New Compact VM Four-Phase Oscillator Employing Only Single Z-Copy VDTA and All Grounded Passive Elements

N. Herencsar[1], R. Sotner[2], J. Koton[1], J. Misurec[1], K. Vrba[1]
[1]*Department of Telecommunications, Brno University of Technology, Technicka 12, 616 00 Brno, Czech Republic*
[2]*Department of Radio Electronics, Brno University of Technology, Technicka 12, 616 00 Brno, Czech Republic*
herencsn@feec.vutbr.cz

***Abstract*—In this paper, a new compact voltage-mode four-phase oscillator employing single z-copy voltage differencing transconductance amplifier (ZC-VDTA) and only grounded passive elements is introduced. The use of only grounded capacitors and resistors makes the proposed circuit ideal for integrated circuit implementation. The condition of oscillation and the frequency of oscillation are independently adjustable. The passive and active sensitivities of the proposed circuit configuration are low. Experimental measurement results using readily available Maxim Integrated ICs MAX435 are given to prove the theory.**

***Index Terms*—Analog signal processing, four-phase oscillator, voltage-mode, z-copy voltage differencing transconductance amplifier, ZC-VDTA.**

I. INTRODUCTION

Sinusoidal oscillators are linear electric circuits that are used in wide area of electronics and represent an important unit in many radio receivers, telecommunication, instrumentation, control and data monitoring systems [1]–[3]. Recently the voltage-mode (VM) four-phase oscillators, which are special type of multiphase oscillators, have received considerable attention in the literature [4]–[13]. In Table I the available circuits are listed and compared based on relevant criterions. The given survey shows that these oscillator structures are based on operational amplifiers (Op-Amps) [4], [7], differential difference current conveyors (DDCCs) [5], second-generation current conveyors (CCIIs) [6], [8], [9], differential output-current inverter buffered amplifier (DO-CIBA) [10], voltage differencing inverting buffered amplifiers (VDIBAs) [12], or dual-output controlled gain current follower buffered amplifiers (DO-CG-CFBAs) and current amplifier (CA) [13]. In addition, the Complementary Metal–Oxide–Semiconductor (CMOS)-RC based oscillators are recently also popular [11]. Considering the number of active elements in above mentioned VM four-phase oscillators it can be seen that at least two active building blocks (ABBs) are required for their realization. However, our detailed study showed that used ABBs in [10] and [12] represent an interconnection of two sub-circuits such as current inverter and differential output buffered amplifier in case of [10] or operational transconductance amplifier (OTA) [14] and unity-gain inverting voltage buffer in [12]. It should be also mentioned that in [5] and [7] additional voltage followers/inverters are needed. Hence, in these circuits excessive number of ABBs is used. From the monolithic integration point of view, circuits that employ only grounded passive elements are attractive. Only circuits in [6], [8], and [9] satisfy this crucial criterion. However, the oscillator in [8] employs one additional capacitor (in total three) that significantly increases the chip area in case of integration.

In 2008, set of new ABB concepts have been introduced [14] from them recently probably the voltage differencing transconductance amplifier (VDTA) received the most of attention [15]–[19]. The VDTA belongs to new group of ABBs so-called ‘voltage differencing’ elements and it is a ‘voltage’ counterpart of the well-know current differencing transconductance amplifier (CDTA) [14].

In this paper, to increase the universality of the conventional VDTA, the “z-current copy” technique is with advantage used, which was previously introduced for other circuit concepts [14]. In [15]–[19] VDTA-based VM and current-mode (CM) second- and four-order filters, lossless grounded & floating inductance simulators, and CM quadrature oscillators were published. Based on CM concept from [19], this paper presents the first VM four-phase quadrature oscillator using VDTA in the literature and its practical realization including amplitude gain control (AGC) circuit. The proposed circuit employs only single z-copy VDTA. Hence, the number of ABBs against [4]–[13] is reduced. Moreover, it employs only grounded capacitors and

Manuscript received January 30, 2013; accepted May 21, 2013.
Ing. Norbert Herencsar, Ph.D. was supported by the project CZ.1.07/2.3.00/30.0039 of Brno University of Technology. Research described in this paper was also in part supported by the project SIX CZ.1.05/2.1.00/03.0072 from the operational program Research and Development for Innovation, by the project WICOMT CZ.1.07/2.3.00/20.0007 financed from the operational program Education for competitiveness, and Czech Science Foundation projects under No. P102/11/P489 and P102/09/1681.

resistors that make the circuit ideal for integrated circuit implementation. Experimental measurement results on frequency of oscillation equal to 4 MHz with satisfactory total harmonic distortion are included to support the theory.

TABLE I. COMPARATIVE STUDY WITH PREVIOUSLY REPORTED VM FOUR-PHASE OSCILLATORS.

Ref.	ABB type	No. of ABBs	No. of grounded *R / C*	No. of floating *R / C*	Results	f_0 (Hz)	THD (%)
[4]	Op-Amp	4	0 / 2	10 / 0	measurements	22.89 k	< 0.1
[5]	DDCC	4^b	2 / 2	2 / 0	simulations	500 k	–
[6]	CCII	3	6 / 2	0 / 0	simulations	10 k	–
[7]	Op-Amp	5^b	0 / 1	3 / 1	simulations	10 k	–
[8]	CCII	3	5 / 3	0 / 0	simulations	1 M	–
[9]	CCII	2	5 / 2	0 / 0	simulations	1 M	–
[10]	DO-CIBA	2	0 / 2	3 / 0	measurements	1 M	0.07
[11]	$–^a$	–	0 / 0	4 / 2	simulations	160.2 k	< 2.5
[12]	VDIBA	2	1 / 1	0 / 1	simulations	8.5 M	< 2.25
[13]	DO-CG-CFBA+CA	3	0 / 2	3 / 0	simul. / meas.	978 k / 2.5 M	< 1 / < 0.6
Prop.	ZC-VDTA	1	3 / 2	0 / 0	measurements	4 M	0.4 – 3.1

Notes:
– Not mentioned or not applicable;
[a] CMOS-RC circuit; [b] Ref. [5] includes one voltage inverter and one voltage follower, [7] includes two voltage inverters and two voltage followers.

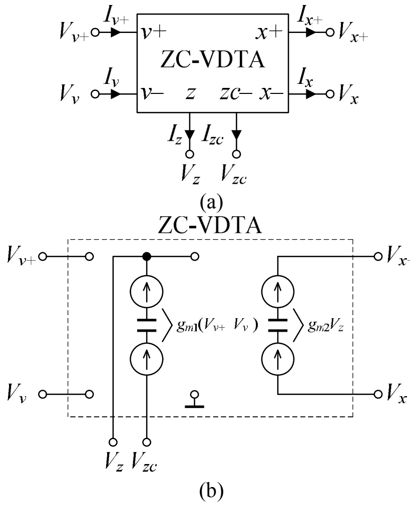

Fig. 1. (a) Circuit symbol and (b) behavioral model of ZC-VDTA.

II. CIRCUIT DESCRIPTION

The circuit symbol and behavioral model of ZC-VDTA are shown in Fig. 1(a) and Fig. 1(b), respectively. The ZC-VDTA essentially consists of two balanced-output OTAs, wherein the difference of input voltages V_{v+} and V_{v-} is transferred by the first transconductance gain g_{m1} to current at the terminals *z* and *zc–* (negative of *z*) and the voltage drop at the terminal *z* is transferred to current at the terminals *x+* and *x–* (negative of *x+*) by second transconductance gain g_{m2}. In practice both transconductances $g_{m1,2}$ can be simultaneously electronically controlled by either external DC bias currents or voltages. All six terminals exhibit high-impedance values. Using standard notation, the terminals relationship of an ideal ZC-VDTA can be characterized by the following hybrid matrix

$$\begin{bmatrix} I_z \\ I_{zc-} \\ I_{x+} \\ I_{x-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ -g_{m1} & g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} V_{v+} \\ V_{v-} \\ V_z \end{bmatrix}. \quad (1)$$

The proposed realization of VM four-phase oscillator employing single ZC-VDTA, two capacitors, and three resistors, all in grounded form, is shown in Fig. 2. Using (1), routine circuit analysis yields the following characteristic equation (CE).

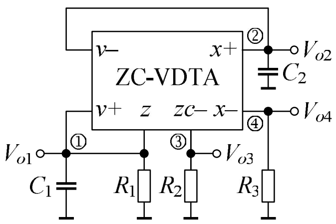

Fig. 2. Proposed VM four-phase oscillator.

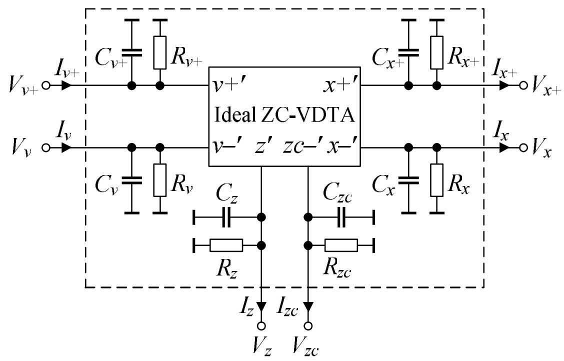

Fig. 3. Model of the ZC-VDTA including parasitic elements.

$$\text{CE}: \quad s^2 C_1 C_2 R_1 + s C_2 \left(1 - g_{m1} R_1\right) + g_{m1} g_{m2} R_1 = 0. \quad (2)$$

From (2) the condition of oscillation (CO) and the frequency of oscillation (FO) can be evaluated as:

$$\text{CO}: \quad g_{m1} R_1 \geq 1, \quad (3)$$

$$\text{FO}: \quad f_0 = \frac{1}{2\pi} \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}}. \quad (4)$$

From (3) and (4) it is clear that the CO can be controlled independently of FO by means of varying the resistor R_1 and the FO can be adjusted by the transconductance g_{m2}, respectively. Thus, the proposed oscillator is an SRCO and provides independent control of the CO and the FO.

III. NON-IDEAL ANALYSIS

For a complete analysis, it is important to take into account parasitics of active element shown in Fig. 3:

– $I_z = \alpha_1 g_{m1} V_d$, $I_{zc-} = -\alpha_2 g_{m1} V_d$, $I_{x+} = \beta_1 g_{m2} V_z$, $I_{x-} = -\beta_2 g_{m2} V_z$, where $V_d = (V_{v+} - V_{v-})$, α_i and β_i represent transconductance gains of the ZC-VDTA that differ from their ideal values by transconductance tracking errors ε_{1i} and ε_{2i} ($|\varepsilon_{1i}|, |\varepsilon_{2i}| \ll 1$), where $i = 1, 2$.

– The parasitic resistances R_{v+}, R_{v-} and parasitic capacitances C_{v+}, C_{v-} appear between the high-impedance $v+$ and $v-$ input terminals of the ZC-VDTA and ground, respectively, and their typical values in case of ZC-VDTA implementation by Maxim Integrated ICs MAX435 are 800 kΩ ‖ 5 pF.

– The parasitic resistances R_z, R_{zc-} and parasitic capacitances C_z, C_{zc-} appear between the high-impedance z and $zc-$ auxiliary terminals of the ZC-VDTA and ground, respectively, and their typical values are 3.48 kΩ ‖ 10 pF and 3.5 kΩ ‖ 5 pF, respectively.

– The parasitic resistances R_{x+}, R_{x-} and parasitic capacitances C_{x+}, C_{x-} appear between the high-impedance $x+$ and $x-$ output terminals of the ZC-VDTA and ground, respectively, and their typical values are 3.5 kΩ ‖ 5 pF.

Considering the effect of aforementioned non-idealities on the proposed oscillator shown in Fig. 2, the following useful analysis can be provided:

– At the node 1 the parasitic resistances R_{v+}, R_z and capacitances C_{v+}, C_z are absorbed into external resistor R_1 and capacitor C_1, respectively, as they appear in shunt with them and in analysis below they are labeled as R_1' and C_1'.

– At the node 2 the parasitic capacitances C_{v-} and C_{x+} are absorbed into external capacitor C_2 as it appears in shunt with them and in further analysis it is labeled as C_2'. Furthermore, it must be also mentioned that in the same node the parasitic resistances R_{v-} and R_{x+} are also in shunt and in further analysis labeled as R_{vx}.

– At nodes 3, 4 the parasitic resistances R_{zc-}, R_{x-} are absorbed into external resistors R_2 and R_3, respectively, as they appear in shunt with them and labeled as R_2' and R_3'.

Thus, the non-ideal effects of parasitic impedance at 1st, 3rd, and 4th nodes of the proposed oscillator are reduced, if not completely eliminated. At the node 2 the parasitic capacitance can also be absorbed in the external capacitor, but the presence of parasitic resistance R_{vx} at this node would change the type of the impedance, which should be of a purely capacitive character. A possible solution is to make the operating frequency $f_0 > 1/(2\pi R_{vx} C_2)$. Taking into account the aforementioned non-idealities, except for the parasitic capacitances C_{zc-} and C_{x-}, the CE in (2) becomes

$$\text{CE}': \; s^2 C_1' C_2' R_{vx} R_1' + s\left(C_1' R_1' + C_2' R_{vx} - \alpha_1 C_2' R_{vx} R_1' g_{m1}\right) + \\ + \alpha_1 \beta_1 R_{vx} R_1' g_{m1} g_{m2} - \alpha_1 R_1' g_{m1} + 1 = 0, \tag{5}$$

which by neglecting the parasitic resistance R_{vx} turns to a form

$$\text{CE}'': s^2 C_1' C_2' R_1' + s C_2' \left(1 - \alpha_1 R_1' g_{m1}\right) + \\ + \alpha_1 \beta_1 R_1' g_{m1} g_{m2} = 0, \tag{6}$$

that only by non-ideal transconductance gains α_1 and β_1 differs from the ideal CE in (2) and subsequently from the ideal CO and FO in (3) and (4). Hence, in practice a precise design of the ZC-VDTA should be considered to alleviate the non-ideal effects.

IV. Measurement Results

In order to confirm the theoretical study, the behavior of the proposed VM four-phase oscillator has been verified by experimental measurements. The complete circuit configuration of the proposed oscillator supplemented by AGC circuit including specific values of passive elements is shown in Fig. 4. In measurements the ZC-VDTA was implemented using commercially available ICs MAX435 by Maxim Integrated. The DC power supply voltages were equal to ±5 V. Generated voltages in all nodes are available through additional voltage buffers. For this purpose operational amplifier LT1364 was used. The AGC circuit contains cascade diode doubler and BS250 FET transistor. Experimental measurements were carried out using RIGOL DS1204B four-channel oscilloscope and HP4395A network-spectrum analyzer. The spectrum analyzer requires impedance matching (50 Ω). Therefore, the voltage buffers LT1364 have been very important.

Measurement results are shown in Fig. 5–Fig. 7. Figure 5 shows all four transient responses together. Experimentally measured oscillation frequency was $f_0 \cong 4$ MHz, which matches well with theory. The frequency spectrum for V_{o2} is depicted in Fig. 6.

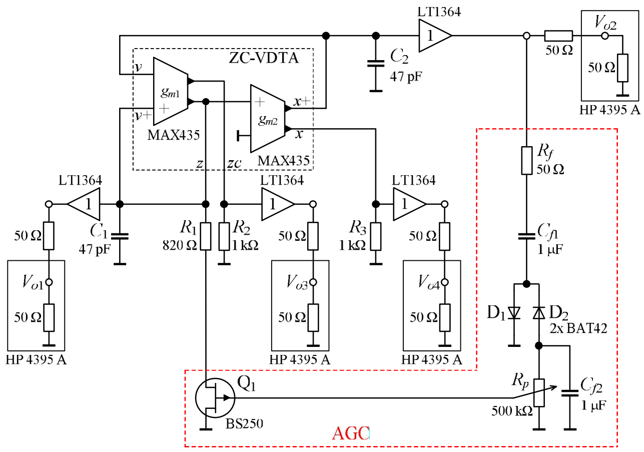

Fig. 4. Complete circuit configuration used for experimental test.

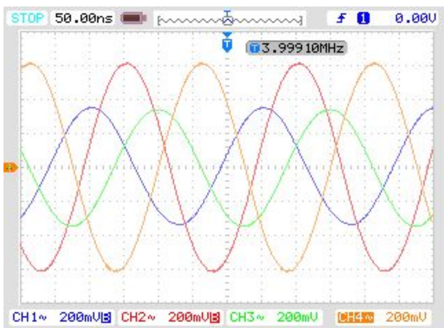

Fig. 5. Measurement results: transient responses at all four outputs (V_{o1} - blue color, V_{o2} - red color, V_{o3} - green color, V_{o4} - orange color).

THD value obtained from measurements for output amplitudes V_{o2} at $f_0 \cong 4$ MHz was 0.58 %. Tunability of f_0 via g_{m2} and output voltage levels and THD vs. f_0 during the tuning process are shown in Fig. 7. Ideal frequency range of FO tuning was calculated from 2.18 to 14.49 MHz. However, this calculation does not take into account the main real features of active elements used. Therefore, expected range of FO = {1.65 – 11} MHz was obtained by more accurate calculation, which includes mainly parasitic capacitances and low values of resistance in high-impedance nodes (outputs of MAX435).

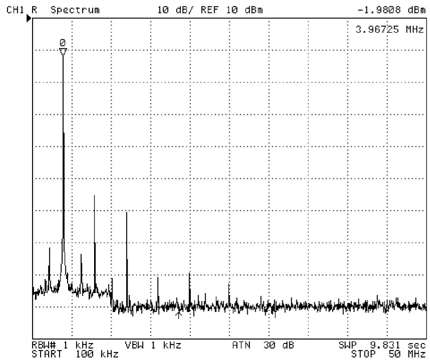

Fig. 6. Frequency spectrum for V_{o2}.

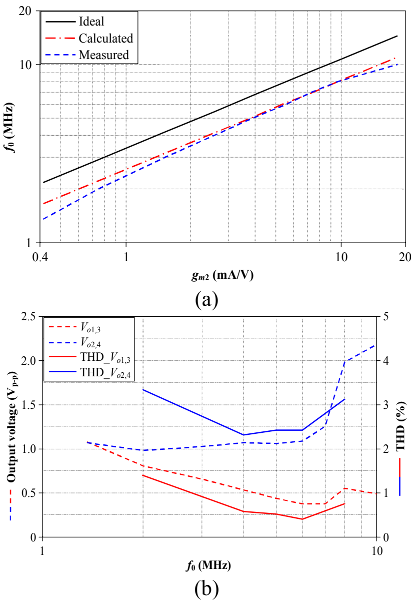

Fig. 7. (a) Tunability of f_0 via g_{m2}, (b) output voltage levels and THD vs. f_0 during the tuning process.

Measured frequency range corresponds with expected calculations, since FO was in range from 1.36 MHz–10 MHz. Adjustment of FO was realized by changes of transconductance g_{m2} from 0.4 mA/V to 18.3 mA/V. For $V_{o1,3}$ output amplitudes reached values from 0.5 V to 1 V and for $V_{o2,4}$ from 1.1 V to 2.2 V, respectively. THD values fluctuate between 0.4 %–1.4 % and 2.3 %–3.1 % for outputs $V_{o1,3}$ and $V_{o2,4}$, respectively. In addition, the amplitude of $V_{o1,3}$ are almost unchangeable in range from 1.36 MHz to 7 MHz. In overall, obtained results match very well with theory.

V. CONCLUSIONS

This paper presented a new compact voltage-mode four-phase oscillator employing recently introduced single z-copy voltage differencing transconductance amplifier and only grounded passive elements. The use of only grounded capacitors and resistors makes the proposed circuit ideal for integrated circuit implementation. The condition of oscillation and the frequency of oscillation are independently adjustable. Experimental results using commercially available integrated circuits confirm the feasibility of the proposed circuit.

REFERENCES

[1] N. Herencsar, J. Koton, K. Vrba, I. Lattenberg, "New voltage-mode universal filter and sinusoidal oscillator using only single DBTA", *Int. Journal of Electronics*, vol. 97, no. 4, pp. 365–379, 2010. [Online]. Available: http://dx.doi.org/10.1080/00207210903325229

[2] A. Meister, T. Ruuben, "Some signal processing aspects in software defined radios", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering)*, no. 4, pp. 97–100, 2008.

[3] M. Vaitkunas, A. Dosinas, V. Bartkevicius, J. Daunoras, "Respiratory signal estimation using non-invasive measurements", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering)*, no. 1, pp. 35–38, 2009.

[4] S. J. G. Gift, "The application of all-pass filters in the design of multiphase sinusoidal systems", *Microelectronics Journal*, vol. 31, no. 1, pp. 9–13, 2000. [Online]. Available: http://dx.doi.org/10.1016/S0026-2692(99)00084-1

[5] J.–W. Horng, C.–L. Hou, C.–M. Chang, Y.–T. Lin, I.–C. Shiu, W.–Y. Chiu, "First-order allpass filter and sinusoidal oscillators using DDCCs", *Int. Journal of Electronics*, vol. 93, no. 7, pp. 457–466, 2006. [Online]. Available: http://dx.doi.org/10.1080/00207210600711481

[6] N. Minhaj, "Current conveyor-based voltage-mode two-phase and four-phase quadrature oscillators", *Int. Journal of Electronics*, vol. 94, no. 7, pp. 663–669, 2007. [Online]. Available: http://dx.doi.org/10.1080/00207210701405876

[7] T. Parveen, I. A. Khan, M. T. Ahmed, "Realization of four phase sinusoidal quadrature oscillator using operational amplifier", *Journal of Active and Passive Electronic Devices*, vol. 2, pp. 171–176, 2007.

[8] N. Minhaj, "CCII-based single-element controlled quadrature oscillators employing grounded passive components", *Int. Journal of Recent Trends in Engineering*, vol. 1, no. 3, pp. 294–296, 2009.

[9] P. Beg, I. A. Khan, M. T. Ahmed, "Tunable four phase voltage mode quadrature oscillator using two CMOS MOCCIIs", in *Proc. Int. Conf. on Multimedia, Signal Processing and Communication Technologies IMPACT 2009*, Aligarh, India, 2009, pp. 155–157.

[10] V. Biolkova, J. Bajer, D. Biolek, "Four-phase oscillators employing two active elements", *Radioengineering*, vol. 20, pp. 334–339, 2011.

[11] A. Lahiri, N. Herencsar, "CMOS-based active RC sinusoidal oscillator with four-phase quadrature outputs and single-resistance-controlled (SRC) tuning laws", *AEU – Int. Journal of Electronics and Communications*, vol. 66, no. 12, pp. 1032–1037, 2012. [Online]. Available: http://dx.doi.org/10.1016/j.aeue.2012.05.008

[12] N. Herencsar, S. Minaei, J. Koton, E. Yuce, K. Vrba, "New resistorless and electronically tunable realization of dual-output VM all-pass filter using VDIBA", *Analog Integrated Circuits and Signal Processing*, vol. 74, no. 1, pp. 141–154, 2013. [Online]. Available: http://dx.doi.org/10.1007/s10470-012-9936-2

[13] R. Sotner, N. Herencsar, J. Jerabek, J. Koton, T. Dostal, K. Vrba, "Electronically controlled oscillator with linear frequency adjusting for four-phase or differential quadrature output signal generation", *Int. Journal of Circuit Theory and Applications*, 2013. [Online]. Available: http://dx.doi.org/10.1002/cta.1919

[14] D. Biolek, R. Senani, V. Biolkova, Z. Kolka, "Active elements for analog signal processing: classification, review, and new proposals", *Radioengineering*, vol. 17, no. 4, pp. 15–32, 2008.

[15] A. Yesil, F. Kacar, H. Kuntman, "New simple CMOS realization of voltage differencing transconductance amplifier and its RF filter application", *Radioengineering*, vol. 20, no. 3, pp. 632–637, 2011.

[16] J. Satansup, T. Pukkalanun, W. Tangsrirat, "Electronically tunable single-input five-output voltage-mode universal filter using VDTAs and grounded passive elements", *Circuits, Systems, and Signal Processing*, vol. 32, no. 3, pp. 945–957, 2013. [Online]. Available: http://dx.doi.org/10.1007/s00034-012-9492-0

[17] D. Prasad, D. R. Bhaskar, M. Srivastava, "Universal current-mode biquad filter using a VDTA", *Circuits and Systems*, vol. 4, no. 1, pp. 32–36, 2013. [Online]. Available: http://dx.doi.org/10.4236/cs.2013.41006

[18] D. Prasad, D. R. Bhaskar, "Grounded and floating inductance simulation circuits using VDTAs", *Circuits and Systems*, vol. 3, no. 4, pp. 342–347, 2012. [Online]. Available: http://dx.doi.org/10.4236/cs.2012.34048

[19] D. Prasad, D. R. Bhaskar, "Electronically controllable explicit current output sinusoidal oscillator employing single VDTA", *ISRN Electronics*, vol. 2012, pp. 1–5, 2012. [Online]. Available: http://dx.doi.org/10.5402/2012/382560