Development of Differential Amplifier Based the Second Generation Current Conveyors

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ABSTRACT

In this article, developments of Second Generation Current Conveyors (CCII) that are realized by based on the use of a differential amplifier (diff-amp) as a circuit building block are reviewed. The basic concepts of current conveyor are firstly outlined. One of the first CMOS-based promising techniques to implement CCII that proposed by Surakampontorn et al. is reviewed [9-11]. The applications of Surakampontorn's CCII as basic circuit building blocks to realize analog circuits and systems and the modifications methods to provide multiple outputs CCIIs are outlined and discussed. Based on feedback mechanisms, diff-amp-based CCIIs that are designed by modified from the CCII are also outlined and discussed. In order to understand the improvement, the characteristics of the CCIIs that have been compared through simulation results by Hassanenin et al. [11] are presented. Finally, the concept of chemical current conveyor (CCCII) is also noted.

1. INTRODUCTION

In the past analog signal processing performs a signal processing through a voltage signal (voltage mode). Research in analog integrated circuit design has recently gone in the direction of low power low voltage applications, especially in the environment of portable systems where power supply are driven by a single cell low voltage battery. Therefore, traditional voltage mode techniques are going to be replaced by the current mode approach.

Second generation current conveyor (CCII) has shown to be one of the major basic circuit building blocks for current-mode signal processing, in particular for low power and low voltage applications [1-8]. Analog active circuit systems can be realized by a suitable connection of one or two CCIIs [1-8]. Until now, a wide number of CMOS-based current conveyor circuits have been proposed in literatures. But, however, in this work only current conveyor that realized by based on the employment of a differential pair as circuit building block will be considered [9-11].

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2. SECOND GENERATION CURRENT CONVEYOR

2.1 Basic principle

A first generation current conveyor (CCI) was firstly introduced by Sedra and Smith in 1968 [7]. Later, a second generation current conveyor (CCII) was proposed by A. Sedra and K.C. Smith in 1970 [8]. The CCII has proven to be a more useful building block for active filter design and signal processing applications than the CCI. Shown in the block diagram of Fig. 1, a CCII is a three port network that the relations of the voltages and currents of the ports can be defined in the form of hybrid parameter as

$$\begin{bmatrix} i_Y \\ V_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ i_X \\ V_Z \end{bmatrix} \quad (1)$$

where, the plus and minus signs denote positive and negative current, respectively. On the other hand, we can rewrite the eq. (1) as

$$i_Y = 0, V_y = V_x \quad \text{and} \quad i_Z = \pm i_X \quad (2)$$

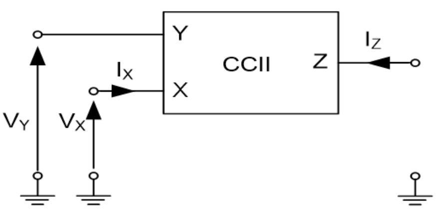


Fig.1: *Block diagram of CCII.*

From eq. (2), we can be inferred that the voltage of the low impedance port X follows the voltage at high impedance port Y. The current flowing at port Z is proportional to the current flowing into the port X.

2.2 Differential-pair-based CCII circuits

Fig. 2 shows the circuit diagram of the first possible solution of CMOS-based CCII that was proposed by Surakampontorn et al. [9]. In fact, this is a CMOS-based version of the bi-polar based voltage to current converter circuit that introduced by Pookaiyaudom et al. [12]. The circuit is operated

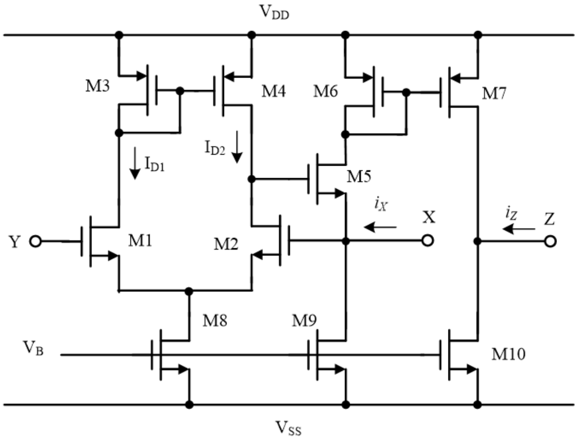


Fig.2: *Surakampontorn et al. CCII [9].*

in class A. Transistors M1, M2 and M8 form as a diff-amp. Since, the current mirror M3-M4 forces the drain currents $Id_1 = Id_2$, the gate source voltages of transistors M1 and M2 are equaled, or $V_{gs1} \approx V_{gs2}$. This means that the diff-amp functions as a voltage follower, then forces $V_Y \approx V_X$. Transistor M5 and current mirror M6-M7 are used to sense the current flowing from port X to port Z. If the source and drain currents of M5 are equaled and the current gain of the current mirror M6-M7 is equaled to 1, then $i_Z \approx i_X$.

From routine analysis of the circuit of Fig. 2, the voltage transfer ratio, the input impedance at port X and the output impedance at port Z can be respectively given by

$$\frac{V_X}{V_Y} = \frac{g_{m1}}{g_{m1} + g_{d2} + g_{d3}} \quad (3)$$

$$i_Z/i_X \cong g_{m7}/g_{m6} \quad (4)$$

$$r_X = \frac{g_{d2} + g_{d4}}{g_{m5}(g_{m1} + g_{d2} + g_{d4})} \quad (5)$$

$$r_Z = \frac{1}{g_{d7} + g_{d10}} \quad (6)$$

Where g_{mi} and g_{di} are the transconductance gain and the drain conductance, respectively, of the transistor i. Ideally, $V_X/V_Y = 1, i_Z/i_X = 1, r_X = 0$ and $r_Z = \infty$. From the W. S. Hassanein et al. report, V_X/V_Y is about 0.99938, i_Z/i_X is about 1.0037, $r_X = 5.9\Omega$ and $r_Z = 100k\Omega$ [11]. The value of parasitic impedance at port X or r_X is quite low and the impedance at port Z is high, as required by the current conveyor characteristics.

3. APPLICATIONS AND MODIFICATIONS

The CCII of the Fig. 2 has proved useful in a large number of applications. This is due to that the circuit structure is simple, its characteristic is reasonable accurate, and its can be easily modified. We can identify the applications in four categories as follows.

3.1 Active Circuit Building Blocks

The CCII of the Fig. 2 has been employed as basic building blocks to realize CCII-based analog signal processing circuits in many different ways. For examples, active capacitance multipliers [13], V-I scalar circuits [14], and low-sensitivity biquadratic filters [15]. In the reference 16, the CCII has been constructed as current followers to realize a multiple output active filter based on current follower. Using the CCII of Fig. 2, a new circuit cell which is the combination of the CCII+ and CCII-was proposed and used to simulate resistively terminated LC ladder filters by Sedef and Acar [17] .

3.2 Dual and Multiple Outputs CCIIs

In this case, the CCII of Fig.2 have been modified to provide multiple outputs in order to realize analog signal processing circuits using less number of active circuit elements [21-26]. Fig. 3 (a) show the circuit diagram of the dual outputs CCII. We can see that, from Fig. 3, M9, M14 and current mirrors M10-M11 and M15-M16 are used to copy and inverse the direction of the current to provide i_Z-. To provide more output ports, a multiple outputs CCII as shown in Fig. 4 will be employed [19].

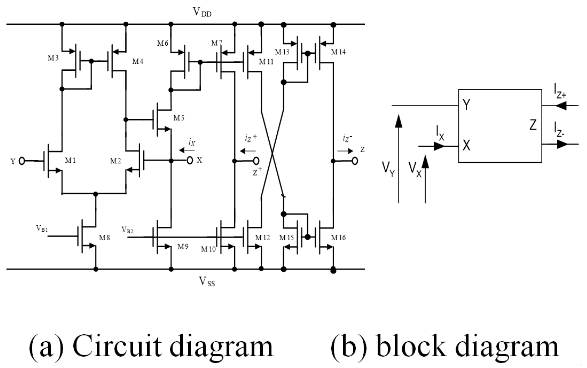


Fig.3: *Dual Outputs CCII [19-20].*

The dual output CCII found applications in analog signal processing circuits, in particular filters that provide more than one output. Its has been used to realize, for examples, a PID controller and instrumentation amplifier [20], a current-mode universal biquadratic filter with five inputs and two outputs [21], and a higher-order immittance function [22]. The applications for the multiple outputs of the Fig. 4 are for examples, a MOCCII current-mode KHN filter [23], a current-mode transimpedance-mode universal biquadratic filter [24], a configuration insensitive multifunctional current-mode biquad [25], and a universal current-mode filter with multiple inputs and one output [26].

In addition, based on the modification of the CCII of Fig. 2, a four terminal floating nullor (FTFN) [28] and a current conveyor circuit using only NMOS

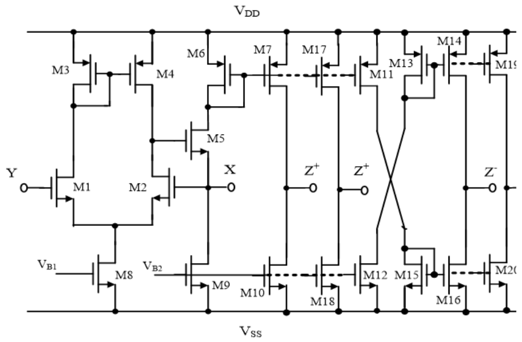


Fig.4: *Multiple Outputs CCII [21-26].*

transistors [29], were also proposed.

3.3 CCIIs with Improved Performance

Some of new CCIIs that based on the modification of the circuit structure of the Fig. 2 are outlined in this section. Different feedback mechanisms around diff-amp were proposed to force $V_{GS1} \approx V_{GS2}$. In 1992, the CCII of Fig. 5(a) was proposed by Laopoulos et al., where M5, M6, M12 and M13 form as high loop gain feedback part to provide low r_X [30]. A simple CCII as shown in Fig. 5(b) was proposed by Palmisano and Palumbo in 1995 [31]. This CCII, M1 of the diff-amp is driven by the constant current IB from M3, while M4 forms as a common to feedback the current IB to diode-connected M2.

In stead of using regular current mirror, R. Wojtyna employed a special regular cascade current mirror in order to design the CCII to operate for ± 3V supply voltage [32]. A differential difference CCII with its applications was proposed by W. Chiu et al. in [33]. A voltage conveyor that was obtained on the basis of the CCII in the Fig. 2 was described by I.M. Filanovsky in reference 34. S. Emami et al. proposed a new circuit structure that can be configured as CCII+ and/or CCII- without needing an additional current mirror in [35]. A class-A CMOS CCII suitable for high frequency applications based on the used of flipped voltage follower was presented by Hassanein et al. [36]. The simulations results and a fair comparison between the proposed CCII and Surakampontorn CCII were also given. Last but not least, a low power second generation current conveyor circuit allows measuring the mechanical frequency response of the nanocantilever structure in the megahertz range was proposed in [37].

3.4 Others Differential Amplifier Based CCII circuits

The CCII with the circuit structure similar to the Fig.2 was proposed by Liu et al. as shown in Fig. 5(c), but the PMOS common sources M5 is used to feedback to port X instead [38]. The weak point is that Liu's CCII gives low offset only for the case that signal current i_X is small. Fig. 5(d) shows the CCII using two diff-amp stages was proposed by Ismail and Soliman, where the feedback path is similar to the circuit of Fig. 5(b) [39]. Fig. 5(e) shows a high precision CCII that proposed by Yodprasit [40], where two feedback paths to port X, through M5 and M6, were used. Due to the feedbacks, the offset voltage of Yodprasit's CCII is very low and not depends on i_X. But, however, due to too much feedback to port X, bandwidth of the circuit is quite low. Later on Hassan and Soliman have improved this problem by adding of source follower sections at the input stage [41]. In addition, H.O. Elwan et al. was introduced a class-A CMOS CCII that can work with single supply voltage. This CCII was then modified to work as a class AB while maintaining the rail to rail swing capability as shown in Fig. 5(f).

Table 1 shows the comparison of the performance of the CCIIs of Fig. 2 and Fig. 5 that were studied by Hassanein et al. [11]. We can see that Surakampontorn's CCII of Fig.2 provides a moderate characteristic with high values of offset. Yodprasit's CCII of Fig 5(f) provides the good performance but with narrow bandwidth. Current conveyors of the Fig. 5(b), Fig. 5(c) and Fig. 5(f) give large bandwidth but r_X are quite large.

4. MODIFICATION OF CCII DEFINITION

4.1 Electronically tunable CCIIs

An electronically tunable CCII (ECCII) was proposed by Surakampontorn and Thitimasjshima in 1988, where its voltages and currents of the ports can be defined in the form of hybrid parameter as [43]

$$\begin{bmatrix} i_Y \\ V_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm A_0 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ i_X \\ V_Z \end{bmatrix} \quad (7)$$

Later on, in 1992, Surakampontorn and Kumwachara proposed an electronically tunable CMOS ECCII, by co-operate a small signal current gain stage with the CCII in the Fig.2 in order to adjust the current gain by electronic means [43-44]. This building block will allow easy realization of analog functions with controlled characteristics.

The circuit of Fig. 6 was employed to realize electronically tunable current-mode biquadratic active filters [45,-47]. Also, by this new concept, new ECCIIs have been proposed in the literatures [48-53].

4.2 Chemical Current Conveyor

Recently, Pookaiyaudom et al. have propose the concept of chemical current conveyor (CCCII) by integrate ISFET (Ion-Seletive Field Effect Transistor) which is a chemical sensor with the CCII circuit [51-54]. The characteristic of the CCCII and it block diagram are shown in the Fig. 7. From the figure,

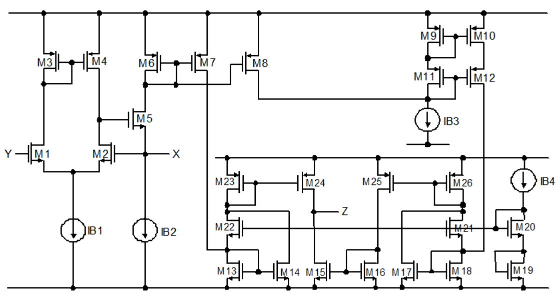
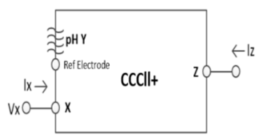


Fig.5: *CMOS-based ECCII [43].*

since the chemical sensor ISFET is attached to port Y, the voltage at the low impedance port X will follow the voltage of the high impedance PH-Y port and the current of port X is transfer to the output port Z. Usually, the output of the CCCII is in the form of current or voltage that is related to the pH value. However, if a computing circuit is cooperating, the output value can also be arranged in the form that related to the time integral or time derivative val;ue.

$$\begin{bmatrix} i_{pH} \\ V_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} V_{pH} \\ i_X \\ V_Z \end{bmatrix} \tag{8}$$

6(a) Hybrid parameter



6(b) Block diagram [52,53]

Fig.6: *Positive CCCII+.*

5. CONCLUSION

In this article, one of the first CMOS-based CCII that implemented by based on the use of long tail pair differential amplifiers is reviewed. The applications of the CCII as basic circuit building blocks and the modifications to be multiple outputs CCIIs are outlined. Differential-amplifier-based CCII circuits that are designed by modified from Surakampontorn et al. CCII are also discussed.

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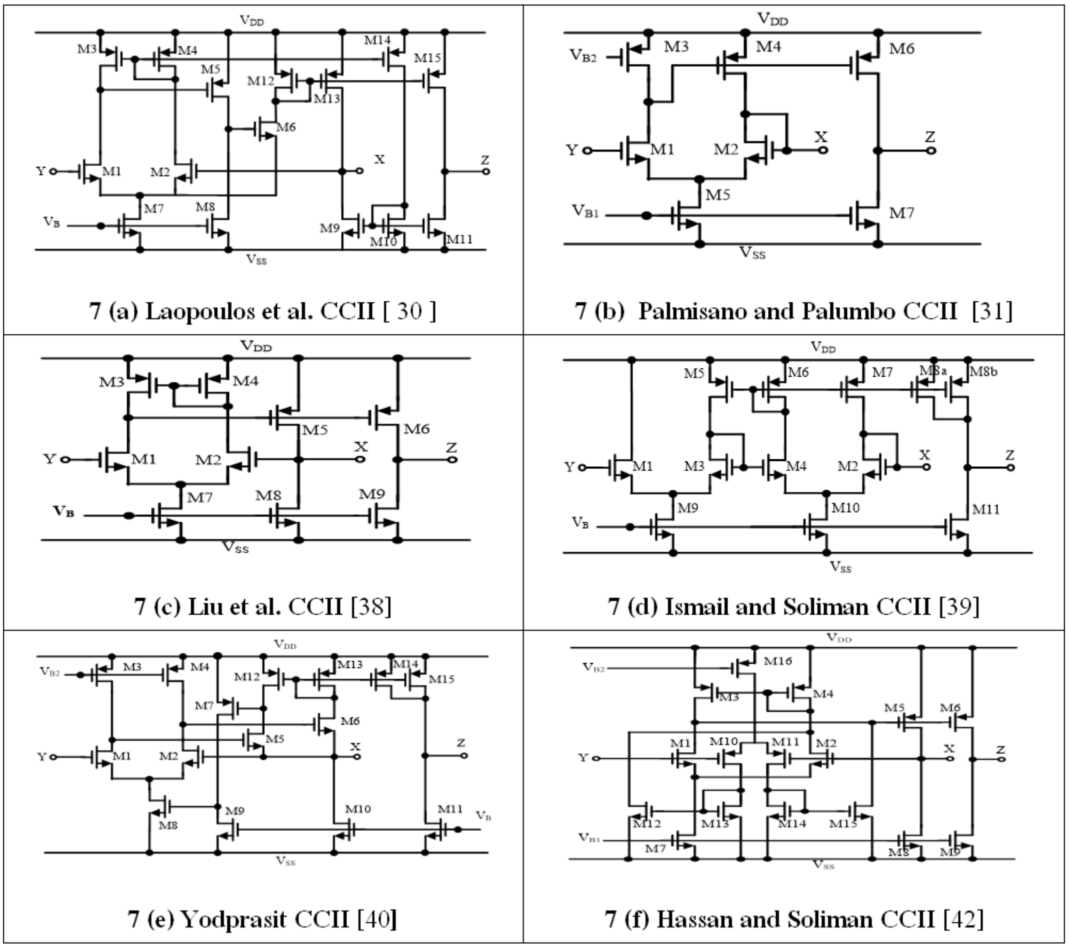

7 (a) Laopoulos et al. CCII [30]

7 (b) Palmisano and Palumbo CCII [31]

7 (c) Liu et al. CCII [38]

7 (d) Ismail and Soliman CCII [39]

7 (e) Yodprasit CCII [40]

7 (f) Hassan and Soliman CCII [42]

Fig. 7: *Diff-amp Based Second Generation Current Conveyors.*

Table 1: *Comparison of the CCII performances [11].*

Parameter	unit	Fig. 2	Fig. 5(a)	Fig. 5(b)	Fig. 5(c)	Fig. 5(d)	Fig. 5(e)	Fig. 5(f)
Input Voltage range	V	-0.73 to 0.2	-0.5 to 0.7	-0.3 to 0.7	-0.5 to 0.8	-0.4 to 0.9	-0.5 to 0.2	-1.46 to 0.85
A_V (Average values)	-	0.99385	0.99996	1.00014	0.99998	0.989	0.999998	0.99995
Voltage offset variation	mV	-4.52 to 2.27	-0.066 to - 0.007	-0.642 to 0.506	-0.078 to -0.056	-4.77 to 12.34	-0.0025 to -0.00047	-0.771 to -0.043
F_{3db} of voltage transfer gain	MHz	776	2.7	1800	1660	589	7.5	1995
Input current range	µA	-100 to 100	-150 to 150	-100 to 100	-100 to 100	-200 to 200	-100 to 100	-100 to 100
A_I (Average values)	-	1.0037	0.99998	0.9946	0.99991	1.0038	1.01034	0.99995
Current offset variation	µA	-1.04 to - 0.0006	-0.001 to 0.0036	0.583 to 2.35	-0.0035 to 0.006	1.05 to 3.08	-2.2300 to -0.044	-0.004 to 0.0058
F_{3db} of current transfer gain	MHz	66	23	94.5	95	66.8	6.6	115
r_X	Ω	5.9	3.5	14.63	10.46	6.92	0.1	9.14

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