Resistor-less Realization of Third-Order Quadrature Sinusoidal Oscillators Using CMOS VDIBAs

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Abstract: This article presents the two third-order sinusoidal quadrature oscillators (TOQSOs). These oscillators utilize three voltage differencing inverting buffered amplifiers (VDIBAs) along with three grounded capacitors (GCs), rendering them well-suited for integration within integrated circuits (ICs). The proposed configurations offer two quadrature voltage outputs. A significant advantage of these new oscillators is their self-regulating electronic control over both the condition of oscillation (CO) and the frequency of oscillation (FO). This control is achieved through separate transconductance elements for each oscillator. Moreover, the sensitivity analysis of FO concerning the active and passive components reveals that they exhibit low sensitivity. Another noteworthy feature of the presented oscillator designs is their low total harmonic distortion (THD), which enhances their overall performance. To validate the feasibility of these oscillators, PSPICE simulations have been conducted using 0.18um TSMC parameters, confirming their practicality and effectiveness.

Keywords: Voltage Differencing Inverting Buffered Amplifier; TOQSO; Voltage mode; Analog Circuit Design

1. Introduction

The analog signal processing (ASP) has experienced substantial growth and progress throughout recent decades. It encompasses diverse facets, including the design of analog active filters, sinusoidal oscillators, quadrature sinusoidal oscillators, and higher-order oscillators utilizing active building blocks. These foundational components find extensive utility in contemporary communication and instrumentation systems. Notably, sinusoidal oscillators have garnered significant attention and are widely applied in telecommunications, control systems, instrumentation, and measurement systems. Another crucial variant is the quadrature sinusoidal oscillator (QSO), generating output voltages and currents with a 90-degree phase disparity. QSOs play a pivotal role in quadrature mixers, single-sideband generators, vector generators, and selective voltmeters [2]. In recent times, the attention has shifted towards third-order sinusoidal oscillators due to their elevated waveform quality, minimal harmonic content, heightened accuracy, and reduced noise in comparison to their second-order counterparts [4]-[43]. The literature abounds with various designs of third-order sinusoidal oscillators, each offering distinct features like orthogonal control, non-interfering control, complete independence in control, electronic manipulation of the oscillation condition (CO) and oscillation frequency (FO), as well as providing either voltage or current quadrature outputs. This paper in on third-order sinusoidal oscillators and delivers a comparative overview of previously documented endeavors. Some of these undertakings utilized mixed active devices for implementing third-order quadrature oscillators [13] - [15], [21], necessitating a greater number of MOSFETs and BJTs as opposed to the proposed approach [4] - [43]. Certain designs incorporated floating capacitors [6, 18, 23, 24, 30, 34, 39, 41], while others lacked electronic control over CO and FO [6, 8, 12, 15, 18, 20, 22-24, 30, 39, 42], or the independent manipulation of both CO and FO [6], [17], [18], [20], [24], [36], [38].A comprehensive survey reveals that limited research has been conducted on third-order quadrature oscillators using voltage differencing inverting buffered amplifiers (VDIBAs) [44] - [49]. Consequently, a significant scope exists for creating novel configurations of third-order quadrature oscillators utilizing VDIBAs. Consequently, this paper presents two novel TOQSO configurations utilizing three VDIBAs and three grounded capacitors (GCs). These configurations enable electronically self-regulating CO without affecting the FO. Both CO and FO can be electronically controlled using separate transconductance elements. The feasibility and performance of the proposed circuits have been verified through PSPICE simulations, employing a CMOS VDIBA implementation with 0.18µm TSMC parameters.

2. DESIGN APPROACH OF PROPOSED TOQSOs

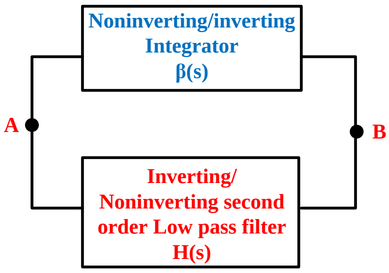


Fig. 1. Scheme for realizing TOQSO using low pass filter

The proposed third-order quadrature oscillators (TOQSOs) are based on two distinct design approaches. The first approach involves cascading an inverting second-order low-pass filter with a non-inverting integrator within a loop that utilizes unity feedback. The second approach utilizes a cascading of a non-inverting second-order low-pass filter with an inverting integrator, also within a loop with unity feedback. The schematic representation of these two designs is depicted in Figure 3. In both cases, the resulting circuits form closed-loop systems with a loop gain denoted as H(s)β(s). The criterion for the oscillation of these TOQSOs is determined by this closed-loop system.

$$1- H(s) \beta(s) = 0 \quad (1)$$

When Equation (1) is fulfilled, the system will exhibit quadrature phase oscillations at nodes A and B, respectively. The general characteristics equation (CE) of the third-order quadrature oscillators can be derived as follows:

$$CE: b_3 s^3 + b_2 s^2 + b_1 s^1 + b_0 = 0$$

All the roots of equation (2) must lie in right half of s plane for oscillations and using the Routh Hurwitz criterion, CO and FO obtained,

$$CO: b_0 b_3 \geq b_1 b_2 \quad (3)$$

$$FO: \omega_0 = \sqrt{\frac{b_3}{b_1}} \; or \; \sqrt{\frac{b_2}{b_0}} \quad (4)$$

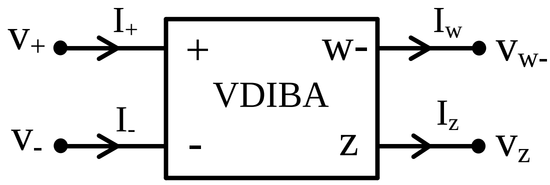
In the prior art of work, various approaches have been used to design TOQSO circuits.

3. PROPOSED CONFIGURATIONS

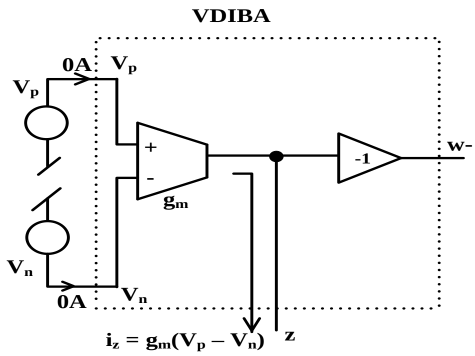
The VDIBA (Voltage Differencing Inverting Buffered Amplifier) is a four-terminal active device. It combines a differential transconductance stage with a unity-gain inverting buffer amplifier to generate voltage output. The behavior of VDIBA can be described by the following equations [44].

$$I_+ = 0, \; I_- = 0$$
$$I_z = g_m (V^+ - V^-) \quad (5)$$
and
$$V_{w^-} = -\beta V_z$$

In Equation (5), β represents the non-ideal voltage gain. The ideal value of β is unity (β = 1), and gm denotes the transconductance of the VDIBA. The symbolic representation and behavioral model of the VDIBA are illustrated in Figure 2.



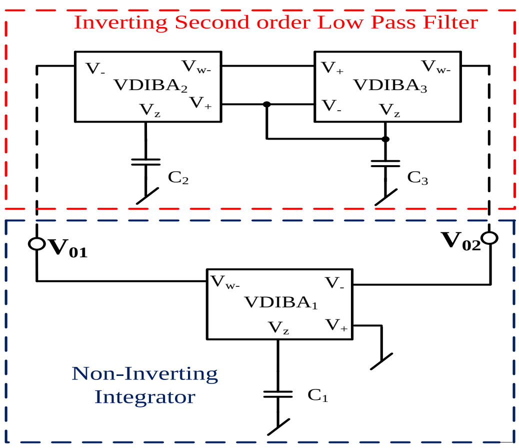
(a)



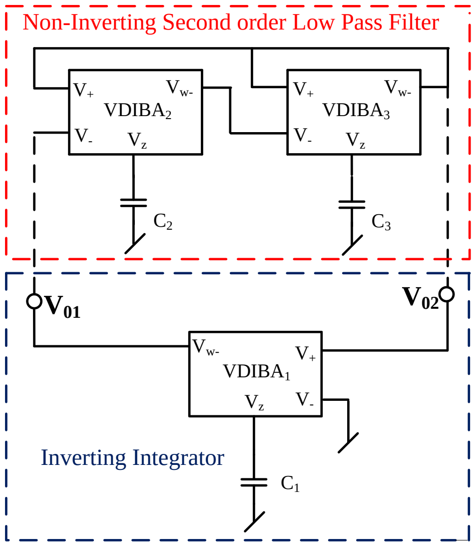
(b)

Fig. 2. (a) Symbolic notation (b) Equivalent model of VDIBA

The proposed voltage-mode TOQSO circuits are shown in Fig. 3.



(a)



(b)

Fig. 3. Proposed two new resistors-less (a) TOQSO-I (b) TOQSO-II

Assuming an ideal VDIBA, performing routine circuit analyses on the proposed circuits leads to the following expression for the characteristic equation (CE):

$$s^3C_1C_2C_3 + s^2C_1C_2g_{m_3} + sC_1g_{m_2}g_{m_3} + g_{m_1}g_{m_2}g_{m_3} = 0$$

Assuming $C_1 = C_2 = C_3 = C$, and after applying Routh-Hurwitz criterion on equation (6) gives the following expressions of CO and FO:

CO: $$g_{m_1} = g_{m_3} \quad (7)$$

FO: $$\omega_0 = \sqrt{\frac{g_{m_1}g_{m_2}}{C_1C_2}} \quad \text{or} \quad \sqrt{\frac{g_{m_3}g_{m_2}}{C_2C_3}} \quad (8)$$

Both TOQSO circuits share the same characteristic equation (CE), condition of oscillation (CO), and frequency of oscillation (FO). Equation (7) and (8) demonstrate that these proposed circuits offer independent control over CO and FO. CO can be electronically set using [variable/control parameter], while FO can be tuned by [another variable/control parameter]. Additionally, as the configurations include integrators, the proposed circuits also provide quadrature output voltage. The quadrature relationship between output voltages V01 and V02 can be expressed as:

$$\frac{V_{01}(s)}{V_{02}(s)} = \frac{g_{m_1}}{sC_1}; \qquad \frac{V_{01}(j\omega)}{V_{02}(j\omega)} = \frac{g_{m_1}}{j\omega C_1}e^{-90^o} \quad (9)$$

Equation (9) tells that the output voltages V_{01} and V_{02} of the suggested TOQSOs are phase-shifted by 90 degrees, indicating a quadrature relationship.

4. NON-IDEAL ANALYSIS OF PROPOSED TOQSOs

The presence of parasitic elements in the VDIBA can impact the performance of the proposed TOQSOs parameters. To challenge this issue, a non-ideal analysis has been executed employing a non-ideal VDIBA model. This model factors in a parallel amalgamation of Rz and 1/sCz at terminal Z, while Rw represents the parasitic resistance at the W-terminal of the VDIBA. Furthermore, a tracking error β is considered for the voltage at the W-terminal, with its non-ideal equation expressed as Vw- = (-βVz + IwRw), where $\beta = 1-\varepsilon_p$ and ε_p is significantly smaller than 1. Taking these non-ideal parameters into account, the expressions for the CE CO, and FO of the proposed TOQSOs can be written as:

CE:

$$\begin{aligned} &s^3(C_1+C_z)(C_2+C_z)(C_3+C_z)R_z^3 + \\ &s^2\left\{\begin{matrix}(C_1+C_2+2C_z)(C_3+C_z)+ \\ (C_1+C_z)(C_2+C_z)(1+g_{m_3}R_z\beta)\end{matrix}\right\}R_z^2 + \\ &s\left\{\begin{matrix}(C_1+C_2+2C_z)(1+g_{m_3}R_z\beta)R_z + \\ (C_1+C_z)g_{m_2}g_{m_3}\beta^2R_z^3 + (C_3+C_z)R_z\end{matrix}\right\} \\ &+ g_{m_1}g_{m_2}g_{m_3}\beta^3R_z^3 + \\ &g_{m_2}g_{m_3}\beta^2R_z^2 + (g_{m_1}R_z+1) = 0 \end{aligned} \quad (10)$$

CO:

$$\begin{aligned} &\{(C_1+C_z)(C_2+C_z)(C_3+C_z)\}\times \\ &\left\{\begin{matrix}g_{m_1}g_{m_2}g_{m_3}\beta^3R_z^3 + g_{m_2}g_{m_3}\beta^2R_z^2 + \\ (g_{m_1}R_z+1)\end{matrix}\right\} = \\ &\left\{\begin{matrix}(C_1+C_2+2C_z)(C_3+C_z)+ \\ (C_1+C_z)(C_2+C_z)(1+g_{m_3}R_z\beta)\end{matrix}\right\}\times \\ &\left\{\begin{matrix}(C_1+C_2+2C_z)(1+g_{m_3}R_z\beta)+ \\ (C_1+C_z)g_{m_2}g_{m_3}\beta^2R_z^2 + (C_3+C_z)\end{matrix}\right\} \end{aligned}$$

(11)

FO:

$$\omega_0 = \sqrt{\frac{\begin{matrix}g_{m_1}g_{m_2}g_{m_3}\beta^3R_z^3 + g_{m_2}g_{m_3}\beta^2R_z^2 + \\ (g_{m_1}R_z+1)\end{matrix}}{R_z^2\left\{\begin{matrix}(C_1+C_2+2C_z)(C_3+C_z)+ \\ (C_1+C_z)(C_2+C_z)(1+g_{m_3}\beta R_z)\end{matrix}\right\}}} \quad (12)$$

The non-idealities in VDIBA have a significant influence on the suggested TOQSOs performance.as evident from equations (10) - (12). To mitigate the effects of parasitic, it is recommended to ensure the following conditions: $R_{MOS2} >> R_W$, $R_{MOS1} << R_Z$, $C_Z >> C_i$ (i = 1-3). To quantify the numerical value of FO owing to non-ideal effects, precise values for passive and parasitic components have been substituted: C_z= 0.367pF, R_z = 131.93kΩ, R_w = 42.36Ω, β = 0.944, $C_1 = C_2 = C_3$ = 100pF, g_{m1} = 519µS, g_{m2} = 360 µS, and g_{m3} = 415µS. As a result, the non-ideal FO is determined to be 752.868kHz, whereas the ideal value of FO is 720.14kHz.

5. Sensitivity Analysis

Sensitivity stands as a pivotal metric in evaluating the efficacy of any circuit. It measures the extent to which a circuit is influenced by the introduction of parasitic and other non-ideal elements. Values of sensitivity below unity indicate improved circuit performance in the presence of such non-idealities. The conventional sensitivity method is employed to assess the sensitivities of FO. This method can be mathematically expressed as:

$$S_X^{F(x)} = \left(\frac{X}{F(x)}\right)\frac{\delta F(x)}{\delta X} \quad (13)$$

Let F(x) represent the parameter for which sensitivities must be evaluated in respect to X, where X is the significant parameter. Using equation (13), we calculated the sensitivities of FO to passive and parasitic components, yielding the following results:

$$S_{g_{m_1}}^{\omega_0} = \frac{1}{2}\frac{g_{m_1}g_{m_2}g_{m_3}\beta^3R_z^3 + g_{m_1}R_z}{A} \quad (14a)$$

$$S_{g_{m_2}}^{\omega_0} = \frac{1}{2}\frac{g_{m_1}g_{m_2}g_{m_3}\beta^3R_z^3 + g_{m_2}g_{m_3}\beta^2R_z^2}{A} \quad (14b)$$

$$S_{g_{m_3}}^{\omega_0} = \frac{1}{2}\frac{B\{g_{m_1}g_{m_2}g_{m_3}\beta^3R_z^3 + g_{m_2}g_{m_3}\beta^2R_z^2\} - A\{R_z\beta(C_1+C_z)(C_2+C_z)\}}{AB} \quad (14c)$$

$$S_{\beta}^{\omega_0} = \frac{1}{2}\frac{B\begin{Bmatrix} g_{m_1}g_{m_2}g_{m_3}3\beta^2R_z^3 + \\ g_{m_2}g_{m_3}2\beta R_z^2 \end{Bmatrix} - A\begin{Bmatrix} R_z g_{m_3}(C_1+C_z) \\ (C_2+C_z) \end{Bmatrix}}{AB} \quad (14d)$$

$$S_{R_z}^{\omega_0} = \frac{R_z}{2}\frac{B\begin{Bmatrix} g_{m_1}g_{m_2}g_{m_3}\beta^3 3R_z^2 + \\ g_{m_1}g_{m_3}\beta 2R_z + g_{m_1} \end{Bmatrix} - A\begin{Bmatrix} 2R_z(C_1+C_2+2C_z)(C_3+C_z) + \\ (C_1+C_z)(C_2+C_z)g_{m_3}\beta \end{Bmatrix}}{AB} \quad (14e)$$

$$S_{C_1}^{\omega_0} = -\frac{1}{2}\frac{\{(C_2+C_z)(g_{m_3}\beta R_z+1) + C_1R_z^2(C_3+C_z)\}}{B} \quad (14f)$$

$$S_{C_2}^{\omega_0} = -\frac{1}{2}\frac{C_2\{R_z^2(C_3+C_z) + (C_1+C_z)(g_{m_3}\beta R_z+1)\}}{B} \quad (14g)$$

$$S_{C_3}^{\omega_0} = -\frac{1}{2}\frac{C_3R_z^2(C_1+C_2+2C_z)}{B} \quad (14h)$$

$$S_{C_z}^{\omega_0} = -\frac{1}{2}\frac{\begin{Bmatrix} (C_1+C_2+2C_z) \\ (g_{m_3}R_z+1) + C_zR_z^2 \\ ((C_1+C_2+2C_3+4C_z)) \end{Bmatrix}}{B} \quad (14i)$$

Here

$$A = g_{m_1}g_{m_2}g_{m_3}\beta^3R_z^3 + g_{m_2}g_{m_3}\beta R_z^2 + g_{m_1}R_z + 1,$$

$$B = R_z^2\begin{Bmatrix} (C_1+C_2+2C_z)(C_3+C_z) + \\ (C_1+C_z)(C_2+C_z)(1+g_{m_3}\beta R_z) \end{Bmatrix}$$

The calculated sensitivities in equations (14a) through (14i) have been determined mathematically, considering the following parameter values: Cz = 0.367pF, Rz = 131.93kΩ, Rw = 42.36Ω, β = 0.944, and C1 = C2 = C3 = 100pF, g_{m1} =519µS, g_{m2} = 360 µS and g_{m3} =415µS. Thus, the numerical values of the sensitivities are found to be:

$$S_{g_{m_1}}^{\omega_0} = 0.4937,\ S_{g_{m_2}}^{\omega_0} = 0.4999,\ S_{g_{m_3}}^{\omega_0} = .4999,$$

$$S_{C_1}^{\omega_0} = -0.2865,\ S_{C_2}^{\omega_0} = -0.0057,\ S_{C_3}^{\omega_0} = -0.0149$$

$$S_{C_z}^{\omega_0} = -0.5614,\ S_{R_z}^{\omega_0} = 0,\ S_{\beta}^{\omega_0} = \frac{1}{2}$$

$$S_{C_1}^{\omega_0} = -0.5,\ S_{C_2}^{\omega_0} = -0.5,\ S_{C_Z}^{\omega_0} = 0,\ S_{R_0}^{\omega_0} = -0.5,$$

$$S_{R_Z}^{\omega_0} = -0.0087,\ S_{g_{m_1}}^{\omega_0} = 0.508,\ S_{g_{m_2}}^{\omega_0} = 0.0147$$

and $S_{\beta^+}^{\omega_0} = 0.508$

Based on the preceding computations, it is evident that the sensitivities derived for FO concerning various passive and parasitic components yield negative values, all of which remain below 0.5.

6. SIMULATION RESULTS

PSPICE simulation results utilizing a CMOS VDIBA created using the 180nm TSMC technology specifications validated the correctness of the recommended designs for TOQSOs.The CMOS realization of the VDIBA is illustrated in Figure 4, with the corresponding aspect ratios of the transistors employed in Figure 4 detailed in Table 1.

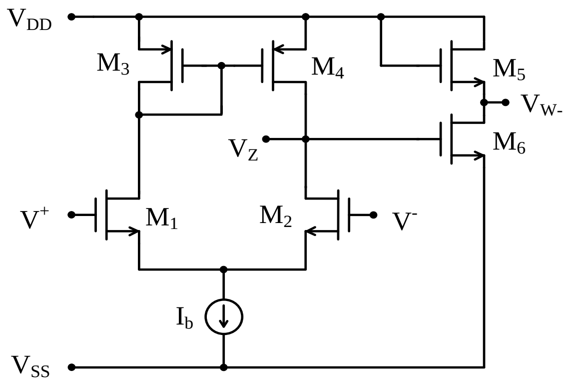
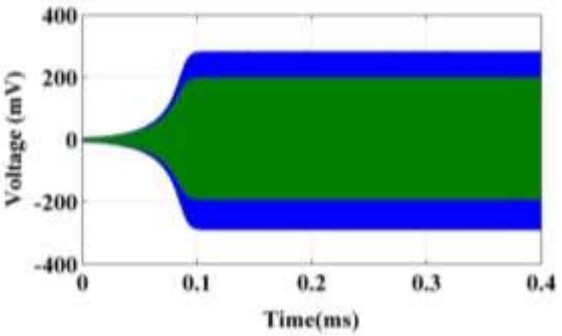


Figure. 4 An exemplary CMOS implementation of VDIBA [44], V_{DD} = $-V_{SS}$ = 0.9V

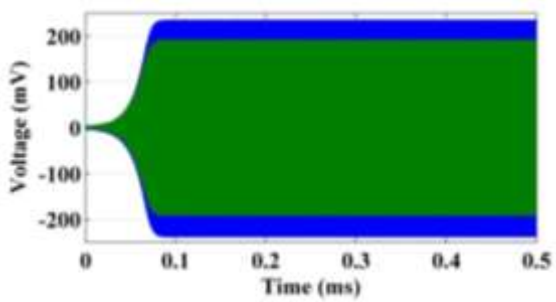
Table 1. The aspect ratios of MOSFETs.

Transistor	W/L (µm)
M1-M4	18/1.08
M5-M6	54/0.18

The TOQSO-I and TOQSO-II were designed to operate at 706.14 kHz nominal frequency. C1 = C2 = C3 = 100pF, g_{m1} = 519S, g_{m2} = 360 S, and g_{m3} = 415S are the passive components chosen. Figure 5 depicts the transient responses of the output voltages for the suggested circuits, whereas Figure 6 depicts the steady-state reactions of the quadrature waveforms of the output voltages. Figure 7 depicts the XY plot (Lissajous pattern), and Figure 8 depicts the frequency spectra of the output voltages.

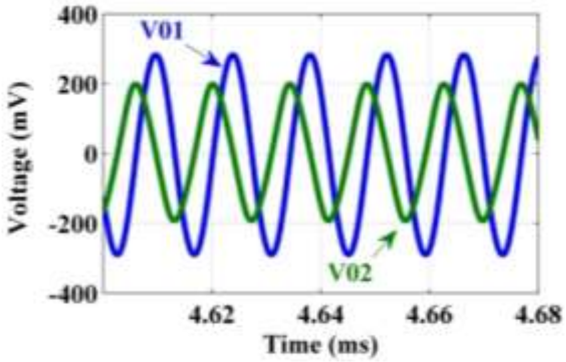


(a)



(b)

Figure 5: Transient response of (a) TOQSO-I (b) TOQSO-II



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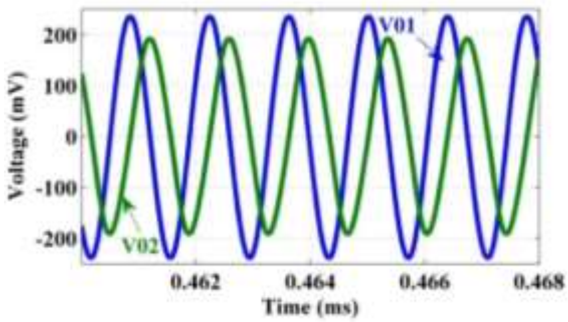
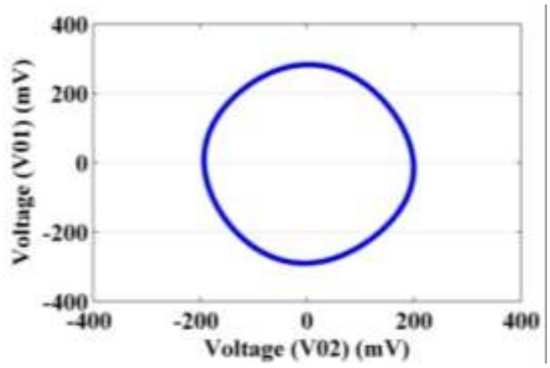
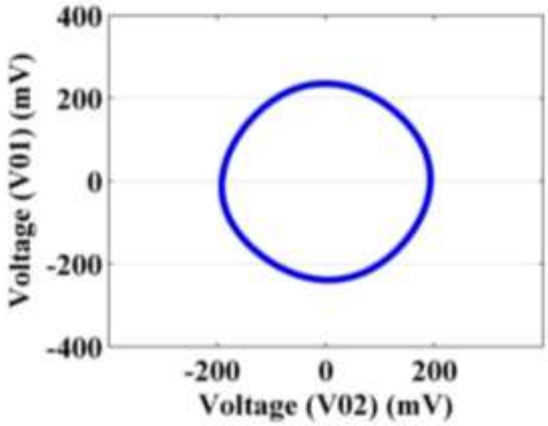


(b)

Figure 6: Steady state response of (a) TOQSO-I (b) TOQSO-II

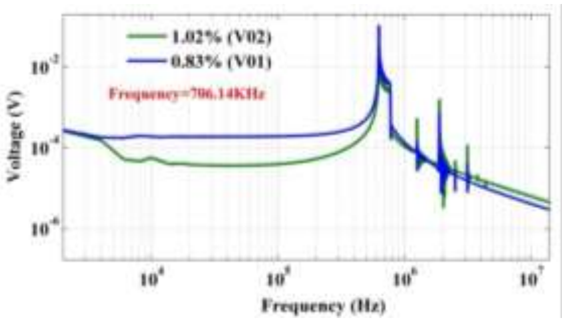


(a)



(b)

Figure 7: Lissajous pattern of (a) TOQSO-I (b) TOQSO-II



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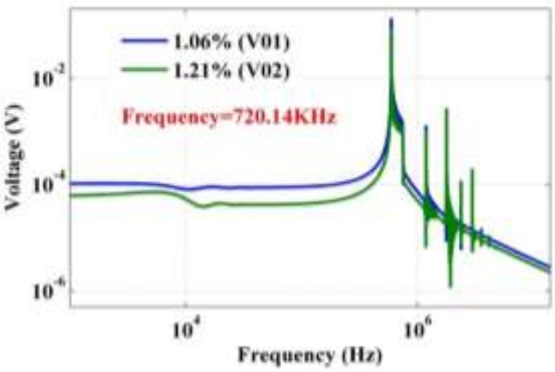
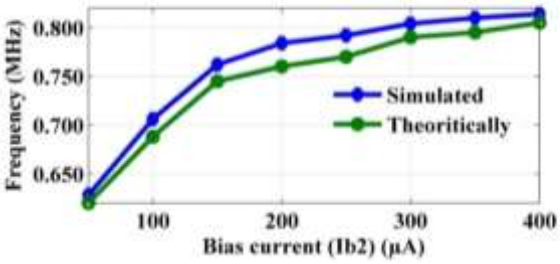


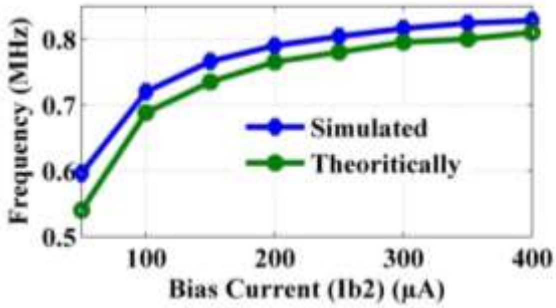
(b)

Figure 8: Frequency spectrum of (a) TOQSO-I (b) TOQSO-II

The simulated frequencies achieved for the proposed TOQSOs are 706.14 kHz exhibiting close proximity to the theoretical value of 688.028 kHz The changes in the oscillation frequency (FO) across the proposed circuits are visualized in Figure 9, where the bias current Ib2 (gm2) was systematically adjusted within the range of 50µA to 400µA. Furthermore, the change in Total Harmonic Distortion (THD) for various frequency values has been simulated, and the results are shown in Figure 10.

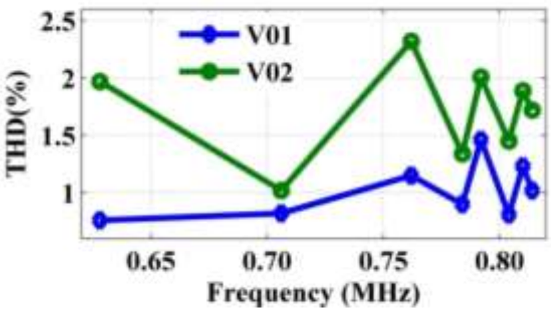


(a)

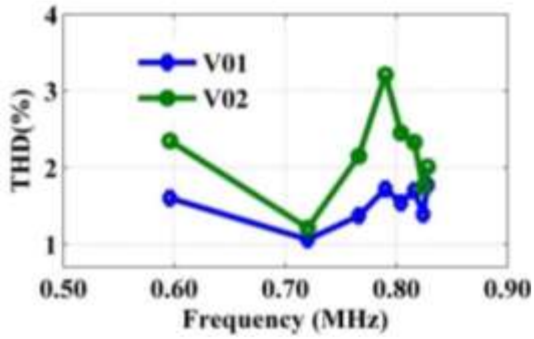


(b)

Figure 9: variation in frequency TOQSOs with respect to biasing current (a) TOQSO-I (b) TOQSO-II



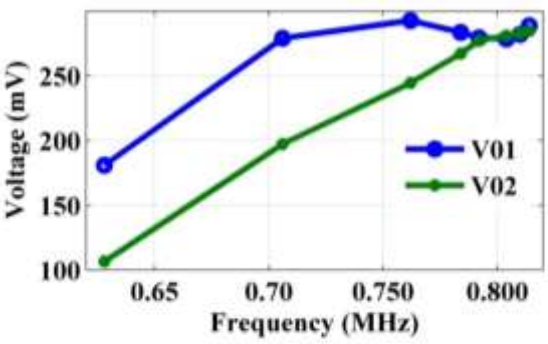
(a)



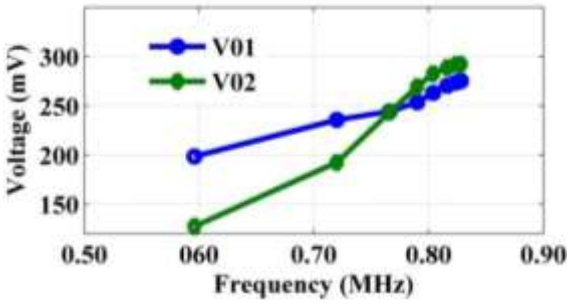
(b)

Figure 10: Variations of THD with different frequencies of (a) TOQSO-I (b) TOQSO-II

In addition, we calculated the amplitude profiles of the output voltages at various frequency values, and the resulting simulated results are graphically represented in Figure 11.



(a)



(b)

Figure 11: Amplitude level of the quadrature output voltages of (a) TOQSO-I (b) TOQSO-II

The simulation results shown in Figures 5–11 validate the functioning of the suggested TOQSOs.

7. Comparison of Proposed Configurations with Earlier Reported TOQSOs

This section contains, a comprehensive comparison is drawn between the distinct attributes of the suggested TOQSOs and those of previously documented TOQSOs that incorporate a variety of active building blocks.

Table 2. Comparitive features of proposed configurations with previously reported TOQSO configurations

Ref.	No. of active devices used	No. of passive components		Whether all capacitors grounded	Outputs		Electronically controllable	Independent control of		No. of BJTs and MOSFETs used	THD (%) and Sensitivity
		R	C		CM	VM		CO	FO		
[4] Fig. 7	3OTA	0	3	YES	NO	YES	YES	YES	NO	16M	NM/NA
[4] Fig. 11	4OTA	1	3	YES	NO	YES	YES	NO	YES	18M	NM/NA
[5]	4CCCII	0	3	YES	YES	NO	YES	NO	YES	NA	1/NA
[6] Fig. 1	3CCII	3	3	NO	NO	YES	NO	NO	NO	NA	NM/-0.5
[6] Fig. 2	3CCII	2	5	NO	NO	YES	NO	NO	NO	NA	NM/-0.5
[6] Fig. 3	3CCII	5	3	NO	NO	YES	NO	NO	NO	NA	NM/-0.5
[7]	3CDTA	0	3	YES	YES	NO	YES	YES	NO	83M	2.5713/0.5
[8]	3DVCC	3	3	YES	YES	YES	NO	NO	YES	54M	NM/0.5
[9]	2CCCCTA	0	3	YES	YES	NO	YES	YES	YES	70B	1.106/≤0.5
[10]	3CDTA	0	3	YES	YES	YES	YES	YES	YES	83M	10.4≤0.5
[11]	3CCCII	0	3	YES	YES	YES	YES	NO	YES	59M	1.93/NA
[12]	2MO-CCII	3	3	YES	YES	YES	NO	YES	NO	40M	2.95/NA
[13]	1DDCC+2OTA	1	3	YES	NO	YES	YES	YES	YES	28M	NM/NA
[14]	1CCCDTA+1OTA	0	3	YES	YES	YES	YES	YES	YES	55M	1.8/≤-0.5
[15]	2CCII+1UVC	3	3	YES	NO	YES	NO	YES	YES	110M	0.86/NA
[16]	1MCCFTA	0	3	YES	YES	NO	YES	YES	NO	47M	4.59/≤-0.5
[17]	4CCCII	1	3	YES	NO	YES	YES	NO	NO	74M	<1/NA
[18]	2OTRA	4	3	NO	NO	YES	NO	NO	NO	28M	6.3/NA
[19]	1MCCCTA	0	3	YES	YES	YES	YES	YES	YES	47M	5.53/≤0.5
[20]	3DVCC	3	3	YES	YES	YES	NO	NO	NO	54M	1.82/≤0.5
[21]	1DDCC+1VDTA	1	3	YES	YES	NO	YES	YES	YES	20M	2.95/NA
[23]	3OTRA	5	3	NO	NO	YES	NO	NO	YES	48M	4.8/NA
[24] Fig. 2	3OTRA	5	3	NO	NO	YES	NO	NO	NO	42M	0.57/NA
[24] Fig. 3	3OTRA	5	3	VG	NO	YES	NO	NO	NO	42M	0.7/NA
[25]	2VDTA	0	3	YES	YES	NO	YES	NO	YES	36M	0.9/NA
[26]	2VDTA	0	3	YES	NO	YES	YES	NO	YES	16M	2.39/NA
[27]Fig.4(a)	2DVCCTA	3	3	YES	YES	YES	YES	YES	YES	52M	NM/NA
[27]Fig.4(b)	2DVCCTA	3	3	YES	YES	YES	YES	YES	YES	52M	NM/NA
[29] Fig. 3	2CDTA	0	3	YES	YES	NO	YES	YES	YES	76M	NM/≤0.5
[29] Fig.4	3CDTA	0	3	YES	YES	NO	YES	YES	YES	111M	NM/≤0.5
[30] Fig. 2	2OTRA	3	3	NO	NO	YES	NO	YES	YES	28M	1.17/≤-0.5
[30] Fig. 3	2OTRA	3	3	NO	NO	YES	NO	YES	NO	28M	1.32/≤-0.5
[31]	3VDBA	2	3	YES	NO	YES	YES	YES	NO	48M	1.92/NA
[32]	2MODVCCTA	2	3	YES	YES	YES	YES	YES	YES	47M	<1.3/≤0.5
[33]	2MO-CCCCTA	0	3	YES	YES	YES	YES	YES	YES	54M	1.7465/≤0.5

[34]	2VDBA	1	3	NO	NO	YES	YES	YES	YES	32M	2.55/≤0.5
[35]	1CDCTA	0	3	YES	YES	YES	YES	YES	YES	56M	3.33/NA
[36]	1MCCFTA	0	3	YES	YES	YES	YES	NO	NO	53M	0.26/-0.5
[37]	2VDTA	0	3	YES	NO	YES	YES	YES	YES	42M	4.5/≤0.5
[38]	1FDCCII	3	3	YES	YES	YES	NO	NO	NO	59M	1.66/-0.5
[39]	2OTRA	4	3	NO	NO	YES	NO	NO	YES	28M	1.83/≤0.5
[40]	2VDIBA	1	3	YES	NO	YES	YES	YES	YES	12M	NM/≤1
[41]	2FDCCII	0	3	NO	YES	YES	YES	NO	YES	83M	3/≤1
[42]	2VDCC	3	3	YES	YES	YES	NO	YES	YES	44M	1.89/≤0.5
[43]	3OTA	0	3	YES	YES	NO	YES	YES	YES	24M	<0.5/NM
Proposed work	**3 VDIBA 3 VDIBA**	**0**	**3**	**YES**	**NO**	**YES**	**YES**	**YES**	**YES**	**18M**	**0.8/≤0.5 1.06/≤0.5**

NM=not mentioned; THD=total harmonic distortion; CM= current mode; VM= voltage mode; NA= not available; CO = Condition of oscillation; FO= frequency of oscillation

Abbreviations: VDIBA: voltage differencing inverting buffered amplifier; MODVCCTA: multi output differential voltage current conveyor transconductance amplifier; DVCCTA: differential voltage current conveyor transconductance amplifier; OTRA: operational transresistance amplifier; CCCII: current controlled current conveyor; DVCC: differential voltage current conveyor; CDTA: current differencing transconductance amplifier; CCCCTA: current controlled current conveyor transconductance amplifier; MO-CCII: Multi output current conveyor; VDTA: voltage differencing transconductance amplifier; VDBA: voltage differencing buffered amplifier; MOCCCCTA: multiple-output current controlled current conveyor transconductance amplifier; MCCFTA: modified current-controlled current follower transconductance amplifier; CCII: second-generation current conveyor; CFOA: current feedback operational amplifier; VDCC: voltage differencing current conveyor; CDCTA: current differencing cascaded transconductance amplifier; CCCDTA: current controlled current differencing transconductance amplifier; FDCCII: fully differential second-generation current conveyor; DDCC: differential difference current conveyor; UVC: universal voltage conveyor; MCCCCTA: modified current-controlled current conveyor transconductance amplifier.

8. Concluding Remarks

Two novel voltage-mode Third-Order Quadrature Oscillators (TOQSOs) have been introduced, employing three voltage differencing inverting buffered amplifiers (VDIBAs) and three grounded capacitors (3GCs). These newly presented configurations exhibit the capability to autonomously regulate the CO while leaving the FO undisturbed. The CO and FO can be independently controlled through separate transconductances. Through a non-ideal analysis, the attained values were compared against the ideal expectations. The sensitivities of FO with respect to passive components and parasitic elements were scrutinized and found to be under 0.5. The practical viability of the proposed circuits was established through simulation in the PSPICE environment, employing a VDIBA realized with 0.18µm CMOS technology. The resultant total harmonic distortion (THD) for the output voltages stood at approximately 0.82% and 1.06%. As a consequence, these novel TOQSO configurations contribute to the diversity of TOQSO designs available within the existing body of literature.

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