Anirut IAMAREJIN[1], Suwat MANEEWAN[2], Peerawut SUWANJAN[1], Winai JAIKLA[1]

King Mongkut's Institute of Technology Ladkrabang (1), Buriram Rajabhat University (2)

Current-mode variable current gain first-order allpass filter employing CFTAs

***Abstract**. In this study, a current-mode first order allpass filter using current follower transconductance amplifiers (CFTAs) is proposed. The features of the circuit are that: the pole frequency, phase response and current gain can be electronically controlled via the input bias current: the circuit description is very simple, consisting of 2 CFTAs, 1 resistor and 1 grounded capacitor, without any component matching requirements. Consequently, the proposed circuit is very appropriate to further develop into an integrated circuit. Low input and high output impedances of the proposed configuration enable the circuit to be cascaded in current-mode without additional current buffers. The PSpice simulation results are depicted. The given results agree well with the theoretical anticipation.*

***Streszczenie.** W artykule przedstawiono przesuwnik fazowy prądowy pierwszego rzędu, wykorzystujący wzmacniacz CFTA. Do właściwości układu należy możliwość kontroli częstotliwości biegunowej, odpowiedzi fazowej i wzmocnienia prądowego przy pomocy wejściowego prądu stałego. Obwód składa się z dwóch układów CFTA, rezystora i uziemionego kondensatora. Przedstawione wyniki symulacyjne z programu PSpice potwierdzają skuteczność działania układu. (**Zastosowanie układu CFTA w przesuwniku fazowym prądowym pierwszego rzędu o zmiennym wzmocnieniu prądu**).*

KEY WORDS: first order all pass filter; current-mode; CFTA
Słowa kluczowe: przesuwnik fazowy pierwszego rzędu, prądowy, CFTA

Introduction

In recent years, a number of papers have been published dealing with the realization of current-mode circuits [1-3] due to their certain advantages compared to voltage-mode circuits. They offer to the designer several excellent features such as inherently wide bandwidth, greater linearity, wider dynamic range, simple circuitry and low power consumption [4]. An analog filter is the main standard research topics in current-mode circuit designs. One of most popular analog current-mode filters is a first-order allpass filter (APF) or phase shifter circuit. This filter is a very useful function blocks of many analog signal processing applications. It is frequently used in many active circuits such as, phase shifters, oscillators and high-Q band-pass filters [5-9]. Especially, the first order all-pass filter with gain controllability is very useful for design in many analog circuits to avoid the use of external amplifiers, for examples quadarture oscillator [10] and multiphase sinusoidal oscillator [11] with non-interactive control for oscillation condition and oscillation frequency.

Several realizations of current-mode first-order allpass filter using different active building blocks have appeared in the literature. These include realizations using current differencing buffered amplifier (CDBA)5, current conveyors [12-15], current controlled current conveyors (CCCIIs) [16], OTAs [17-19], differential voltage current conveyor (DVCC) [20], current operational amplifier (COA) [21] and current differencing transconductance amplifier (CDTA) [10-11], [22-26]. However, most of the previous current-mode APFs are uncontrollability of current gain and require element-matching conditions.

The aim of this paper is to propose a current-mode gain controllable first-order allpass filter, emphasizing on the use of the current follower transconductance amplifiers. The features of the proposed circuit are that: the current gain and phase shift can be electronically controlled: the circuit employs 2 CFTAs, 1 resistor and 1 grounded capacitor, which is suitable for fabricating in monolithic chip. The proposed APF also exhibits high-output and low-input impedances, which is easy cascading in the current-mode operation. The performances of the proposed circuit are illustrated by PSpice simulations, they show good agreement with the calculation.

Theory and Principle

The Current Follower Transconduce Amplifier

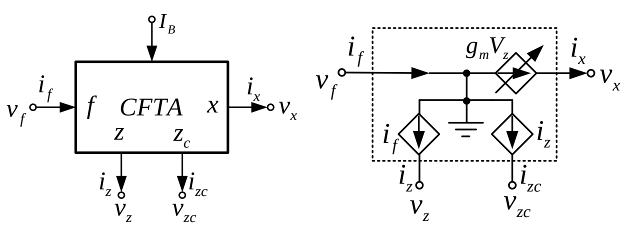
Since the proposed circuit is based on CFTA [27], a brief review of CFTA is given in this section. The schematic symbol and the ideal behavioural model of the CFTA are shown in Fig. 1(a) and (b). It has one low-impedance current input *f* port. The current I_f flows from port ***z***. In some applications, to utilize the current through z terminal, an auxiliary z_c (z-copy) terminal is used. The internal current mirror provides a copy of the current flowing out of the z terminal to the z_c terminal. The voltage v_z on z terminal is transferred into current using transconductance g_m, which flows into output terminal x. The g_m is tuned by I_B. In general, CFTA can contain an arbitrary number of x terminals, providing currents I_x of both directions. The characteristics of the ideal CFTA are represented by the following hybrid matrix:

$$\begin{bmatrix} V_f \\ I_{z,zc} \\ I_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} I_f \\ V_x \\ V_z \end{bmatrix}. \qquad (1)$$

For CMOS CFTA, the g_m is written as

$$g_m = \sqrt{kI_B}\ , \qquad (2)$$

where $k = \mu_O C_{OX}\left(W/L\right)$. Here k and IB are the physical transconductance parameter of the MOS transistor and input bias current, respectively.



(a) (b)

Fig.1. CFTA (a) Symbol (b) Equivalent circuit

Table 1. Comparison between various APFs

Ref	Design technique	No. of Active Element	Grounded C only	No. of R+C	Electronic Tune	Gain Controllability	Matching Condition	High Output Impedance
[5]	CDBA	1	No	1+1	No	No	No	Yes
[12]	CCII	1	No	3+1	No	No	Yes	Yes
[13]	CCIII	1	No	1+1	No	No	No	No
[14]	CCII	2	Yes	1+2	No	No	Yes	Yes
[15]	CCIII	1	No	3+1	No	No	Yes	Yes
[16]	CCCII	2	Yes	0+1	Yes	No	No	Yes
[17]	OTA	2	Yes	1+1	Yes	No	Yes	Yes
[18]	OTA	2	Yes	2+1	Yes	No	Yes	Yes
[19]	OTA	1	No	0+1	Yes	No	No	No
[20]	DVCC	1	No (cir. 1, 3, 4, 6) Yes (cir. 2, 5)	2+1 (cir. 1, 3, 5) 1+2 (cir. 2, 4, 6)	No	No	Yes	Yes
[21]	COA	1	No	1+1	No	No	No	Yes
[10]	CDTA	1	No	2+1	Yes	Yes	No	Yes
[11]	CCCDTA	1	Yes	1+1	Yes	Yes	No	Yes
[22]	CDTA	1	No	1+1	Yes	No	No	Yes
[23]	CDTA	1	No	2+1	Yes	Yes	No	Yes
[24]	CDTA	1	No	0+1	Yes	No	No	Yes
[25]	CDTA	1	Yes	0+1	Yes	No	No	Yes
[26]	CDTA	1	Yes	0+1	Yes	No	No	Yes
Proposed APF	CFTA	2	Yes	1+1	Yes	Yes	No	Yes

* No use of external capacitor

Proposed Current-mode First-order Allpass Filter

The proposed current-mode APF is illustrated in Fig. 2. It consists of 2 CFTAs, 1 resistor and 1 grounded capacitor. The sign ± in the first CFTA shows plus or minus polarity of the current output. It also seen that low input and high output impedances are achieved. It is should be note that the proposed APF can avoid the use of external resistor by using current-controlled CFTA proposed by Norbert Herencsar et. al. [28]. Considering the circuit in Fig. 2 and using CFTA properties in section 2.1, the current transfer function can be rewritten as

$$\frac{I_{out}(s)}{I_{in}(s)} = \pm g_{m1} R \left(\frac{sC - g_{m2}}{sC + g_{m2}} \right). \quad (3)$$

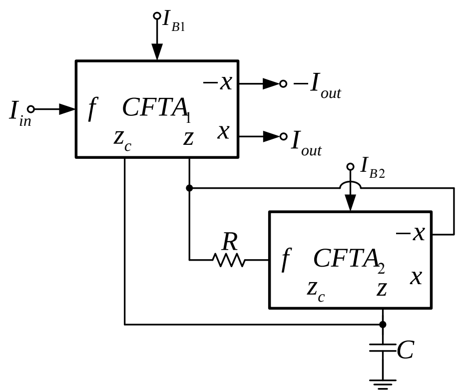


Fig.2. Proposed variable current gain first-order allpass filter

From Eq. (3), the natural frequency, current gain and phase responses of the proposed circuit are

$$\omega_0 = \frac{g_{m2}}{C}, \quad (4)$$

$$G(\omega) = \left| \frac{I_{out}}{I_{in}} \right| = g_{m1} R, \quad (5)$$

$$\phi(\omega)_{+} = 180 - 2\tan^{-1}\left(\frac{\omega C}{g_{m2}} \right), \quad (6)$$

and

$$\phi(\omega)_{-} = -2\tan^{-1}\left(\frac{\omega C}{g_{m2}} \right), \quad (7)$$

If g_{m1} and g_{m2} can be controlled by input bias current as shown in Eq. (2), the current gain can be electronically adjusted by I_{B1} without affecting the natural frequency and phase responses. It is also seen that the natural frequency and phase responses can be electronically and independently tuned from the current gain by I_{B2}.

Comparison with Previous Works

Besides the inherent advantages of the proposed APF over other previous works, the proposed circuit in Fig. 2 is compared with several previous current-mode APFs. These APFs are based on current differencing buffered amplifier (CDBA) [5], current conveyors [12-15], current controlled current conveyors (CCCIIs) [16], OTAs [17-19], differential voltage current conveyor (DVCC) [20], current operational amplifier (COA) [21] and current differencing trans-conductance amplifier (CDTA) [10-11], [22-26]. The results are shown in Table 1.

Simulation Results

To prove the performances of the proposed filter, the PSPICE simulation program was used for the examination. Internal construction of CFTA used in simulation is shown in Fig. 3. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0.25µm TSMC CMOS technology29. The aspect ratios of PMOS and NMOS transistor are listed in Table 2. The circuit was biased with ±1.25V supply voltages, V_{BB}=-0.55V, C=0.1nF, I_{B1}=I_{B2}=100µA and R=0.75kΩ. Simulated gain and phase responses of the non-inverting APF are given in Fig. 4. Phase response for different I_{B2} is shown in Fig. 5. This result confirms that the angle natural frequency can be electronically controlled by setting I_{B2} as shown in Eq. (6). The time-domain response of the proposed filter is shown in Fig. 6 where a sine wave of 25µA amplitude and 1.5MHz is applied as the input to the filter and the output is about 90 phase-shifted. The output currents for different values of I_{B1} are shown in Fig. 7. It is seen that the current gain can be electronically/independently adjusted from the natural frequency and its phase shift as expressed in Eq. (5).

Table 2. Dimensions of the MOS Transistors

Transistor	W (μm)	L (μm)
M1, M2	1	0.25
M16, M17	15	0.25
M22	4.7	0.25
Another PMOS	5	0.25
Another NMOS	3	0.25

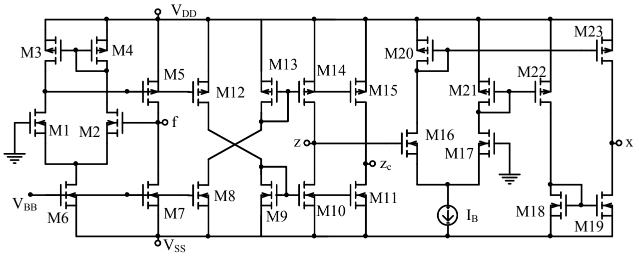


Fig.3. Internal construction of CFTA

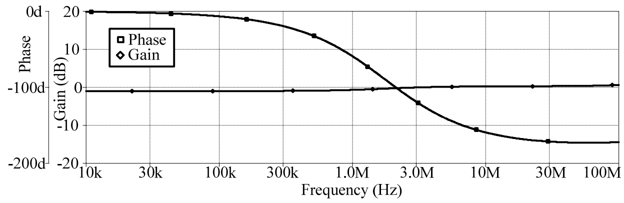


Fig.4. Gain and phase responses of the proposed allpass filter.

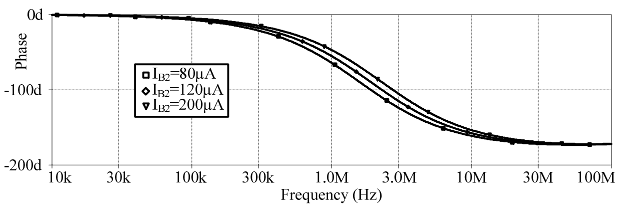


Fig.5. Simulated phase responses of the proposed allpass filter when I_{B2} is varied.

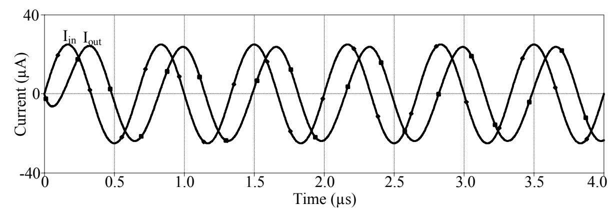


Fig.6. Filter response to a 1.5MHz sinusoidal input signal.

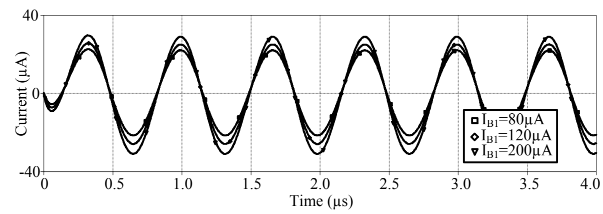


Fig.7. Output currents for different values of I_{B1}.

Conclusions

This paper proposes an electronically tunable current-mode first-order allpass filter with gain controllability. It consists of 2 CFTAs, 1 resistor and 1 grounded capacitor. So it is easy to fabricate in IC form to use in battery-powered or portable electronic equipments such as wireless communication devices. The PSpice simulation results were depicted, and agree well with the theoretical anticipation.

REFERENCES

[1] Keawon, R. Jaikla, W., A resistor-less current-mode quadrature sinusoidal oscillator employing single CCCDTA and grounded capacitors, *Przegląd Elektrotechniczny (Electrical Review)*, 8 (2011), 138-141.

[2] Summart, S. Thongsopa, C. Jaikla, W. OTA based current-mode sinusoidal quadrature oscillator with non-interactive control, *Przegląd Elektrotechniczny (Electrical Review)*, 7a (2012), 14-17.

[3] Jaikla, W. Lahiri, A., Resistor-less current-mode four-phase quadrature oscillator using CCCDTAs and grounded capacitors, *Int J Electron Commun*, 66 (2012), 214-218.

[4] Toumazou C., Lidgey F.J., Haigh D.G., Analogue IC design: the current-mode approach. Peter Peregrinus: London, (1990)

[5] Toker, A., Ozoguz, S., Cicekoglu, O., Acar, C., Current-mode all-pass filters using current differencing buffered amplifier and a new high-Q bandpass filter configuration, *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, 47(2000), 949-954.

[6] Schauman, R., Valkenburg, E., Design of analog filters. New York: Oxford University Press, (2001).

[7] Comer, D.J., Mcdermid, J.E., Inductorless bandpass characteristics using all-pass network, *IEEE Transaction on circuit Theory*, 15(1968), 501-503.

[8] Metin, B., Herencsar, N., Pal, K., Supplementary first-order all-pass filters with two grounded passive elements using FDCCII supplementary first-order all-pass filters with two grounded passive elements using FDCCII, *Radioengineering*, 20(2011), 433–437

[9] Sharma, S., Rana, S., Pal, K., Realisation of high Q notch / allpass filter using low-voltage current conveyor, Indian *Journal of Pure & Applied physics*, 48(2010), 435–437

[10] Keskin, A.U., Biolek, D., Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA), *IEE Proc.-Circuits Devices Syst.*, 153(2006), 214-218

[11] Jaikla, W., Prommee, P., Electronically tunable current-mode multiphase sinusoidal oscillator employing CCCDTA-based allpass filters with only grounded passive elements., *Radioengineering*, 20 (2011), 594–599

[12] Higashimura, M., Fukui, Y., Realization of current mode all-pass networks using a current conveyor., *IEEE Transaction on circuits and systems*, 37(1990), 660–661

[13] Maheshwari, S., Khan I.A., Novel first-order current-mode allpass sections using CCIII, *Active and Passive Elec. Comp*, 27(2004), 111-117.

[14] Horng, J. W., Hou, C. L., Chang, C. M., Chung, W. Y., Liu, H. L., Lin C.T. High-output impedance current-mode first- order allpass networks with four grounded components and two CCIIs. Int. Journal of Electronics, 93(2006), 613-621.

[15] Un, M., Kacar, F., Third generation current conveyor based current-mode first order all-pass filter and quadrature oscillator., *Istanbul University - Journal of Electrical and Electronics Engineering*, 8(2008), 529-535.

[16] Singthong, P., Siripruchyanun, M., Jaikla, W., Electronically controllable first-order current-mode allpass filter using CCCIIs and its application., *In Proceedings of the 18th International Conference Mixed Design of Integrated Circuits and Systems (MIXDES)*, (2011), 314-318

[17] AL-Hashim, B., Dudek, F., Sun, Y., Current-mode delay equalizer design using multiple output OTAs., *Analog Integrated Circuits and Signal Processing*, 24(2000), 163–169.

[18] Psychalinos, C., Pal, K., A novel all-pass current-mode filter realized using a minimum number., *Frequenz* (2010), 30-32.

[19] Metin, B., Pal, K., Minaei, S., Cicekoglu, O., Trade-offs in the OTA-based analog filter design., *Analog Integrated Circuits and Signal Processing*, 60(2009), 205–213.

[20] Minaei, S., Ibrahim, M.A., General configuration for realizing current-mode first-order all-pass filter using DVCC., *Int. J. Electron.*, 92(2005), 347–356

[21] Kilinc, S., Cam, U., Current-mode first-order allpass filter employing single current operational amplifier., *Analog Integrated Circuits and Signal Processing*, 41(2004), 43–45

[22] Jaikla, W., Siripruchyanun, M., Bajer, J., Biolek, D., A simple current-mode quadrature oscillator using single CDTA., *Radioengineering*, 17 (2008), 33–40

[23] Jaikla, W., Siripruchyanun, M., Biolek, D., Biolkova, V., High-output-impedance current-mode multiphase sinusoidal oscillator employing current differencing transconductance amplifier-based allpass filters. *International Journal of Electronics*, 97(2010), 811–826

[24] Tangsrirat, W, Tanjaroen, W., Pukkalanun, T.,. Current-mode multiphase sinusoidal oscillator using CDTA-based allpass

sections, *International Journal of Electronics and Communications (AEU)*, 63(2009), 616-622
[25] Lahiri, A., Chowdhury, A., A novel first-order current-mode all-pass filter using CDTA., *Radioengineering*, 18(2009), 300-305
[26] Pandey, N., Paul, S.K., Single CDTA-based current mode All-pass filter and Its applications., *Journal of Electrical and Computer Engineering 2011*, (2011)
[27] Biolek, D., Senani, R., Biolkova, V., Kolka, Z., Active elements for analog signal processing: classification, review and new proposals. *Radioengineering*, 17(2008) 15-32.
[28] Herencsar, N., Koton, J., Vrba, K., Lahiri, A., Cicekoglu, O., Current-controlled CFTA-based current-mode SITO Universal Filter and Quadrature Oscillator., *Proc of APPEL 2010*, Pilsen, Czech Republic, (2010), 121-124.
[29] Prommee, P., Angkeaw, K., Somdunyakanok, M.,Dejhan, K., CMOS-based near zero-offset multiple inputs max–min circuits and its applications., *Analog Integr.Circuits Signal Process*, 61(2009) 93–105.

***Authors**: Anirut Iamarejin is working toward Master of Science in Industrial Education (Electrical Communications Engineering), Faculty of Industrial Education, King Mongkut's Institute of Technology Ladkrabang (KMITL), Email: sai_jack@hotmail.com*
Peerawut Suwanjan and Winai Jaikla, Department of Engineering Education, Faculty of Industrial Education, King Mongkut's Institute of Technology Ladkrabang, Ladkrabang, Bangkok, 10520, Thailand, E-mail: kspeeraw@kmitl.ac.th, winai.ja@hotmail.com.
Suwat Maneewan, Department of Electronic Technology, Faculty of Industrial Technology, Buriram Rajabhat University, Buriram, 31000, Thailand, Email: suwat_m@hotmail.com

The correspondence address is:
e-mail: winai.ja@hotmail.com