# A NEW CURRENT CONVEYOR-BASED TRANSIMPEDANCE ACTIVE FILTER

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## ABSTRACT

**The well-known advantages of the current-mode operation, such as greater bandwidth, lower power-consumption, better linearity compared to their voltage-mode counterparts, becomes more attractive with the introduction of second-generation current conveyors (CCIIs). In the recent years many voltage-mode or current-mode active filters employing current conveyors appeared in the literature. Besides the voltage- and current-mode operations, in some special filtering applications mixed-mode operations are necessary. The mixed-mode filters are called transimpedance and transadmittance filters, whose input variables are current and voltage whereas the output variables are voltage and current, respectively. There are only a few publications on mixed-mode filters in the literature. The aim of this work is to introduce a new transimpedance filter employing CCIIs as the active element. The proposed active filter produces lowpass (LP) and bandpass (BP) filter responses at its outputs simultaneously. Furthermore, its natural frequency can be adjusted electronically by using a translinear conveyor as the active element. The proposed transimpedance filter eliminates the need for the current to voltage converter. An important application of this circuit is the reconstruction filter of a D/A converter with current output. The theoretical predictions were confirmed with SPICE simulations.**

## I. INTRODUCTION

In the last years electronic circuits are fabricated almost as integrated circuits (ICs) due to taking the points such as cost, reliability, mass production capability into consideration. Especially in the last decade, thanks to the developments in the IC technology, the active element dimensions have been considerably reduced and on the same chip area much more complex circuitry can be integrated. The result of this fact brings increasing power dissipation problems. Today, in addition to the digital systems, mixed-signal systems are also fabricated with VLSI technology, which contains digital and analog building blocks on the same chip. These mixed-signal ICs also employ A/D and D/A converters, which are placed between the analog and digital parts. To overcome the heating problems due to the increased power dissipation, the supply voltages must be decreased in the mixed-signal ICs similar to the digital counterparts. However, decreasing the supply voltages yields also decreasing the output dynamic range of the conventional voltage-mode analog circuits. To overcome this trade-off and to make use of the well known other advantages of current-mode operation, it seems a good solution to process currents instead of voltages in analog circuits [1]. One of the most important milestones of current-mode operation is the introduction of the second-generation current conveyor (CCII) [2]. Besides many analog circuit applications, also active filter circuits based on CCIIs are published in the literature in the last three decades [3-6].

On the other hand, voltage-to-current and current-to-voltage converters are also necessary at the interface of the voltage-mode and current-mode circuits [7]. If filtering is necessary at these interfaces in the case of using of mixed-mode filters (transimpedance and transadmittance filters) the above mentioned converters are unnecessary. To the best knowledge of the authors, there are only three papers published in the literature until now; one of them is on a transadmittance filter [8], and the others are on transimpedance filters [9,10]. For example, if a transimpedance filter is used at current output of D/A converters as a reconstruction filter, a current-to-voltage converter is unnecessary. The transimpedance filters presented in previous works employ a large number of active and passive elements [9,10]

The aim of this paper is to present a new CCII-based transimpedance filter employing reduced number of active and passive elements. This filter produces LP and BP responses at its outputs simultaneously. Furthermore, all of the capacitors of this circuit are grounded, which enables its implementation using standard IC processes. Moreover, this circuit can also be implemented using current-controlled current conveyors (CCCIIs). In this case the resulting circuit is an active-C filter and it enjoys electronic tunability. These are very important from the integrated circuit implementation point of view.

## II. THE PROPOSED TRANSIMPEDANCE FILTER

CCII is a high-performance active element in active network synthesis, which is constructed using unity gain cells. The circuit symbol of CCII is shown in Figure 1 [2].

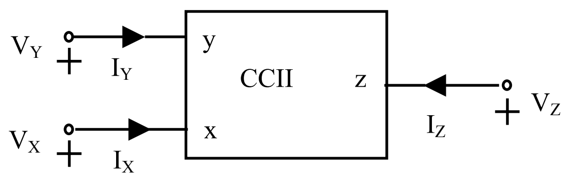



Figure 1 The circuit symbol of CCII

The terminal relations of a CCII can be given as follows [2]:

$$I_Y=0\,, \qquad V_X=V_Y\,, \qquad I_Z=\pm I_X \tag{1}$$

Plus and minus signs in the last part of Eqn. (1) indicate the positive and the negative types of conveyors (CCII+ and CCII-) respectively. Taking the tracking nonidealities of the CCII into account the terminal relations can be rewritten as:

$$I_Y=0\,, \qquad V_X=\beta V_Y\,, \qquad I_Z=\pm\alpha I_X \tag{2}$$

where $\beta=1-\varepsilon_v$, $\alpha=1-\varepsilon_i$, are voltage and current gains. Here, $\varepsilon_v$ ($|\varepsilon_v|<<1$) and $\varepsilon_i$ ($|\varepsilon_i|<<1$) are voltage and current tracking errors respectively.

A transimpedance filter with current input and voltage outputs producing BP and LP responses should satisfy the following transfer functions:

$$\frac{V_{O1}}{I_{in}}=\frac{\dfrac{s}{C_1}}{s^2+s\dfrac{1}{C_1R_1}+\dfrac{1}{C_1R_1C_2R_2}} \tag{3a}$$

$$\frac{V_{O2}}{I_{in}}=\frac{-\dfrac{1}{C_1C_2R_2}}{s^2+s\dfrac{1}{C_1R_1}+\dfrac{1}{C_1R_1C_2R_2}} \tag{3b}$$

Eqns. (3a) and (3b) correspond to the signal-flow graph shown in Figure 2

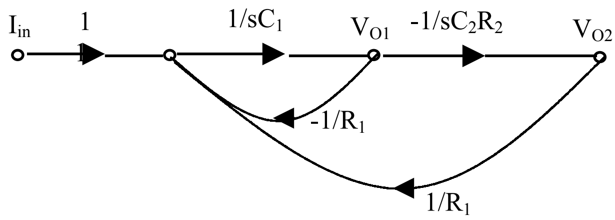



Figure 2 The signal flow graph of the transimpedance filter with LP and BP responses

The quality factor and the natural angular frequency of the filter can be expressed as for the ideal and nonideal cases:

$$Q=\sqrt{\frac{C_1R_1}{C_2R_2}} \qquad \omega_o=\sqrt{\frac{1}{C_1R_1C_2R_2}} \tag{4}$$

$$Q=\sqrt{\alpha_2\beta_1\beta_2\frac{C_1R_1}{C_2R_2}} \qquad \omega_o=\sqrt{\frac{\alpha_2\beta_1\beta_2}{C_1R_1C_2R_2}} \tag{5}$$

From Eqns. (4) and (5) it is apparent that the passive and active sensitivities of the presented filter are not more than ½ in magnitude. In Figure 3a and 3b the sub-graphs of the signal-flow graph illustrated in Figure 2 and their corresponding basic circuits are given.

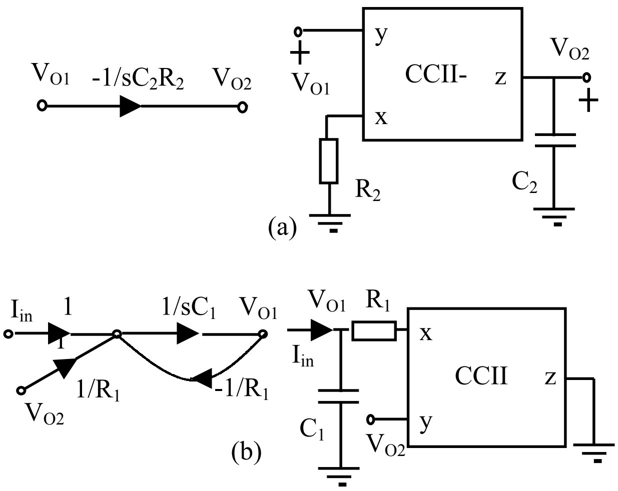



Figure 3 The sub-graphs of the signal-flow graph shown in Fig. 2 and their corresponding CCII-based circuits; (a) inverting voltage-mode lossless integrator, (b) the proposed transimpedance integrator.

The circuit shown in Fig. 3a is a classical voltage-mode lossless integrator. However, the circuit illustrated in Fig. 3b is new. This circuit can be considered as a transimpedance lossy integrator with current summing property. By combining these sub-circuits according to the graph shown in Fig. 2 the proposed transimpedance filter illustrated in Fig. 4 is obtained. This active filter produces BP and LP responses at its outputs simultaneously.

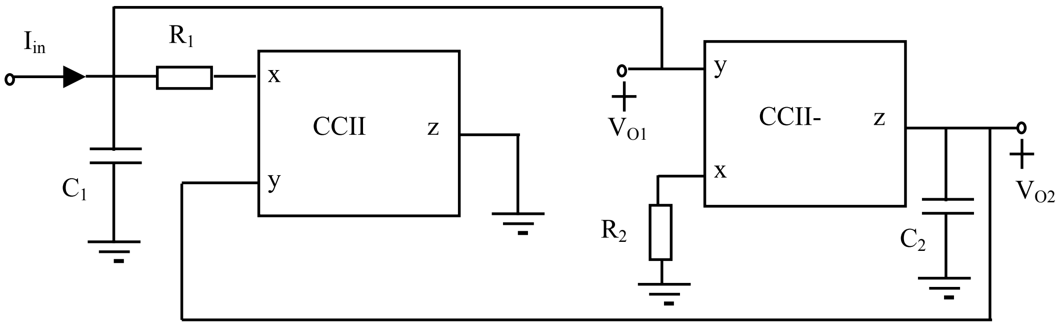



Figure 4 The proposed transimpedance filter.

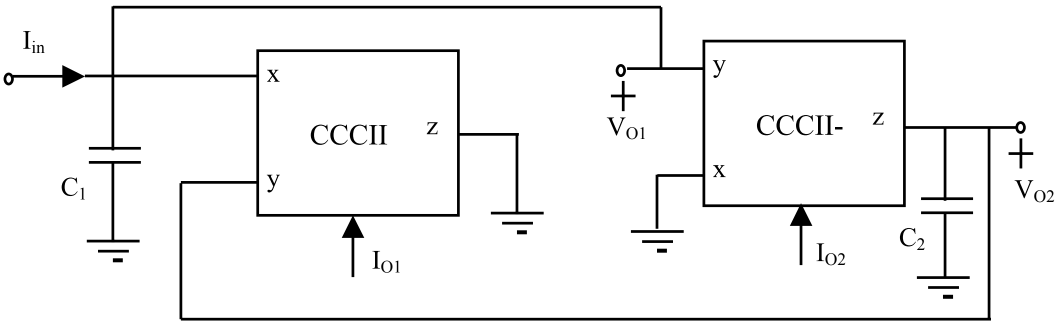



Figure 5 The proposed filter employing CCCIIs

All the capacitors of the proposed filter are grounded; therefore this circuit can be implemented using standard IC processes. On the other hand, it is obvious from Fig. 4 that resistors are connected to the x-terminals of the conveyors. Thus, when translinear conveyors are used as active elements instead of classical CCIIs, the resulting circuit is an active-C circuit with electronic tuning capability. It is well known that, the parasitic X-terminal resistance ($r_X$) of the translinear conveyor can be adjusted via a biasing current and the active element with this property is called the current controlled current conveyor (CCCII) [11]. The proposed transimpedance filter employing CCCIIs is shown in Fig. 5.

It should be noted again that the proposed transimpedance filter shown in Fig.5 has the following advantages:

i) employs only grounded capacitors,

ii) enjoys electronic tuning of the natural angular frequency,

iii) does not employ any passive resistors

## III. SIMULATION RESULTS

In order to verify the theoretical analyses given above SPICE simulations are performed using the CMOS translinear conveyors illustrated in Figs. 6a and 6b [12]. The supply voltages are chosen as ±2.5V. 0.35µ CMOS process parameters are used from AMS. The dimensions of transistors of these conveyors are given in Table 1.

The X-terminal resistance $r_X$ of the CMOS translinear conveyors can be expressed as:

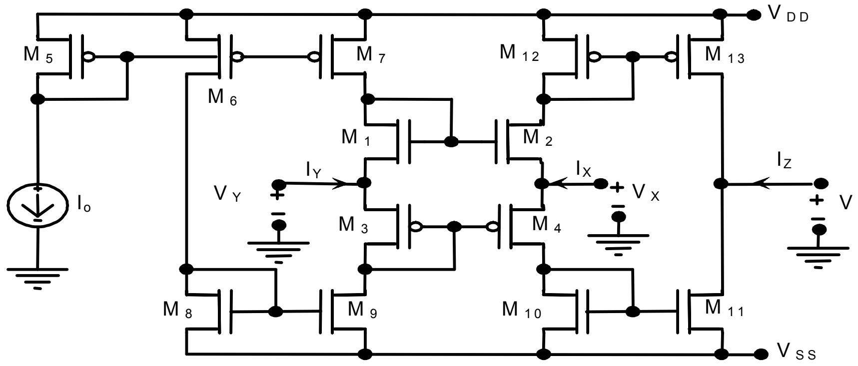
$$r_X = \frac{1}{g_{m2} + g_{m4}} \qquad g_{mi} = \sqrt{2\beta_i I_O}\ , \quad i=2,4 \qquad (6)$$

From Eqn.(6) it is obvious that $r_X$ can be adjusted via $I_O$.

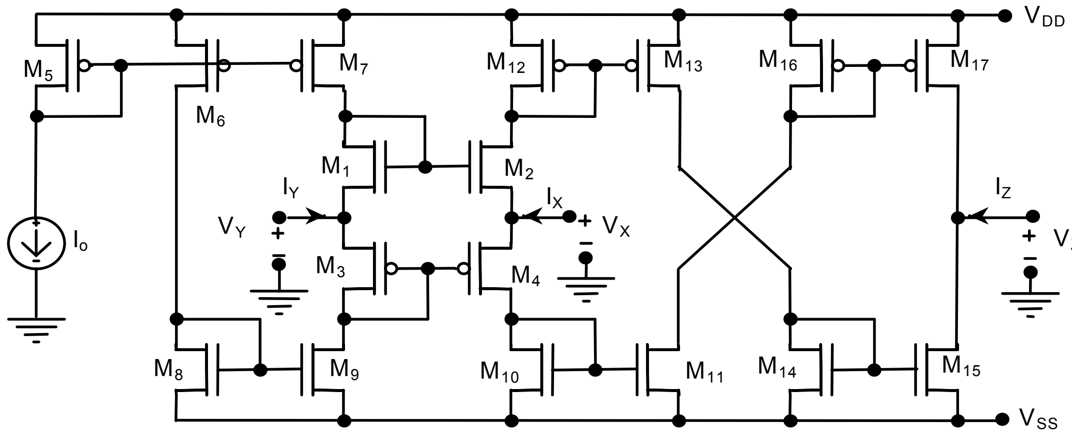
Table 1 The device dimensions of the CMOS translinear conveyors shown in Figs. 6a and 6b.

| Transistor | W [µm] | L [µm] |
|---|---|---|
| $M_1$, $M_2$ | 20 | 0.35 |
| $M_3$, $M_4$ | 60 | 0.35 |
| $M_5$, $M_6$, $M_7$ | 30 | 2 |
| $M_8$, $M_9$ | 10 | 2 |
| $M_{10}$, $M_{11}$, $M_{14}$, $M_{15}$ | 10 | 1 |
| $M_{12}$, $M_{13}$, $M_{16}$, $M_{17}$ | 30 | 1 |

The LP frequency response of the presented filter is illustrated in Fig. 7 for capacitor values $C_1$=10pF, $C_2$=20pF (Q=0.707) while the biasing currents are changed through $I_O=I_{O1}=I_{O2}$=100µA, 150µA and 200µA. The BP response is depicted in Figure 8 for the same biasing currents, but for the capacitor values $C_1$=20pF, $C_2$=10pF (Q=1.414). From Figs. 7 and 8 it is obvious that the corner/center frequency of the proposed transimpedance filter can easily be adjusted. On the other hand, the quality factor can be adjusted with capacitor ratios. Simulation results verify the theoretical predictions.




(a)




(b)

Figure 6 CMOS translinear conveyors (a) positive type, (b) negative type

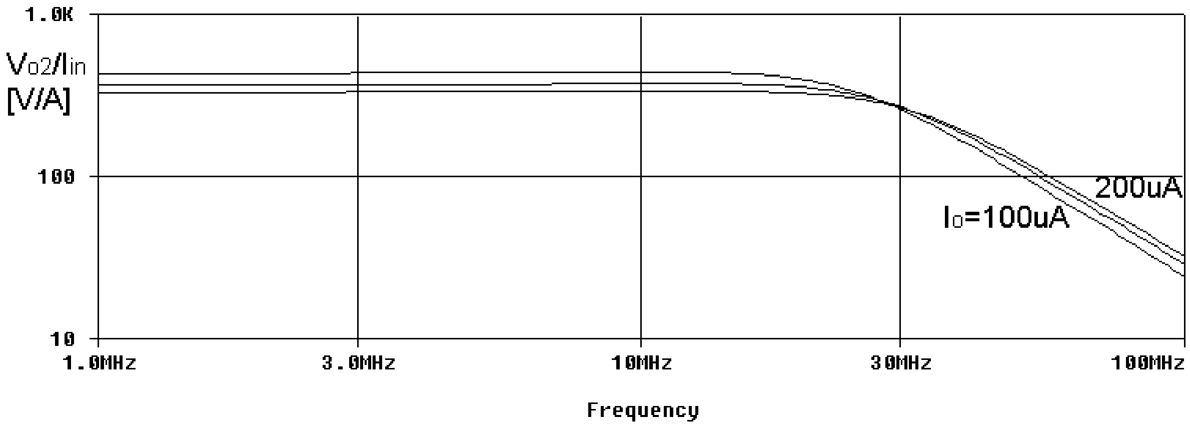



Figure 7 The LP frequency response of the presented filter shown in Fig. 5 ($C_1$=10pF, $C_2$=20pF, $I_O$=$I_{O1}$=$I_{O2}$=100, 150, 200μA)

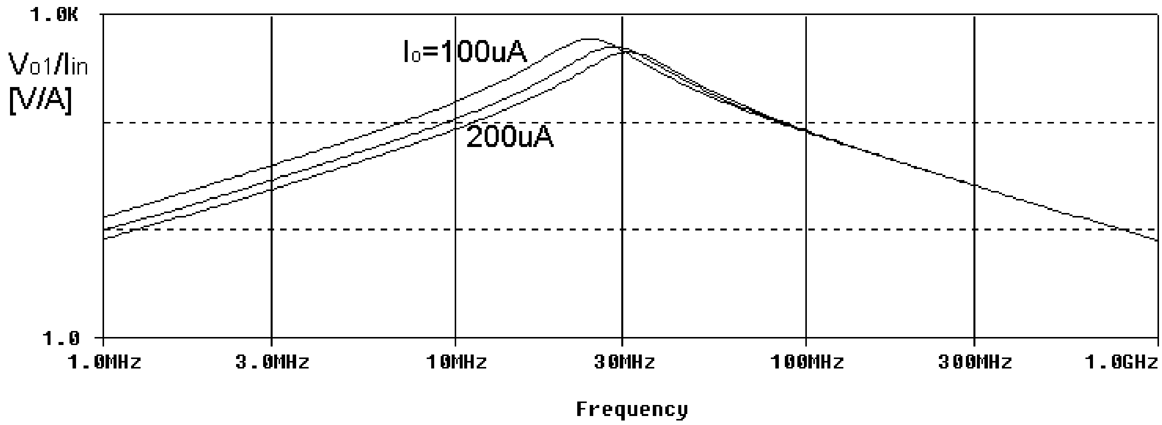



Figure 8 The BP frequency response of the presented filter shown in Fig. 5 ($C_1$=20pF, $C_2$=10pF, $I_O$=$I_{O1}$=$I_{O2}$=100, 150, 200μA)

## V. CONCLUSION

In this paper a novel mixed-mode filter with current input and voltage outputs is presented. The presented circuit offers the following features:

- It produces LP and BP responses simultaneously.
- It eliminates the need for a current-to-voltage converter.
- It employs fewer passive and active elements compared to the previously reported counterparts.
- Because the capacitors in the presented filter are all grounded, it is suitable for implementation using standard CMOS processes with a single poly silicon layer.
- Using CCCIIs as active elements the filter corner/center frequency can be adjusted electronically. In this case the filter uses two grounded capacitors, but does not employ any external resistors.
- SPICE simulations verify the performance of the presented filter.

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