Equivalent circuit of CDBA

Ideal current and voltage characteristics of the CDBA can be described by

$$V_p = 0,\ V_n = 0,\ I_z = I_p - I_n,\ V_w = V_z. \qquad (1)$$

By taking the non-idealities of the CDBA into account, the above terminal equations can be rewritten as

$$V_p = 0,\ V_n = 0,\ I_z = \alpha_p I_p - \alpha_n I_n,\ V_w = \beta V_z, \qquad (2)$$

where αp and αn are the current gains, and β is the voltage gain. These gains can be expressed by using the current tracking errors $|\varepsilon p| << 1$ and $|\varepsilon n| << 1$ and the voltage tracking error $|\varepsilon v|<<1$ as

$$\alpha_p = 1 - \varepsilon_p,\ \alpha_n = 1 - \varepsilon_n,\ \beta = 1 - \varepsilon_v. \qquad (3)$$

According to the equations mentioned above and equivalent circuit shown in Figure 1, the current through z-terminal is the difference of the currents through p-terminal and n-terminal, hence, the z-terminal is called current output; p- and n-terminals are non-inverting and inverting input terminals, respectively. Since the voltage at the w-terminal follows the voltage of z-terminal, it is called voltage output. Note that the input terminals, through which i_p and i_n flows, are internally grounded, where ideally the input impedance of the terminals p and n are internally zero.

3. CMOS realization of CDBA

The proposed CDBA consists of two principal blocks: a current differencing circuit which has finite input resistances and a voltage buffer circuit. The proposed realization of the CDBA in a CMOS configuration is shown in Fig. 2.

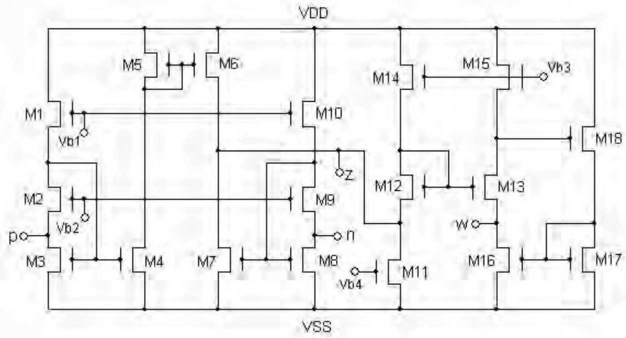


Fig. 2. A CMOS implementation of the CDBA

The transistors M1 to M10 form the input stage of the CDBA element. In the current mirrors of the input stage, flipped voltage followers (FVF) [23] are used. Feedback in FVF results in very low input resistances at the input terminals. Input resistance of the p and n terminals can be given using the output resistance of FVF. In the circuit, to construct the current mirrors, outputs of FVF are used as inputs of CDBA. M2, M3 and M8, M9 are FVF transistors. Thanks to the flipped voltage followers, input resistances of both p and n terminals are found as 25Ω.

4. CDBA-Based All-Pass Filter

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 [24].

Proposed first order all-pass filter circuit and its voltage transfer functions are given in Fig. 3.

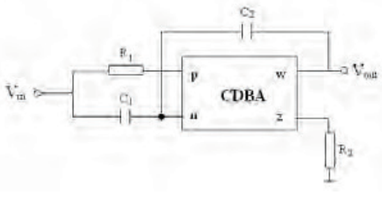
Proposed Circuit	Transfer Function
	$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_1}\left(\frac{1 - sC_1R_1}{1 + sC_2R_2}\right)$ $R_1 = R_2$ $C_1 = C_2$

Fig. 3. Proposed first order all-pass filter

The transfer functions of the all-pass filter which is given in Fig. 3 are expressed as:

$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_1}\left(\frac{1 - sC_1R_1}{1 + sC_2R_2}\right) \qquad (4)$$

5. 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 [25] as shown in Fig. 4. CDBA-based voltage-mode quadrature oscillator can be implemented using this structure. In this circuit, the proposed all-pass filter and a voltage-mode integrator employing a CDBA with two matched resistors and capacitors are employed as shown in Figure 5.

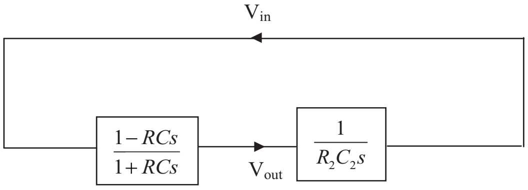


Fig. 4. Realization block diagram for quadrature oscillator

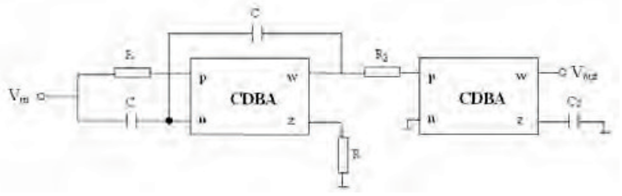


Fig. 5. CDBA-based quadrature oscillator circuit

For providing a sinusoidal oscillation, the loop gain of the circuit is set to unity at s = j ω, i.e.

$$\left(\frac{1-sCR}{1+sCR}\right)\left(\frac{1}{sC_3R_3}\right)_{s=j\omega} = -1 \qquad (5)$$

From Equation (5) oscillation condition and frequency can be found respectively as

$$R_3C_3 = RC \qquad (6)$$

$$\omega_0 = \sqrt{\frac{1}{RCR_3C_3}} \qquad (7)$$

For simplicity, from Equation (6) and (7), oscillation frequency becomes

$$\omega_0 = \frac{1}{RC} \qquad (8)$$

6. Simulation Results

In order to demonstrate the applicability of the proposed all-pass filter circuit shown in Fig. 3 the simulations were performed using a CMOS realization of CDBA shown in Fig. 2. The MOS transistors are simulated using TSMC CMOS 0.35µm process model parameters. Supply voltages are taken as 1.2V and -1.2V and Vb1=-0.2V, Vb2=0.3V and Vb3=0.3V biasing voltages are used. The aspect ratios of the transistors are given in Table 1.

Table 1. Transistors aspect ratios for the proposed circuit

M1= 30µ/0.7µ	M10= 30µ/0.7µ
M2= 30µ/0.7µ	M11= 30µ/0.7µ
M3= 90µ/2.1µ	M12= 150µ/3.5µ
M4= 90µ/2.1µ	M13= 150µ/3.5µ
M5= 150µ/3.5µ	M14= 30µ/0.7µ
M6= 150µ/3.5µ	M15= 30µ/0.7µ
M7= 90µ/2.1µ	M16= 150µ/3.5µ
M8= 90µ/2.1µ	M17= 90µ/2.1µ
M9= 30µ/0.7µ	M18= 90µ/2.1µ

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_1=10kΩ, R_2=20kΩ and C_1=C_2=10pF which results in a 1.59MHz center frequency. Simulation results of the filter response given in Fig. 6 which follows theoretical results. Fig. 7 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 passive element values mentioned above.

A 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=1kΩ, C_1=C_2=10pF, R_3=5 kΩ, and C_3=2pF to obtain 15.9MHz oscillation frequency. The output waveforms of the oscillators shown in Fig. 8 are in good agreements with the predicted theory.

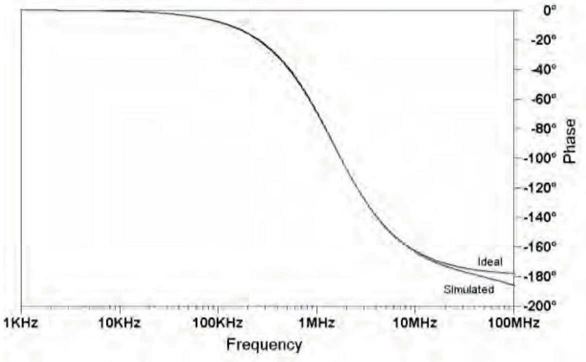


Fig. 6. PSPICE simulation result of the proposed filter

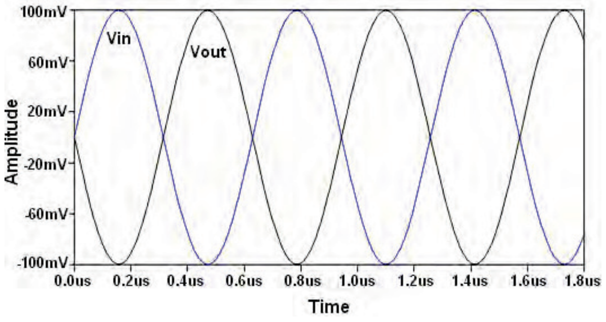


Fig. 7. Simulated time-domain response of the proposed filter

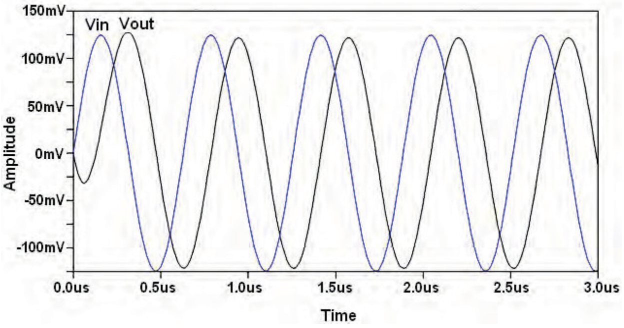


Fig. 8. Simulated output waveforms of the oscillator

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.

7. Conclusion

CDBA, current differencing buffered amplifier, is a multi-terminal active component with two inputs and two outputs. The CDBA is simplifying the implementation, free from parasitic capacitances and it is able to operate in the frequency range of more than hundreds of MHz. 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.

A new current differencing buffer amplifier, CDBA is presented. A new and simple CMOS realization of this element is given. An application example of a voltage-mode all-pass filter employing the proposed CMOS CDBA realization has been presented. PSPICE simulations were performed with a CMOS realization of the CDBA and its filter application. A first order all-pass filter circuit is chosen as an application example in order to demonstrate the performance of the CDBA. The feasibility of the proposed first-order all-pass filter is illustrated on the design of a quadrature oscillator. Simulation results show that filter characteristics are in good agreement with theory.

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