NOVEL ALL-PASS FILTERS WITH REDUCED NUMBER OF PASSIVE ELEMENTS USING A SINGLE CURRENT CONVEYOR

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ABSTRACT

Four new configurations realising first-order all-pass filters are proposed. Using these configurations two types of first-order voltage-mode all-pass filters are derived. The circuits employ a second-generation current conveyor (CCII+), and only three passive components. For each topology only a simple component matching constraint is required. Since the current conveyor is a high performance active element, the circuits proposed are suitable for wide band applications. The derived filters can be easily cascaded if an additional voltage buffer is used providing low output impedance. Derived filter structures use reduced number of passive components compared to previously reported counterparts. To illustrate the design possibilities provided by the introduced circuits an oscillator circuit consisting of proposed all-pass filters is constructed and tested.

1. INTRODUCTION

First- and high-order allpass filters are widely used in analog signal processing in order to shift the phase while keeping the amplitude constant [1], to produce other type of frequency response and to implement frequency selective circuits with high quality factor [1]. Current conveyors and current feedback amplifiers are also receiving much attention for their potential advantages such as inherent wider bandwidth, simpler circuitry, lower power consumption and wider dynamic range [2]. Considering the advantages of these circuits, recently several voltage-mode [3-5] and current-mode [6-10] all-pass filters using different active components have been reported in the literature. Many of these filters employ great number of passive components and element matching conditions; one filter topology among them [6] requires no element-matching condition, but it uses two active components. Many single CCII+- based first-order all-pass networks are also tabulated [5], but many of them use great number of passive components. In this work we propose four novel single CCII+-based first-order all-pass filters, which use two resistors and one capacitor. The produced all-pass responses are available with a simple matching condition.

2. ACTUAL SECOND GENERATION CURRENT CONVEYOR

Considering the non-idealities arising from the physical implementation of CCII+ illustrated in Fig. 1, its terminal relationship can be given as:

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

where α, and β are respectively current and voltage gains which can be expressed as $\alpha=1-\varepsilon_i$, $\beta=1-\varepsilon_v$, with $|\varepsilon_i|<<1$, $|\varepsilon_v|<<1$. ε_i denotes the current tracking error and ε_v denotes voltage-tracking error respectively.

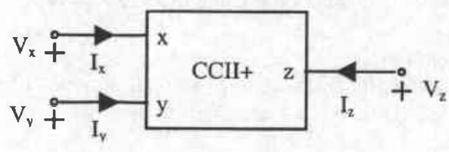

Figure 1 Terminal voltages and currents of the second-generation current conveyor

3. PROPOSED FILTER TOPOLOGIES

There are two basic types of first-order all-pass filters:

i) (first type all-pass filter):

$$T_1(s)=\frac{V_{out}}{V_{in}}=\frac{G-sC}{G+sC}=\frac{1-sCR}{1+sCR} \quad (2)$$

ii) (second type all-pass filter):

$$T_2(s)=\frac{V_{out}}{V_{in}}=-\frac{G-sC}{G+sC}=-\frac{1-sCR}{1+sCR} \quad (3)$$

These filters have the following phase responses for ideal case, respectively:

$$\varphi_1(\omega)=-2arctg(\omega CR) \quad (4a)$$

$$\varphi_2(\omega)=180^\circ-2arctg(\omega CR) \quad (4b)$$

Based on these two basic all-pass filter types, four new filter topology's are derived.

a) Topology I:

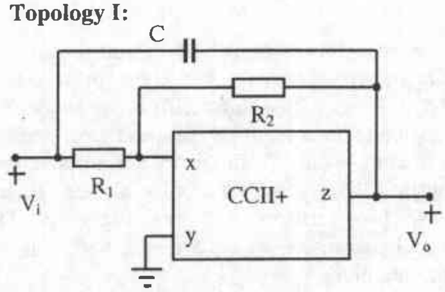

Figure 2 All-pass filter circuit (Topology I)

The voltage transfer function of the first all-pass filter (Topology I) illustrated in Fig.2 can be expressed as:

$$\frac{V_o}{V_i}=-\frac{\alpha}{1+\alpha}\frac{R_2}{R_1}\frac{1-s\dfrac{CR_1}{\alpha}}{1+sC\dfrac{R_2}{1+\alpha}} \quad (5)$$

with matching condition:

$$\frac{R_1}{\alpha}=\frac{R_2}{1+\alpha} \quad (6)$$

In this case the second type all-pass response is obtained. For the nominal value of the current gain (i.e. α=1) the matching condition simplifies to $R_1=R_2/2$.

b) Topology II:

The transfer function of the second all-pass filter (Topology II) shown in Fig.3 is given by

$$\frac{V_o}{V_i}=-\alpha\frac{R_2}{R_1}\frac{1-s\dfrac{CR_1}{\alpha}}{1+sCR_2} \quad (7)$$

with matching condition:

$$\frac{R_1}{\alpha}=R_2 \quad (8)$$

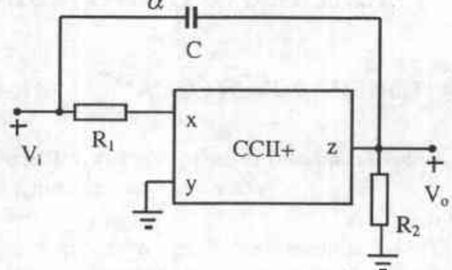

Figure 3 All-pass filter circuit (Topology II)

The second type all-pass response is obtained. For the nominal value of the current gain (i.e. α=1) the matching condition simplifies to $R_1=R_2$.

c) Topology III:

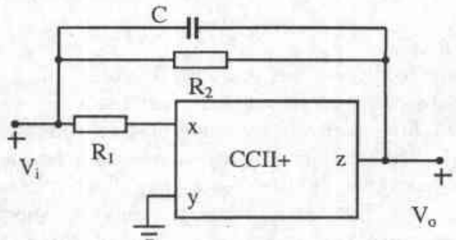

Figure 4 All-pass filter circuit (Topology III)

The voltage transfer function of the third all-pass filter (Topology III) shown in Fig.4 can be expressed as:

$$\frac{V_o}{V_i}=-\frac{\alpha R_2-R_1}{R_1}\frac{1-s\dfrac{CR_1R_2}{\alpha R_2-R_1}}{1+sCR_2} \quad (9)$$

with matching condition:

$$2R_1=\alpha R_2 \quad (10)$$

The second type all-pass response is obtained. For the nominal value of the current gain (i.e. α=1) the matching condition simplifies to $R_1=R_2/2$.

d) Topology IV:

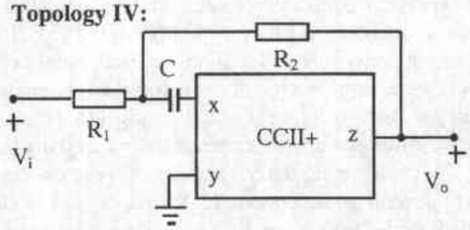

Figure 5 All-pass filter (Topology IV)

The transfer function of the fourth all-pass filter (Topology IV) shown in Fig.5 can be written as:

$$\frac{V_o}{V_i} = \frac{1 - s\alpha CR_2}{1 + (1+\alpha)sCR_1} \qquad (11)$$

where the matching condition is

$$(1+\alpha)R_1 = \alpha R_2 \qquad (12)$$

In this case the first type all-pass response is obtained. For the nominal value of the current gain (i.e. α=1) the matching condition simplifies to $2R_1=R_2$.

In the proposed configurations the CCII+s are operating as a current follower and therefore the voltage tracking errors do not appear in the transfer function equations. Furthermore all of the above mentioned filters are affected by load impedances, and to avoid this a voltage buffer can be placed at the output of the circuits. In this case the used active element is called as a current feedback amplifier (CFOA). The voltage gain of the voltage buffer appears in transfer function equations in terms of multiplier, and therefore the effect of the voltage tracking error of the voltage buffer can be easily compensated. The passive and active sensitivities of the gain and phase responses for the presented filters except the third circuit are less than unity in magnitude similar to those of the all-pass implementations given in [6]. For the third circuit these sensitivities can be kept less than 2.

4. SIMULATION RESULTS AND DISCUSSION

In order to verify the above given theoretical analysis allpass filters with unity gain and a pole frequency of $f_C \cong 159$kHz is designed using the proposed configuration of Fig. 2 with passive element values of R_1=20kΩ, R_2=40kΩ, C=50pF (second-type all-pass), and Fig. 5 with passive element values R_1=10kΩ, R_2=20kΩ, C=50pF. The active elements used in these designs are the commercially available CFOA AD844/AD of Analog Devices with supply voltages of V_{DD}=12V and V_{SS}=-12V. Theoretical results, simulation results and measurement data of the gain and phase responses are depicted in Fig. 6 and 7 for the second and first type all-pass filter respectively. Simulation results and measurement data given in Fig. 6 and 7 agree quite well with the theoretical analysis. Note that, for the second type all-pass filters a resistor is connected at the x-input of the CCII+ in series, which can compensate the r_X parasitic resistance of the CCII+. For the first type filter shown in Fig. 5 a capacitor is connected at the x-input instead of a resistor. In this case the parasitic resistance limits the bandwidth of the filter at relatively lower frequencies compared to the second-type filters, which is easily remarkable from Fig. 7. Finally note also that discrepancies in gain and phase characteristics in high frequencies arise from poles of current gain of the AD844/AD, which are not taken into account in this study.

To illustrate an application of the presented topologies an oscillator is built by cascading two allpass filters given in Fig.2 and Fig. 5 closing the loop to provide a loop gain of -1 at the pole frequency. The resulting circuit is shown in Fig. 8. The oscillation angular frequency is given by

$$\omega = \frac{1}{\sqrt{\tau_1 \tau_2}} \qquad (13)$$

where $\tau_1 = C_1 R_2/2$ and $\tau_2 = C_2 R_4$. The calculated value of the oscillation frequency obtained from Eq. (13) is f_{osc}=159kHz which is in close agreement with the measurement results where f_{osc}=147kHz.

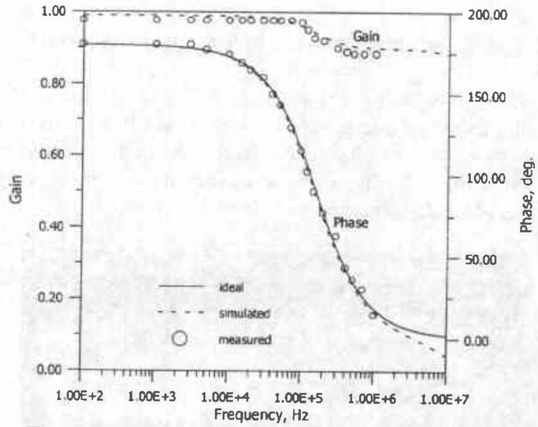

Figure 6 Theoretical, simulation and measurement results of the AP filter in Fig. 2.

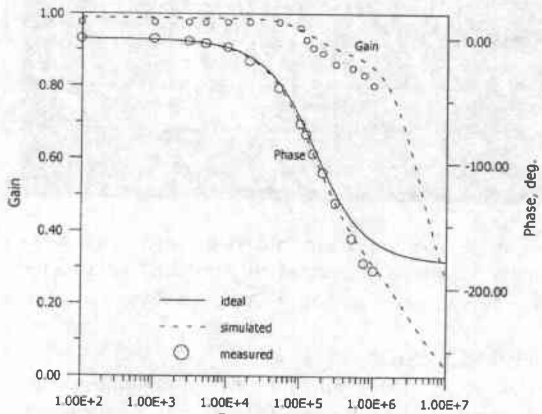

Figure 7 Theoretical, simulation and measurement results of the first type AP filter in Fig. 5

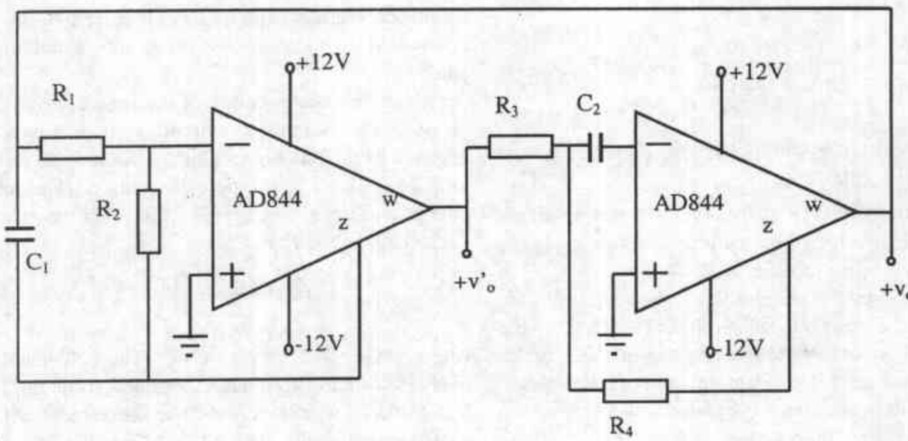

Figure 8. An application example of quadrature sinusoidal oscillator constructed by cascading two allpass filters

Two outputs with a certain phase shift can be obtained and quadrature outputs are possible if the two all-pass section exhibit equal time constants. Quadrature output waveforms of the oscillator shown in Fig.8 is experimentally obtained and illustrated in Fig.9.

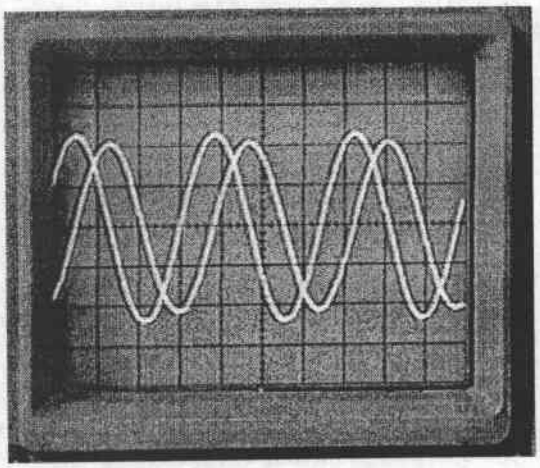

Figure 9. Experimentally obtained output waveforms of the oscillator illustrated in Fig.8 and constructed with two all-pass sections (5V/div, 2μs/div).

5. CONCLUSION

Four voltage-mode all-pass filter configurations are proposed using CCII+ or CFOA as active component, which are suitable for high performance analog signal processing. The proposed circuits are derived from two different types of fist-order all-pass filters, which enable flexible circuit synthesis. Note that the proposed filters use a reduced number of passive and single active elements, namely two resistors, one capacitor, as well as one CCII+ or CFOA. Furthermore they do require a simple matching condition, which is quite important in mass production. Moreover they are cascadable because of low impedance of output-terminal of the voltage buffer if it is used.

REFERENCES:

[1] D.T. Comer, D.J. Comer, and J.R. Gonzales, A high-frequency integrable bandpass filter configuration, IEEE Trans. Circuits and Systems-II: Analog and Digital Signal Processing, 44, no.10, 856-861, 1997.

[2] B. Wilson, Recent developments in current conveyors and current-mode circuits, IEE Proc. Pt G, 137, 63-77, 1990,.

[3] R.I. Salawu, Realization of an all-pass transfer function using the second generation current conveyor, Proc. of IEEE, 68, no. 1, 183-184, 1980.

[4] A.M. Soliman, Generation of current conveyor-based all-pass filters from op-amp based circuits, IEEE Trans. On Circuits and Systems-II: Analog and Digital Signal Processing, 44, no. 4, 324-330, 1997.

[5] O. Çiçekoğlu, and H. Kuntman, All-pass filters using a single current conveyor, to be published in Int. J. Electronics, 1999.

[6] A. Fabre, and J.P. Longuemard, High performance current processing allpass filters ,Int. Journal of Electronics, 66, no.4, 619-632, 1989.

[7] A. Fabre, F. Martin, and M. Hanafi, Current mode allpass/notch and bandpass filters with reduced

sensitivities, Electronics Letters, 26, 1495-1496, 1990.

[8] C.M. Chang, Current-mode allpass notch and bandpass filter using single CCII, Electronics Letters, 27, Is 20, 1812-1813, 1991.

[9] M. Higashimura, and Y. Fukui, Realisation of current-mode allpass networks using a current conveyor, IEEE Trans. Circuits and Systems, 37, 660-661, 1990.

[10] M. Higashimura, Current-mode allpass filter using FTFN with grounded capacitor, Electronics Letters, 27, 1182-1183, 1991.