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New Two Simple Sinusoidal Generators with Four 45º Phase Shifted Voltage Outputs Using Single FDCCII and Grounded Components

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ABSTRACT

Two new 45º phase shifted sinusoidal oscillator configurations employing single Second Generation Fully Differential Current Conveyor (FDCCII), two grounded capacitors and two grounded resistors are presented. The proposed oscillators can provide four sinusoidal voltage outputs with each a 45º phase difference. These circuits can also be utilized as voltage-mode quadrature oscillators. Additional output stages incorporation in FDCCII can also result in current outputs spaced 45 degree apart. The proposed circuits enjoy the simplicity and less passive and active component. The Total Harmonic Distortion (THD) of the output waveforms was reasonability values (less than 4.5%). The circuits can supply two equi-quadrature outputs and the Lissajous patterns confirm the quadrature voltage output waveforms. The workability of the circuits is simulated by PSPICE 0.18 µm CMOS technology. The non-ideal analysis and simulation results verifying theoretical analyses are also investigated.

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1. INTRODUCTION

In analog circuit design, sinusoidal oscillators are linear circuits and represent important basic blocks in electric and electronic engineering applications, as for example in signal processing, instrumentation, measurement, communication and control systems [1-5]. Many types of multiphase sinusoidal oscillators (MSOs) have various applications. They can be found in telecommunications for phase modulators, quadrature mixers [6] and single-sideband generators [7], for measurement purposes in vector generators or selective voltmeters [8] or in power electronic system [9].

Numerous multiphase sinusoid oscillator circuits employing different types of active elements such as operational transconductance amplifier (OTA), current feedback operational amplifier (CFOA), current differencing buffered amplifier (CDBA), current differencing transconductance amplifier (CDTA) current conveyors (CCs) and its different variations have been reported in the literature. [10]-[23].

Fully differential signal processing can be used to extend the dynamic range of analog blocks [24]. Therefore fully differential circuit configurations have been widely used in high frequency analog applications such as switch capacitor filters and mute standard wireless receivers [25], [26] and the references cited therein. Recently fully differential current conveyor (FDCC) based oscillator as a single active element in the circuit design was introduced in the literature [27]-[29].

There are many papers which design of multiphase sine-wave oscillator with four 45º phase shifted voltage outputs using different active and passive components in the literature. Z-copy voltage differencing transconductance amplifier (ZC-VDTA) and five passive elements are used in the design of [30], while the design of [31] uses single Z-copy controlled gain voltage differencing current conveyor (ZC-CG-VDCC) and four active components. Two Differential Voltage Current Conveyors (DVCCs) and four passive components are used in the design of [32].

FDCCs based voltage mode 45º phase shift outputs have not been earlier attempted in the available literature. This paper presents two new dual mode multiphase oscillator topologies using only a single FDCC, two capacitors and two resistors. The proposed topologies are preferred for IC fabrication due to all the passive components are grounded. These topologies can generate four sinusoidal voltage outputs each with 45º phase difference. These topologies can also be utilized as voltage-mode quadrature oscillators. Additional Z+ and Z- stages incorporation in FDCCII can also result in two sinusoidal current-mode outputs each with 45º separation. Simultaneous four current outputs can also be generated with additional Z stages and two voltages to current converters such as CCII converter.

2. PROPOSED CIRCUITS

The FDCCII was introduced by Alzaher, Elwan and Ismail in 2000 [33], where each of the terminals has been doubled with respect to the original CCII. It is an eight-terminal analog building block shown symbolically in Figure 1, where Y1, Y2, Y3 and Y4 terminals are high impedance terminals while X+ and X- terminals are low impedance ones. The Z+ and Z- terminals exhibit high impedance nodes suitable for current outputs.

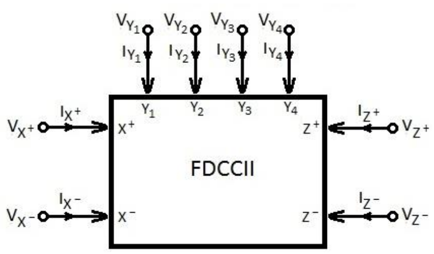


Figure 1. Circuit symbol of FDCCII

The ideal terminal characteristics of FDCCII can be defined by the hybrid matrix as given by Equation 1.

$$\begin{bmatrix} V_{X+} \\ V_{X-} \\ I_{Z+} \\ I_{Z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{X+} \\ I_{X-} \\ V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ V_{Y4} \end{bmatrix} \tag{1}$$

The proposed circuits are shown in Figure 2.

(a) Circuit (I) (b) Circuit (II)

Figure 2. Proposed circuits

Routine analysis of these circuits, which provide four voltage outputs each with 45º phase difference yield the following characteristic equation:

$$s^2C_1C_2 + s(C_2G_2 - C_1G_1) + G_1G_2 = 0 \quad (2)$$

The frequency of oscillation (FO) and the condition of oscillation (CO) can be obtained as

CO: $C_2G_2 \le C_1G_1$ (3)

FO: $f_o = \frac{1}{2\pi}\frac{1}{\sqrt{C_1C_2R_1R_2}}$ (4)

From Figure 2, under steady state and depending on the FDCC terminal characteristic equation, the currents I_{o1} (I_{R1}) and I_{o3} (I_{C2}) are equal hence the phase shift between V_{o1} and V_{o3} is 90º also the currents I_{o2} (I_{C1}) and I_{o4} (I_{R2})are equal hence the phase shift between V_{o2} and V_{o4} is 90º, therefore the relationship between output voltages V_{o1}, V_{o2}, V_{o3} and V_{o4} are

$$\frac{V_{o1}}{V_{o3}} = (sC_2R_1) \quad (5)$$

$$\frac{V_{o4}}{V_{o3}} = \frac{1}{2}(1 + sC_2R_1) \quad (6)$$

$$\frac{V_{o3}}{V_{o2}} = (1 + sC_1R_2) \quad (7)$$

Therefore at oscillating frequency, it can be easily shown that

$$V_{o1} = \sqrt{2} * V_{o4}\angle 45^{o} \quad (8)$$

$$V_{o4} = \frac{1}{\sqrt{2}} * V_{o3}\angle 45^{o} \quad (9)$$

$$V_{o3} = \sqrt{2} * V_{o2}\angle 45^{o} \quad (10)$$

It is clear from equations (8-10) that the phase difference between V_{o1}, V_{o2}, V_{o3} and V_{o4} is 45º. Figure 3 explains the phasor sequence and amplitude diagram of the output voltages.

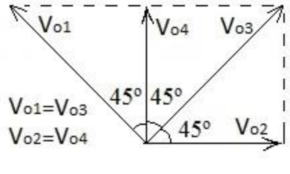


Figure 3. Phasor and voltage amplitude diagram of the proposed sinusoidal generators

Also, the phasor diagram shows two equi-quadrature voltage outputs. The first quadrature oscillator has been formed between V_{o1} and V_{o3} which their magnitude equals $\sqrt{2}$ the magnitude of the other outputs of the second quadrature oscillator represented by V_{o2} and V_{o4}. With the four voltage outputs, proposed circuits can simultaneously obtain two current output waveforms each with 45º separation by adding Z^+ and Z^- stages incorporation in FDCCII. Getting four current output waveforms can be done by adding two voltage to current converters such as CCII converter and connect them to X$^-$ and Z$^-$ terminals.

3. NON IDEAL ANALYSIS

Incorporating the two sources of tracking errors into the ideal characteristic equation of the FDCCII leads to

$$\begin{bmatrix} V_{X+} \\ V_{X-} \\ I_{Z+} \\ I_{Z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \beta_{11} & -\beta_{12} & \beta_{13} & 0 \\ 0 & 0 & -\beta_{21} & \beta_{22} & 0 & \beta_{24} \\ \alpha_{01} & 0 & 0 & 0 & 0 & 0 \\ 0 & \alpha_{02} & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{X+} \\ I_{X-} \\ V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ V_{Y4} \end{bmatrix} \tag{11}$$

where $\beta_v = 1 - e_v$ and $e_v(|e_v| << 1)$ denote the differential voltage tracking errors and $\alpha_i = 1 - e_i$ and $e_i(|e_i| << 1)$ denote the current tracking errors.

The non-ideal expression for the output voltages of Figure 3 is given by

$$s^2 C_1 C_2 + s\left[\frac{C_2 G_2}{\beta_{12}\alpha_1} + C_1 G_1\left(\beta_{21}\alpha_2 - \frac{\beta_{11}}{\beta_{12}}\alpha_2(\beta_{22} + \beta_{24})\right)\right] + \frac{\beta_{21}\alpha_2}{\beta_{12}\alpha_1} G_1 G_2 = 0 \tag{12}$$

The FO and CO of the proposed circuits under non-ideal conditions are now found as

CO: $$C_2 G_2 \le C_1 G_1 \alpha_1 \alpha_2 [\beta_{11}(\beta_{22} + \beta_{24}) - \beta_{12}\beta_{21}] \tag{13}$$

FO: $$f_o = \frac{1}{2\pi}\sqrt{\frac{\beta_{21}\alpha_2 G_1 G_2}{\beta_{12}\alpha_1 C_1 C_2}} \tag{14}$$

From the above, the active and passive sensitivities of the frequency of oscillation are found as

$$S_{C_1}^{f_o} = S_{C_2}^{f_o} = S_{R_1}^{f_o} = S_{R_2}^{f_o} = S_{\alpha_1}^{f_o} = S_{\beta_{12}}^{f_o} = -\frac{1}{2},\ S_{\alpha_2}^{f_o} = S_{\beta_{21}}^{f_o} = \frac{1}{2},\ S_{\beta_{13}}^{f_o} = 0 \tag{15}$$

The active and passive sensitivities of the frequency of oscillation are found to be in the range $-1/2 \le S_x^F \le 1/2$, and the circuit, thus, enjoys low sensitivities.

4. SIMULATION RESULTS

The proposed generator circuits have been simulated to verify the theoretical analysis. The voltage mode oscillator of Figure 2(I) has been selected to verify the circuit performance. The FDCCII was realized based on the CMOS implementation from [34] as shown here in Figure 4.

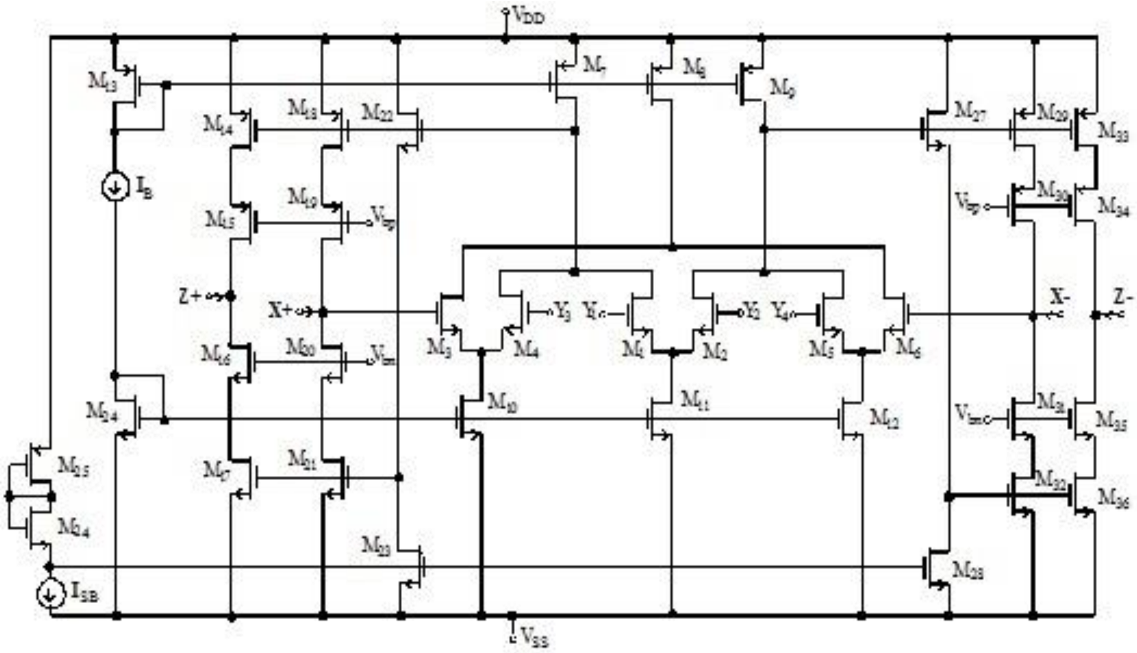


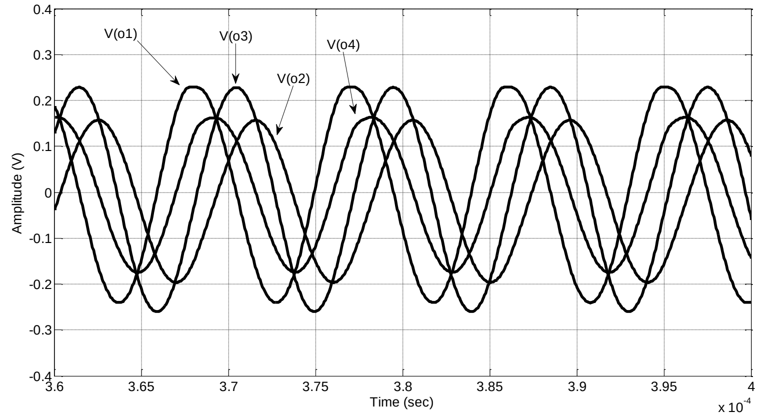
Figure 4. CMOS realization of the FDCCII [34]

PSPICE simulation based upon a CMOS FDCCII was implemented using 0.18 μm technology where the aspect ratios of the MOSFETs are shown in Table 1.

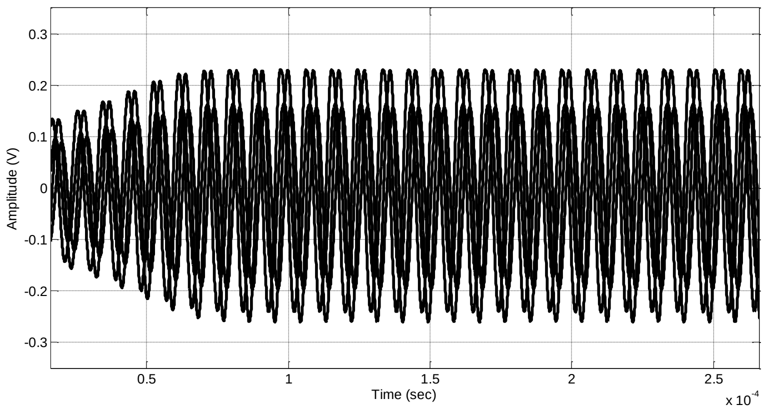
Table 1. Aspect ratios of MOSFETs

MOS transistors	W/L (μm)
M_1- M_6	0.25/0.18
M_7, M_8, M_9, M_{13}	0.25/0.18
M_{10}, M_{11}, M_{12}, M_{24}	0.25/0.18
M_{14}, M_{15}, M_{18}, M_{19}, M_{25}, M_{29}, M_{30}, M_{33}, M_{34}	0.5/0.18
M_{16}, M_{17}, M_{20}, M_{21}, M_{26}, M_{31}, M_{32}, M_{35}, M_{36}	0.5/0.18
M_{22}, M_{23}, M_{27}, M_{28}	0.25/0.18
M_{14}, M_{15}, M_{18}, M_{19}, M_{25}, M_{29}, M_{30}, M_{33}, M_{34}	0.5/0.18

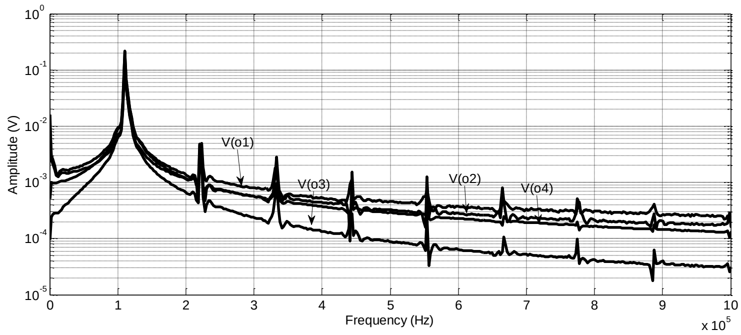
The CMOS FDCCII was biased with DC power supply voltages V_{DD}= +1.5 V, V_{SS}= −1.5V along with I_B = 33 μA, I_{SB} = 25 μA, V_{bp}= 0.25 V, and V_{bn} = − 0.3 V. To achieve the oscillator with f_o = 112 kHz, the passive component values were chosen as R_1 = R_2 = 20 kΩ, and C_1 = C_2 = 71 pF. Figure 5 shows the PSPICE-generated 45^o phase shift voltage output waveforms of the oscillator realized from the proposed circuit, where the waveforms coincide with the phases and magnitudes of the phasor diagram shown in Figure 3. The Transient and steady state voltage output waveforms are shown in Figure 5(a) and 5(b) respectively. The frequency spectrums of these waveforms are shown in Figure 5(c). SPICE simulations frequency of generated voltage output waveforms has been found to be 111. 7 kHz. The Total Harmonic Distortion (THD) of the output waveforms was 1.44 - 4.53 %. Thus, a very good matching between theoretical values and PSPICE simulations is observed.



(a) Transient voltage output waveforms



(b) Voltage output waveforms



(c) Frequency spectrum

Figure 5. PSPICE Simulation results of the 45^o phase shift Oscillator realized from the proposed circuits

The circuit has two quadrature outputs and the Lissajous patterns confirm the quadrature voltage output waveforms as shown in Figure 6.

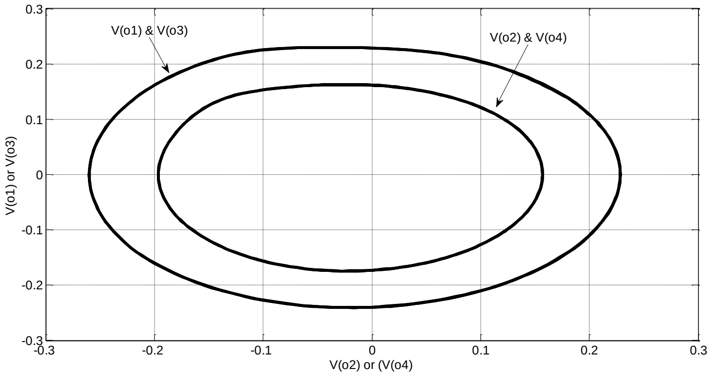


Figure 6. Lissajous patterns of quadrature voltage output waveforms (V_{o1} with V_{o3}) (V_{o2} with V_{o4})

By adding Z^+ and Z^- stages incorporation in FDCCII and two CCII converters (to change the voltage to current) connected to X^- and Z^- terminals the circuit can provide four current output waveforms each with 45° separation as shown in Figure 7.

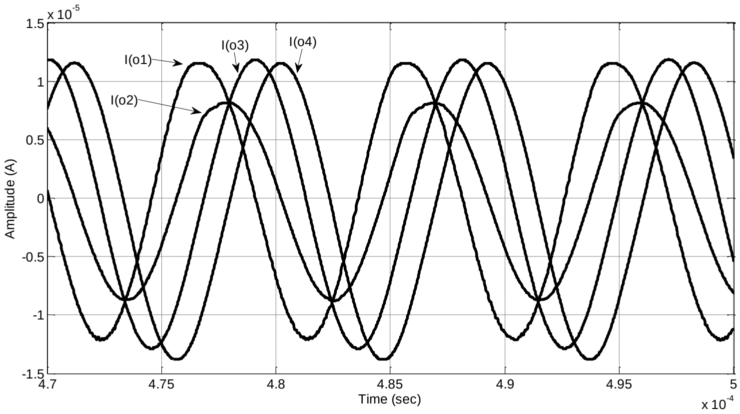


Figure 7. Current output waveforms

5. COMPARATIVE WITH OTHER WORKS

A comparison of multiphase sine-wave generator provides four 45° phase shifted voltage outputs using different active component presented recently in [30-32] (and the references cited therein) and proposed circuits are discussed below. The circuit in [30] uses single Z-copy voltage differencing transconductance amplifier (ZC-VDTA), two capacitors and three resistors. The drawback of ZC-VDTA is affected by temperature due to its transconductance. However, the circuit has more passive components. The circuit in [31] uses single Z-copy controlled gain voltage differencing current conveyor (ZC-CG-VDCC), two capacitors and two resistors. This circuit has one 45° phase shift between two voltage outputs and 90° between the other two outputs not equi-quadrature as presented in the proposed circuits which the outputs increase 45° sequentially. Also, this circuit suffers from the temperature effect due to the existence of transconductance in the internal circuit. The circuits of [30] and [31] are more complicated as compared with proposed circuits. The circuit in [32] uses the same passive component employed in the proposed circuits but it uses more active elements (two Differential Voltage Current Conveyors (DVCCs)), as well as FDCC has more current gain and bandwidth than DVCC [35] with same characteristics. Therefore the proposed circuits enjoy the simplicity and less active and passive components.

6. CONCLUSION

It is shown in this paper that two new circuits which are used single active element can generate four 45° phase separation voltage outputs. Because has the fully differential circuit which is suitable for analog signal applications, FDCCII is used as an active element in these circuits. Also, these proposed circuit used only four passive components (two capacitors and two resistors). In addition, these circuits can achieve two voltage-mode equi-quadrature oscillators and can also provide four current output waveforms each with 45^o separation by adding output stages incorporation in FDCCII and two CCII converters.

The previously reported 45^o phase difference outputs oscillators in the literature may more complicate of the active circuits or more elements of the active or passive components as compared with the proposed circuits. Due to all the passive components of the proposed circuit are grounded therefore is preferred for IC fabrication. PSPICE 0.18 µm CMOS technology has been used to simulate the performance of the circuits. The simulation results are given to verify the presented theoretical analyses.

REFERENCES

[1] R. Senani, "New types of sine wave oscillators", *IEEE Trans. on Instrumentation and Measurement,* vol. 34, no. 3, pp. 461-463, 1985.

[2] R. Senani and D.R. Bhaskar, "Single-op-amp sinusoidal oscillators suitable for generation of very low frequencies", *IEEE Trans. on Instrumentation and Measurement*, vol. 40, no. 4, pp. 777- 779, 1991.

[3] D.R. Bhaskar and R. Senani, "New CFOA-based single-element-controlled sinusoidal oscillators", *IEEE Trans. on Instrumentation and Measurement*, vol. 55, no. 6, pp. 2014-2021, 2006.

[4] F. Syifaul, E. Hakkun and Suwasono, "Design and Fabrication of LC-Oscillator Tool Kits Based Op-Amp for Engineering Education Purpose", *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 1, no. 1, pp. 88- 100, January 2016.

[5] M.M. Elsherbini, M.F. Elkordy and A.M. Gomaa, "Design and Simulation for UHF Oscillator using SAWR with Different Schematics", *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 1, no. 2, pp. 294-299, January 2016.

[6] J. Dunlop and D.G. Smith, "Telecommunications Engineering", (3rded.). CRC Press, 1994.

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

[8] Anritsu Emea Limited. MG3700A vector signal generator datasheet, from http://www.eu.anritsu.com/files/MEG3700A_ El17301.pdf**.**

[9] 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.

[10] I.A. Khan, *et al.*, "Tunable OTA based multiphase sinusoidal oscillators", *International journal of Electronics*, vol. 72, pp. 443-450, 1992.

[11] D.S. Wu, *et al.*, "Multiphase sinusoidal oscillator using second generation current conveyors", *Int. J. Electronics*, vol. 78, no. 4, pp. 645-651, 1995.

[12] K. Klahan, *et al.*, "Realization of multiphase sinusoidal oscillator using CDBAs", in *Circ. Sys. Proc. of the IEEE Asia-Pacific Conf.*, 2004, pp. 725–728.

[13] P. Mongkolwai, *et al.*, "CFOA-based single resistance controlled quadrature oscillator", in *Control and Information Technology, Proceedings of the International Conference on Instrumentation*, 2008, pp. 1147–1150, 2008.

[14] W. Tangsrirat, and W. Tanjaroen, "Current-mode multiphase sinusoidal oscillator using current differencing transconductance amplifiers", *Cir. Sys. Signal Process*, vol. 21, pp. 81-93, 2008.

[15] W. Tangsrirat, *et al.*, "Current-mode multiphase sinusoidal oscillator using CDTA-based allpass sections", *Int. J. Electron. Commu. (AEU)*, vol. 63, pp. 616-622, 2009.

[16] W. Jaikla, *et al.*, "High output-impedance current-mode multiphase sinusoidal oscillator based on CDTA-allpass filters", *Int. Journal of Electronics*, vol. 97, no. 7, pp. 811-826, 2010.

[17] D.R. Bhaskar, *et al.*, "Electronically-Controlled Current-mode second order Sinusoidal Oscillators Using MO-OTAs and Grounded Capacitors", *Circuits and Systems*, vol. 2, no. 1, pp. 65-73, 2011.

[18] P. Prommee, and K. Dejhan, "An integrable electronic-controlled quadrature sinusoidal oscillator using CMOS operational transconductance amplifier", *Int. Journal of electronics*, vol. 89, no. 5, pp. 365-379, 2002.

[19] S. Siripongdee, *et al.*, "Electronically Controllable Current-Mode Multiphase Sinusoidal Oscillator for Biomedical Tissue Measurement Systems", *International Journal of Bioscience, Biochemistry and Bioinformatics*, vol. 4, no. 1, pp. 57-59, 2014.

[20] S. Maheshwari, "Voltage mode four phase sinusoidal generator and its useful extensions", *Active and passive electronic components*. 2013, Article ID 685939, 8 pages, 2013.

[21] D.R. Bhaskar, *et al.*, "New SRCO with explicit current-mode output using two CCs and grounded capacitors", 6th International Conference on Electrical and Electronics Engineering 6-8 November 2009, Bursa, Turkey, 2009.

[22] K.K. Abdalla, *et al.*, "Configuration for Realizing a Current-Mode Universal Filter and Dual-Mode Quadrature SRCO", IET Circuits, Devices and Systems, vol, 6, no. 3, pp. 159-167, 2012.

[23] K. Gurumurthy, P. Neeta and P. Rajeshwari, "New Realization of Quadrature Oscillator using OTRA", *International Journal of Electrical and Computer Engineering (IJECE)*, vol, 7, no. 4, pp. 1815-1822, 2017.

[24] A.A. El-Adawy, *et al.*, "A novel fully differential current conveyor and its applications for analog VLSI", *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, vol. 47, no. 4, pp. 306-313, 2000.

[25] S.A. Mahmoud, "New Fully-Differential CMOS Second-Generation Current Conveyer", *ETRI Journal*, vol. 28, no. 4, pp. 495-501, 2006.

[26] S.A. Mahmoud, "Fully differential CMOS CCII based on differential difference transconductor", *Analog Integrated Circuits and Signal Processing*, vol. 50, no. 3, pp. 195–203, 2007.

[27] C.M. Chang, *et al.*, "Current mode single resistance controlled oscillators using only grounded passive elements", *Electronics Letters*, vol. 38, no. 39, pp. 1071-1072, 2002.
[28] J. Mohan, *et al.*, "Mixed-mode quadrature oscillators using single FDCCII", *J. of Active and Passive Electronic Devices*, vol. 2, 227–234, 2007.
[29] J.W. Horng, *et al.*, "Current or/and voltage-mode quadrature oscillators with grounded capacitors and resistors using single FDCCIIs", *WSEAS Transection on circuits and systems*, vol. 7, no. 3, pp. 129-138, 2008.
[30] N. Herencsar, *et al.*, "New compact VM four-phase oscillator employing only single Z-copy VDTA and all grounded passive elements", *Elektronika IR Electrotechinka*, vol. 19, no. 10, pp. 87-90, 2013.
[31] R. Sotner, *et al.*, "Second-order simple multiphase oscillator using Z-copy controlled-gain voltage differencing current conveyor", *Elektronika IR Electrotechinka*, vol. 20, no. 9, pp. 13-18, 2014.
[32] S. Maheshwari, "Sinusoidal generator with π/4 shifted four/eight voltage outputs employing four grounded components and two/six active elements", *Active and passive electronic components*, 2014, 7 pages, 2014.
[33] H.A. Alzaher, *et al.*, "CMOS fully differential second-generation current conveyor", *Electron. Lett*., vol. 36, p.p1095-1096, 2000.
[34] M.C. Chun, and H.P. Chen, "Single FDCCII-based tunable universal voltage-mode filter", *Circuits Systems and Signal Processing*, vol. 24, no. 2, pp. 221–227, 2005.
[35] H.F. Hamed and A.A. Khalaf, "Differential voltage current conveyor and fully differential current conveyor in standard CMOS technology for low voltage analog circuits applications", in *Electronics, Circuits and Systems, 12th IEEE International Conference 2005*, pages 1-4, 2005. DOI: 10.1109/ICECS.2005.4633384

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