American Journal of Electrical and Electronic Engineering, 2018, Vol. 6, No. 3, 85-89
Available online at http://pubs.sciepub.com/ajeee/6/3/2

DOI:10.12691/ajeee-6-3-2

Current-mode Quadrature Oscillator Using CFCC

Alok Kumar Singh[1], Pragati Kumar[2], Raj Senani[3,*]

[1]Department of Electronics and Communication Engineering, Delhi Technological University, New Delhi, India
[2]Department of Electrical Engineering, Delhi Technological University, New Delhi, India
[3]Division of Electronics and Communication Engineering, Netaji Subhas Institute of Technology, New Delhi, India
*Corresponding author: senani@ieee.org

Receive September 02, 2018; Revised October 16, 2018; Accepted November 02, 2018

Abstract In this communication, a Current Follower Current Conveyor (CFCC)-based quadrature oscillator circuit has been proposed which employs a resonator-negative resistor configuration and provides oscillations in quadrature from two high impedance current output terminals of the CFCCs. The workability of the quadrature oscillator has been verified using PSPICE simulations using a CMOS CFCC implementable in 0.18 micron TSMC technology.

Keywords: *current follower, current conveyor, current-follower-current-conveyor, quadrature oscillator, current-mode oscillator, current- mode circuits*

Cite This Article: Alok Kumar Singh, Pragati Kumar, and Raj Senani, "Current-mode Quadrature Oscillator Using CFCC." *American Journal of Electrical and Electronic Engineering*, vol. 6, no. 3 (2018): 85-89. doi: 10.12691/ajeee-6-3-2.

1. Introduction

A quadrature sinusoidal oscillator (QSO) circuit provides two sinusoids with 90^0 phase difference and finds several applications in communication and measurement systems. In communication systems they are used in quadrature mixers, single-sideband generators and direct-conversion receivers while in measurement systems such oscillators are used in vector generators or selective voltmeters (see [1] and references cited therein).

During the last two decades, many new active building blocks have been proposed in the domain of analog signal processing, a comprehensive review of which was presented in [2], wherein several new active building blocks (ABB) were also proposed. Many of the new ABBs proposed in [2] have been employed in the past to realize QSOs and other signal processing applications, which include Current Differencing Buffered Amplifier (CDBA) [3,4], Voltage Differencing Buffered Amplifier (VDBA) [5], Voltage Differencing Transconductance Amplifier (VDTA) [6], Voltage Differencing current conveyor (VDCC) [7], Current Differencing Transconductance Amplifier (CDTA) [8-12], Multiple-Output Current Controlled Current Differencing Transconductance Amplifier (MO-CCCDTA) [13], Modified Current Differencing Transconductance Amplifier (MCDTA) [14], Current Follower Transconductance Amplifier (CFTA) [15], Z-copy Current Follower Transconductance Amplifier (ZC-CFTA) [16], Second-Generation Current Conveyor Transconductance Amplifier (CCII-TA) [17], Differential-Input Buffered and Transconductance Amplifier (DBTA) [18], Current-Feedback Operational Amplifier (CFOA) [19], Differential Voltage Current Conveyor (DVCC) [20], Differential Voltage Current-Controlled Conveyor Transconductance Amplifier (DVCCCTA) [21], Voltage Differencing Inverting Voltage Buffered Amplifier (VDIBA) [22], Voltage Differencing-Differential Input Buffered Amplifiers (VD-DIBA) [23,24] and Programmable Current Amplifier [25].

It may be mentioned that while the QSOs presented in [3,4,5,7,16-24] operate in voltage mode (VM), those presented in [6,8-17,21,25] operate in current mode (CM). Also, of the various QSO circuits quoted above, only the circuits presented in [3,4] and [12] offer fully-decoupled condition of oscillation and frequency of oscillation. Furthermore, out of [3,4] and [12], the QSOs described in [3,4] are VM oscillators while the QSO described in [12] is a CM oscillator.

It has been observed from the literature survey that a new building block named Multi-output Current Follower Current Conveyor (MO-CFCC) which was also proposed in [2] has not been utilized for the realization of QSOs so far while recently its applications in the realization of simulated impedances have been reported in [26,27]. In this letter, we propose a QSO realized with CFCC to fill this void. The workability of the proposed oscillator has been verified using PSPICE simulations in 0.18 micron TSMC technology.

2. CFCC-based Realization of the Current-mode Quadrature Oscillator

CFCC [2] is a five-terminal ABB with the following functionalities: the current at the z terminal is an inverted copy of the input current at 'p' terminal; the terminal 'i' tracks the potential at the terminal z and two complementary currents at the output terminals are available which are copies of the current at the 'i' terminal. To provide additional functionality to the CFCC, a copy of the current at the 'z' terminal may also be provided resulting in the Z-copy CFCC (ZC-CFCC). The symbolic representation and relations between the various port variables for this ABB are shown in Figure 1, and equation (1) respectively.

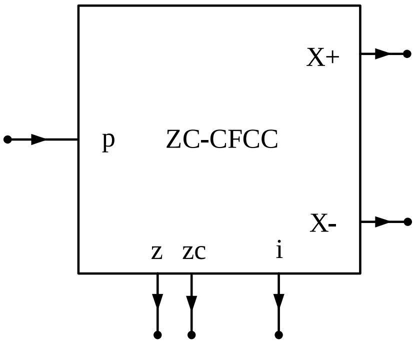

Figure 1. Symbolic notation of the ZC-CFCC

$$\begin{bmatrix} V_p \\ I_z \\ V_i \\ I_{x+} \\ I_{x-} \\ I_{zc} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_p \\ V_z \\ I_i \\ V_{x+} \\ V_{x-} \\ V_{zc} \end{bmatrix}. \tag{1}$$

The proposed current-mode quadrature oscillator circuit using CFCCs is shown in Figure 2 which consists of a parallel RLC resonator made from the CFCC along with R_4, R_5, C_1 and C_2 and a NIC-simulated negative resistor realized by the ZC-CFCC along with the resistors R_1, R_2 and R_3.

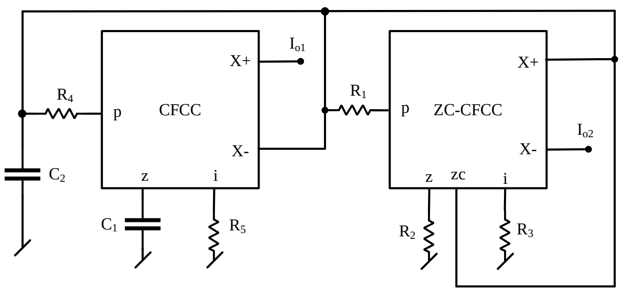

Figure 2. The proposed CFCC-based current mode quadrature oscillator

A straight forward routine analysis of the circuit given in Figure 2 yields the following characteristic equation (CE):

$$s^2 R_1R_3R_4R_5C_1C_2 + sR_5C_1\left(R_1R_3 - R_2R_4\right) + R_1R_3 = 0. \tag{2}$$

From equation (2), the condition of oscillation (CO) and frequency of oscillation (FO) are found to be:

CO:

$$R_1R_3 = R_2R_4. \tag{3}$$

FO:

$$\omega_{osc} = \frac{1}{\sqrt{R_4R_5C_1C_2}} \tag{4}$$

However, for quadrature oscillator design, we must look into the interrelationship between I_{01} and I_{02} which is found to be

$$\frac{I_{01}}{I_{02}} = -\frac{R_1R_3}{sR_2R_4R_5C_1}. \tag{5}$$

Under sinusoidal steady state, equation (5) reduces to

$$\frac{I_{01}}{I_{02}} = \frac{j}{\omega_0 R_5C_1}. \tag{6}$$

The phase difference φ is, thus, equal to 90^o.

3. Non-ideal Considerations

For a non-ideal analysis of the proposed oscillator, we have considered the various parasitic resistances and capacitances associated with the different terminals of the CFCC as follows: R_p represents the parasitic input resistance of the **p** port whereas R_z, C_z represent the resistance and capacitance at the z-terminal of the CFCC; similarly, R_{zc} and C_{zc} represent resistance and capacitance at the **zc** terminal while R_i represents the output resistance of the voltage buffer of the MO-CCII (resistance looking into the i terminal); on the other hand, R_{x+} and C_{x+} represent output resistance and output capacitance at the x+ terminals of the CFCC and finally, R_{x-} and C_{x-} represent the output resistance and the output capacitance at the x-terminals of the CFCC. A straight forward analysis of the proposed oscillator, incorporating all the parasitic immittances described above, gives the following third order characteristic equation:

$$\begin{aligned} & s^3 R_aR_bR_cR_dR_eR_fR_zC_aC_bC_z \\ & +s^2 (R_aR_cR_dR_eR_fR_zC_aC_b + \\ & R_aR_bR_cR_eR_fR_zC_aC_z + R_aR_bR_cR_dR_eR_zC_aC_z \\ & +R_aR_bR_cR_dR_eR_fC_bC_z) \\ & +s(R_aR_cR_eR_fR_zC_a + R_aR_cR_dR_eR_zC_a \\ & +R_aR_cR_dR_eR_fC_b + R_aR_bR_cR_fR_zC_z \\ & +R_aR_bR_cR_eR_fC_z + R_aR_bR_cR_dR_eC_z \\ & -R_bR_dR_eR_fR_zC_a) + R_aR_cR_fR_z \\ & +R_aR_cR_eR_f + R_aR_cR_dR_e - R_bR_dR_eR_f = 0 \end{aligned} \tag{7}$$

where

$$\begin{aligned} & R_a = R_1 + R_p,\ R_b = R_2 \parallel R_z, \\ & R_c = R_3 + R_i,\ R_d = R_4 + R_p, \\ & R_e = R_5 + R_i,\ R_f = R_{x+} \parallel R_{x-} \parallel R_{zc}, \\ & C_a = C_1 + C_z \text{ and } C_b = C_2 + C_{zc} + C_{x+} + C_{x-}. \end{aligned}$$

We have measured the values of the various parasitic resistances and capacitances of the CFCC employed in the present work (see Figure 3) by carrying out detailed PSPICE simulations. The measured values of these non ideal parameters are found to be as summarized in Table 1.

Table 1. The SPICE-measured values of the various parasitics of the CMOS ZC-CFCC

S.No.	Parameter	Value
1	R_p	**591Ω**
2	R_i	**591Ω**
3	R_z	**4.9178 M Ω**
4	C_z	**6.2988×10^{-14}F**
5	R_{zc}	**4.9178 M Ω**
6	C_{zc}	**7.3938×10^{-15}F**
7	R_{x+}	**4.9862 MΩ**
8	C_{x+}	**7.3954×10^{-15}F**
9	R_{x-}	**4.7752 MΩ**
10	C_{x-}	**7.4062×10^{-15}F**

The following approximations (ensured by selecting appropriate values of the terminating resistances and capacitances) R_1 , R_2, R_3 ,R_4 ,R_5, << R_f and C_1, C_2>>C_{x+}, C_{x-}, C_z and C_{zc} lead to a second order approximation of the CE from which the non-ideal CO and FO are now given by

CO:

$$(R_1+R_p)(R_3+R_i)=(R_2 \parallel R_z)(R_4+R_p) \tag{8}$$

FO:

$$\omega_{osc}^{'}=\omega_{osc}\frac{1}{\sqrt{\left[\begin{array}{l}\left(1+\dfrac{R_p}{R_4}\right)\left(1+\dfrac{R_i}{R_5}\right)\left(1+\dfrac{C_z}{C_1}\right)\\ \times\left(1+\dfrac{(C_{zc}+C_{x+}+C_{x-})}{C_2}\right)\end{array}\right]}}. \tag{9}$$

The interrelationship between I_{01} and I_{02} is found to be

$$\begin{aligned}\frac{I_{01}}{I_{02}}&=-\frac{R_z(1+sR_bC_z)}{R_e(1+sR_zC_a)}\\ &=-\frac{R_z[1+s(R_2\parallel R_z)C_z]}{(R_5+R_i)[1+sR_z(C_1+C_z)]}.\end{aligned} \tag{10}$$

The non-ideal expression of the phase difference φ is given by

$$\begin{aligned}\varphi&=\tan^{-1}\omega_{osc}^{'}R_zC_a-\tan^{-1}\omega_{osc}^{'}R_bC_z\\ &=\tan^{-1}R_z\sqrt{\frac{(C_1+C_z)}{\left[\begin{array}{l}(C_2+C_{zc}+C_{x+}+C_{x-})\\ \times(R_1+R_p)(R_5+R_i)\end{array}\right]}}\\ &-\tan^{-1}\frac{(R_2\parallel R_z)C_z}{\sqrt{\left[\begin{array}{l}(R_1+R_p)(R_5+R_i)(C_1+C_z)\\ \times(C_2+C_{zc}+C_{x+}+C_{x-})\end{array}\right]}}.\end{aligned} \tag{11}$$

Subject to the approximations used in the non-ideal analysis, it may be observed that the phase difference between the two output currents would be very close to 90^o (as the angle corresponding to the argument of the first arctangent term will be close to ninety degree because of the very large value of R_z while the angle corresponding to the argument of the second arctangent term will be very small because of the very small value of C_z). We have calculated the phase difference using the values of different parasitic resistances and capacitances given in Table 1 as per equation (11) and found it to be equal to 89.52^o for a design frequency of 1.59 MHz.

4. PSPICE Simulation Results

We now present some SPICE simulation results to demonstrate the workability of the proposed structure. The CMOS implementation of the CFCC [27] shown in Fig. 3 using 0.18 micron TSMC process technology has been used to verify the workability of the circuit presented in this paper. The values of the DC bias currents and voltages were taken as 40 µA and ± 2.5V respectively. The oscillator was designed for a frequency of 1.59 MHz by appropriately selecting the passive components as follows: C_1= C_2=10 pF, R_1=10 kΩ, R_2=10700 Ω, R_3=10 kΩ, R_4=10 kΩ, R_5=10 kΩ. From SPICE simulations the oscillation frequency was found to be 1.50 MHz. The output waveforms are shown in Figure 4(a). The quadrature relationship of the generated waveform is indicated by the Lissajous pattern shown in Figure 4(b). The measured phase difference was found to be 90.91^o. Figure 5 shows the FFT of the generated waveforms. Total harmonic distortion (THD) for current output I_{01} was found to be 3.2 % and for the current output I_{02} as 5.3 %. These simulation results thus, prove the workability of the proposed circuit.

5. Concluding Remarks

In this letter, a recently proposed active building block, namely, the CFCC has been used to devise a current-mode QSO. The workability of the circuit has been substantiated by SPICE simulations based on a CMOS CFCC implementable in 0.18 µm CMOS technology. The letter has, thus, added a new application of the CFCC in the area of quadrature oscillator realization, whose applications explored and known so far were only in the realization of the simulated impedances of various kinds [26,27].

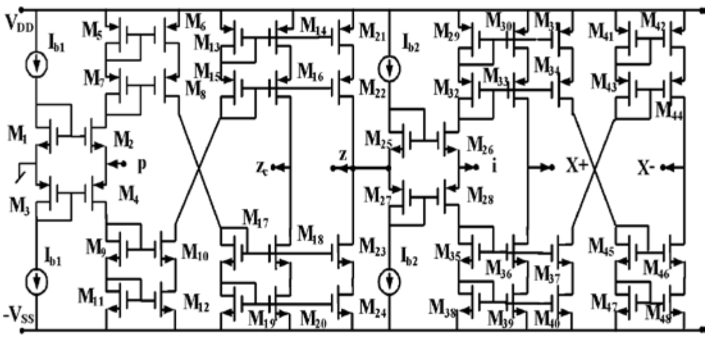

Figure 3. An exemplary CMOS implementation of the ZC-CFCC [26]

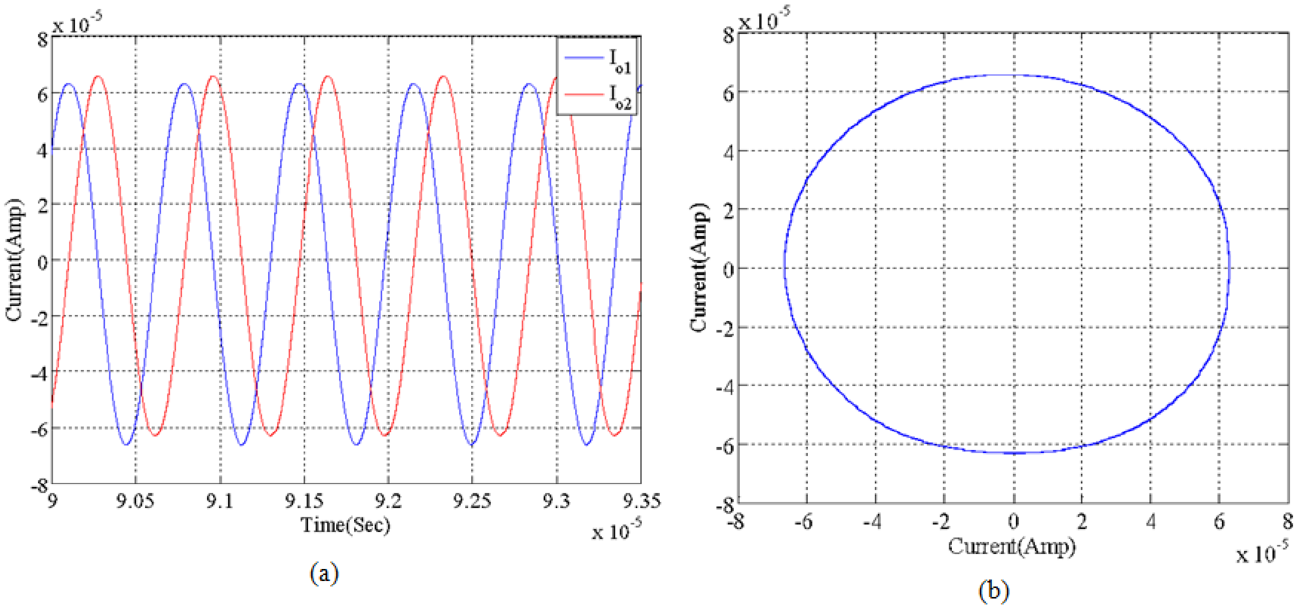

Figure 4. PSPICE Simulation Results (a) Quadrature oscillator waveforms (b) Lissajous pattern

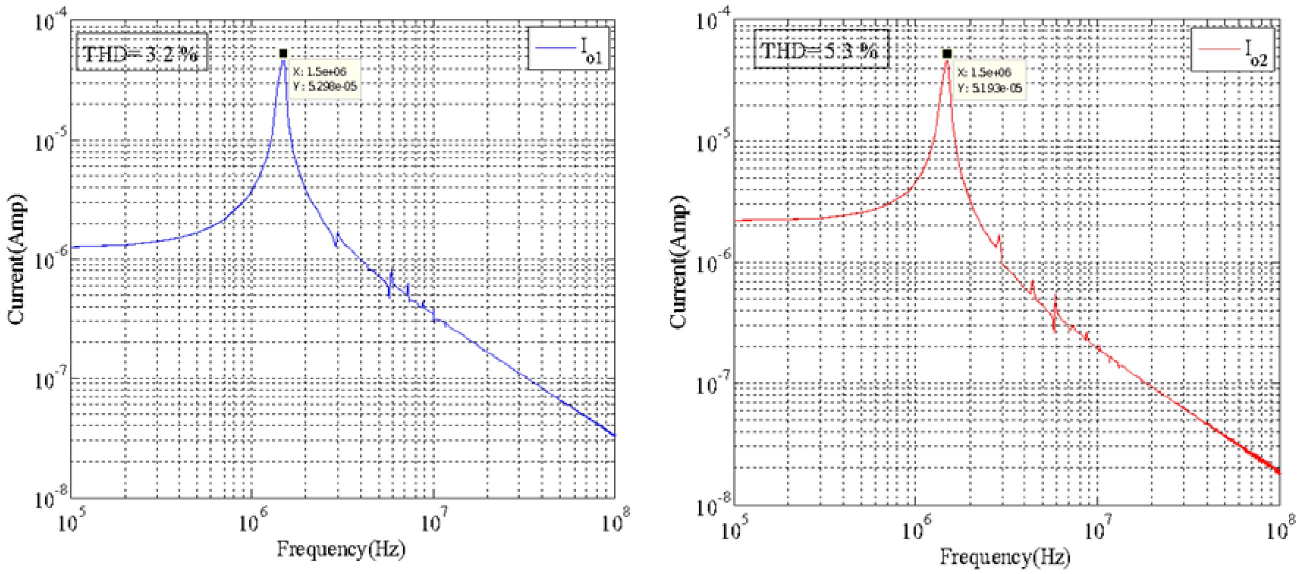

Figure 5. FFT of the waveforms of $I_{o1}$and I_{o2} at 1.50 MHz

References

[1] Senani, R., Bhaskar, D. R., Singh, V. K., and Sharma, R. K., Sinusoidal oscillators and waveform generators using modern electronic circuit building blocks, Springer International Publishing, Switzerland, 2016.

[2] Biolek, D., Senani, R., Biolkova, V., and Kolka, Z., "Active elements for analog signal processing: Classification, review, and new proposals", *Radioengineering*, 17(4), 15-32. Dec.2008.

[3] Pathak, J. K., Singh, A. K., and Senani, R., "Systematic realisation of quadrature oscillators using current differencing buffered amplifiers", *IET Circuits, Devices and Systems*, 5(3), 203-211, Mar.2011.

[4] Lahiri, A., "New Realizations of Voltage-Mode quadrature oscillators using current differencing buffered amplifiers", *Journal of Circuits, Systems and Computers*, *19*(05), 1069-1076, May 2010.

[5] Malhotra, C., Ahalawat, V., Kumar, V. V., Pandey, R., and Pandey, N., "Voltage differencing buffered amplifier based quadrature oscillator", in *2016 IEEE 1st International conference on power electronics, intelligent control and energy systems (ICPEICES)*, 1-4.

[6] Prasad, D., Srivastava, M., and Bhaskar, D. R., "Electronically controllable fully-uncoupled explicit current-mode quadrature oscillator using VDTAs and grounded capacitors", *Circuits and Systems*, 4(2), 169-172, 2013.

[7] Sotner, R., Kledrowetz, V., Jerabek, J., and Prokop, R., "Simple CMOS voltage differencing current conveyor-based electronically tunable quadrature oscillator", *Electronics Letters*, 52(12), 1016-1018, 2016.

[8] Jin, J., and Wang, C., "Current-mode universal filter and quadrature oscillator using CDTAs", *Turkish Journal of Electrical Engineering and Computer Sciences*, 22(2), 276-286, 2014.

[9] Summart, S., Thongsopa, C., and Jaikla, W., "New current-controlled current-mode sinusoidal quadrature oscillators using CDTAs", *AEU - International journal of electronics and communications*, 69(1), 62-68, 2015.

[10] Lahiri, A., "New current-mode quadrature oscillators using CDTA. *IEICE Electronics Express*, 6(3), 135–140, 2009.

[11] Jaikla, W., Siripruchyanun, M., Bajer, J., and Biolek, D. (2008). A simple current-mode quadrature oscillator using single CDTA", *Radioengineering*, 17(4), 33-40.

[12] Keskin, A. U., and Biolek, D., "Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA)", *IEE Proceedings- Circuits, Devices and Systems*, 153(3), 214-218, 2006.

[13] Prasad, D., Bhaskar, D. R., and Singh, A. K., “Electronically controllable grounded capacitor current-mode quadrature oscillator using single MO-CCCDTA”, *Radioengineering”*, 20(1), 354-359, 2011.

[14] Li, Y., “Electronically tunable current-mode quadrature oscillator using single MCDTA”, *Radioengineering”*, 19(4), 667-671, 2010.

[15] Kumari, S., and Gupta, M., “Design and analysis of high Transconductance Current Follower Transconductance Amplifier (CFTA) and its applications”, *Analog Integrated Circuits and Signal Processing”*, 93(3), 489-506, 2017.

[16] Tangsrirat, W., Mongkolwai, P., and Pukkalanun, T., “Current-mode high-Q bandpass filter and mixed-mode quadrature oscillator using ZC-CFTAs and grounded capacitors”, *Indian Journal of Pure and Applied Physics*, 50(8), 600-607, 2012.

[17] Lahiri, A., “Explicit-current-output quadrature oscillator using second-generation current conveyor transconductance amplifier”, *Radioengineering*, 18(4), 522-526, 2009.

[18] Herencsar, N., Koton, J., Vrba, K., and Lahiri, A., “New voltage-mode quadrature oscillator employing single DBTA and only grounded passive elements”, *IEICE Electronics Express*, 6(24), 1708-1714, 2009.

[19] Tangsrirat, W., and Surakampontorn, W., “Single-resistance-controlled quadrature oscillator and universal biquad filter using CFOAs”, *AEU-International Journal of Electronics and Communications*, 63(12), 1080-1086, 2009.

[20] Maheshwari, S., Mohan, J., and Chauhan, D. S., “High input impedance voltage-mode universal filter and quadrature oscillator”, *Journal of Circuits, Systems and Computers*, 19(7), 1597-1607, 2010.

[21] Jaikla, W., Siripruchyanun, M., and Lahiri, A., “Resistorless dual-mode quadrature sinusoidal oscillator using a single active building block”, *Microelectronics Journal*, 42(1), 135-140, 2011.

[22] Channumsin, O., and Tangsrirat, W., “VDIBA-based sinusoidal quadrature oscillator”, *Przeglad Electrotechniczny*, 93(3), 248-25, 2017.

[23] Pushkar, K. L., “Electronically controllable quadrature sinusoidal oscillator using VD-DIBAs”, *Circuits and Systems*, 9(3), 41-48, 2018.

[24] Bajer, J., Vavra, J., and Biolek, D., “Voltage-mode quadrature oscillator using VD-DIBA active elements”, in 2014 *IEEE Asia Pacific Conference on Circuits and Systems* (Ishigaki), 197-200.

[25] Herencsar, N., Lahiri, A., Vrba, K., and Koton, J.,“An electronically tunable current-mode quadrature oscillator using PCAs”, *International Journal of Electronics*, 99(5), 609-62, 2012.

[26] Singh, A. K., Kumar, P., and Senani, R.,“New grounded immittance simulators employing a single CFCC, *The Journal of Engineering*, 17(8), 435-447, 2017.

[27] Singh, A. K., Kumar, P., and Senani, R., “Electronically tunable grounded/floating inductance simulators using Z-copy CFCCC. *Turkish Journal of Electrical Engineering and Computer Sciences*, 26(2), 1041-1055, (2018).