Synthesis of Voltage-Mode All-pass Filter Employing Single Current Operational Amplifier

Hasan Çiçekli, Ahmet Gökçen

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. Using the proposed topology, two non-inverting and two inverting all-pass filters can be realized by modifying three admittances. 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 using PSPICE simulation program. Simulation is done for both CMOS based COA using the MOSIS 0.35 micron CMOS process parameters and AD844 based COA using the Spice Macromodel parameters of AD844 by Analog Devices.

Keywords**—**All-pass filters, Circuit Topology, Current Conveyors, Current Operational Amplifiers

I. 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 [1]. Other types of active circuits such as sinusoidal oscillators and high-Q band-pass filters are also realized by using all-pass filters.

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 [2]-[12]. Among the reported COA based filter topologies, none of them is employing COA implemented by current conveyors and providing both non-inverting and inverting filter functions. Current conveyor based COA implementation technique used in this paper 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 non-inverting and inverting all-pass filter circuits that can be realized from one topology and contribute to workability of the proposed circuits by using an alternative way to implement the COA active building block.

Hasan Çiçekli is with the Department of Informatics, Mustafa Kemal University, 31001, Hatay, Turkey (corresponding author to provide phone: +90 530 553 4199; fax: +90 326 267 3840; e-mail: hcicekli@gmail.com).

Ahmet Gökçen is with the Department of Electrical and Electronics Engineering, İskenderun Technical University, 31200, Hatay, Turkey (e-mail: ahmetgkcn@gmail.com).

II. Circuit Description of COA

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

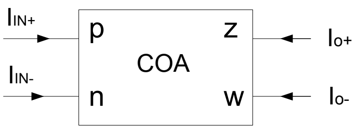


Fig. 1 COA's schematic symbol

The defining equation of COA can be given as

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

In (1), A is the open-loop current gain and ideally approaches 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 [3]. Also, the current differencing and internally grounded inputs of COA make it possible to implement the COA-based circuits with MOS-C realization [8].

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 [5]. The COA used in this paper is implemented by using three current conveyor blocks as shown in Fig. 2 [13]. Since CCII+ and CCII- can be obtained from dual output CCII, then it is possible to implement the COA by using only dual output current conveyor blocks in the architecture.

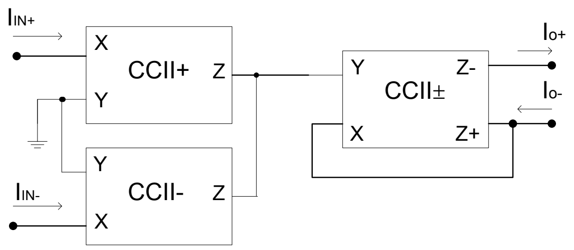


Fig. 2 COA implementation by using current conveyors

III. Proposed Circuit Topology

The proposed voltage-mode all-pass filter topology based on single COA is shown in Fig. 3. The circuit analysis of the proposed filter using (1) yields the following transfer function:

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

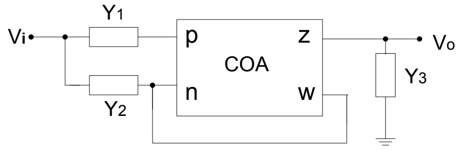
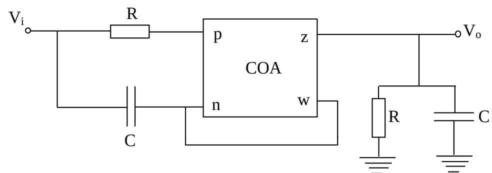
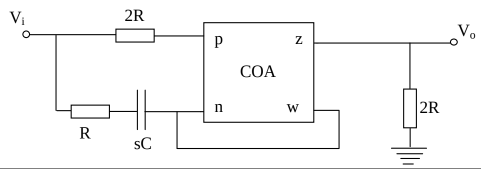
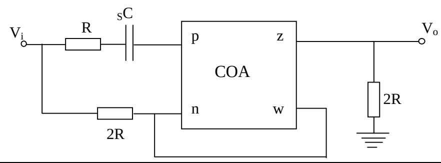
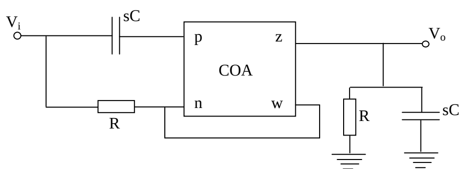


Fig. 3 Proposed circuit topology

As it is seen from Table I, four all-pass filter circuits can be realized by different combinations of the three admittances. Transfer functions and the resulted circuits are also given in the same table.

TABLE I ADMITTANCE COMBINATIONS, TRANSFER FUNCTIOINS AND CIRCUIT SCHEMATICS

All-pass Filter Type	Y_1	Y_2	Y_3	Transfer Function	Circuit Schematic
Non-inverting	$Y_1 = G$	$Y_2 = sC$	$Y_3 = sC + G$	$T(s) = \frac{sC - G}{sC + G}$	
Non-inverting	$Y_1 = G/2$	$Y_2 = \frac{1}{\frac{1}{sC} + \frac{1}{G}}$	$Y_3 = G/2$	$T(s) = \frac{sC - G}{sC + G}$	
Inverting	$Y_1 = \frac{1}{\frac{1}{sC} + \frac{1}{G}}$	$Y_2 = G/2$	$Y_3 = G/2$	$T(s) = -\frac{sC - G}{sC + G}$	
Inverting	$Y_1 = sC$	$Y_2 = G$	$Y_3 = sC + G$	$T(s) = -\frac{sC - G}{sC + G}$	

Considering the first non-inverting all-pass circuit; for simplicity, if the component values are choosen as $R_1 = R_3 = R$ and $C_2 = C_3 = C$, then transfer function of the circuit can be found as

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

The radian frequency of the circuit is calculated as

$$\omega_0 = \frac{1}{RC} \tag{4}$$

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

$$S_R^{\omega_0} = S_C^{\omega_0} = -1 \tag{5}$$

The proposed filter has a frequency dependent phase given by

$$\varphi = \pi - 2\tan^{-1}\omega_0 RC \tag{6}$$

IV. Simulation Results

The proposed circuit’s performance has been evaluated for two different implementation of COA by PSPICE simulation program using the MOSIS 0.35 μm CMOS process parameters and AD844 Macro-model parameters. The circuit schematic of dual output CMOS CCII used to implement the COA is given in Fig.4 [14] and W/L parameters of MOS transistors used in simulation are as reported in [14].

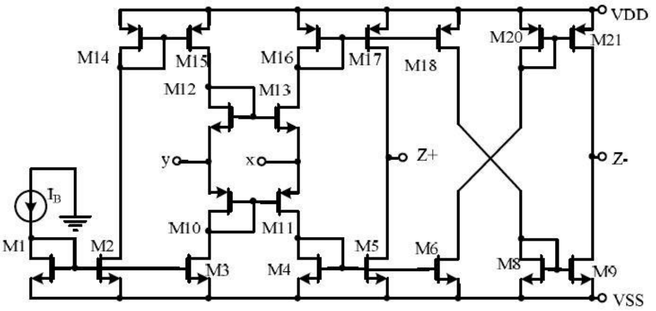
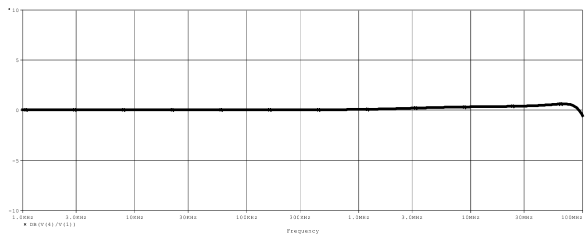
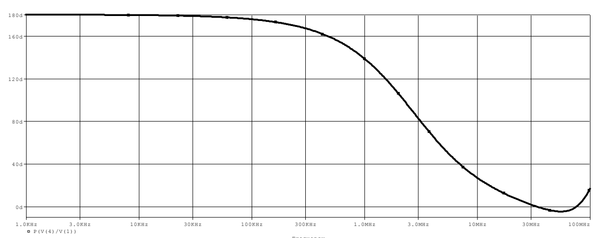


Fig. 4 Circuit schematic of dual output CMOS CCII

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.5 shows the frequency responses of the proposed all-pass filter employing CMOS 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.



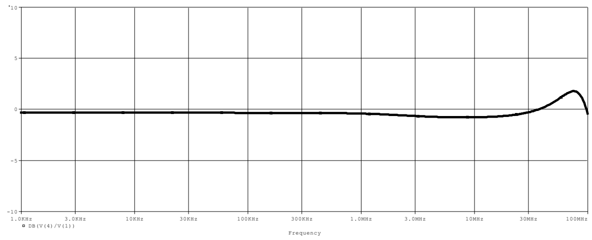
(a)



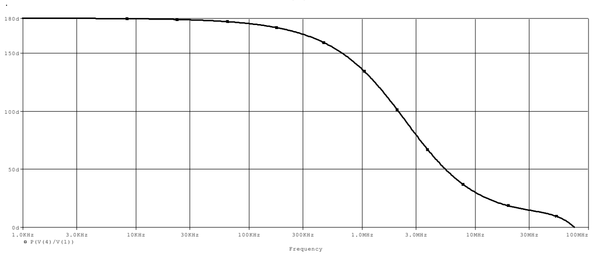
(b)

Fig.5 Simulation results of the proposed all-pass filter circuit employing CMOS based COA.
(a) Gain(dB), (b) Phase response

The second simulation is done by using AD844 SPICE Macro-model parameters to check the workability of the proposed circuit. The circuit is supplied with symmetrical ±10 V and the passive component values are choosen as R=1.2 kΩ and C=50 pF. This yields a central frequency of $f_0 = 2.49$ MHz which is very close to the calculated value. Fig.6 shows the frequency responses of the proposed all-pass filter employing AD844 based COA. The phase error is 3.4 % and the power dissipation of the circuit is 0.65 W.



(a)



(b)

Fig.6 Simulation results of the proposed all-pass filter circuit employing AD844 based COA.
(a) Gain(dB), (b) Phase response

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

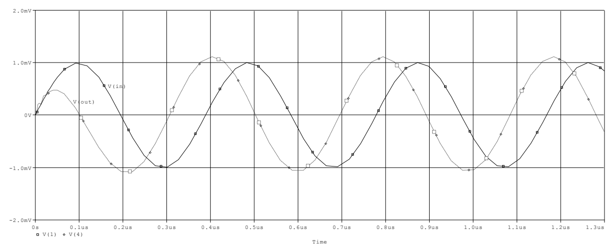


Fig.7 Time domain response of the proposed all-pass filter circuit

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

TABLE II. THD RESULTS OF THE PROPOSED FILTER AT CENTRAL FREQUENCY OF 2.57 MHZ

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

V. Conclusions

In this paper, a new voltage-mode all-pass filter topology based on single COA is presented. The circuit topology provides two non-inverting and two inverting filter functions by modifying only three admittances. To check the workability of the circuits, one of the non-inverting all-pass filter is simulated through PSPICE program 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 proposed circuit achieves a good THD performance.

It is expected that the proposed filters will be useful in various analog signal processing applications.

ACKNOWLEDGMENT

The authors would like to thank the reviewers for their constructive comments.

REFERENCES

[1] D. Berners, (2008, November 19), *Allpass Filters,* Available: http:// http://www.uaudio.com/blog/allpass-filters/

[2] S. Kılınç, U. Çam, "Akım Modlu Alçak ve Yüksek Geçiren Süzgeçlerin Akım İşlemsel Kuvvetlendiricisi İle Gerçeklenmesi", *Elektrik-Elektronik-Bilgisayar Müh. 10. Ulusal Kongresi*, İstanbul, 18-21 Eylül 2003, Bildiri Kitabı Cilt II, s. 314-317.

[3] M. Altun, H. Kuntman, "A High-Drive Fully Differential Current Mode Operational Amplifier Providing High Output Impedance and Filter Application", *Proceedings of ELECO 2007: The 5th International Conference on Electrical and Electronics Engineering,* Bursa, Turkey, 5- 9 th December 2007, pp. 44-47.

[4] S. Yamaçlı, H. Kuntman, "Novel current-mode active only electronically tunable multifunction filter using COAs and OTAs", P*roceedings of ELECO 2005: The 4th International Conference on Electrical and Electronics Engineering, Bursa,* Turkey, 7- 11 December 2005, pp.59-63.

[5] M. A. Youssef, A.M. Soliman, " A Novel CMOS Realization of the Differential Input Balanced Output Current Operational Amplifier And Its Applications", *Journal of Analog Integrated Circuits and Signal Processing,* vol. 44, Issue 1, pp. 37-53, July 2005.

[6] S. Kılınç, U. Cam, "Current-mode first-order allpass filter employing Single current operational amplifier", *Journal of Analog Integrated Circuits and Signal Processing,*vol.41, Issue 1, pp. 47-53, October 2004.

[7] M. Altun, H. Kuntman, "Yüksek başarımlı, tümüyle farksal akım Modlu işlemsel kuvvetlendirici (COA) tasarımı ve tüm geçiren süzgeç yapısında kullanımı", *ELECO 2006, Elektrik-Elektronik ve Bilgisayar Mühendisliği Sempozyumu,* Bursa, 6-10 Aralık 2006, Bildiri Kitabı (Elektronik), s. 46-49.

[8] S. Kılınç, M.Saygıner, U. Çam, H. Kuntman, "Simple and accurate macromodel for current operational amplifier (COA)", *Proceedings of ELECO 2005: The 4th International Conference on Electrical and Electronics Engineering*, Bursa, Turkey, 7-11 December 2005, pp.1-5.

[9] M. Altun, "Akım Modlu İşlemsel Kuvvetlendirici Tasarımı ve Uygulamaları", M.Sc. Thesis, Electronics and Communication Engineering Dept.,Istanbul Technical University, Istanbul,Turkey, 2007.

[10] K. Cheng, H. Wang, "Design of Current Mode Operational Amplifier with Differrential–Input and Differential-Output", *IEEE International Symposium on Circuits and Systems*, Hong Kong, 9-12 June 1997, pp. 153-156.

[11] I. Mucha, "Current Operational Amplifiers:Basic Architecture,Properties Properties Exploitation and Future", *Journal of Analog Integrated Circuits and Signal Processing*, vol.7, Issue 3, pp.243- 255, May 1995.

[12] A. Uygur, H. Kuntman, "Basit ve Kullanışlı Bir Akım İşlemsel Kuvvetlendiricisi Tasarımı", *ELECO 2004: Elektrik-Elektronik ve Bilgisayar Mühendisliği Sempozyumu*, Bursa, 8-12 Aralık 2004, Bildiri Kitabı (Elektronik-Bilgisayar), s. 6-10.

[13] T. Kaulberg, "A CMOS Current-Mode Operational Amplifier*", IEEE Journal of Solid-State Circuits*, vol. 28, No. 7, pp. 849- 852, July 1993.

[14] S. Na Songkla, W.Jaikla, "Realization of Electronically Tunable Current-mode First-order Allpass Filter and Its Application", *International Conference on Electrical, Computer, Electronics and Communication Engineering*, Italy, 28-29 February 2012, pp. 40-43.