A Novel MO-DXCCII based CMQO Operated at Low Voltage

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Abstract—In this paper, a new current-mode quadrature oscillator (CMQO) is proposed using two grounded capacitors and two resistors along with two multi-output dual-X second generation current conveyors (MO-DXCCII). The proposed circuit provides three current outputs simultaneously with high output impedances. The circuit of proposed quadrature oscillator also enjoys the low active and passive sensitivities. The new circuit is suited for high frequency and low operating voltage operation also. The proposed circuit is also made resistorless by using MOS based active resistors. HSPICE simulation results are given to confirm the theory.

Index Terms— Current-mode; Quadrature oscillator; DXCCII; Analog signal processing.

I. INTRODUCTION

In integrated circuits, current-mode circuits offer several advantages over voltage-mode circuits such as large bandwidth, simple circuitry, wider dynamic range, high speed and very low power consumption [1]. A CMQO provides two sinusoid currents with 90° phase difference and it is widely used in a large number of applications such as in communication, power electronics, measurement and instrumentation systems and signal processing. As a result, the technical literature is very well filled by a number of circuits of CMQO realized using different types of active elements such as current-controlled current conveyor (CCCII) [2-4], differential voltage current conveyor (DVCC) [5-6], current differencing transconductance amplifier (CDTA) [7-10], current differencing buffered amplifier (CDBA) [11], current conveyor transconductance amplifier (CCTA) [12], current controlled current conveyor transconductance amplifier (CCCCTA) [13-14] and current controlled current differencing transconductance amplifier (CCCDTA) [15-16]. Third order CMQOs are reported in [2, 3 and 9]. The all-pass filter is cascaded with integrator to obtain the quadrature oscillator circuit in [7, 8 and 16], while in [8] two all-pass filters are cascaded to obtain the quadrature oscillator. The circuits reported in [7, 8, 12, 13, 15 and 16] offer the advantages of high impedance outputs. A current-mode circuit with high output impedance cab be easily cascaded. The frequency of oscillation and condition of oscillation in [7, 12, 13, 15 and 16] can be controlled independently.

In this paper, a new CMQO based on MO-DXCCII is presented. A dual-X second generation current conveyor (DX-CCII) is a versatile element, which has a large number of applications in analog signal processing [17-22]. The proposed circuit employs two MO-DXCCIIs, two grounded capacitors and two resistors. The proposed quadrature oscillator is derived from the all-pass filter [19]. A RC integrator is

connected in cascade with the all-pass filter to obtain the proposed quadrature oscillator. The non-ideal and parasitic study of the proposed circuit is also performed. The proposed circuit offers the following advantages: (i) three current outputs simultaneously, (ii) low active and passive sensitivities, (iii) high output impedances, (iv) total harmonic distortion of each output is low, (v) operated at low voltage, (vi) high frequency of oscillation and (vii) resistorless realization. HSPICE simulation results are given to validate the performance of the proposed circuit. This paper is arranged as follows: the details of proposed CMQO along with non-ideal and parasitic analysis are given in section 2. HSPICE simulation results are given in section 3. The resistorless realization of proposed circuit is given in section 4. Finally, section 5 contains the concluding remarks.

II. PROPOSED CIRCUIT

A DX-CCII [20] was first introduced by A. Zeki and A. Toker. It combines the characteristics of both the second generation current conveyor and inverting second generation current conveyor. "Fig. 1," shows the CMOS implementation of MO-DXCCII. The port relationship of MO-DXCCII can be specified as

$$
\begin{bmatrix} I_Y \\ V_{X+} \\ V_{X-} \\ I_{Z1+} \\ I_{Z2+} \\ I_{Z1-} \\ I_{Z2-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_Y \\ I_{X+} \\ I_{X-} \end{bmatrix} \tag{1}
$$

The proposed circuit of CMQO is shown in "Fig. 2,". It is composed of two MO-DXCCIIs, two grounded capacitors and two resistors. The characteristic equation of the circuit is given as below

$$
s^2 + s \frac{(R_2 C_2 - R_1 C_1)}{R_1 R_2 C_1 C_2} + \frac{1}{R_1 R_2 C_1 C_2} = 0 \tag{2}
$$

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

$$
\text{FO:} \quad f_0 = \frac{1}{2 \pi \sqrt{R_1 R_2 C_1 C_2}} \tag{3}
$$

$$
\text{CO:} \quad R_2 C_2 \leq R_1 C_1 \tag{4}
$$

The various current outputs shown in "Fig. 3," are related as

$$
I_1 = j\omega R_2 C_2 I_3, \quad I_2 = -I_3 \tag{5}
$$

The sensitivities of FO with respect to passive components can be given as

$$
S^{f_0}_{C_1, C_2, R_1, R_2} = -\frac{1}{2} \tag{6}
$$

It is to be observed from "(6)" that all the passive sensitivities are less than unity in magnitude.

A. Non-ideal analysis

By considering the non-idealities of MO-DXCCII, the relationship between voltages and currents at different ports of MO-DXCCII can be written as

$$
V_{X+} = \beta_{1i} V_Y, \quad V_{X-} = \beta_{2i} V_Y, \quad I_{Z1+} = \alpha_{1i} I_{X+},
$$

$$I_{Z2+} = \alpha_{2i} I_{X+}, \ I_{Z1-} = \alpha_{3i} I_{X-} \text{ and } I_{Z2-} = \alpha_{4i} I_{X-} \qquad (7)$$

Here, β_{1i} and β_{2i} are voltage transfer gains from Y terminal to X+ and X- terminals, respectively α_{1i} and α_{2i} are current transfer gains from X+ terminal to Z_{1+} and Z_{2+} terminals, respectively and α_{3i} and α_{4i} are current transfer gains from X- terminal to Z_{1-} and Z_{2-} terminals, respectively with i = 1 corresponding to MO-DXCCII (1) and i = 2 corresponding to MO-DXCCII (2).

The proposed circuit is reanalyzed assuming the non-ideal MO-DXCCII; the modified characteristic equation is found as

$$s^2 + s\frac{(R_2 C_2 - \alpha_{41}\alpha_{32}\alpha_{12}\beta_{12}R_1 C_1)}{R_1 R_2 C_1 C_2} + \frac{\alpha_{32}\alpha_{12}\beta_{12}(\alpha_{11}\alpha_{31} + \alpha_{21}\alpha_{31} - \alpha_{41})}{R_1 R_2 C_1 C_2} = 0 \qquad (8)$$
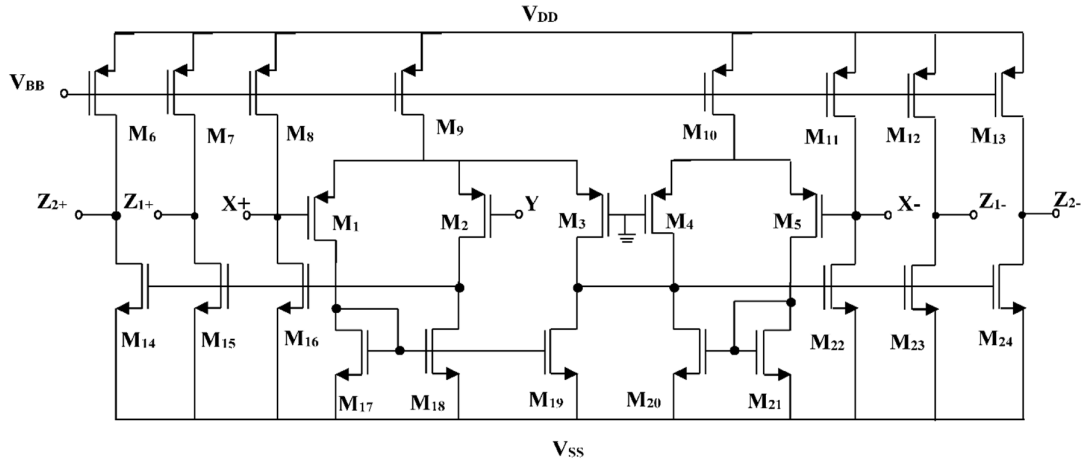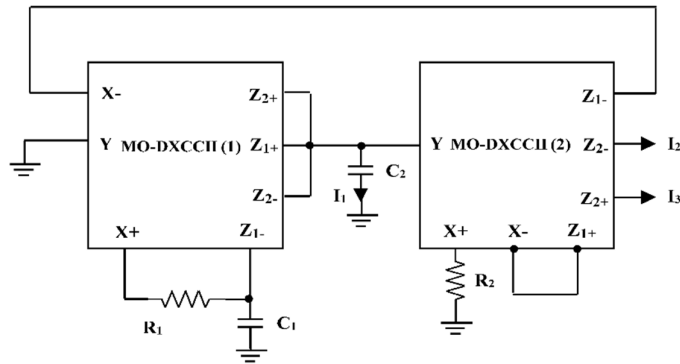

Figure1. The CMOS implementation of MO-DXCCII

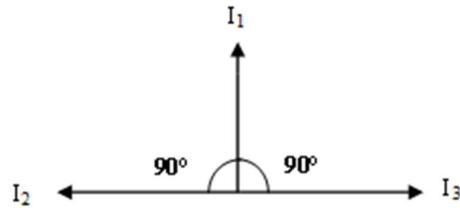Figure2. Proposed circuit of CMQO

Figure3. Phasor diagram showing quadrature current outputs

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The modified FO and CO can be given as

$$\text{FO: } f_0 = \frac{1}{2\pi} \sqrt{\frac{\alpha_{32}\alpha_{12}\beta_{12}(\alpha_{11}\alpha_{31}+\alpha_{21}\alpha_{31}-\alpha_{41})}{R_1 R_2 C_1 C_2}} \qquad (9)$$

$$\text{CO: } R_2 C_2 \leq \alpha_{41}\alpha_{32}\alpha_{12}\beta_{12}R_1 C_1 \qquad (10)$$

The sensitivities of FO with respect to active and passive components can be found as

$$S_{\alpha_{32},\alpha_{12},\beta_{12}}^{f_0} = \frac{1}{2} \qquad (11)$$

$$S_{\alpha_{11}}^{f_0} = \frac{\alpha_{11}\alpha_{31}}{\alpha_{11}\alpha_{31}+\alpha_{21}\alpha_{31}-\alpha_{41}} \qquad (12)$$

$$S_{\alpha_{31}}^{f_0} = \frac{\alpha_{31}(\alpha_{11}+\alpha_{21})}{\alpha_{11}\alpha_{31}+\alpha_{21}\alpha_{31}-\alpha_{41}} \qquad (13)$$

$$S_{\alpha_{21}}^{f_0} = \frac{\alpha_{21}\alpha_{31}}{\alpha_{11}\alpha_{31}+\alpha_{21}\alpha_{31}-\alpha_{41}} \qquad (14)$$

$$S_{\alpha_{41}}^{f_0} = \frac{-\alpha_{41}}{\alpha_{11}\alpha_{31}+\alpha_{21}\alpha_{31}-\alpha_{41}} \qquad (15)$$

$$S_{C_1,C_2,R_1,R_2}^{f_0} = -\frac{1}{2} \qquad (16)$$

Equations (11) to (16) shows that the sensitivity figures for FO are all within unity in magnitude, which implies good sensitivity performance of the circuit.

B. Parasitic Effects

A parasitic model of MO-DXCCII is shown in "Fig. 4,". The parasitic study of MO-DXCCII involves parasitic resistances R_{X+} and R_{X-} at X+ and X- terminals respectively, a parallel combination ($R_Y // C_Y$) at Y terminal and parasitic at Z_{1+}, Z_{2+}, Z_{1-} and Z_{2-} terminals are $(R_{Z1+}//C_{Z1+})$,$(R_{Z2+}//C_{Z2+})$,$(R_{Z1-}//C_{Z1-})$ and $(R_{Z2-}//C_{Z2-})$, respectively [20]. The effects of parasitic capacitance at Y and Z ports of MO-DXCCII are negligible as these capacitors are quite small as compared to external capacitors. The parasitic resistances at X+ terminals of both MO-DXCCIIs can be merged with external resistors, because X+ terminals of both MO-DXCCIIs are connected to external resistors. There will be a little deviation in FO of proposed circuit due to these parasitic which can be minimized by pre-warping the component values used in circuit. However, a reanalysis of the proposed circuit of quadrature oscillator is done which yields the following characteristic equation

$$s^2 + s\frac{A}{R_1' R_2' C_1' C_2'} + \frac{B}{R_1' R_2' C_1' C_2'} = 0 \qquad (17)$$

where, $A = R_2' C_2'\left(1+\dfrac{R_1'}{R_{Z1-}}\right) - R_1' C_1' + \dfrac{R_1' R_2' C_1'}{R'}$ and $B = \dfrac{R_2'}{R'}\left(\dfrac{R_1'}{R_{Z1-}}+1\right) - \left(\dfrac{R_1'}{R_{Z1-}}-1\right)$,

where, $R' = R_{Y2} // R_{Z11+} // R_{Z21+} // R_{Z21-}$, $R_1' = R_1 + R_{X1+}$, $R_2' = R_2 + R_{X2+}$, $C_1' = C_1 + C_{Z11-}$ and $C_2' = C_2 + C_{Y2} + C_{Z11+} + C_{Z21+} + C_{Z21-}$.
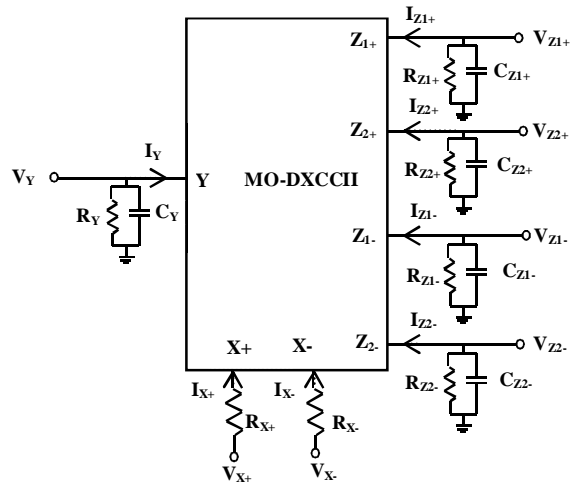
Figure4. Parasitic model of MO-DXCCII

III. SIMULATION RESULTS

The proposed circuit of CMQO is simulated using HSPICE with 0.18 µm TSMC CMOS process parameters. The supply voltages used were $V_{DD} = -V_{SS} = 1.25V$ and biasing voltage was $V_{BB} = 0.3V$. The values of external components used in circuit was $C_1 = C_2 = 1pF$, $R_1 = 2K\Omega$ and $R_2 = 1.59K\Omega$. The theoretical FO for these values of external components was 89.25 MHz. The simulation results for the three current outputs are shown in Fig. 5. The simulated FO was found to be 93 MHz. The simulated FO deviates from theoretical FO because of the non-ideal and parasitic effects described in section 2. The total harmonic distortion (THD) of each output is found with-in 1.4%. "Fig. 6," shows the simulated Fourier spectrum of output currents. In addition, to confirm the 90° phase difference between the current outputs, the lissajous patterns are given in "Fig. 7," and "Fig. 8,". The usefulness of new circuit is to be especially emphasized keeping in view the design frequency which is quite high.
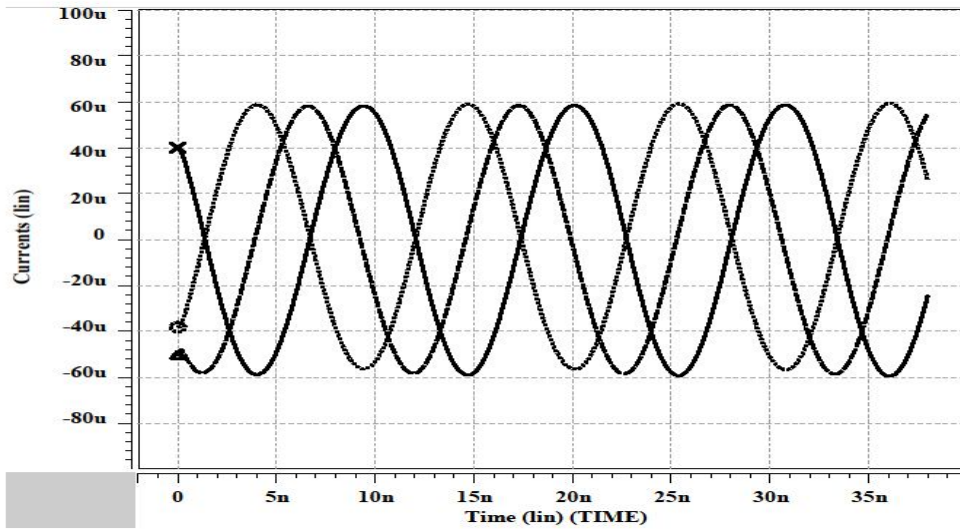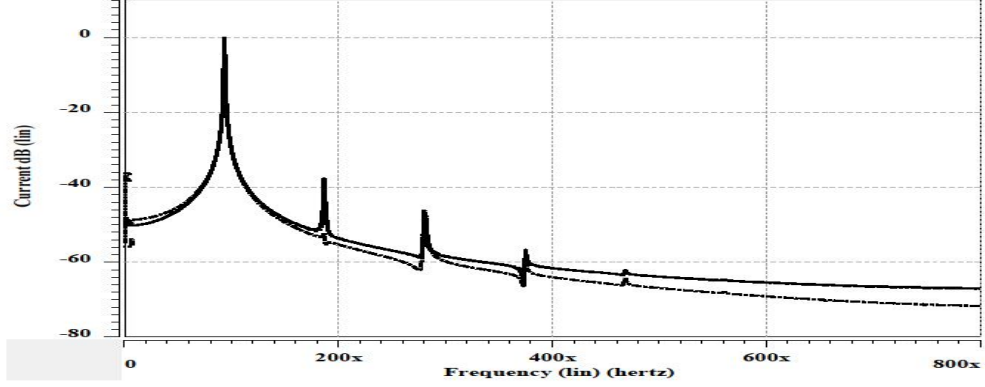

Figure5. Quadrature current output waveforms
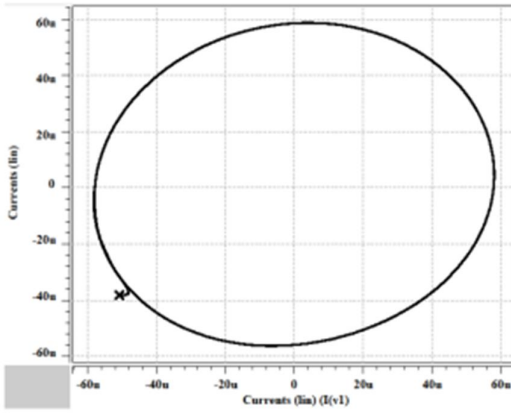
Figure6. Frequency spectrum of current outputs

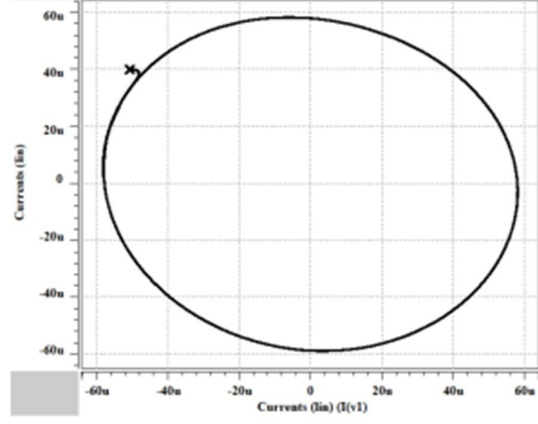Figure7. Lissajous pattern showing 90° phase difference between output currents (I_1 and I_2)

Figure8. Lissajous pattern showing 90° phase difference between output currents (I_1 and I_3)

IV. RESISTORLESS REALIZATION OF PROPOSED CIRCUIT

The proposed circuit was made resistorless by using a single n-MOS transistor biased in triode region in place of floating resistor (R_1), and two n-MOS transistor based grounded resistor in place of grounded resistor (R_2) [23]. A possible realization of resistorless CMQO is shown in "Fig. 9,". The characteristic equation of the proposed resistorless circuit is given as below

$$s^2 + s\frac{(R_{M_2}C_2 - R_{M_1}C_1)}{R_{M_1}R_{M_2}C_1C_2} + \frac{1}{R_{M_1}R_{M_2}C_1C_2} = 0 \tag{18}$$

where, R_{M1} and R_{M2} are the equivalent resistances of n-MOS transistor $M_{R3,}$ and n-MOS transistors M_{R1} and M_{R2} respectively in Fig. 9 and expressions of R_{M1} and R_{M2} are given as

$$R_{M1} = \left[\mu C_{OX}\left(\frac{W}{L}\right)(V_{C2} - V_T)\right]^{-1} \tag{19}$$

$$R_{M2} = \left[2\mu C_{OX}\left(\frac{W}{L}\right)(V_{C1} - V_T)\right]^{-1} \tag{20}$$

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The FO and CO of resistorless circuit can be obtained as

$$\text{FO: } f_0 = \frac{1}{2\pi \sqrt{R_{M1} R_{M2} C_1 C_2}} \tag{21}$$

$$\text{CO: } R_{M2} C_2 \leq R_{M1} C_1 \tag{22}$$

The resistorless circuit was simulated by taking the aspect ratios $(W/L)_{MR1} = (W/L)_{MR2} = 0.45$ μm/ 0.18 μm, $(W/L)_{MR3} = 0.36$ μm/ 0.18 μm and capacitors values were selected as $C_1 = C_2 = 1$ pF. The FO of resistorless circuit is tuned to 88 MHz when controlling voltage were selected as $V_{C1} = 1.1$ V and $V_{C2} = 1.059$ V. The three current outputs and their Fourier spectrums are shown in "Fig. 10'" and "Fig. 11," respectively.
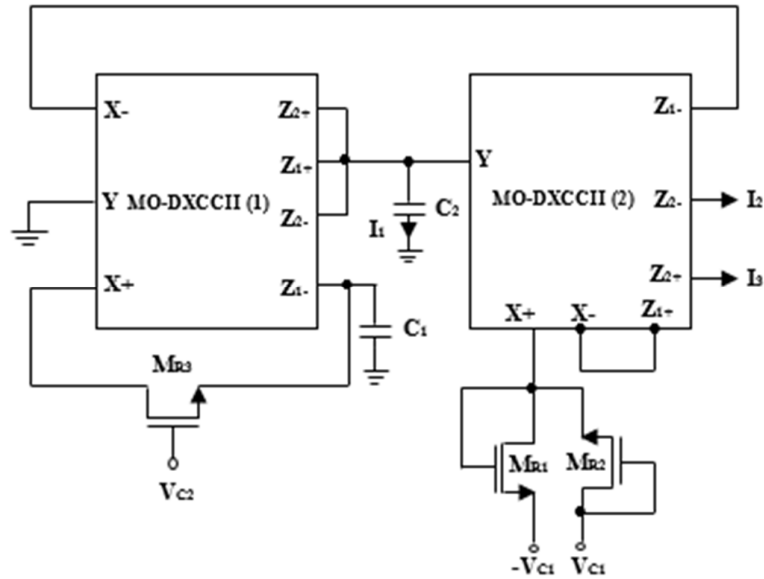

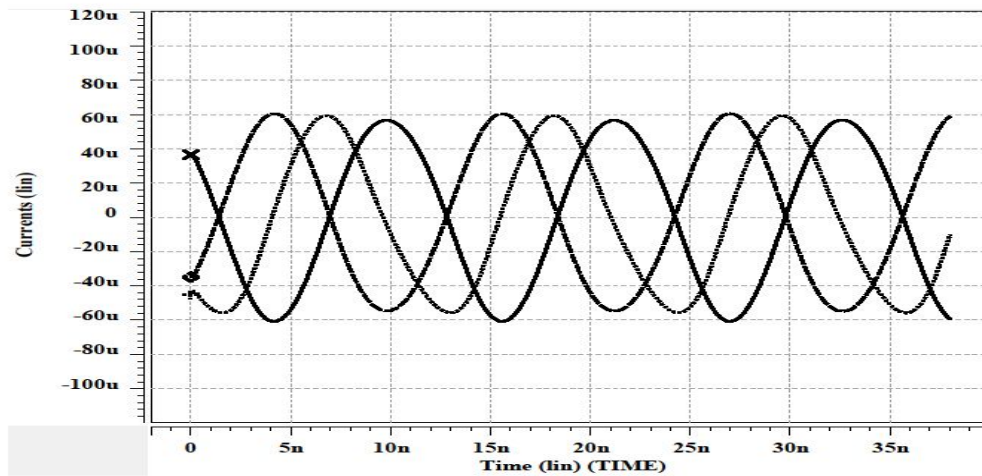Figure9. Proposed resistorless circuit of CMQO

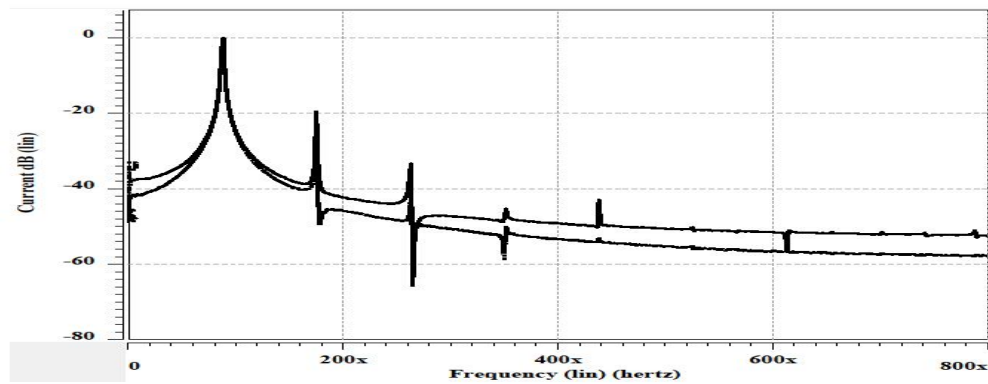Figure10. Quadrature current output waveforms

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Figure11. Frequency spectrum of three current outputs

V. CONCLUSION

This paper presents a new CMQO based on two MO-DXCCIIs as active elements, two grounded capacitors and two resistors. The proposed circuit provides three quadrature current outputs simultaneously with high output impedances and each output exhibited low harmonic distortion. The proposed circuit also enjoys the low active and passive sensitivities. The performance of proposed circuit is quite good by keeping in view low operated voltage and high frequency of oscillation. This paper also includes the non-ideal and parasitic study of the proposed circuit of quadrature oscillator. Further, with the help of MOS based active resistors, the proposed circuit was made resistorless. HSPICE simulation results are given to confirm the theoretical analysis.

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