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Current controlled current differential current conveyor: a novel building block for analog signal processing

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Abstract: In this paper, a novel active block for analog signal processing is presented, namely the current controlled current differential current conveyor (CCCDCC). This multi terminal block has most features of the well-known CCII (Second Generation Current Conveyor) and CCCDTA (Current Controlled Current Differencing Tranconductance Amplifier) to simplify the realization of current-mode analog filters suitable for signal processing. The proposed block and its applications were simulated in 0.18 μm CMOS process at ± 0.9 V supply voltages. All of results were obtained by Hspice and with a high detailed transistor library.

Keywords: current conveyor, filter realization, analog processing circuit, current differential, current-mode

Classification: Integrated circuits

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1 Introduction

The interest in designing current-mode circuits mainly originate from their higher bandwidth, speed advantages, simpler circuit, and wider dynamic range [1, 2, 3, 4, 5]. Current conveyors (CC) as an example of current-mode circuits are helpful devices widely used in analog signal processing. Several applications such as filtering, inductor simulation, impedance converting, amplification, and oscillation are acquirable with current conveyors. Many types of CCs have been reported since 1968, but they principally function by directing a current and voltage signal from one port to another.

Second generation current conveyors (CCII) are comprehensive building blocks for a variety of circuits. Hence, many CCII's modifications have been introduced to increase the usefulness of this element. Differential difference current conveyor (DDCC) [4], differential voltage current conveyors (DVCC) [5], and fully differential second generation current conveyor (FD-CCIIs) [6] are a few examples of these elements. In addition to modified circuit, some analog block also drive out from current conveyors, as an example, CDTA (Current Differencing Transconductance Amplifier), introduced by Biolek [7], has been found as a useful analog block for current-mode signal processing [8]. Recently, CCCDTA (Current Controlled Current Differencing Transconductance Amplifier) modified CDTA whose current inputs resistances are controllable, is proposed by Siripruchyanun [9].

One of the most uses of CCCDTA and other mentioned current-mode blocks is realizing filters. Hence many structures for filters have been presented by means of various blocks; still, need at least two building blocks for realizing a current-mode high-pass filter seems necessary in most available current conveyor based building blocks.

This paper introduces a new element, so called a current controlled current differential current conveyor (CCCDCC). This block has differencing feature of CDTA and CCII benefits, but main advantage of proposed block is that a high-pass\low-pass filter can be easily realized with just one CC-CDCC.

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2 The proposed novel analog block

The CCII is a single-ended device, while most modern high performance analog integrated circuits use differential signal paths. In order to use benefits of differential feature and customary applications of CCII, we presented a novel block, CCCDCC, whose circuit symbol and internal circuitry are shown in Fig. 1 (a) and Fig. 1 (c), respectively. Here, X_1 and X_2 behave as differential current input tracking Y voltage owing to their input resistance. Z_d and Z_{-d} are the differential current output terminals, Z and Z_- are the replica of terminal X_1 input current providing negative or positive CCII. The number of current output terminals can be increased if necessary. I_B implies to bias current of CCCDCC. Regarding all the current directions flow to inside of the block, Eq. (1) represents the terminal relations of the device. The resistances of current inputs can be obtained by direct analysis, if $g_{m1} = g_{m5}$ and $g_{m2} = g_{m6} = g_m$ input resistance terminal will be as Eq. (2) where $\beta_n = \mu_n C_{ox}(W/L)$ is the physical parameter of MOS transistor. Hence R_{X1} and R_{X2} can be controlled by bias current. We employ class AB CCII which has low power consumption and high frequency. Also, using low voltage low power current mirrors (CM) [10] cause high output resistance while transistors work properly in 0.18 μm CMOS technology; the gate terminal of upper MOSFETs of CMs, like M_{n1} and M_{P1}, are connected to ground, and are not shown for simplicity.

$$\begin{bmatrix} V_{X1} \\ V_{X2} \\ I_Y \\ I_Z \\ I_{-Z} \\ I_{Zd} \\ I_{-Zd} \end{bmatrix} = \begin{bmatrix} R_{X1} & 0 & 1 & 0 & 0 & 0 & 0 \\ R_{X2} & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{X1} \\ I_{X2} \\ V_Y \\ V_Z \\ V_{-Z} \\ V_{Zd} \\ V_{-Zd} \end{bmatrix} \tag{1}$$

$$R_{X1,X2} = \frac{1}{g_{m2} + g_{m6}} - \frac{I_B}{I_{in}(g_{m2} + g_{m6})} \left(\frac{g_{m2}}{g_{m1}} - \frac{g_{m6}}{g_{m5}} \right) = \frac{1}{2g_m} = \frac{1}{\sqrt{8\beta_n I_{B1}}} \tag{2}$$

3 Applications

Generally, a current-mode high pass filter can be brought about by a low pass filter and a differencing block as shown in Fig. 1 (b). Disadvantage of this realization is using two analog blocks for a first order high-pass filter. Therefore, if we are going to realize a high-pass filter by means of analog processors or Field Programmable Analog Array (FPAA), internal connection of two blocks will make parasitic effects. In order to decrease these effects we use presented blocks to form a high-pass and low-pass filter by just one CCCDCC. Fig. 1 (d) depicts the filters whose functions can be expressed by:

$$I_{HP} = -\left(\frac{I_{in}}{R_{X2}C_1S + 1} - I_{in} \right) = \left(\frac{R_{X2}C_1SI_{in}}{R_{X2}C_1S + 1} \right) \tag{3}$$

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$$I_{LP} = (-I_{HP} + I_{in}) = \left(\frac{I_{in}}{R_{X2}C_1S + 1}\right) \tag{4}$$

The cutoff frequency and its sensitivities are obtained as Eq. (5)

$$\omega_c = \frac{1}{R_{X2}C_1}, \quad S^{\omega_c}_{R_{X2}C_1} = -1 \tag{5}$$

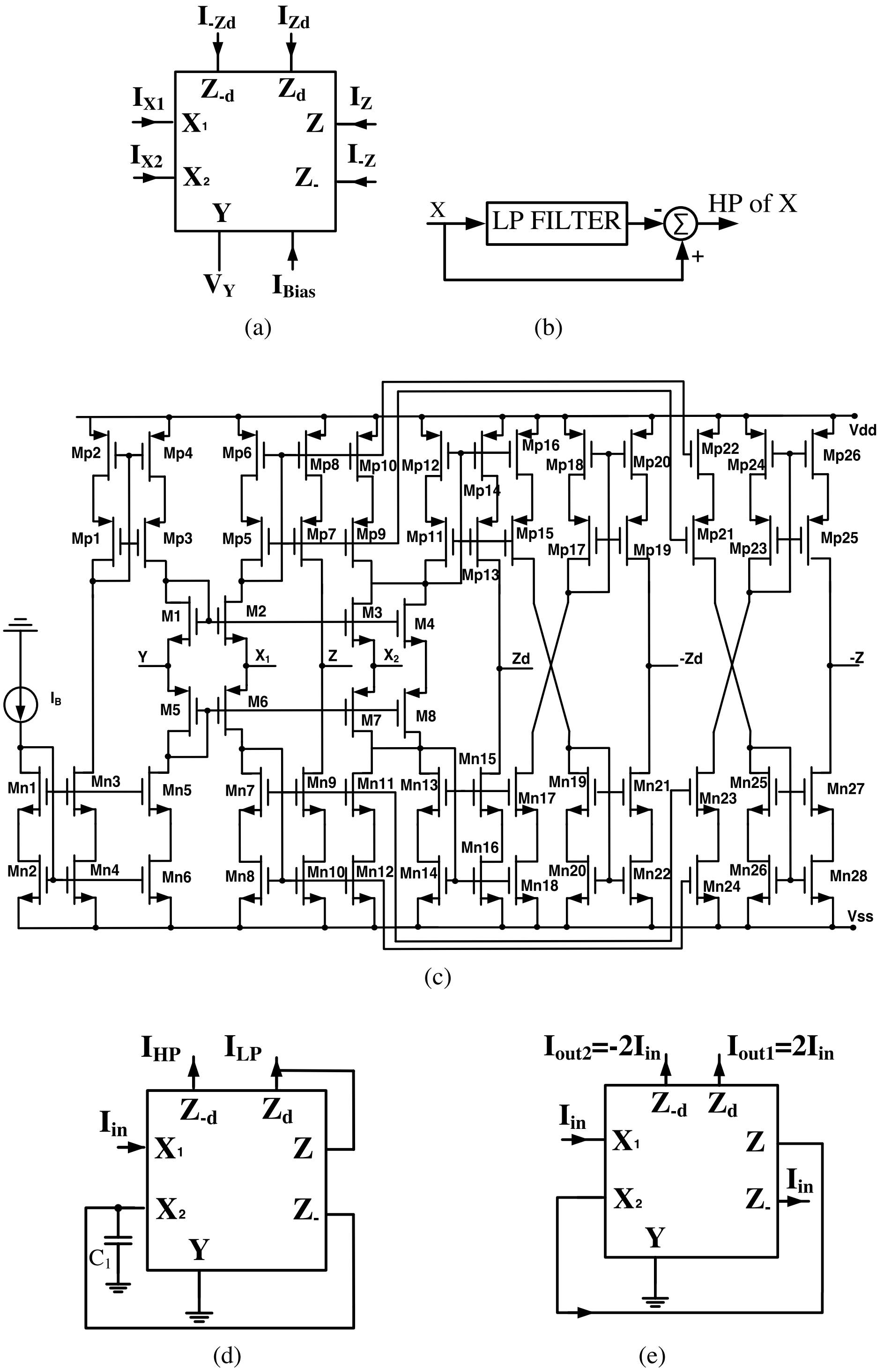

Fig. 1. The proposed CCCDCC and its applications (a) Symbol (b) Conventional method for realizing High pass filter (c) CMOS internal circuit (d) LP and HP filter (e) A Current Doubler

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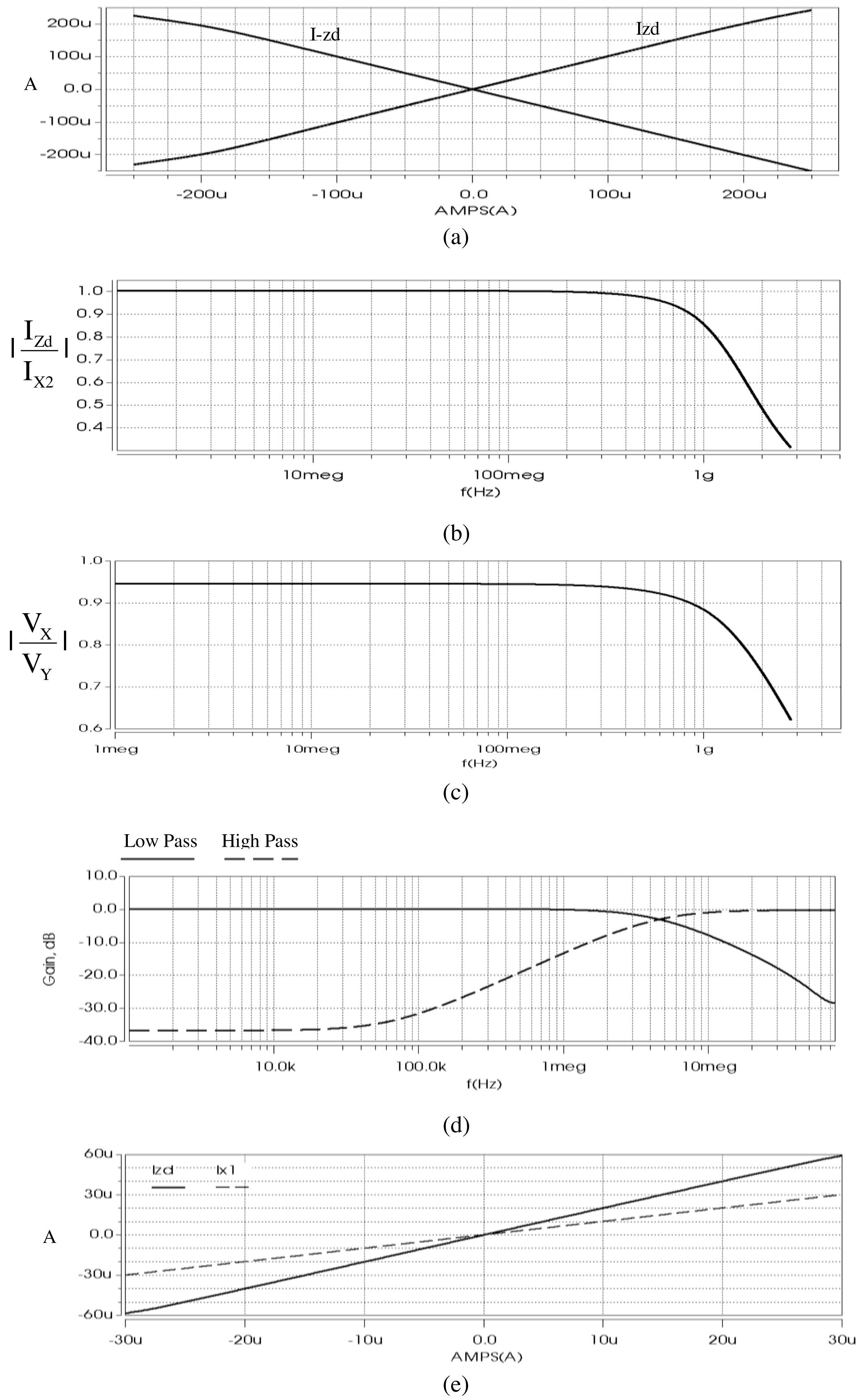

Fig. 2. Simulation results of proposed CCCDCC and its applications (a) the dc current transfer (b) The current gain (c) The Voltage gain (d) The Gain of high/low pass filter (e) The dc response of current doubler

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Another simple application is doubling of input current which can be achieved by means of just one CCCDCC shown in Fig. 1 (e).

4 Simulation results and comparison

The proposed novel building block was designed and simulated in 0.18 μm CMOS technology and the results were obtained by Hspice simulator.

The dimension values of transistors M1-M4, M5-M8, Mn1-Mn6, Mn7-Mn28, Mp1-Mp4, Mp5-Mp26, are 10 μm/0.18 μm, 4.14 μm/0.18 μm, 4.05 μm/0.18 μm, 4.14 μm/0.18 μm, 8 μm/0.18 μm, and 10 μm/0.18 μm, respectively.

Some simulation results are demonstrated in Fig. 2; the ac current gain and dc transfer response between X_2 port to Z_d and Z_{-d} ports are shown in Fig. 2 (b) and Fig. 2 (a), respectively. The ac voltage gain is also shown in Fig. 2 (c). Fig. 2 (d) represents the magnitude responses of the first-order high pass and low pass filter, respectively, designed at $f_C = 4.42$ MHz: $C = 30$ pF and $R_{X2} = 1.2$ KΩ. Finally, Fig. 2 (e) depicts the current output of proposed current doubler.

The power supply was ± 0.9 V while the bias current was $I_b = 30\,\mu$A.

Because of the fact that proposed CCCDCC is a novel block, comparison of the presented work with other blocks is not quite fair, as some blocks maybe design for specific purpose. But to show that the characteristics of the presented circuits are not far from other recent well-known blocks, we compare our results with similar works in Table I. The output resistance, current linear range, its power consumption, and THD are better, compare to what are reported in [1, 9].

Table I. Comparison of presented CCCDCC with similar works

Parameters	Presented CCCDCC	[1]	[9]
Technology(μm)	0.18	0.18	0.35
Voltage Suply(V)	±0.9	1.8	±1.5
Power consumption(mW)	0.706	1.71	1.48
-3dB bandwidth (GHz)	1.377 (Izd/Ix2) 1.071 (Izd/Ix1) 1.203 (Iz/Ix1) 2.5 (Vy/Vx)	0.574 (Iz/Ix1) 2.5 (Vy/Vx)	0.311 (Izd/Ix2) 0.282 (Izd/Ix1)
Input current linear range	-200 µA to 200 µA	-200 µA to 200 µA	-100 µA to 100 µA
Voltage dynamic range	-0.45 V to 0.45 V	-0.4 V to 0.4 V	N/R
THD(%)	0.555	1.02	N/R
Rx1 and Rx2 range	0.619 kΩ to 31.8 kΩ	N/R	0.821 kΩ to 25.1 kΩ
Rz, Rzd	1.4 MΩ	N/R	1.03 MΩ

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5 Conclusion

A novel current-conveyor-based building block was discussed. Due to its differential and CCII features, a low-pass/high-pass filter can be realized by just one proposed block, CCCDCC. Moreover, the device had high performance and could operate at high frequencies. Thus, it can be applied in high frequency circuits such as video or RF processors. The design was simulated in 0.18 μm CMOS technology. The results were obtained by Hspice simulator and a couple of applications were proposed.

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