Electronically Tunable Current-mode Multiphase sinusoidal Oscillator Employing CDCTA-based Allpass Filters

K. Pitaksuttayaprot, and W. Jaikla

***Abstract*—** An implementation of current-mode multiphase sinusoidal oscillators (MSOs) is presented. The odd and odd/even phase systems can be realised using current differencing cascaded transconductance amplifier (CDCTA)-based all-pass filters. The condition of oscillation and frequency of oscillation can be controlled electronically and independently through adjusting the current of the CDCTA. The high output impedances facilitate easy driving an external load without additional current buffers. The proposed MSOs provide odd or even phase signals that are equally spaced in phase and equal amplitude. The circuit requires one CDCTA, one grounded resistor and one grounded capacitor per phase without additional current amplifier. The results of PSPICE simulations using BJT CDCTA are included to verify theory.

***Keywords*—** Current Differencing Cascaded Transconductance Amplifier; (CDCTA).

I. Introduction

MULTIPHASE sinusoidal oscillator (MSO) is important blocks for various applications. For example, in telecommunications it is used for phase modulators, quadrature mixers [1], and single-sideband generators [2]. In measurement system, MSO is employed for vector generator or selective voltmeters [3]. It can also be utilized in power electronics systems [4]. Recently, current-mode circuits have been receiving considerable attention of due to their potential advantages such as inherently wide bandwidth, lower slew-rate, greater linearity, wider dynamic range, simple circuitry and low power consumption [5]. Many active building blocks (ABBs) have been proposed to realize the current-mode circuit. The interesting active element, called current differencing cascaded transconductance amplifier (CDCTA) [20], is introduced to provide new possibilities in the current-mode circuit. It is really current-mode element whose input and output signal are currents. In addition, output currents of CDCTA can be electronically adjusted.

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Several realizations of current-mode MSOs using different active building blocks are available in the literature. These include realizations using current follower (CF) [8], CCCII [9]-[11], CDTA [12]-[14], CDBA [15], CFOA [16], and CCCCTA [17] and CCCDTA [18-19]. The CF-based MSO in [8] requires two current followers, one floating resistor, and one floating capacitor for each phase and thus the circuit is not suitable for monolithic integration. Moreover, it cannot be electronically controlled. The CCCII-based MSOs [9]-[11] enjoy high-output impedances and electronic tunability. However, the first one requires a large number of external capacitors. In addition, the oscillation condition can be provided by tuning the capacitance ratio of external capacitors, which is not easy to implement. The second reported circuit requires additional current amplifiers, which makes the circuit more complicated and increases its power consumption. CDTA-based current-mode MSOs in [12] is based on lossy integrators, where as the circuits in [13] and [14] contain CDTA-based allpass sections. They exhibit good performance in terms of electronic tunability, high-output impedances, and independent control of the oscillation frequency and the oscillation condition. However, MSOs in [12] and [13] require an additional current amplifier, which is implemented by two CDTAs. Moreover, the output currents of the MSO, utilizing the CDTA-based lossy integrators, are of different amplitudes. The MSO employing CDTA-based allpass sections [13] requires two CDTAs in each allpass section, and the circuitry becomes more extensive. While MSO using CDTA-based allpass sections [14] requires floating capacitor. Consequently, it occupies a larger chip area for VLSI design. In addition, its power consumption is also increased.

The purpose of this study is to introduce a new current-mode multiphase sinusoidal oscillator. The features of the proposed circuit are the following: (I) Use of grounded capacitors and identical circuit configuration for each section in the MSO topology. (II) The electronic tunability of oscillation condition and oscillation frequency. (III) High-impedance current outputs. (IV) The possibility of generating multi-phase signals for both an even and odd number of equally-spaced in phases. (V) Independent tuning of the oscillation frequency and the oscillation condition. (VI) Equality of amplitudes of each phase due to utilizing identical sections. (VII) Requirement for only one CDCTA as the active element for each phase without any additional current amplifiers.

II. THEORY AND PRINCIPLE

A. CDCTA Overview

The characteristics of the ideal CDCTA are represented as the following hybrid matrix.

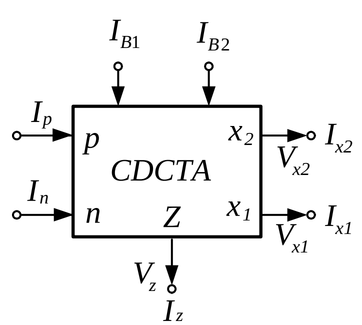
$$\begin{bmatrix} I_z, I_{zc} \\ I_{x1}, I_{x1c} \\ I_{x2}, I_{x2c} \\ V_{x2} \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & g_{m1} & 0 \\ 0 & 0 & 0 & g_{m2} \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_z \\ V_{x1} \end{bmatrix}, \qquad (1)$$

where g_m is the transconductance of the CDCTA. This g_m can be adjusted by external input bias current I_B . For bipolar junction transistor CDCTA, the transconductances can be shown in Eqs. (2) and (3) . The symbol and the equivalent circuit of the CDCTA are illustrated in Fig. 1 .

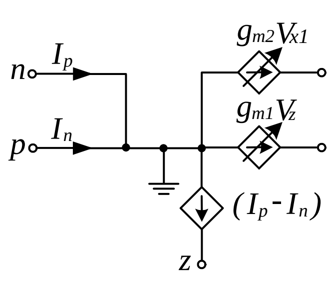
$$g_{m1} = \frac{I_{B1}}{2V_T}, \qquad (2)$$

and

$$g_{m2} = \frac{I_{B2}}{2V_T}. \qquad (3)$$



(a)



(b)

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

B. Principle of n-cascaded Allpass-based MSO

The generalized structure of MSO by cascading the n identical stages (n≥2) is shown in Fig. 2 which containing the first-order allpass filter for each phase. The output of nth stage is fed back to the input of the first stage, and the signal of the last section is inverted for even phase system and non-inverted for odd phase system. It is found in Fig. 2 that the system can provide one phase per one allpass filterwithout any additional external amplifier. The system loop gain can be written as follows :

$$L(s) = -\left(k\frac{sa-1}{sa+1}\right)^n. \qquad (4)$$

where the symbols k is the current gain and a denotes the natural frequency of each allpass section. At the oscillation frequency ω_{osc}, the Barkhausen's condition can be written as

$$L(j\omega_{osc}) = -\left(k\frac{j\omega_{osc}a-1}{j\omega_{osc}a+1}\right)^n = 1. \qquad (5)$$

From (5), the magnitude and the phase of the system loop gain can be expressed as follows:

$$\left|L(j\omega_{osc})\right| = 1, \qquad (6)$$

and

$$\angle H(j\omega_{osc}) = 2n\phi = 2n((-2\tan^{-1}(\omega_{osc}a)) = -2\pi. \qquad (7)$$

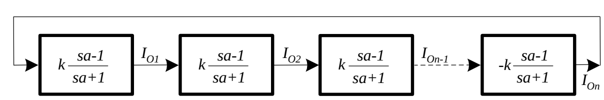


Fig. 2. MSO block diagram for odd/enven phase

Equation (7) shows that for n - phase systems, each phase is shifted by $-360^\circ/2n$. Hence the oscillation condition (OC) and the oscillation frequency (OF) are given by the formulae

$$\text{OC:} \quad k = 1, \qquad (8)$$

and

$$\text{OF:} \quad \omega_{osc} = \frac{1}{a}\tan\left(\frac{\pi}{2n}\right). \qquad (9)$$

Considering (8) and (9), the oscillation condition can be controlled independently of the oscillation frequency by the gain k, while the oscillation frequency can be changed by the natural frequency a .

C. Proposed Current-mode MSO

As mentioned in the above section, the proposed MSO is based on identical first-order allpass sections. A prospective CDCTA-based implementation is shown in Fig. 3. It is seen that the proposed first-order allpass circuit consists of 1 CDCTA, 1 grounded capacitor and 1 grounded resistor. The current transfer function can be written as follows:

$$L(s) = g_{m2}R\left(\frac{s\dfrac{C}{g_{m1}}-1}{s\dfrac{C}{g_{m1}}+1}\right)^{n}. \qquad (10)$$

According to Eqs. (8) and (9), the oscillation condition and oscillation frequency are as follows:

$$\text{OC:} \quad g_{m2}R = 1, \qquad (11)$$

and

$$\text{OF:} \quad \omega_{osc} = \frac{g_{m1}}{C}\tan\left(\frac{\pi}{2n}\right). \qquad (12)$$

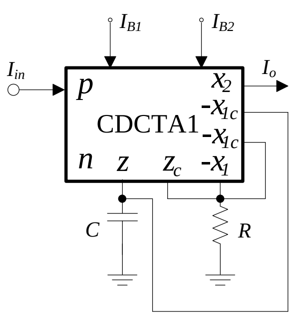


Fig. 3. CDCTA-based allpass filter

From Eqs. (10) and (11), if $g_{m1}=I_{B1}/2V_T$ and $g_{m2}=I_{B2}/2V_T$, theFO and CO is modified as

$$\frac{I_{B2}R}{2V_T} = 1, \qquad (11)$$

and

$$\omega_{osc} = \frac{I_{B1}}{2V_T C}\tan\left(\frac{\pi}{2n}\right). \qquad (12)$$

From Eqs. (11) and (12), it can be seen that the CO can be adjusted electronically/independently from the FO by varying I_{B2} while the oscillation frequency can be electronically adjusted by I_{B1}. The resulting current-mode MSO is shown in Fig. 4 for odd/even phase system, respectively. It is found from Fig. 4 that the current mirrors are required to split the bias currents I_{B1} and I_{B2} to each allpass section. In addition, it can be seen that the proposed MSOs enjoy high-output impedances which facilitate easy driving an external load without additional current buffers.

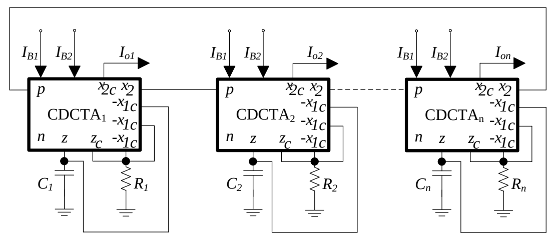


Fig. 4. Proposed current-mode MSO for odd/even phase system

III. RESULTS OF COMPUTER SIMULATION

To prove the performances of the proposed current-mode MSO, the PSpice simulation program was used for the examination. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [21]. The CDCTA has been simulated using the bipolar technology structure [22] of Fig. 5. The circuit was biased with ±2.5V supply voltages. Firstly, an odd three-phase sinusoidal oscillator (n=3) based on the structure in Fig. 2 has been designed on the basis of Fig. 4. The component values are as follows: I_{B1}=100μA, I_{B2}=62μA, C=0.1nF and R=1kΩ. The simulated output waveforms, I_{O1}, I_{O2} and I_{O3} are shown in Fig. 6 and 7. The frequency of oscillation achieved was 2.93MHz. The frequency spectrum of output currents are shown in Fig. 8. The total harmonic distortion is about 2.88%.

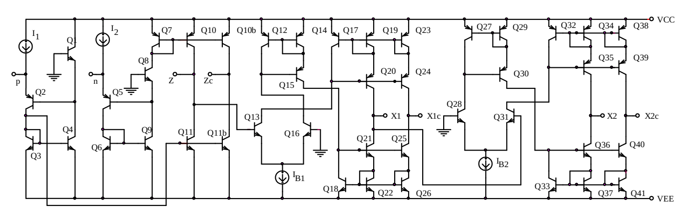


Fig. 5. Internal construction of CDCTA

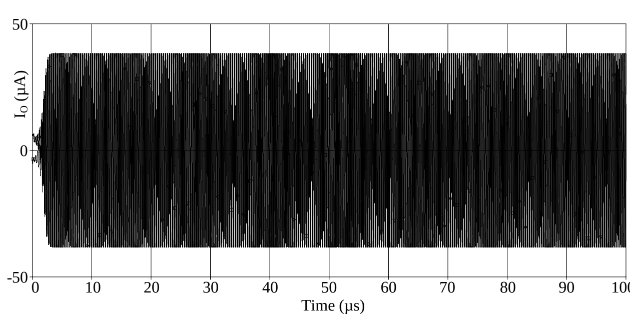


Fig. 6. Output waveforms during initial state (n=3)

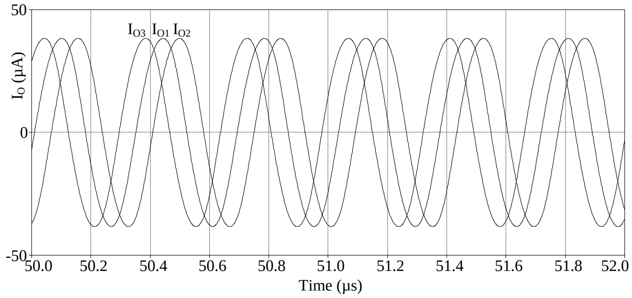


Fig. 7. Current outputs of the proposed MSO (n=3)

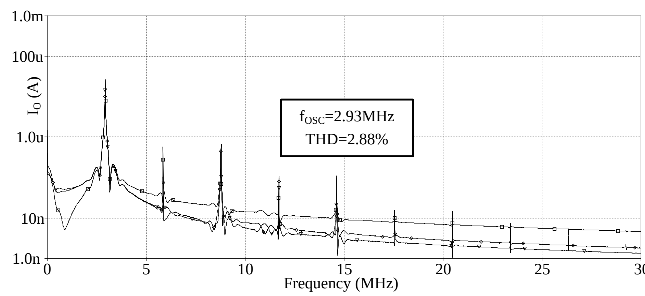


Fig. 8. Spectrum of Current outputs of the proposed MSO (n=3)

Secondly, an even four-phase sinusoidal oscillator (n=4) based on the structure in Fig. 2 has been designed on the basis of Fig. 4. The component values are as follows: I_{B1}=110μA, I_{B2}=62μA, C=0.1nF and R=1kΩ. The simulated output waveforms, I_{O1}, I_{O2}, I_{O3} and I_{O4} are shown in Figs. 9 and 10. The frequency of oscillation achieved was 3.74MHz. The frequency spectrum of output currents are shown in Fig.11. The total harmonic distortion is about 2.76%.

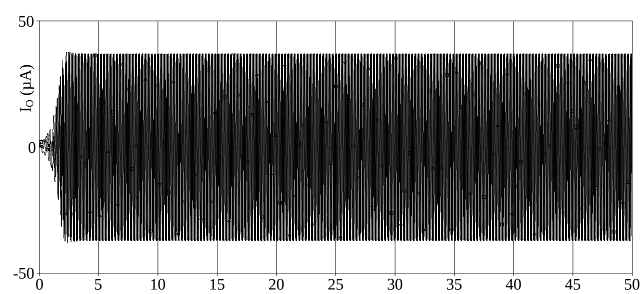


Fig. 9. Output waveforms during initial state (n=4)

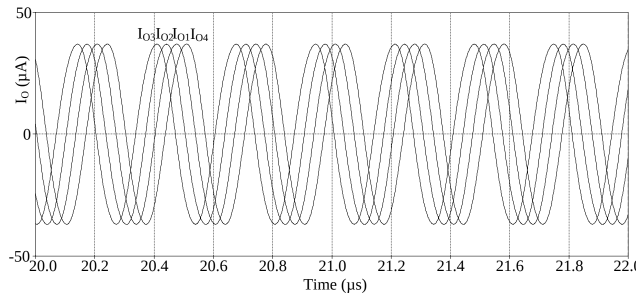


Fig. 10. Current outputs of the proposed MSO (n=4)

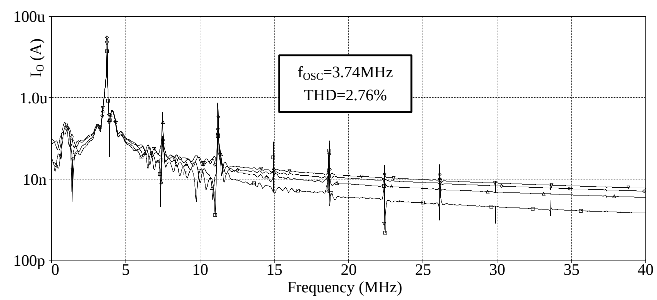


Fig. 11. Spctrum of Current outputs of the proposed MSO (n=4)

IV. CONCLUSION

A new current-mode multiphase sinusoidal oscillatos using CDCTA-based lossy integrators with grounded capacitors have been presented. The features of the proposed circuit are that: oscillation frequency and oscillation condition can be independently tuned; the proposed oscillator consists of merely 1 CDCTA and 1 grounded capacitor for each phase and no additional current amplifier and availability of explicit current outputs from high-output impedance terminals. PSPICE simulation results agree well with the theoretical anticipation..

REFERENCES

[1] J. Dunlop and D.G.Smith, "Telecommunications Engineering," 3rd ed. CRC Press, 1994.

[2] W. Tomasi, "Electronic Communications System," New Jersey: Prentice- Hall Inc., 1998.

[3] Anritsu Emea Limited, "MG3700A vector signal generator datasheet," Availableat:http://www.eu.anritsu.com/files/ MEG3700A_El17301.pdf..

[4] G. Eirea, and S.R. Sanders, "Phase current unbalance estimation in multiphase buck converters," IEEE Transactions on Power Electronics, vol. 23, pp. 137-143,2008.

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

[6] R. Prokop and V.Musil, "New modern circuit block CCTA and some its applications," The Fourteenth International Scientific and Applied Science Conference - Electronics ET'2005, (Sofia: TU Sofia), Book 5, pp.93-98,2005.

[7] M. Siripruchyanun and W.Jaikla, "Current controlled current convey or transconductance amplifier (CCCCTA): a building block for analog signal processing," Electrical Engineering, vol. 90, pp. 443–453,2008.

[8] M.T. Abuelma'Atti, "Current-mode multiphase oscillator using current followers" Microelectronics Journal, vol. 25, 457–461,1994.

[9] G D.Skotis, and C. Psychalinos, “Multiphase sinusodal oscillators using second generation current conveyors,” Int. J. Electron.Commu.(AEU), vol.64,pp.1178-1181,2010.

[10] M.T. Abuelma'atti, and M.A.Al-Qahtani, “A new current- controlled multiphase sinusoidal oscillator using translinear current conveyor,” IEEE Transactions on Circuits and Systems, vol. 45, 881–885,1998.

[11] C. Loescharataramdee, W.Kiranon, W.Sangpisit and W.Yadum, “Multiphase sinusoidal oscillators using translinear current conveyors and only grounded passive components,” Proceeding of Southeastern Symposium on System Theory, 2004, 59-63.

[12] W. Tangsrirat and W. Tanjaroen, “Current-mode multiphase sinusoidal oscillator using current differencing transconductance amplifiers,” Circuits, Systems and Signal Processing, vol. 27, pp. 81- 93,2008..

[13] W. Tangsrirat, W. Tanjaroen, and T. Pukkalanun, “Current-mode multiphase sinusoidal oscillator using CDTA-based allpass sections,” International Journal of Electronics and Communications (AEU), vol. 63, pp. 616- 622, 2009.

[14] W. Jaikla, M. Siripruchyanun, D. Biolek, and V. Biolkova, “Highoutput-impedance current-mode multiphase sinusoidal oscillator employing current differencing transconductance amplifier-based allpass filters,” International Journal of Electronics, vol. 97, pp. 811–826, 2010.

[15] K.Klahan, W.Tangsrirat, and W. Surakampontorn, “Realization of multiphase sinusodal oscillator using CDBAs,” IEEE Asia-Pacific Conf. Circ. Sys., pp. 725-728, 2004.

[16] D.-S. Wu, S.-I. Liu, Y.-S. Hwang, and Y.-P. Wu, “Multiphase sinusoidal oscillator using the CFOA pole,” IEE Proc. Circuits Devices Syst,vol.142,pp. 37-40, 1995.

[17] P. Uttaphut, “New Current-mode Multiphase Sinusodal Oscillators Based on CCCCTA-based Lossy Integrators,”Electrical Review, pp. 291-295, 2012.

[18] M. Kumngern, “Current-mode multiphase sinusoidal oscillator using current-controlled current differencing transconductance amplifiers,” 2010 IEEE International Conference of Electron Devices and Solid-State Circuits (EDSSC), 2010.

[19] W. Jaikla, and P. Prommee, “Electronically tunable current-mode multiphase sinusoidal oscillator employing CCCDTA-base allpass filters with only grounded passive elements,” Radioengineering, vol.20, no.3, pp. 594-599,2011.

[20] X. Jun, W. Chunhua, and J. Jie, “Current Differencing CascadedTransconductance Amplifier(CDCTA) and Its Applications on Current-Mode nth-Order Filters,”Circuits,System, and Signal Processing, Springer Science+Business Media New York 2013.

[21] Frey D., Log-domain filtering: an approach to current-mode filtering, IEE Proceedings-Circuits, Devices and Systems, pp. 406-416, 1993.

[22] W. Tangsirrat and w. Tanjaroen,"Current-mode sinusoidal quadrature oscillator with independent control of oscillation frequency and condition using CDTAs," Indian Journal of Pure &Applied Physics,vol48, ,pp.363-366, May, 2010.

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