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New Voltage-Mode All-pass Filter Topology Employing Single Current Operational Amplifier

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Abstract

In this paper, a new voltage-mode all-pass filter topology based on single current operational amplifier (COA) and the implementation of COA by using current conveyors are presented. The proposed topology employs three admittances and single active circuit element. COA implementation by using current conveyor blocks as sub-circuit contributes to workability of the COA employing circuits by using commercially available integrated circuits that can be employed as current conveyor. The validity of the proposed filter is verified by PSPICE simulation programme by using the MOSIS 0.35 micron CMOS process parameters. The simulation results agree well with the theoretical analysis and the circuit achieve a good total harmonic distortion (THD) performance.

Keywords:
All-pass filters, Circuit Topology, Current Conveyors, Current Operational Amplifiers.

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Introduction

All-pass filter is one of the most commonly used filter types. The purpose of this filter is to add phase shift (delay) to the response of the circuit. The amplitude of an all-pass filter is unity for all frequencies and the phase response, however, changes from 0° to 180° for a one-pole filter over the desired frequency range. All-pass filters are used in circuit design to perform various frequency-dependent time-alignment or time-displacement functions and they play essential role in audio systems (Berners, 2008). Other types of active circuits such as sinusoidal oscillators and high-Q band-pass filters are also realized by using all-pass filters.

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It is well known that current-mode circuits received a great attention as a new alternative since they have some advantages such as low power consumption at high frequency, high signal dynamic range, high speed, and better noise performance when compared to traditional voltage-mode circuits.

Current-mode technique also give us opportunity to design both current-mode and voltage-mode circuits. Many works about current-mode building blocks, such as current feedback operational amplifiers and current conveyers have already been reported. The current operational amplifier (COA) is still emerging as one of the most important current-mode active building blocks and it is the exact current-mode dual of the voltage-mode operational amplifier (VOA). There are some CMOS implementations of COA and COA based filter circuits in the literature (Kılınç and Çam, 2003; Altun and Kuntman,2007 ; Yamaçlı and Kuntman, 2005; Youssef and Soliman, 2005; Kılınç and Çam, 2004; Altun and Kuntman, 2006; Kılınç *et al.,* 2005; Altun, 2007; Cheng and Wang, 1997; Mucha, 1995; Uygur and Kuntman, 2004). Among the reported filters, none of them is employing current conveyor based COA. Current conveyor based COA implementation technique used in this work make it possible to employ the circuit by using commercially available integrated circuits that can be employed as current conveyor such as AD844. This technique allows the COA to provide low input impedance and very small input offset current. The aim of this work is to present a new single COA based voltage mode all-pass filter circuit and contribute to workability of the proposed circuit by using an alternative way to implement the COA active building block.

Circuit Description of COA

The schematic symbol of dual input-dual output COA is shown in Figure 1.

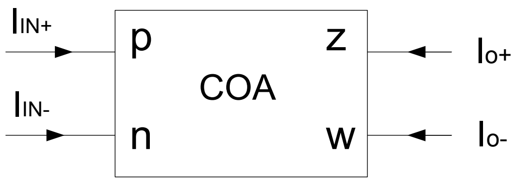


Figure 1. COA's schematic symbol

The defining equation of COA can be given as

$$\begin{bmatrix} V_{IN+} \\ V_{IN-} \\ I_{O+} \\ I_{O-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ A & -A & 0 & 0 \\ -A & A & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{IN+} \\ I_{IN-} \\ V_{O+} \\ V_{O-} \end{bmatrix} \tag{1}$$

In (1), A is the open-loop current gain and ideally approaches to infinity. The infinite open-loop current gain forces the input currents to be equal. Thus, the COA must be used in feedback configuration that is similar to the VOA. The use of high open-loop gain of COA allows obtaining accurate transfer function. A COA should exhibit a very low input resistance (ideally zero), and a very high output resistance (ideally infinite). Thanks to high output impedance, COA-based current-mode circuits can easily be cascaded without additional buffers. Differential signalling at input has many advantages such as better noise performance, reduced even-odd harmonics and increased dynamic range (Altun and Kuntman, 2007). Also, the current differencing and internally grounded inputs of COA make it possible to implement the COA-based circuits with MOS-C realization(Kılınç *et al.*, 2005).

An ideal COA is mainly an infinite gain current controlled current source, but in practical cases the gain becomes a function in frequency exhibiting a single pole response, this will guarantee the stability of the closed loop systems (Youssef and Soliman, 2005).

The COA used in this paper is implemented by using three current conveyor blocks as shown in Figure 2 (Kaulberg, 1993). Since CCII+ and CCII- can be obtained from dual output CCII, it is possible to implement the COA by using only dual output current conveyor blocks in the architecture. This technique let the designer to implement the COA by using commercially available integrated circuits that can be employed as current conveyor.

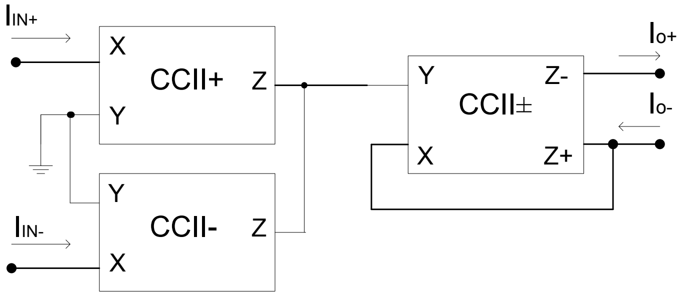


Figure 2. COA implementation by using current conveyors

Proposed Circuit Topology

The proposed voltage-mode all-pass filter topology based on single COA is shown in Figure 3.

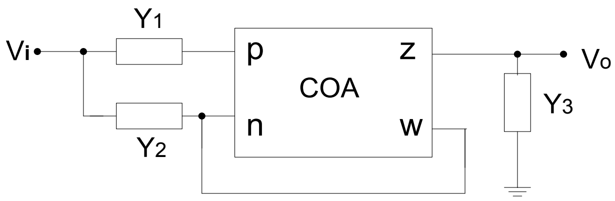


Figure 3. Proposed circuit topology

The circuit analysis of the proposed filter using (1) yields the following transfer function

$$\frac{V_0}{V_i} = \frac{Y_2 - Y_1}{Y_3} \tag{2}$$

To obtain an all-pass filter, the admittance combinations are taken as shown in Table I. For simplicity, the component values are choosen as $R_1 = R_3 = R$ and $C_2 = C_3 = C$.

Table I. Admittance Combinations

$\mathbf{Y_1}$	$\mathbf{Y_2}$	$\mathbf{Y_3}$
$Y_1 = G$	$Y_2 = sC$	$Y_3 = sC + G$

The resulting all-pass filter circuit is shown in Figure 4.

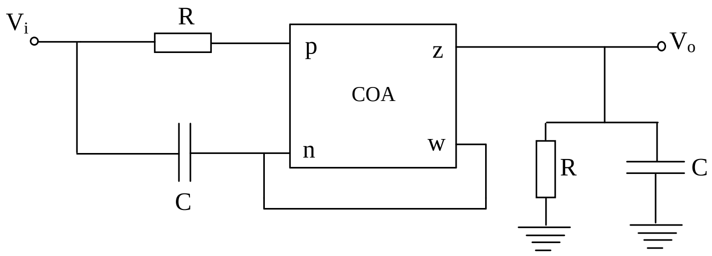


Figure 4. Proposed all-pass filter circuit

The transfer function of the circuit can be arranged as

$$T(s) = \frac{s-1/RC}{s+1/RC} \quad (3)$$

The radian frequency of the circuit is

$$\omega_0 = \frac{1}{RC} \quad (4)$$

The sensitivity of radian frequency to the passive components are all calculated as

$$S_R^{\omega_0} = S_C^{\omega_0} = -1 \quad (5)$$

The proposed filter has a frequency dependent phase given by

$$\varphi = \pi - 2tan^{-1}\omega_0 RC \quad (6)$$

Simulation Results

The proposed circuit's performance has been evaluated for the MOS implementation of COA by PSPICE simulation programme using the MOSIS 0.35 µm CMOS process parameters. The circuit schematic of dual output CMOS CCII used to implement the COA is given in Figure 5 and W/L parameters of MOS transistors used in simulation are as reported in (Songkla and Jaikla, 2012).

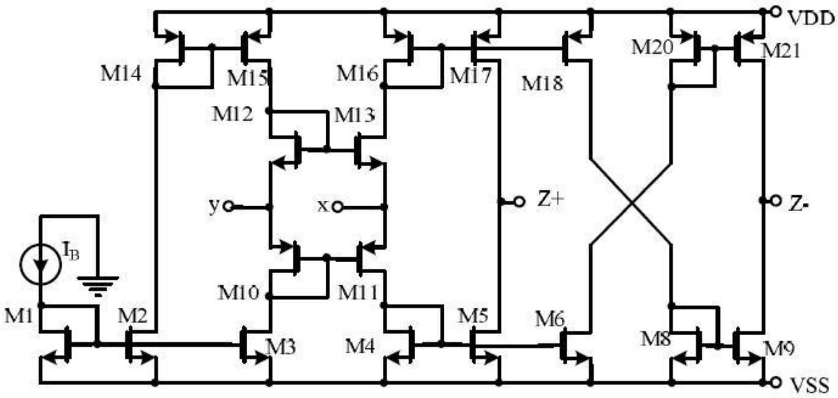
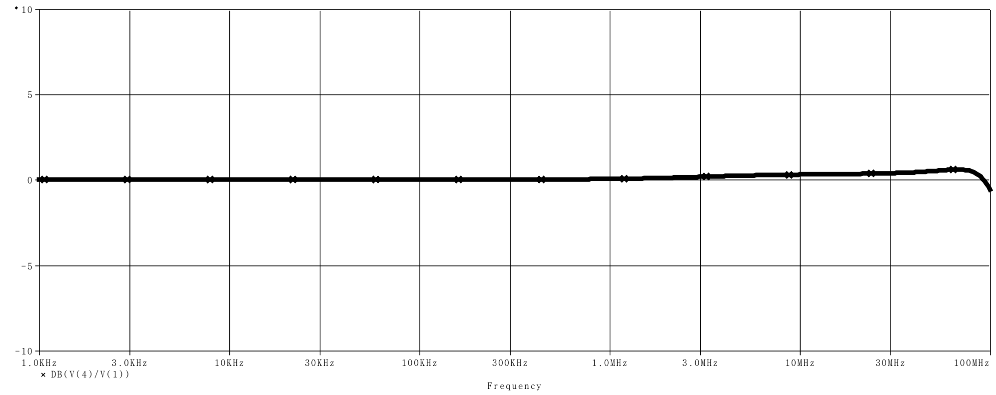
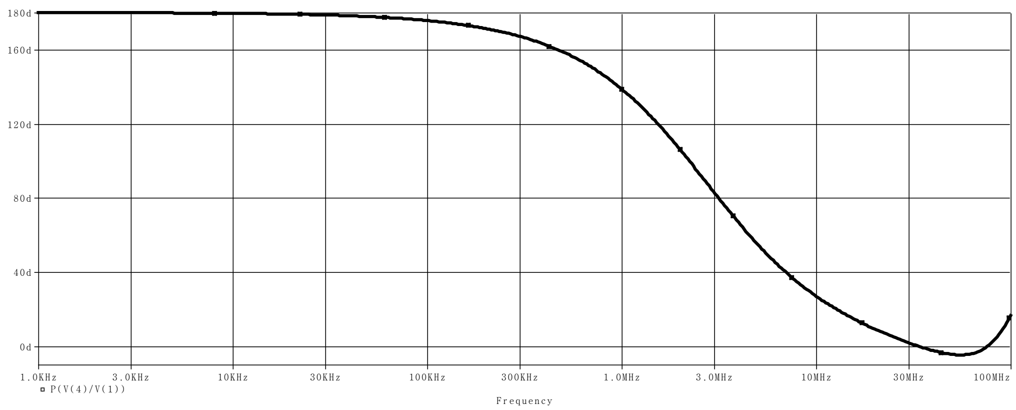


Figure 5. Circuit schematic of dual output CMOS CCII (Songkla and Jaikla, 2012)

The circuit is supplied with symmetrical voltages of ±1.25V. The biasing currents are taken as $I_{B(CCII+)} = I_{B(CCII-)} = 50\ \mu A$ and $I_{B(CCII\pm)} = 10\ \mu A$. The passive component values are choosen as R=1.2 kΩ and C=50 pF. This yields a central frequency of $f_0 = 2.57$ MHz which is very close to the calculated value of f_0 is 2.65 MHz. Fig.6 shows the frequency responses of the proposed all-pass filter employing MOS based COA. As it is seen from the figures, proposed filter responses behave very close to the ideal filter responses. The phase error is 2.6 % and the power dissipation of the circuit is 2.40 mW.



(a)



(b)

Figure.6. Simulation results of the proposed all-pass filter circuit employing MOS based COA. (a) Gain(dB), (b) Phase response

Fig. 7 shows the time domain response of the proposed all-pass filter employing MOS based COA for a sinusoidal input signal having 1 mV amplitude at 2.57 MHz.

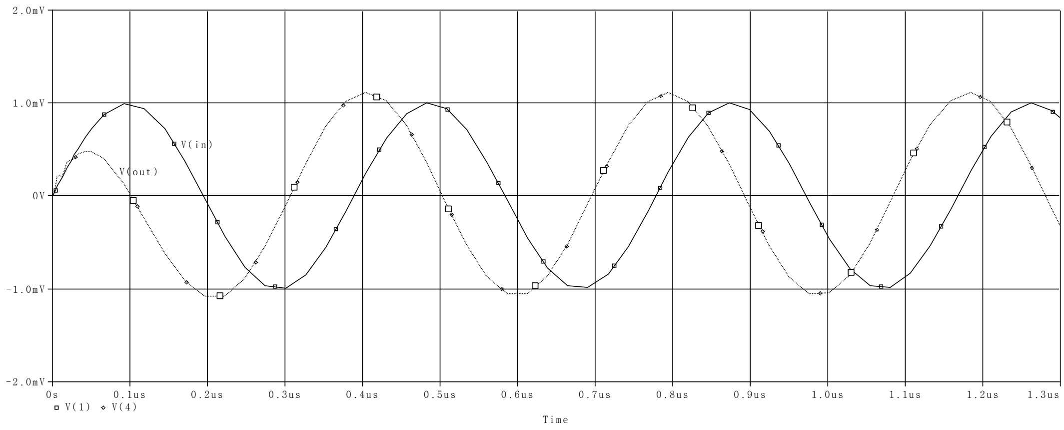


Fig.7. Time domain response of the proposed all-pass filter circuit

In order to investigate the distortion performance of the proposed filter, total harmonic distortion (THD) values at 2.57 MHz are measured through PSPICE programme. The results are given in Table II. Up to 100 mV peak to peak input signal value yields THD result less than 1 %. Hence, the proposed circuit has a good THD performance.

Table II. THD Results of the Proposed Filter at Central Frequency of 2.57 MHz

Input Voltage	**THD (%)**
100 μV	0.62
500 μV	0.86
1 mV	0.51
5 mV	0.54
10 mV	0.61
100 mV	0.86

Conclusions

In this paper, a new voltage-mode all-pass filter topology using MOS based COA is presented. The proposed topology employs three admittances and single active element. The circuit is simulated through PSPICE programme to check it's workability and the related simulation results are given. It is seen that the simulation results verify the theory and the proposed filter has good performance in terms of working with high accuracy and using an alternative way of COA implementation that is a contribution to workability of COA based circuits. Also, the THD performance of the circuit is shown to be good.

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