

Low Voltage Mixed-mode Multi Phase Oscillator Using Single FDCCII

J. Mohan, B. Chaturvedi and S. Maheshwari

Abstract— In this paper a new low voltage mixed-mode multiphase quadrature oscillator employing a single fully differential second generation current conveyor, two resistors and two grounded capacitors is proposed. The proposed circuit provides two quadrature voltage outputs and three quadrature current outputs simultaneously. In addition, the proposed circuit has been made load insensitive so that it is capable of providing high output impedance current outputs without using additional current followers. Moreover, the proposed circuit of load insensitive quadrature oscillator provides four phase current outputs and two voltage outputs, simultaneously. Non ideal study is also included. Both the proposed circuits enjoy low active and passive sensitivities. This paper further presents an active-C multiphase oscillator with a single FDCCII and two grounded capacitors. The proposed structures are suitable for low voltage applications. Simulation results using PSPICE program on cadence tool are included.

Index Terms— Mixed-mode, FDCCII, Quadrature oscillator.

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I. INTRODUCTION

QUADRATURE oscillators play an important role in the field of communication and instrumentation systems as they provide two or more sinusoids signals with 90° phase difference. Multi-phase oscillators are an inimitable case of quadrature oscillators. They are also used in many areas of electrical engineering, signal processing, and measurement. The realizations of quadrature oscillators using different variation of current conveyors have received significant attention due to their numerous advantages. Therefore, a number of voltage/current/mixed mode quadrature oscillators using current conveyor and its different variations have been

reported in the literature [1]–[19], [22]–[26]. However, these reported circuits suffer from the one or more limitations as follows

- Use of more than one active element [2]–[4], [6]–[8], [10], [12]–[18], [19], [22]–[24], [26].
- Excessive use of passive components [3], [4], [6], [8]–[10], [12], [14]–[18], [19], [25].
- Non-availability of three or four quadrature current outputs and two quadrature voltage outputs simultaneously [2]–[7], [9]–[11], [13]–[19], [24]–[26].

In this paper, a new low voltage mixed-mode multi-phase oscillator (MPO) circuit using single fully differential second generation current conveyor (FDCCII), two resistors and two grounded capacitors is presented. The proposed circuit offers two quadrature voltage outputs and three quadrature current outputs simultaneously. In addition, the proposed circuit is made to provide four phase load insensitive current outputs with two phase voltage outputs from the same configuration. Moreover, this paper explores another oscillator, namely the active-C MPO which also has the same features as the previous proposed structures with the added advantage of resistorless realization. A comparison study with existing relevant works has been given in Table I.

II. PROPOSED MIXED-MODE MULTI PHASE OSCILLATOR

In 2005, the fully differential second generation current conveyor (FDCCII) is reported to improve the dynamic range in mixed-mode applications where fully differential signal processing is required [20]. The CMOS implementation of FDCCII is shown in Fig. 1. Additional current output terminals ($-Z+$ and $-Z-$) can also be obtained by adding extra current mirrors at the $Z+$ and $Z-$ terminals respectively. The fully differential input voltages from the Y terminals are conveyed to the X terminals and the currents from the X terminals are conveyed to the Z terminals. Using standard notations, the terminals relationship of an ideal FDCCII can be characterized as

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TABLE I: COMPARISON WITH OTHER EXISTING RELEVANT WORKS

| Refs. | Single Active Element Based Structure | Active Element Used | No. of Passive Components | No. of Available Current Outputs | No. of Available Voltage Outputs | Power Supply Used | Designed Frequency Of Oscillation | Technology Used |
|-----------------|---------------------------------------|---------------------|---------------------------|----------------------------------|----------------------------------|----------------------------|-----------------------------------|--------------------------------|
| 1 | No | CC | 4 | 0 | 2 | - | - | - |
| 2 | No | OTA | 3 | 0 | 2 | NA | 300KHz | NA |
| 7 | No | OTA | 2 | 0 | 4 | NA | 10KHz | NA |
| 9 | No | DVCC | 4/6 | 1 | 1 | $\pm 2.5V$ | 1.127MHz | 0.35 μm |
| 10 | No | CDTA | 6 | 2 | 0 | NA | 1MHz | 0.5 μm |
| 11 | Yes | FDCCII | 5 | 2 | 3 | NA | 15.9KHz | NA |
| 13 | No | DDCC | 5 | 0 | 2 | $\pm 2.5V$ | 649KHz | 0.5 μm |
| 14 | No | CCII | 10 | 0 | 3 | $\pm 10V$ | 50KHz | NA |
| 16 | No | DVCC | 5 | 4 | 0 | $\pm 2.5V$ | 1MHz | 0.5 μm |
| 17 | No | OPA | 5 | 0 | 4 | NA | 10KHz | NA |
| 18 | Yes | DO-CIBA | 5/6 | 0 | 4 | NA | 1MHz | NA |
| 22 | No | CCCH | 2 | 4 | 2 | $\pm 2.5V$ | 140KHz | NA |
| 23 | No | DVCC | 4 | 3 | 2 | $\pm 2.5V$ | 4.15MHz | NA |
| 24 | No | DXCCII | 4 | 0 | 2 | $\pm 2.5V$ | 24.93MHz | 0.5 μm |
| 25 | Yes | FDCCII | 5 | 0 | 4 | $\pm 3.3V$ | 15.9MHz | 0.35 μm |
| 26 | No | FDCCII | 4 | 0 | 3 | $\pm 3V$ | 159KHz | 0.35 μm |
| Proposed | Yes | FDCCII | 4 | 4 | 2 | $\pm 1V$ | 15.92MHz | 0.18 μm |

Abbreviations: CC: Current Conveyor, OTA: Operational Transconductance Amplifier, DVCC: Differential Voltage Current Conveyor, CDTA: Current Differencing Transconductance Amplifier, FDCCII: Fully Differential Second Generation Current Conveyor, DDCC: Differential Difference Current Conveyor, CCII: Second Generation Current Conveyor, OPA: Operational Amplifier, DO-CIBA: Differential Output Current Inverter Buffered Amplifier, CCCII: Current Controlled Second Generation Current Conveyor, DXCCII: Dual-X Second Generation Current Conveyor, NA: Not Available.

$$V_{X+} = V_{Y3} + V_{Y1} - V_{Y2}, \quad V_{X-} = V_{Y4} - V_{Y1} + V_{Y2} \quad (1)$$

$$I_{Z1+} = I_{Z2+} = I_{Z3+} = I_{X+}, \quad I_{-Z1+} = I_{-Z2+} = I_{-Z3+} = -I_{X+}, \\ I_{Z1-} = I_{X-}, \quad I_{-Z1-} = -I_{X-} \quad (2)$$

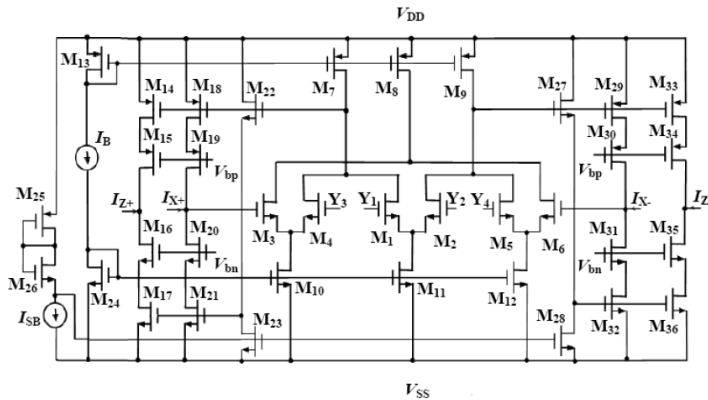


Fig. 1. The CMOS implementation of FDCCII [20]

The proposed mixed-mode MPO is shown in Fig. 2. The proposed circuit employs single FDCCII, two resistors and two grounded capacitors. The analysis of this circuit using (1) and (2) yields the following characteristic equation

$$s^2 + s \left(\frac{1}{R_2 C_1} - \frac{1}{R_1 C_1} \right) + \frac{1}{R_1 R_2 C_1 C_2} = 0 \quad (3)$$

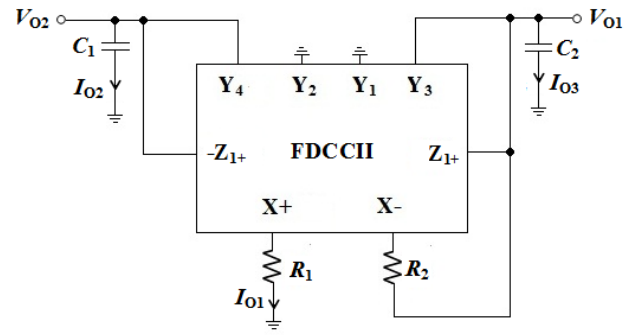


Fig. 2. Proposed low voltage mixed-mode MPO

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

$$FO: \omega_o = \left(\frac{1}{C_1 C_2 R_1 R_2} \right)^{\frac{1}{2}} \quad (4)$$

$$CO: R_1 \leq R_2 \quad (5)$$

The two quadrature voltage outputs (V_{O1} and V_{O2}) and three quadrature current outputs (I_{O1} , I_{O2} and I_{O3}) of the proposed circuit, depicted in Fig. 2, are related as

$$V_{O1} = -j\omega C_2 R_1 V_{O2} \quad (6)$$

$$I_{O3} = -j\omega C_1 R_1 I_{O2}, \quad I_{O1} = -I_{O2} \quad (7)$$

It is to be observed from (6) and (7) that the proposed circuit is capable to realize three quadrature current outputs (I_{O1} , I_{O2} and I_{O3}) and two quadrature voltage outputs (V_{O1} and V_{O2}), simultaneously.

Further, the proposed mixed-mode MPO shown in Fig. 2 is made load insensitive to provide high output impedance current outputs without using additional current followers by adding extra Z terminals as shown in Fig. 3.

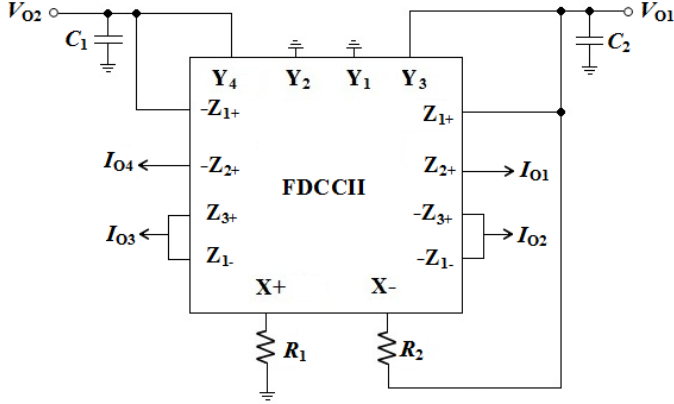


Fig. 3. Proposed Load Insensitive MPO

The proposed circuit of Fig. 3 now provides four load insensitive quadrature current outputs and two quadrature voltage outputs simultaneously. The four quadrature current outputs (I_{O1} , I_{O2} , I_{O3} and I_{O4}) and two quadrature voltage outputs (V_{O1} and V_{O2}) of the proposed circuit, depicted in Fig. 3, are now related as

$$I_{O3} = -j\omega C_1 R_1 I_{O2}, \quad I_{O1} = -I_{O2}, \quad I_{O3} = -I_{O4} \quad (8)$$

$$V_{O1} = -j\omega C_2 R_1 V_{O2} \quad (9)$$

III. NON-IDEAL STUDY

Taking the non-idealities of the FDCCII into account, the relationship of the voltages and currents can be rewritten as

$$V_{X+} = \beta_1 V_{Y1} - \beta_2 V_{Y2} + \beta_3 V_{Y3}, \quad V_{X-} = \beta_6 V_{Y4} - \beta_4 V_{Y1} + \beta_5 V_{Y2} \quad (10)$$

$$I_{Z1+} = \alpha_1 I_{X+}, \quad I_{-Z1+} = -\alpha_2 I_{X+}, \quad I_{Z1-} = \alpha_3 I_{X-}, \quad I_{-Z1-} = -\alpha_4 I_{X-} \quad (11)$$

The parameters $\beta_j(s)$ where, $j=1, 2, 3, 4, 5, 6$ and $\alpha_k(s)$ for $k=1, 2, 3, 4$ are the voltage and current transfer gains from Y terminals to X terminals. These transfer gains differ from unity by the voltage and current tracking errors of the FDCCII. More specifically, $\beta_j = (1-\varepsilon_j)$ and $\alpha_k = (1-\delta_k)$, where ε_j is the voltage tracking error of the FDCCII and δ_k is the current tracking error of the FDCCII. Note that the voltage

and current transfer gains ($\beta_j(s)$ and $\alpha_k(s)$) in the ideal case are equal to unity. The circuits of Fig. 2 and Fig. 3 are reanalyzed using (10) and (11). The modified characteristic equation is given as

$$s^2 + s \left(\frac{\alpha_2 \beta_1}{R_2 C_1} - \frac{\alpha_1 \beta_1}{R_1 C_1} \right) + \frac{\alpha_2 \alpha_3 \beta_1 \beta_2}{R_1 R_2 C_1 C_2} = 0 \quad (12)$$

The modified frequency of oscillation and the condition of oscillation can be obtained as:

$$\text{FO: } \omega_o = \left(\frac{\alpha_2 \alpha_3 \beta_1 \beta_2}{R_1 R_2 C_1 C_2} \right)^{\frac{1}{2}} \quad (13)$$

$$\text{CO: } R_1 \alpha_2 \leq R_2 \alpha_1 \quad (14)$$

The active and passive sensitivities with respect to ω_o are given as follows

$$S_{\alpha_2, \alpha_3, \beta_1, \beta_2}^{\omega_o} = -S_{R_1, R_2, C_1, C_2}^{\omega_o} = \frac{1}{2}, \quad S_{\alpha_1, \alpha_4, \beta_3, \beta_4}^{\omega_o} = 0 \quad (15)$$

Equation (15) shows that all the active and passive sensitivities with respect to ω_o are less than unity in magnitude.

IV. SIMULATION RESULTS

The performance of the proposed mixed-mode MPO is verified using PSPICE with 0.18 μm process CMOS parameters. The supply voltages and currents are $V_{DD} = -V_{SS} = 1 \text{ V}$, $V_{bp} = V_{bn} = 0 \text{ V}$, $I_B = 1.34 \text{ mA}$ and $I_{SB} = 1.12 \text{ mA}$. The proposed mixed-mode MPO circuit is designed using equal values of resistors and capacitors i.e $R_1 = R_2 = 1 \text{ k}\Omega$, $C_1 = C_2 = 10 \text{ pF}$. The theoretical frequency of oscillation is 15.92 MHz. The simulated frequency of oscillation is found to be 15.56 MHz which is close to the designed value. The simulated results for the three current outputs and two voltage outputs are shown in Fig. 4 and Fig. 5.

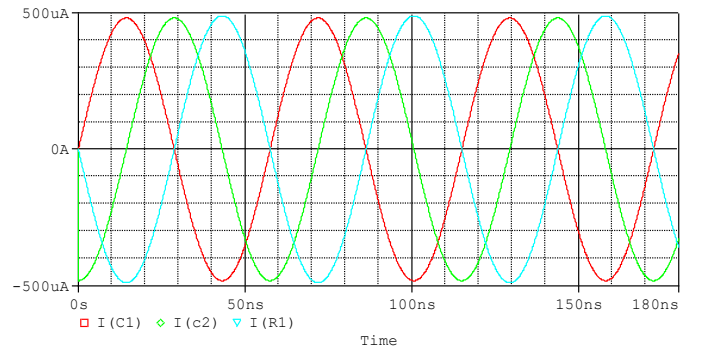


Fig. 4. Three quadrature current outputs at 15.92 MHz

The Fourier spectrum of the output waveforms of Fig. 4 and Fig. 5 are shown in Fig. 6 and Fig. 7, respectively.

Similarly, the load insensitive MPO circuit of Fig. 3 is designed for the same frequency of oscillation with the passive components values as $R_1 = R_2 = 1 \text{ k}\Omega$, $C_1 = C_2 = 10 \text{ pF}$.

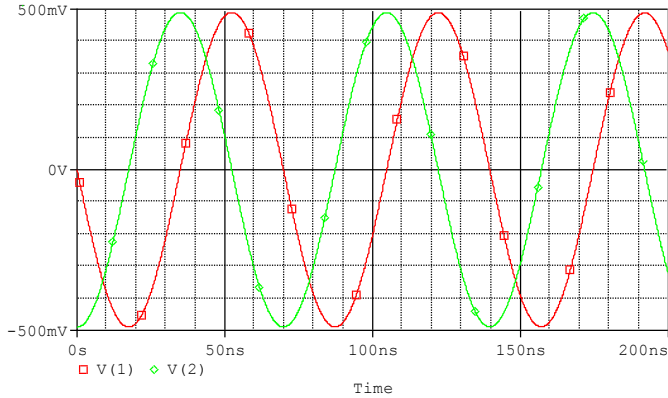


Fig. 5. Two quadrature voltage outputs at 15.92 MHz

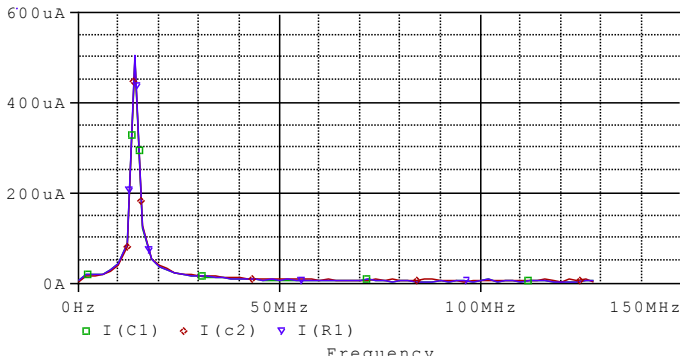


Fig. 6. Fourier spectrums of current outputs

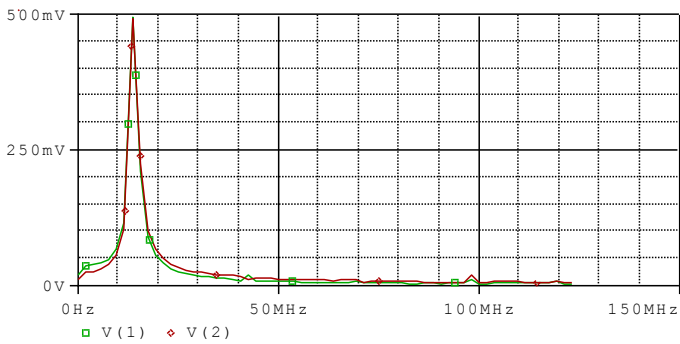


Fig. 7. Fourier spectrums of voltage outputs

The simulated four current output waveforms and two voltage output wave forms are shown in Fig. 8 and Fig. 9.

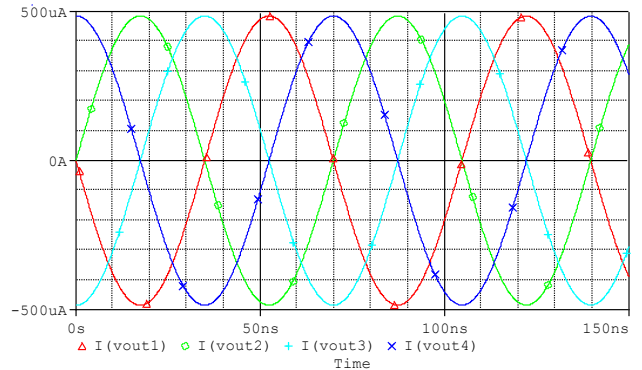


Fig. 8. Four quadrature current outputs at 15.92 MHz

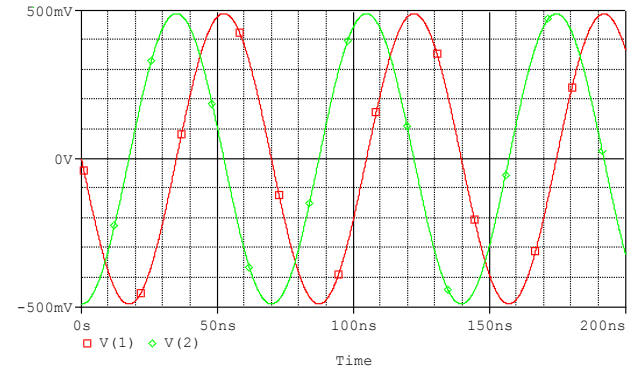


Fig. 9. Two quadrature voltage outputs at 15.92 MHz

The Fourier spectrum of the output waveforms are shown in Fig. 10 and Fig. 11.

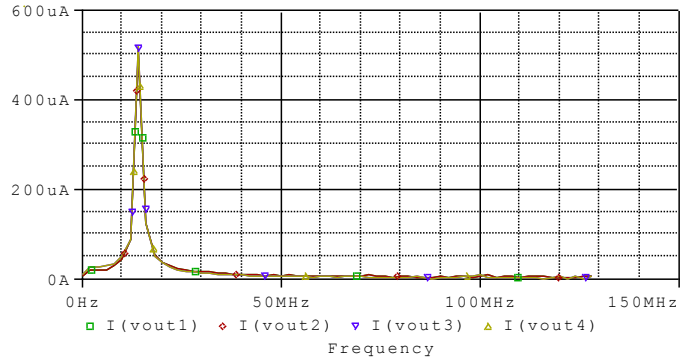


Fig. 10. Fourier spectrums of current outputs

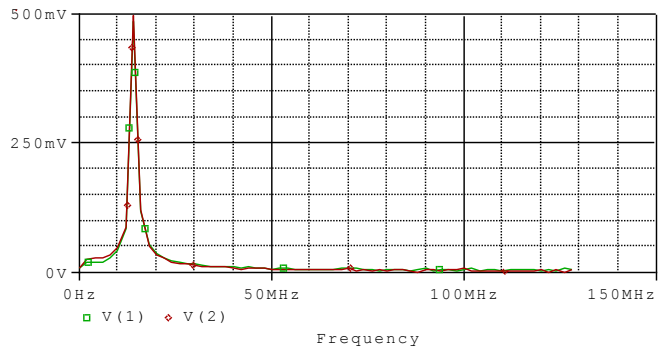
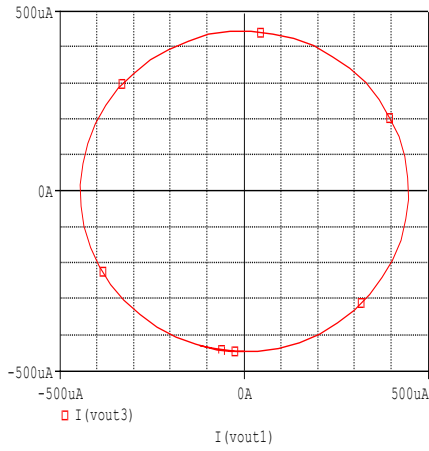
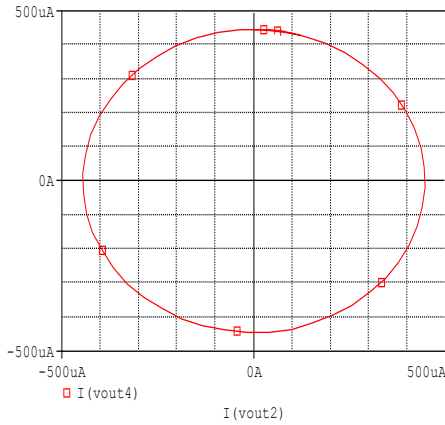


Fig. 11. Fourier spectrums of the voltage outputs

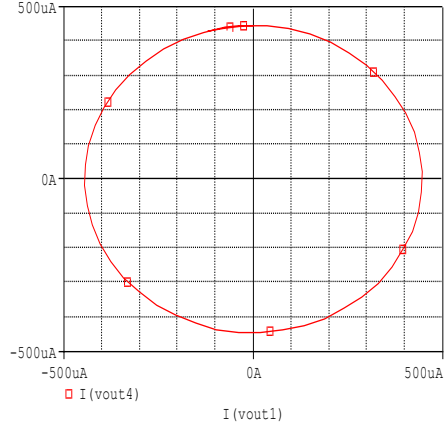
Moreover, the X-Y plots are also shown in Fig. 12 (a)-(e) to verify the quadrature relationships between four current outputs and two voltage outputs.



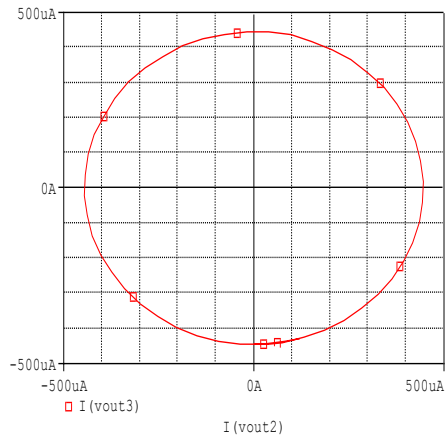
(a)



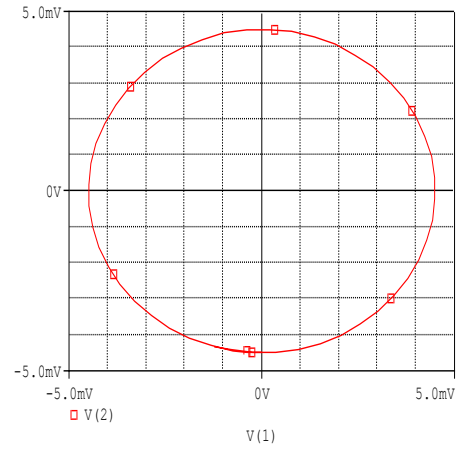
(b)



(c)



(d)



(e)

Fig. 12. The X-Y plots showing quadrature current and voltage relationships

V. ACTIVE-C MULTI PHASE OSCILLATOR

In this section, the proposed MPO of Fig. 3 is made resistorless by replacing the grounded resistor with the two n-MOS transistor based grounded resistor [21] and by replacing the floating resistor with the single n-MOS transistor biased in the triode region. The proposed active-C MPO is shown in Fig. 13.

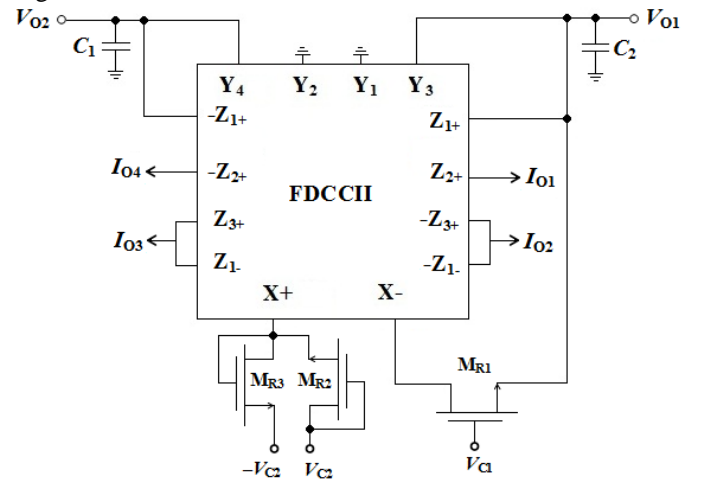


Fig. 13. Proposed active-C MPO

The frequency of oscillation and the condition of oscillation for the proposed active-C MPO can be given as

$$\text{FO: } \omega_o = \left(\frac{1}{C_1 C_2 R_{\text{MOS1}} R_{\text{MOS2}}} \right)^{\frac{1}{2}} \quad (16)$$

$$\text{CO: } R_{\text{MOS1}} \leq R_{\text{MOS2}} \quad (17)$$

where, R_{MOS1} is the equivalent resistance of the n-MOS transistors (M_{R2} and M_{R3}) in Fig. 13 and is given by

$$R_{\text{MOS1}} = \left[2\mu C_{\text{OX}} \left(\frac{W}{L} \right) (V_{\text{C2}} - V_{\text{T}}) \right]^{-1} \quad (18)$$

R_{MOS2} is the equivalent resistance of the n-MOS transistor (M_{R1}) in Fig. 13 and is given by

$$R_{MOS2} = \left[\mu C_{OX} \left(\frac{W}{L} \right) (V_{C1} - V_T) \right]^{-1} \quad (19)$$

where, μ , C_{OX} , V_T , W and L are the carrier mobility, gate capacitance per unit area, threshold voltage, channel width and the length of n-MOS.

The active-C MPO of Fig. 13 was simulated and designed for frequency 15.92MHz. The transistor aspect ratios for the MOS based electronic resistors are selected as $(W/L)_{MR1} = 28.8\mu\text{m}/0.18\mu\text{m}$, $(W/L)_{MR2} = (W/L)_{MR3} = 14.4\mu\text{m}/0.18\mu\text{m}$ and capacitors values are selected as $C_1 = C_2 = 10\text{pF}$. The frequency of oscillation for the proposed circuit is tuned to 15.92MHz by selecting the control voltages as $V_{C1} \cong V_{C2} = -V_{C2} = 0.91$. The four current and two voltage quadrature outputs are shown in Fig. 14 and Fig. 15, respectively.

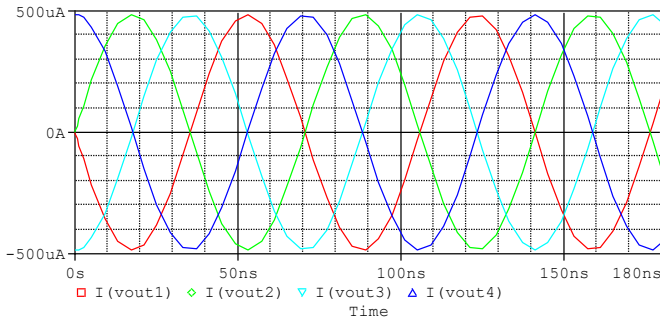


Fig. 14. Four quadrature current outputs at 15.92 MHz

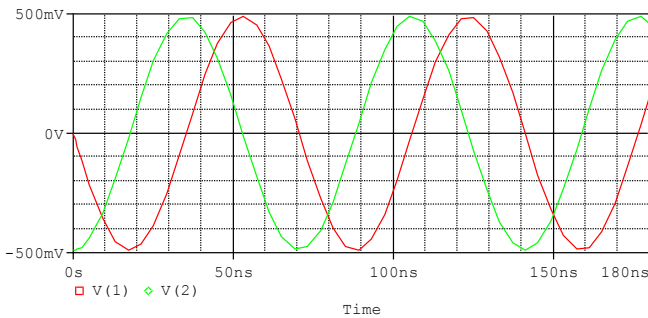


Fig. 15. Two quadrature voltage outputs at 15.92 MHz

The obtained results validate the active-C MPO realization. In order to further support the practical utility of active-C MPO, the control voltage ($V_{C1} \cong V_{C2} = V_C$) was varied so as to vary the FO. Fig. 16 shows the tuning of frequency of oscillation with the control voltages. Both theoretical and simulated FO is found to be close to each other.

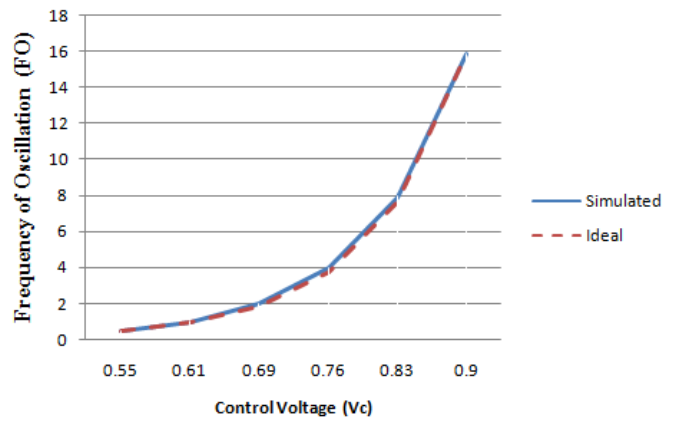


Fig. 16. Variation of FO with control voltage

VI. CONCLUSION

In this paper, a new single FDCCII based low voltage mixed-mode MPO realizing three quadrature current outputs and two quadrature voltage outputs has been proposed. The proposed circuit employs two resistors and two grounded capacitors. Moreover, a load insensitive MPO is also presented. The load insensitive circuit enjoys high impedance current outputs with no additional current followers. The active and passive sensitivities are not more than unity. By employing FDCCII, MOS based active resistors and two grounded capacitors, a new active-C MPO is also realized. All the proposed circuits are operated at low voltage power supply therefore suitable for low voltage applications. PSPICE simulation results on cadence tool have verified the workability of the circuits.

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