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OTA-C CURRENT-MODE SINUSOIDAL QUADRATURE OSCILLATOR BASED ON THIRD-ORDER FILTER STRUCTURES

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Abstract:This paper discusses the realization of OTA based current-mode quadrature oscillator circuits based on third-order integrator based Continuous-Time (CT) filter structures. These quadrature oscillator circuits use three/ five OTAs and three grounded capacitors. The advantages of proposed quadrature oscillator circuits include simple architecture, use of grounded capacitors, independent control on Condition of Oscillation (CO) and good sensitivity of Frequency of Oscillation (FO). The workability of the proposed oscillators is verified with SPICE simulations.

Keywords: Sinusoidal oscillator, third-order quadrature oscillator, OTA, SO-OTA, DO-OTA, TO-OTA

Introduction:

The different active building blocks[1]-[3] used in mixed signal circuit design and analog signal processing include op-amp, CC, CFOA, OTA, OTRA, CCTA etc. Recently there is growing interest in the design of analog filters and oscillators. The sinusoidal quadrature oscillators are used in communication and instrumentation applications. This paper discusses OTA based Current-Mode (CM) quadrature oscillator circuits derived from integrator based third-order filter structures. A brief description of OTA is discussed in section II. The literature review of previously reported quadrature oscillator circuits is briefly summarized in section III. The block diagram showing realization of CM quadrature oscillator using different third-order filter structures and their OTA-C implementation are presented in section III. The analysis of proposed oscillator circuits using non-ideal parameters of OTA is considered in section IV. The section V compares the proposed quadrature oscillators with previously reported circuits. The design methodology and simulation results are presented in section VI. The concluding summary is presented in section VII.

OPERATIONAL TRAN CONDUCTANCE AMPLIFIER

An OTA [1]-[3] is a versatile mixed-mode analog block having two voltage inputs and a current output. In ideal scenario, the OTA acts as a Voltage Controlled Current Source (VCCS) and exhibits infinite input and output impedances. Note that the OTAs have drawn considerable attention in the application areas of analogue signal processing due to their advantages like electronic tenability (i.e., the OTA trans conductance can be adjusted by varying dc bias current), wide bandwidth and suitability for IC implementation. The different types of OTA like SO-OTA (Single-Output OTA), DO-OTA (Dual-Output OTA) and TO-OTA (Triple-Output OTA) [1]-[4] are discussed in the literature, the symbols of which are presented in Fig. 1.

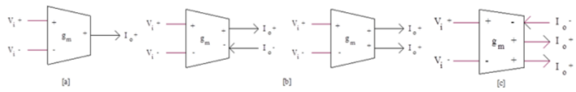


Fig. 1 Circuit symbols of [a] SO-OTA, [b] DO-OTA and [c] TO-OTA

The output currents of SO-OTA, DO-OTA and TO-OTA are given by

$$I_o^+ = I_o^- = g_m(V_i^+ - V_i^-) \qquad (1)$$

where I_o^+, I_o^- are dual output currents, g_m is the transconductance of the OTA, V_i^+ and V_i^- denote non-inverting and inverting input voltages of the OTA respectively. The circuit realization of OTA simulated grounded resistors and the OTA based current-mode integrator circuits [1]-[3], [5] are discussed in the literature.

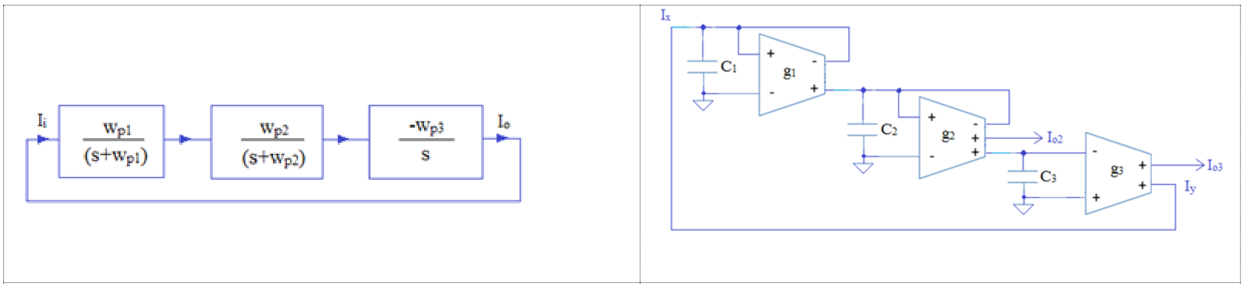
OTA BASED CURRENT-MODE SINUSOIDAL QUADRATURE OSCILLATORS

Several OTA-C voltage-mode (VM) sinusoidal oscillator structures have been proposed [6], [7]. Novel CM OTA-C first-order all-pass filter circuits [8]-[10] and MO-OTA based quadrature oscillator [8]-[9] using first-order all-pass sections were proposed. OTA based CM second order sinusoidal quadrature oscillators are discussed in the literature [11]-[13]. A third-order quadrature oscillatorwith current and voltage outputs based on Differential Voltage Current Conveyors (DVCC) [14], multiple outputs CCII [15] have been proposed. The third-order sinusoidal oscillators employing active blocks like Current Controlled Conveyors (CCCIIs) [16], [17], Operational Tran resistance Amplifier (OTRA) [18], Current Differencing Tran conductance Amplifiers (CDTA) [19], [20] and Current Controlled Current Conveyor Tran conductance Amplifiers (CCCCTA) [21] have been proposed. The third-order VM quadrature oscillator employing Differential Different Current Conveyor (DDCC) and OTAs [22]) has been proposed.The third-order CM quadrature oscillators employing different active blocks (CCCCTA and OTA [23], Current Differencing Tran conductance Amplifier (CCCDTA) and OTA [24]) have been reported. Recently third-order quadrature oscillator circuits have been receiving considerable attention due to their high-accuracy and lower distortion [16], [25] than second-order oscillators. OTA based VM third-order sinusoidal quadrature oscillators [25], [26] have been reported. According to authors' knowledge, OTA based third-order CM oscillator circuits have not been addressed in open literature. Hence it is interesting to consider realization of OTA based third-order CM oscillator circuits.

This section discusses the proposed OTA based CM sinusoidal quadrature oscillators based on third-order CT filter structures. The third-order Characteristic Equation (CE) for the oscillator circuit is obtained by considering the Barkhausen criteria $A(s).\beta = 1$ where $A(s)$ is the gain of the amplifier and β is the feedback factor. The performance measures of proposed oscillator circuits viz. CE, CO, FO and sensitivity of the oscillation frequency with respect to component values are summarized in Table I.

A. Third-order OTA-C CM quadrature oscillator circuit1

The OTA-C implementation of CM quadrature oscillator based on third-order low-pass (LP) filter structure (refer Fig. 2 [a]) consisting of two lossy integrators and one lossless integrator is given in Fig. 2[b].



[a] [b]

Fig. 2 [a] Block diagram showing realization of CM quadrature oscillator using third-order LP filter consisting of two lossy integrators and one lossless integrator, [b] Third-order OTA-C CM quadrature oscillator derived from [a]

B. Third-order OTA-C CM quadrature oscillator circuit2

The generalized block diagram of a sinusoidal quadrature oscillator based on third-order LP filter consisting of a LP biquad (based on the follow the leader feedback (FLF) two-integrator loop structure) and one lossless integrator is shown in Fig. 3[a] and the OTA-C implementation of the same is given in Fig. 3[b].

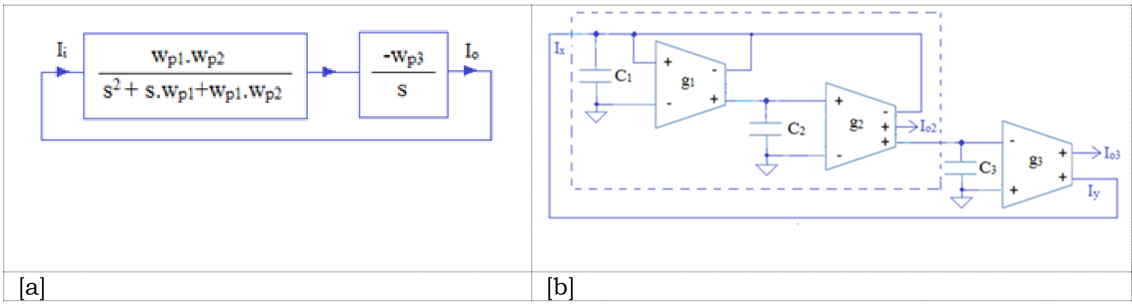


Fig. 3 [a] Block diagram showing realization of CM quadrature oscillator using third-order LP filter consisting of a LP biquad and one lossless integrator, [b] Third-order OTA-C CM quadrature oscillator derived from [a]

C. Third-order OTA-C CM quadrature oscillator circuit3

The block diagram showing realization of quadrature oscillator using third-order LP filter (consisting of three lossy integrators) and a feedback network β is shown in Fig. 4[a]. The OTA-C implementation of the same is given in Fig. 4[b].

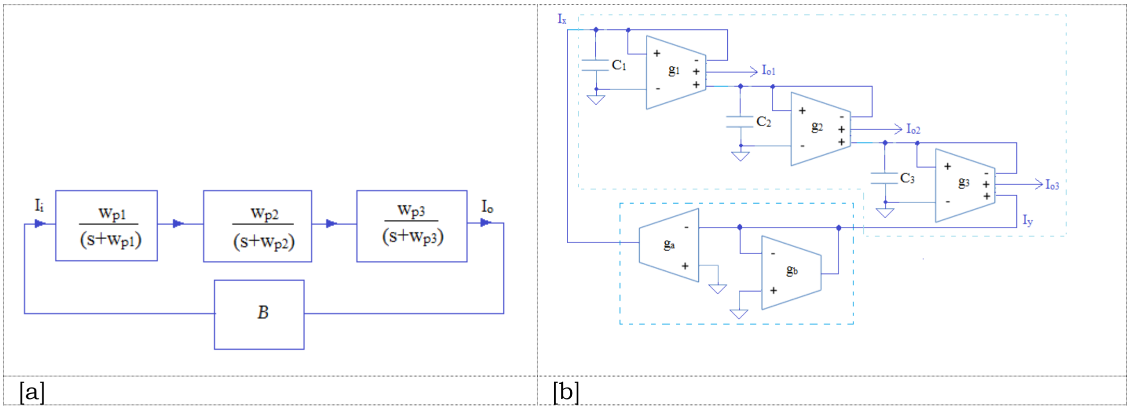


Fig. 4 [a] Block diagram showing realization of quadrature oscillator using third-order LP filter (realized using three lossy integrators) and a feedback network, [b] Third-order OTA-C CM quadrature oscillator derived from [a]

D. Third-order OTA-C CM quadrature oscillator circuit4

Fig. 5[a] illustrates the block diagram showing realization of quadrature oscillator circuit4 using a third-order LP filter (based on FLF three-integrator loop structure) and a feedback network β. The OTA-C implementation of the same is given in Fig. 5[b].

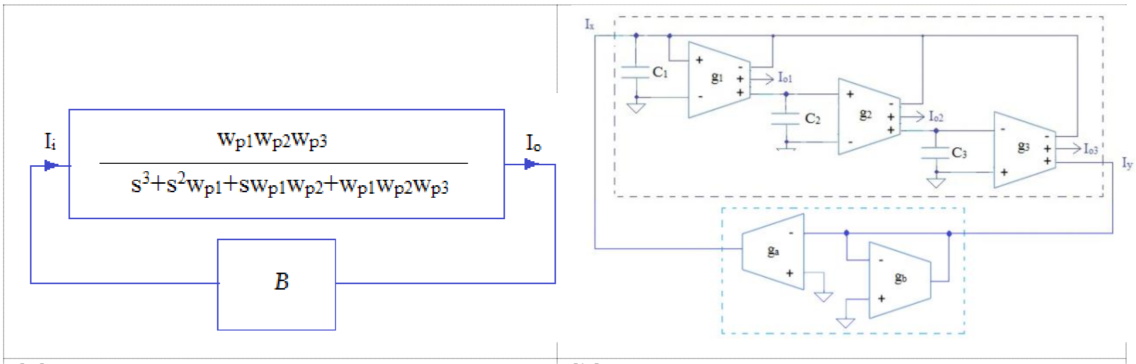


Fig. 5[a] Block diagram showing realization of quadrature oscillator using third-order LP filter (based on FLF three-integrator loop structure) and a feedback network, [b] Third-order OTA-C CM quadrature oscillator derived from [a]

Table-I. Summary of performance measures for proposed third-order quadrature oscillator circuits

Circuit	Characteristic equation of oscillator	CO	FO (ω_o)	Sensitivity of ω_o
Fig. 2[b]	$s^3+s^2\left(\frac{g_1}{C_1}+\frac{g_2}{C_2}\right)+s\frac{g_1g_2}{C_1C_2}+\frac{g_1g_2g_3}{C_1C_2C_3}=0$	$\frac{g_3}{C_3}=\frac{g_1}{C_1}+\frac{g_2}{C_2}$	$\sqrt{g_1g_2/C_1C_2}$	$S^{\omega_o}_{g_1,g_2}=-S^{\omega_o}_{C_1,C_2}=0.5$
Fig. 3[b]	$s^3+s^2\frac{g_1}{C_1}+s\frac{g_1g_2}{C_1C_2}+\frac{g_1g_2g_3}{C_1C_2C_3}=0$	$\frac{g_3}{C_3}=\frac{g_1}{C_1}$	$\sqrt{g_{1,3}g_2/C_{1,3}C_2}$	$S^{\omega_o}_{g_{1,3},g_2}=-S^{\omega_o}_{C_{1,3},C_2}=0.5$ $g_{1,3}=g_1=g_3$; $C_{1,3}=C_1=C_3$
Fig. 4[b]	$s^3+s^2\left(\frac{g_1}{C_1}+\frac{g_2}{C_2}+\frac{g_3}{C_3}\right)+s\left(\frac{g_1g_2}{C_1C_2}+\frac{g_1g_3}{C_1C_3}+\frac{g_2g_3}{C_2C_3}\right)+\frac{g_1g_2g_3\left(1+\frac{g_a}{g_b}\right)}{C_1C_2C_3}=0$	$\frac{g_a}{g_b}=8$	$\frac{g\sqrt{3}}{C}$	$S^{\omega_o}_{g}=-S^{\omega_o}_{C}=1$ $g_1=g_2=g_3=g$; $C_1=C_2=C_3=C$
Fig. 5[b]	$s^3+s^2\frac{g_1}{C_1}+s\frac{g_1g_2}{C_1C_2}+\frac{g_1g_2g_3}{C_1C_2C_3}\left(1+\frac{g_a}{g_b}\right)=0$	$\frac{g_1}{C_1}=\frac{g_3\left(1+\frac{g_a}{g_b}\right)}{C_3}$	$\sqrt{g_1g_2/C_1C_2}$	$S^{\omega_o}_{g_1,g_2}=-S^{\omega_o}_{C_1,C_2}=0.5$

CO: Condition of Oscillation; FO: Frequency of Oscillation

EFFECT OF OTA NON-IDEALITIES

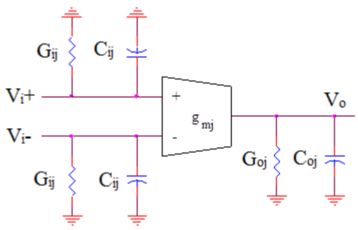


Fig. 6 Non-ideal OTA macro-model

In this section, we consider the effect finite input and output conductances and capacitances of the OTAs, on the CE, CO and FO of the third-order CM quadrature oscillator circuit1 of Fig. 2[b] using non-ideal OTA macro model of Fig. 6. Denoting the finite input and output conductances of the OTAs as G_{ij}, $G_{oj}$and capacitances as C_{ij}, ,C_{oj} for j = 1, 2 for the j[th] OTA and denoting$G_1' = G_{o1} + G_{o3} + G_{i1}$, $G_2' = G_{o2} + G_{o1} + G_{i2}$, $G_3' = G_{o2} + G_{i3}$, $C_1' = C_1 + C_{o1} + C_{o3} + C_{i1}$, $C_2' = C_2 + C_{o1} + C_{o2} + C_{i2}$ and $C_3' = C_3 + C_{o2} + C_{i3}$ the modified characteristic equation for the circuit of Fig. 2[b] can be derived as

$$s^3 + s^2\left\{\frac{(g_1+G_1')}{C_1'} + \frac{(g_2+G_2')}{C_2'} + \frac{G_3'}{C_3'}\right\}$$
$$+s\left\{\frac{(g_1+G_1')(g_2+G_2')}{C_1'C_2'} + \frac{(g_1+G_1')G_3'}{C_1'C_3'} + \frac{(g_2+G_2')G_3'}{C_2'C_3'}\right\} + \left\{\frac{g_1g_2g_3 + (g_1+G_1')(g_2+G_2')G_3'}{C_1'C_2'C_3'}\right\}$$
$$= 0 \qquad (2.1a)$$

The non-ideal CO and FO of the third-order oscillator circuit1are shown to be

$$\frac{(g_1+G_1')}{C_1'}\left(\frac{(g_2+G_2')}{C_2'} + \frac{G_3'}{C_3'}\right) + \frac{(g_2+G_2')G_3'}{C_2'C_3'} = \frac{g_1g_2g_3 + (g_1+G_1')(g_2+G_2')G_3'}{(g_1+G_1')C_2'C_3' + (g_2+G_2')C_1'C_3' + G_3'C_1'C_2'} \quad (2.1b)$$

$$\omega_o' = \sqrt{\frac{(g_1+G_1')(g_2+G_2')}{C_1'C_2'} + \frac{G_3'}{C_3'}\left(\frac{(g_1+G_1')}{C_1'} + \frac{(g_2+G_2')}{C_2'}\right)} \quad (2.1c)$$

V. COMPARISON OF VARIOUS QUADRATURE OSCILLATOR CIRCUITS

In this section, the CM OTA-C third-order quadrature oscillators presented are compared with some of the previously reported oscillators with respect to number of active and passive elements required. (Refer Table I)

Table-I. Comparison of various third-order sinusoidal quadrature oscillators

Ref./ Fig.	Output type	No. of active blocks used	No. of capacitors used	No. of resistors used
[14] Fig. 2	VM/ CM	3 DVCCs (5 extra current outputs)	3 grounded capacitors	2 grounded resistors and 1 floating resistor
[15] Fig. 2	VM/ CM	2 MO-CCII (3 extra current outputs)	3 grounded capacitors	2 grounded resistors and 1 floating resistor
[16] Fig. 3	CM	4 CCCII (3 extra current outputs)	3 grounded capacitors	-
[17] Fig. 3	VM	4 CCCII (3 extra current outputs)	3 grounded capacitors	1 grounded resistor
[18] Fig. 2	VM	3 OTRAs	3 floating capacitors	4 floating resistors
[18] Fig. 3	VM	3 OTRAs	3 floating capacitors	5 floating resistors
[19] Fig. 3	CM	3 CDTAs	3 grounded capacitors	-
[20] Fig. 3	CM	2 CDTAs	3 grounded capacitors	-
[20] Fig. 4	CM	3 CDTAs	3 grounded capacitors	-
[21] Fig. 5	CM	2 CCCCTAs (1 extra current output)	3 grounded capacitors	-
[22] Fig. 5	VM	1 DDCC, 2 SO-OTAs	3 grounded capacitors	1 grounded resistor
[23] Fig. 5	CM	1 CCCCTA, 1 DO-OTA	3 grounded capacitors	-
[24] Fig. 5	CM	1 CCCDTA (2 extra current outputs), 1 SO-OTA	3 grounded capacitors	-
[25] Fig. 7[b]	VM	3 SO-OTAs	3 grounded capacitors	-
[25] Fig. 11	VM	4 SO-OTAs	3 grounded capacitors	1 grounded electronic resistor
[26] Fig. 7	VM	4 SO-OTAs	3 grounded capacitors	6 grounded resistors and 5 floating resistors
This paper Fig. 2[b]	CM	1 TO-OTA, 2 DO-OTAs	3 grounded capacitors	-
This paper Fig. 3[b]	CM	1 TO-OTA, 2 DO-OTAs	3 grounded capacitors	-
This paper Fig. 4[b]	CM	3 TO-OTAs, 2 SO-OTAs	3 grounded capacitors	-
This paper Fig. 5[b]	CM	3 TO-OTAs, 2 SO-OTAs	3 grounded capacitors	-

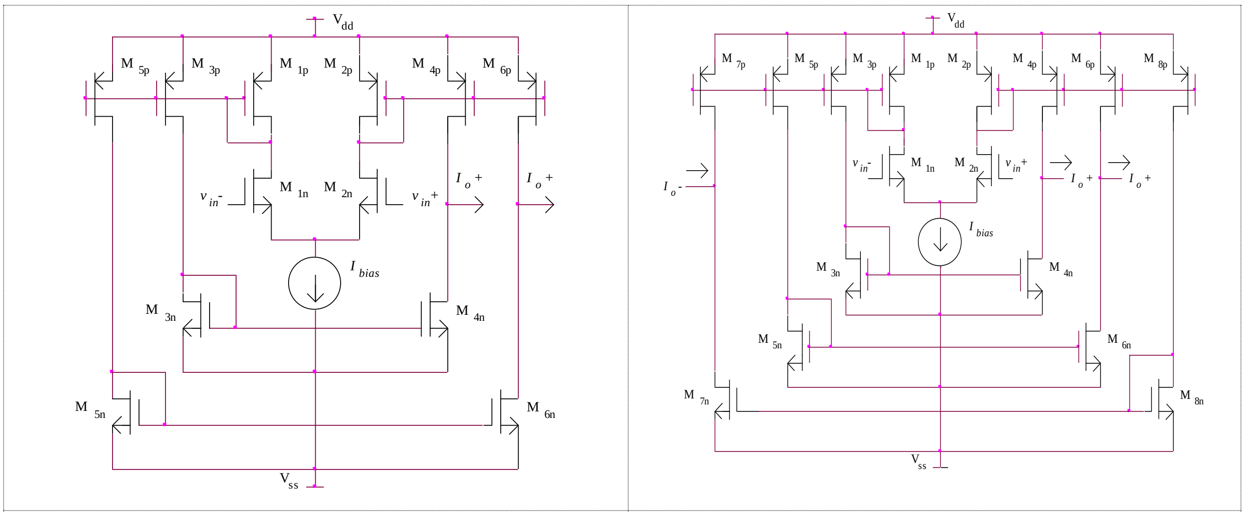
VM: voltage-mode; CM: current-mode; SO: single output; DO: dual output; TO: triple output; MO: multiple output

VI. SIMULATION RESULTS

The proposed OTA based CM third-order sinusoidal quadrature oscillators in Fig. 2[b] and Fig. 3[b] have been simulated using TINA-TI circuit simulator. The device aspect ratios, model parameters and supply voltages used in simulation are given in Table II. The schematic circuits of DO-OTA [10]-[14] and TO-OTA [15] are presented in Fig. 7. The sinusoidal waveforms obtained for quadrature oscillator circuits in Fig. 2[b] and Fig. 3[b] are presented in Fig. 8[a] and [b] respectively.

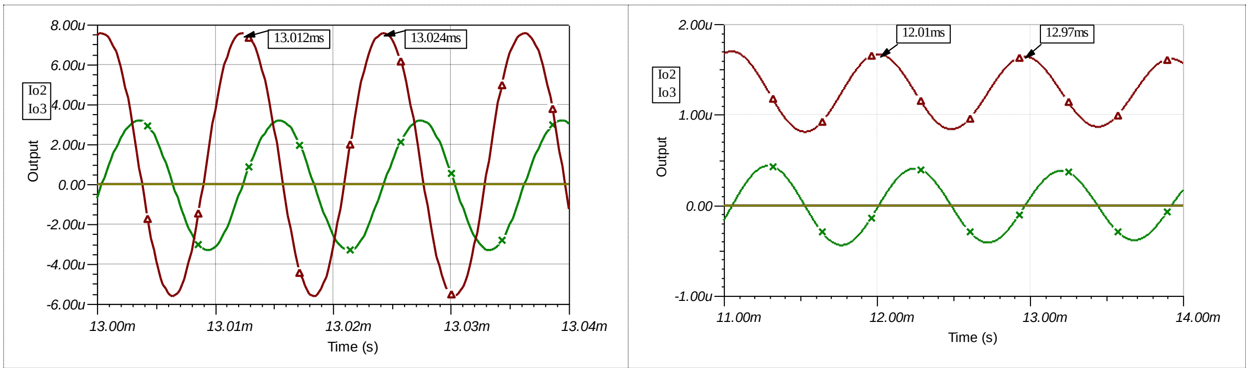
Table-II. Simulation Details

Model parameters used	Level 7 BSIM3 0.5 μm
Aspect ratios for NMOS and PMOS transistor	$W = 4\ \mu m, L = 2\ \mu m$
Supply voltages	V_{dd}= +2V, V_{ss} = -2V



[a] [b]

Fig. 7 CMOS schematic circuit of (a) DO-OTA and (b) TO-OTA



[a] [b]

Fig. 8 Simulated output current waveforms I_{o2}, I_{o3} of OTA based third-order sinusoidal oscillator circuits: [a] Circuit1 in Fig. 2[b] with $C_1 = C_2 = 100\ \text{pF}, C_3 = 45\ \text{pF}, I_{bias1,2,3} = 10\ \mu\text{A}[\ g_{m1,2,3} = 51.52\ \mu\text{s}],\ f_{0,theoretical} = 81.996\ \text{kHz},\ f_{0,practical} = 83.33\ \text{kHz}$; [b] Circuit2 in Fig. 3[b] with $C_1 = C_2 = C_3 = 8\ \text{nF}, I_{bias1,2,3} = 10\ \mu\text{A}\ [\ g_{m1,2,3} = 51.52\ \mu\text{s}],\ f_{0,theoretical} = 1.0249\ \text{kHz},\ f_{0,practical} = 1.0416\ \text{kHz}$;

Conclusion:

This paper presents four OTA-C CM quadrature sinusoidal oscillators based on third-order filter structures. The quadrature oscillators in Fig. 2[b], 3[b] need 1 TO-OTA and 2 DO-OTAs, whereas the oscillators in Fig. 4[b], 5[b] use a feedback network and need 3 TO-OTAs and 2 SO-OTAs. All the quadrature oscillators have a simple structure and use only grounded capacitors. All the proposed oscillators support independent control on CO and provide good sensitivity of oscillation frequency with respect to variation in component values. The simulations were performed for the proposed OTA based sinusoidal oscillators using TINA-TI circuit simulator and the simulation results are found to be in good agreement with theory.

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