Transadmittance Mode First Order LP/HP/AP Filter and its Application as an Oscillator

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Abstract: In this paper new transadmittance mode first order low pass, high pass and all pass filter topologies using operational floating current conveyor (OFCC) is proposed and its application as an oscillator is also put forward. This proposal offers all filter functions at high impedance. Only two OFCCs, two resistors and one grounded capacitor are employed for realization. Workability is verified through SPICE simulations and results conform to the theoretical predictions very well. The proposed circuit is prototyped and tested experimentally for its application as an oscillator.

Keywords: All pass, High pass, Low pass, OFCC, Transadmittance Mode.

1. INTRODUCTION

First order filters specially low pass, high pass and all pass filters are very basic blocks for realization of higher order filter topologies. The first order low pass and high pass filters finds their applications in communication systems while all pass filter is most commonly used analog filter offering capability to modify phase of the input signal with unity magnitude for all frequencies. Over the desired frequency range, phase varies from 0˚ to 180˚ for a one pole filter, due to this frequency dependent time displacement property first order all pass filters may be used in radio systems, communication subsystems such as reconstruction filters and signal generation using multiphase sinusoidal oscillators and quadrature oscillators [1]. As a result a number of such first order filters have been reported earlier [1-16], out of which some are realized in voltage mode (VM) [1-6, 13-15] and in current mode (CM) [5, 7-9, 15, 16] (as well as references cited therein). First order filters with low pass, high pass and all pass functions are reported in VM [4,5] and CM [5] only.

Limited research is available on first order transadmittance mode (TA) filters [10-15] wherein all pass functions are looked into which are useful in baseband receivers. Typically, VM filters are cascaded with CM filters because they does not require any intermittent impedance matching circuitry. Available TA all pass filters are summarized in Table. I and reported implementations use third generation current conveyor (CCIII) [10, 11], modified current...
backward transconductance amplifier (MCBTA) [12], differential input buffered and transconductance amplifier (DBTA) [13, 14] and z-copy voltage differencing current conveyor (ZC-VDCC) [15]. From above literature survey the following findings are concluded- only all pass responses can be achieved in available first order TA mode filter sections [10-15]; more than one response simultaneously i.e. low pass (LP), high pass (HP) and all pass (AP) from single topology is achieved only in first order VM filter [4, 5] and in CM filter [5], but not available in any first order TA mode filters [10-15]; improper input impedances causing cascadability problem in [10-12], low output impedance [13] puts a limit on its merits as a V-I converter, and high passive and floating component count in [10].

Keeping in view the above facts, a new proposal for TA mode first order filter based on current mode active block operational floating current conveyor (OFCC) offering low pass, high pass and all pass responses, is put forward. The aim of this paper is to contribute towards TA mode first order filters by providing solution for proper input and output impedances to improve cascadability, low passive component count, more than one response simultaneously without any changes in configuration and to introduce an application as a sinusoidal oscillator. The OFCC combines the feature of current conveyor and current feedback opamp (CFOA) and also provides proper inputs with additional current outputs at proper impedances make it suitable for TA mode applications. Significant research efforts has introduced many applications using OFCC such as current mode filter [16,17], voltage mode filter [18-20], TA mode filter [21], instrumentation amplifier [22], wheat stone bridge [23], variable gain amplifier [24], readout circuit [25] and current conveyor realizations [26-28].

To the best knowledge of authors, none of the literature is reported for TA mode first order LP/HP/AP filter to overcome all or some of the above mentioned problems. To bridge this gap, a TA mode first order LP/HP/AP filter is proposed in this paper. An application namely sinusoidal oscillator is also included. It uses two OFCCs and three passive components. SPICE simulations are carried out using 0.5 µm CMOS process model by MOSIS (AGILENT) and prototyped using commercially available IC AD844. Followings are the key points of proposal- proper input and output impedances that makes it suitable for V-I converter application; availability of two responses at a time, either LP and HP or AP and HP on high output impedance ports; suitable for higher order filter applications.

This paper is divided into four sections where Section 1 showing literature survey and component along with proposed circuit is described in Section 2. Performance analysis
including implementation and verification responses are reported in Section 3 and further concluded in Section 4.

2. CIRCUIT DESCRIPTION

2.1 OFCC Port Relationship

The symbolic representation of OFCC [26-28] is shown in Fig. 1. The port relationship is given in (1) and describes that \( I_Y = 0, V_X = V_Y, V_W = I_X Z_t, I_{Z+} = I_W, I_{Z-} = -I_W \). On input ports voltage tracking property exists so voltage at port X follows the voltage at port Y. Similarly current tracking exists at output ports and port W current copied to ports \( Z+ \) in phase and \( Z- \) out of phase.

\[
\begin{bmatrix}
I_Y \\
V_X \\
V_W \\
I_{Z+} \\
I_{Z-}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 \\
0 & Z_t & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & -1 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
V_Y \\
I_X \\
I_W \\
V_{Z+} \\
V_{Z-}
\end{bmatrix}
\]

(1)

Where \( Z_t \) is transimpedance gain of OFCC and in practice has a frequency dependent finite value. Port X is low impedance current input and port Y is high impedance voltage input. Port W is low impedance voltage output while \( Z+ \) and \( Z- \) are high impedance current outputs.

2.2 Proposed Filter

In this subsection proposed OFCC based TA mode first order LP/HP/AP filter is described. It employs two OFCCs, two resistors (one floating and one grounded) and one grounded capacitor is shown in Fig. 2.
By applying nodal analysis following filter transfer functions are derived:

\[
I_o = \frac{sC_1(R_2 - R_1) - 1}{V_{in}}
\]

\[
= \frac{(sC_1R_1 + 1)R_2}{(sC_1R_1 + 1)R_2}
\]

(2)

Selecting \( R_2 = R_1 \) in (2) will provide low pass response,

\[
I_o = \frac{I_{LPF}}{V_{in}} = \frac{1}{R_2} \left( \frac{1}{(sC_1R_1 + 1)} \right)
\]

(3)

Similarly \( R_2 = 2R_1 \) will enable all pass function and (2) becomes,

\[
I_o = \frac{I_{APF}}{V_{in}} = \frac{1}{R_2} \left( \frac{1}{sC_1R_1 - 1} \right)
\]

(4)

and high pass function is independent of above conditions so will be available along with low pass or all pass, but one response at a time.

\[
I_{HPF} = -\frac{sC_1}{(sC_1R_1 + 1)}
\]

(5)

The pole frequency is given as \( \omega_o = \frac{1}{C_1R_1} \)

(6)

2.3 Filter application

A Sinusoidal Oscillator is implemented using all pass section as shown in Fig. 3. The routine analysis gives the following characteristic equation:

\[
s^2C_1C_2R_1R_2 + sC_2R_2 - sC_1(R_2 - R_1) + 1 = 0
\]

(7)

The condition of oscillation and frequency of oscillation is derived respectively as:

\[
C_1 = 2C_2, R_2 = 2R_1
\]

(8)

\[
f_o = \frac{1}{8\pi C_2^2 R_2^2}
\]

(9)

Fig. 3 TA mode first order all pass section as an Oscillator
3. PERFORMANCE ANALYSIS

The proposed filter topology is verified through PSPICE simulation program using MOSIS (AGILENT) 0.5 µm CMOS process parameters. The circuit schematic of OFCC is given in Fig. 4 [24] and W/L parameters for MOS transistors used in simulation are reported in Table II [24]. The supply voltages (V_{DD} and V_{SS}) are taken as ±1.5V and bias voltages (V_{B1} and V_{B2}) of ±0.8V are applied.

![Fig. 4 CMOS schematic of OFCC][24]

Table II Transistors’ aspect ratios [24]

| Transistor          | W(μm) / L(μm) |
|---------------------|---------------|
| M1, M2              | 50 / 1        |
| M3, M4, M11, M12, M14, M16, M18, M20 | 50 / 2.5      |
| M5, M7, M10, M15, M17, M19, M21 | 20 / 2.5      |
| M6, M8              | 40 / 2.5      |
| M9, M13             | 100 / 2.5     |

The pole frequency of 159 KHz is selected for proposed first order filters and corresponding component values found are C_1 = 100pF, R_1 = R_2 = 10 k Ω for low pass function while R_1 = 10 k Ω , R_2 = 2R_1 = 20 k Ω to obtain all pass response. High pass response is independent of R_2 thus will be available in both conditions. Thus high pass along with either low pass or all pass will be available simultaneously.

The frequency responses of proposed first order low pass and high pass filter are shown in Fig. 5(a) and selecting another component values will facilitate high pass and all pass responses as shown in Fig. 5(b). Fig. 6 showing phase response of all pass filter and is complied with theoretical predictions. Time domain behavior is also verified to confirm the functionality of all the proposed filter topologies by applying sinusoidal signal of amplitude 1 mV, f_0 = 159 kHz and corresponding transient responses for low pass, high pass and all pass filter are plotted in Fig. 7 (a), Fig. 7 (b) and Fig. 8 (a). For all pass filter topology Lissagous pattern through simulation is also plotted in Fig. 8 (b).
The sinusoidal oscillator as an application of proposed all pass filter section is prototyped using commercially available IC AD844 [29] as shown in Fig. 9 and simulated using CMOS schematic Fig. 4 [24]. Oscillator application is designed for frequency of 859 KHz and corresponding component values chosen are $R_1 = 10 \text{ k}$, $R_2 = 20 \text{ k}$, $C_1 = 0.68 \text{ pF}$ and $C_2 = 1.36 \text{ pF}$. The frequency obtained from simulation is 778.21 KHz while experimental values are 915.23 KHz. Simulated and experimental results are shown in Fig. 10.
4. CONCLUSION

In this paper new TA mode first order LP/HP/AP filter using OFCC and its application as an oscillator is proposed. This proposal offers total three filter functions LP/HP/AP in transadmittance mode at high impedance. Only two OFCCs, two resistors and one grounded capacitor are employed for realization. Workability is verified through PSPICE program and found that simulated results conform the theoretical predictions very well. The proposed circuit is prototyped and tested experimentally for its application as an oscillator.
REFERENCES

[1] S. Maheshwari, “Current conveyor all pass sections: Brief review and novel solution,” Scientific world Journal, vol. 2013, pp. 1-6, 2013. http://dx.doi.org/10.1155/2013/429391

[2] H. Cicekli and A. Gokcen, “Synthesis of voltage mode all pass filter employing single current operational amplifier,” Int. J. of Comm., vol. 10, pp. 76-79, 2016.

[3] N. Pandey, R. Pandey and S. K. Paul, “A first order all pass filter and its application in a quadrature oscillator,” Journal of Electron Devices, vol. 12, pp. 772-777, 2012.

[4] J. W. Horng, “High input impedance first order allpass, highpass and lowpass filters with grounded capacitor using single DVCC,” Indian J. of engg. and materials sciences, vol. 17, pp. 175-178, 2009.

[5] S. Maheshwari and I. A. Khan, “Novel first order allpass sections using a single CCIII,” Int. J. Electronics, vol. 88, no. 7, pp. 773-778, 2001.

[6] A. B. Saied, S. B. Salem and D. S. Masmoudi, “A quadrature oscillator based on a new Optimized DDCC all pass filter,” J. of circuits and systems, vol. 4, pp. 498-503, 2013.

[7] W. Tangsrrirat, W. Tanjaroen and T. Pukkalanum, “Current mode multiphase sinusoidal oscillator using CDTA based allpass sections,” Int. J. Electron. Commun.(AEU), vol. 63, pp. 616-622, 2009.

[8] J. Mohan, “Single active element based current mode allpass filter,” Int. J. of Comp. App., vol. 82, no. 1, pp. 23-27, 2013.

[9] J. Mohan and S. Maheshwari, “Cascadable current mode first order allpass filter based on minimal components,” Scientific world Journal, vol. 2013, pp. 1-5, 2013.

[10] S. Minaei, “A new high performance CMOS third generation current conveyor (CCIII) and its application,” J. of Electrical engineering, Springer Verlag, vol. 85, pp. 147-153, 2003.

[11] U. Cam, “A new transadmittance type first order allpass filter employing single third generation current conveyor,” Analog Int. circuits and signal processing, vol. 43, pp. 97-99, 2005.

[12] N. Herencsar, A. Lahiri, J. Koton, M. Sagbas, U. E. Ayten and K. Vrba, “New MOS-C realization of transadmittance type allpass filter using modified CBTA,” in Int. conf. on applied electronics, IEE, pp. 1-4, September, 2011.

[13] N. Herencsar, J. Koton and K. Vrba, “Differential input buffered and transconductance amplifier based new transadmittance and voltage mode first order allpass filters,” in Int. conf. on electrical and electronics engg., ELECO-2009, pp. 256-259, December, 2009.

[14] N. Herencsar, J. Koton, K. Vrba and B. Metin, “Fully cascadable dual mode allpass filter based on single DBTA,” 35th Int. conf. on telecomm. And signal processing, pp. 374-377, 2012.

[15] R. Sotner, N. Herencsar, J. Jerabek, K. Vrba, T. Dostal, W. Jaikla and B. Metin, “Novel first order allpass filter applications of z-copy voltage differentencing current conveyor,” Indian J. of pure and applied physics, vol. 53, pp. 537-545, 2015.

[16] T. Parveen, “CMOS compatible current mode high output impedance allpass filter single OFC and grounded passive components,” Int. Conf. on Multimedia, Signal Processing and Comm. Tech., IEEE, pp. 107-109, 2011.

[17] N. Pandey, D. Nand, Z. Khan, “Single Input Four Output Current mode filter using Operational Floating Current Conveyor,” J. of Active and Passive Components, vol. 2013, pp. 1-8, 2013.

[18] Y. H. Ghallab, W. Badawy, K. V. I. S. Kaler, M. A. El-Ela, M. H. El-Said, “A New Second-order Active Universal Filter with Single Input and Three Outputs Using
Operational Floating Current Conveyor. In: Proceedings of IEEE International Conference on Microelectronics, pp. 42-45, 2002.

[19] Y. H. Ghallab, M. A. El-Ela and M. Elsaid, “A novel universal voltage mode filter with three inputs and single output using only operational floating current conveyor. In: Proceedings of International conference on Microelectronics, pp. 95-98, 2000.

[20] Y. H. Ghallab, and W. Badawy, “The Operational Floating Current Conveyor and its applications” J. of Circuits, Systems, and Computers. Vol. 15, no. 3, pp. 351–372, 2006.

[21] N. Pandey, D. Nand and Z. Khan, “Operational floating current conveyor based single input multiple output transadmittance mode filter,” Arab J. Sci. Eng., Springer, vol. 39, pp. 7991-8000, 2014.

[22] Y. H. Ghallab, W. Badawy, K. V. I. S. Kaler and B. J. Maundy, “A Novel Current Mode Instrumentation Amplifier Based on Operational Floating Current Conveyor. IEEE Trans. on Inst. and Meas., vol. 54, no. 5, pp. 1941-1949, 2005.

[23] Y. H. Ghallab and W. Badawy, “A New Design of a Current-mode Wheatstone Bridge Using Operational Floating Current Conveyor. In: Proceedings of International Conference on MEMS, NANO and Smart Systems, pp. 41-44, 2006.

[24] H. M. Hassan and A. M. Soliman, “Novel CMOS realizations of Operational Floating Current Conveyor and applications,” J. of Circuits, Systems, and Computers, vol. 14, no. 6, pp. 1113–1143, 2005.

[25] Y. H. Ghallab and W. Badawy, “A New differential PH Sensor Current Mode Readout circuit using only two Operational Floating Current Conveor” In: Proceedings of IEEE International workshop on Biomedical Circuits & Systems, pp. 13-16, 2004.

[26] C. Toumazou, A. Payne, F. J. Lidgey, “Operational Floating Conveyor. Electronic Letters,” vol. 27, no. 8, pp. 651-652, 1991.

[27] A. A. Khan, M. A. Al-Turaigi, M. A. El-Ela, “Operational floating current conveyor: Characteristics, Modeling and applications. In: Proceedings of IEEE Instrumentation and Measurement Technology Conference, Hamamtsu, Japan, pp. 788–790, 1994.

[28] Y. H. Ghallab, M.A. El-Ela, M.H. Elsaid, Operational floating current conveyor: Characteristics, Modeling and Experimental results. In: Proceedings of International Conference on Microelectronics, Kuwait, pp. 59–62, 2000.

[29] “Analog devices, 60 MHz, 2000V/µs, Monolithic Op Amp” Analog Devices Inc., AD844 datasheet, pp. 1-12.

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