Single DD-DXCCII based quadrature oscillator with simultaneous current and voltage outputs

B. Chaturvedi and J. Mohan

Abstract—**In this paper, a versatile quadrature oscillator using single Differential Difference Second Generation Dual-X Current Conveyor (DD-DXCCII) as an active element, two grounded capacitors and three grounded resistors is presented. The proposed oscillator provides two current outputs and three voltage outputs in quadrature relationship simultaneously so named as versatile quadrature oscillator. The proposed versatile quadrature oscillator exhibits the feature of orthogonal control over the frequency of oscillation and condition of oscillation. Effects of non-idealities along with sensitivity analysis are also analyzed. The proposed circuit has low active and passive sensitivities. Parasitic study is further explored. The simulation results with 0.18µm CMOS process parameters using PSPICE are also given. Possible realization of proposed oscillator using AD-844 and LM13600 along with some simulation results are also given for completeness sake.**

Index Terms—**Current Conveyors, Quadrature Oscillators, AD-844.**

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I. Introduction

ONE of the noteworthy things about quadrature oscillators, as in various communication applications, is a requirement of sinusoid signals that are 90^0 phase in difference [1]. In the literature a number of quadrature oscillators based on different active elements are reported [3-25] and the references cited therein. The quadrature oscillators in [3-5, 7-8, 24-25] produced voltage-mode signals and the ones in [9-17, 23] produced current-mode signals. Although some of the quadrature oscillators in [6, 18-22] generated both voltage-mode as well as current-mode signals. Moreover, few of them are based on single active element [9, 10, 12, 13, 16, 19, 23]. A comparison study with existing oscillators has been given in Table 1.

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This paper presents a novel circuit of versatile quadrature oscillator using a single DD-DXCCII along with two grounded capacitors and three grounded resistor. The proposed circuit enjoys the use of single active element and use of grounded components. The proposed circuit of versatile quadrature oscillator contains orthogonal control of frequency of oscillation and condition of oscillation. The proposed versatile quadrature oscillator provides quadrature current-mode outputs and voltage-mode outputs simultaneously.

II. Circuit Description

A. DD-DXCCII

The advantages of the Differential Difference Current Conveyor (DDCC) [2] and the Dual-X Second Generation Current Conveyor DXCCII [14] are combined and hence re-named as DD-DXCCII [26, 27]. Keeping this in consideration, the port relationships of DD-DXCCII are now characterized as:

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ I_{Y3} \\ V_{X+} \\ V_{X-} \\ I_{Z+} \\ I_{Z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 0 & 0 & 0 & 0 \\ -1 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ I_{X+} \\ I_{X-} \\ V_{Z+} \\ V_{Z-} \end{bmatrix} \quad (1)$$

The symbol and CMOS implementation of DD-DXCCII is shown in Fig. 1. The CMOS implementation of DD-DXCCII is a combination of DDCC (M_{25} – M_{34}) with unemployed Z-stages and DXCCII (M_1 – M_{24}). In the CMOS implementation of DD-DXCCII, the X-terminal (gate of M_{30}) of DDCC drives the Y-terminal (gate of M_2) of the DXCCII. The Z+ and Z- stages are realized from the drain of M_{11} and M_{16} transistors. The difference of the Y_1 and Y_2 terminal voltages in addition with the voltage at Y_3 terminal is conveyed to the X+ terminal; the current at the X+ terminal is conveyed to the Z+ terminal and The difference of the Y_2 and Y_1 terminal voltages in subtraction with the voltage at Y_3 terminal is conveyed to the X-terminal; the current at the X- terminal is conveyed to the Z- terminal. In a DD-DXCCII, terminals Y_1, Y_2 and Y_3 exhibit high input impedance. Thus, no current flows in terminals Y_1,Y_2 and Y_3. The terminal X+ and X- exhibit low input impedance and the terminals Z+ and Z- have high output impedance.

TABLE I
COMPARISON WITH OTHER PREVIOUSLY KNOWN OSCILLATOR

Refs.	Single Active Element	Type of Active Element	No. of Resistors	No. of Capacitors	All Grounded Passive Components	No. of Current Outputs	No. of Voltage Outputs	Orthogonal/ Independent controlling	Designed Frequency of Oscillation
3	No	CC	2G	2G	Yes	-	2	NA	-
4	No	OTA	-	2F, 1G	No	-	2	No	300KHz
5	No	OTA	-	2G	Yes	-	4	Yes	10KHz
6	No	CCII	3G	2G	Yes	1	2	Yes	159KHz
7	No	OTA	-	3G	Yes	-	1	Yes	2MHz
8	No	DDCC	3G	2G	Yes	-	2	No	10.61MHz
9	Yes	FTFN	3F, 2G	3G	No	1	-	Yes	NA
10	Yes	CF+	3F	3G	No	2	-	No	NA
11	No	OA & OTA	-	-	-	2	-	No	1MHz
12	Yes	FTFN	2F, 1G	2F, 1G	NO	2	-	Yes	NA
13	Yes	FTFN	2	5	No	1	-	Yes	28KHz
15	No	MOCCII	2G	2G	Yes	8	-	No	358KHz
16	Yes	ZC-CDTA	2F	2G	No	1	-	Yes	59.77KHz
17	No	DVCC	3G	2G	Yes	4	-	Yes	1MHz
18	No	CCCII	-	2G	Yes	4	2	Yes	140KHz
19	Yes	FDCCII	3G	2G	Yes	2	2	No	7.9KHz
20	No	DXCCII	2G	3G	Yes	3	3	Yes	1.7MHz
21	No	ZC-CG-CDBA	3F	2G	No	2	2	Yes	2.75MHz
22	No	DVCC	2G	2G	Yes	3	2	No	4.15MHz
23	Yes	FTFN	3F, 2G	2G	No	2	-	Yes	6.9KHz
24	No	DXCCII	1F, 1G	1F, 1G	No	-	2	No	24.93MHz
25	No	DVCC	3F	3G	NO	-	4	Yes	2.5MHz
Proposed	Yes	DD-DXCCII	3G	2G	Yes	2	2	Yes	26.54MHz

Abbreviations: CC: Current Conveyor, OTA: Operational Transconductance Amplifier, CCII: Second Generation Current Conveyor, DDCC: Differential Difference Current Conveyor, FTFN: Four-Terminal Floating Nullor, CF+: Positive Current Follower, OA: Operational Amplifier, MO-CCII: Multi-Output Second Generation Current Conveyor, ZC-CDTA: Z-Copy Current Differencing Transconductance Amplifier, DVCC: Differential Voltage Current Conveyor, CCCII: Current Controlled Second Generation Current Conveyor, FDCCII: Fully Differential Second Generation Current Conveyor, DXCCII: Dual-X Second Generation Current Conveyor, ZC-CG-CDBA: Z-Copy Controlled Gain Current Differencing Buffered Amplifier, DD-DXCCII: Differential Difference Second Generation Dual-X Current Conveyor, NA: Not Available, F: Floating, G: Grounded.

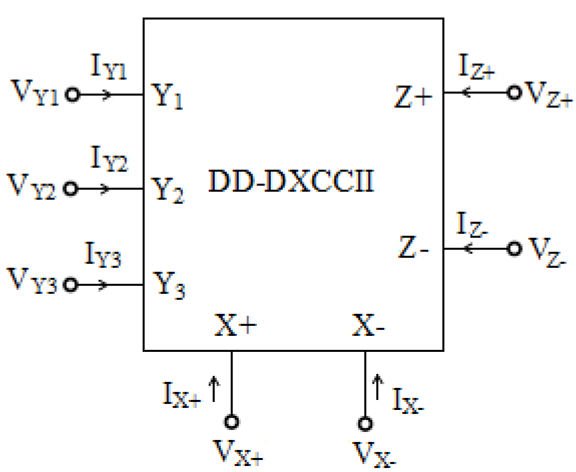

Fig. 1(a). Symbol of DD-DXCCII [26, 27]

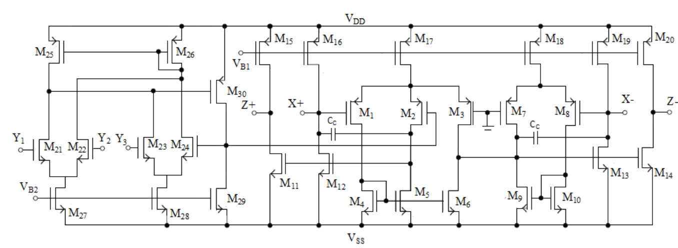

Fig. 1(b). CMOS implementation of DD-DXCCII [26, 27]

B. The Proposed Versatile Quadrature Oscillator

The proposed versatile quadrature oscillator circuit is shown in Fig. 2. Routine analysis of the proposed oscillator using equation (1) yields the following characteristic equation

$$s^2 + s\left(\frac{1}{C_1R_1} + \frac{1}{C_2R_3} - \frac{1}{C_1R_2}\right) + \frac{1}{C_1C_2R_1R_3} = 0 \qquad (2)$$

From equation (2), the frequency of oscillation (FO) and condition of oscillation (CO) are given as

$$\text{FO: } \omega_o = \sqrt{\frac{1}{C_1 C_2 R_1 R_3}} \tag{3}$$

$$\text{CO: } \frac{1}{C_1 R_1} + \frac{1}{C_2 R_3} \geq \frac{1}{C_1 R_2} \tag{4}$$

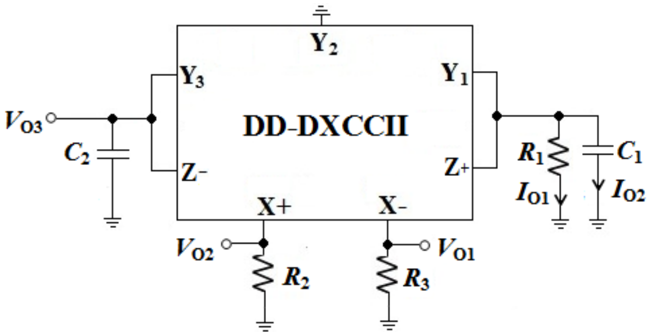

Fig. 2. Proposed versatile quadrature oscillator

It is to be noted from equation (3) and equation (4) that the FO and CO are orthogonally controlled.

The two currents outputs (I_{O1} and I_{O2}) and three voltage outputs (V_{O1}, V_{O2} and V_{O3}) of the proposed versatile quadrature oscillator, shown in Fig. 3 are related as

$$I_{O2} = j\omega C_1 R_1 I_{O1} \tag{5}$$

$$V_{O1} = j\omega C_2 R_2 V_{O3} \tag{6}$$

$$V_{O1} = -V_{O2} \tag{7}$$

Thus, the proposed circuit provides two quadrature current outputs (I_{O1} and I_{O2}) and three quadrature voltage outputs (V_{O1}, V_{O2} and V_{O3}) simultaneously.

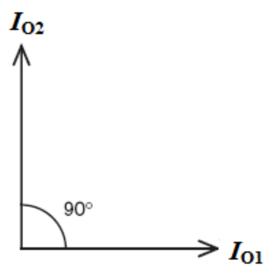

Fig. 3(a). Phasor diagram depicting quadrature current outputs

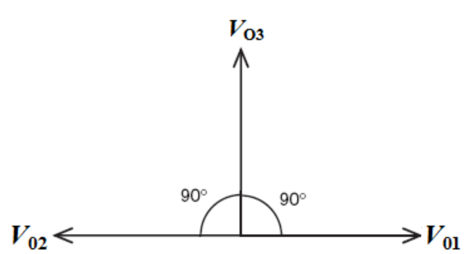

Fig. 3(b). Phasor diagram depicting quadrature voltage outputs

C. Sensitivity Analysis

The detailed analysis of sensitivity shows a vital index of the performance of any active system. The proper definition of sensitivity is given as follows:

$$S_Y^X = \frac{Y}{X}\frac{\partial X}{\partial Y} \tag{8}$$

where, X represents the circuit performance parameters and Y represents the value of the passive elements. Using the above definition, the passive sensitivities with respect to one of the circuit performance parameters i.e. FO (ω_o) are given as below

$$S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = S_{R_1}^{\omega_o} = S_{R_3}^{\omega_o} = -\frac{1}{2} \tag{9}$$

It is to be noted from equation (6) that all the passive sensitivities are less than unity in magnitude and hence the proposed circuit exhibits a good sensitivity performance.

III. Non-ideal and Parasitic Study

A. Non-ideal Study

The proposed circuit is reanalyzed for the DD-DXCCII non-idealities [27], namely voltage transfer gains (β_i, where i = 1, 2, 3, 4, 5, 6) and current transfer gains (α_j, where j = 1, 2). The relationship of the terminal voltages and currents can be rewritten as:

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ I_{Y3} \\ V_{X+} \\ V_{X-} \\ I_{Z+} \\ I_{Z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \beta_1 & -\beta_2 & \beta_3 & 0 & 0 & 0 & 0 \\ -\beta_4 & \beta_5 & -\beta_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \alpha_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_2 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ I_{X+} \\ I_{X-} \\ V_{Z+} \\ V_{Z-} \end{bmatrix} \tag{10}$$

The proposed versatile quadrature oscillator circuit of Fig. 2 is reanalyzed using equation (10) and the non-ideal characteristic equation is found as

$$s^2 + s\left[\frac{1}{C_1 R_1} + \frac{\alpha_2 \beta_6}{C_2 R_3} - \frac{\alpha_1 \beta_1}{C_1 R_2}\right] + \frac{\alpha_2\left(\alpha_1 \beta_3 \beta_4 R_1 + \beta_6 R_2 - \alpha_1 \beta_1 \beta_6 R_1\right)}{C_1 C_2 R_1 R_2 R_3} = 0 \tag{11}$$

From equation (11), the non-ideal FO and CO become as follows

$$\text{FO: } \omega_o = \sqrt{\frac{\alpha_2\left(\alpha_1 \beta_3 \beta_4 R_1 + \beta_6 R_2 - \alpha_1 \beta_1 \beta_6 R_1\right)}{C_1 C_2 R_1 R_2 R_3}} \tag{12}$$

$$\text{CO: } \frac{1}{C_1 R_1} + \frac{\alpha_2 \beta_6}{C_2 R_3} \geq \frac{\alpha_1 \beta_1}{C_1 R_2} \tag{13}$$

Furthermore, by using equation (8), the sensitivities of active (β_i, where i = 1, 2, 3, 4, 5, 6 and α_j, where j = 1, 2) and passive components (R_1, R_2, R_3, C_1 and C_2) with respect to ω_o are again analyzed and given as follows:

$$S_{R_1}^{\omega_o} = -\frac{1}{2}\left[\frac{\alpha_1 \beta_1 \beta_6 R_1 + \alpha_2 \beta_6 R_2 - \alpha_1 \alpha_2 \beta_1 \beta_6 R_1}{\alpha_2\left[\alpha_1 \beta_3 \beta_4 R_1 + \beta_6 R_2 - \alpha_1 \beta_1 \beta_6 R_1\right]}\right] \tag{14}$$

$$S_{R_2}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_1\alpha_2\beta_1\beta_6R_1 - \alpha_1\alpha_2\beta_3\beta_4R_1}{\alpha_2\left[\alpha_1\beta_3\beta_4R_1 + \beta_6R_2 - \alpha_1\beta_1\beta_6R_1\right]}\right] \quad (15)$$

$$S_{\alpha_1}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_1\alpha_2\beta_3\beta_4R_1 - \alpha_1\alpha_2\beta_1\beta_6R_1}{\alpha_2\left[\alpha_1\beta_3\beta_4R_1 + \beta_6R_2 - \alpha_1\beta_1\beta_6R_1\right]}\right] \quad (16)$$

$$S_{\beta_1}^{\omega_o} = -\frac{1}{2}\left[\frac{\alpha_1\alpha_2\beta_1\beta_6R_1}{\alpha_2\left[\alpha_1\beta_3\beta_4R_1 + \beta_6R_2 - \alpha_1\beta_1\beta_6R_1\right]}\right] \quad (17)$$

$$S_{\beta_3}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_1\alpha_2\beta_3\beta_4R_1}{\alpha_2\left[\alpha_1\beta_3\beta_4R_1 + \beta_6R_2 - \alpha_1\beta_1\beta_6R_1\right]}\right] \quad (18)$$

$$S_{\beta_4}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_1\alpha_2\beta_3\beta_4R_1}{\alpha_2\left[\alpha_1\beta_3\beta_4R_1 + \beta_6R_2 - \alpha_1\beta_1\beta_6R_1\right]}\right] \quad (19)$$

$$S_{\beta_6}^{\omega_o} = \frac{1}{2}\left[\frac{\alpha_2\beta_6R_2 - \alpha_1\alpha_2\beta_1\beta_6R_1}{\alpha_2\left[\alpha_1\beta_3\beta_4R_1 + \beta_6R_2 - \alpha_1\beta_1\beta_6R_1\right]}\right] \quad (20)$$

$$S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = S_{R_3}^{\omega_o} = -S_{\alpha_2}^{\omega_o} = -\frac{1}{2} \quad (21)$$

For unity values of current and voltage transfer gains and equal capacitor and resistor design, it is evident from equations (14) – (21) that active and passive sensitivities of ω_o are less than unity in magnitude and hence the circuit exhibits a good sensitivity performance.

B. Parasitic Study

The influence of DD-DXCCII parasitic on the performance of novel quadrature oscillator is further studied. The various ports of DD-DXCCII are characterized by parasitic resistances (R_{Y1}, R_{Y2}, $R_{Y3,}$ R_{X+}, R_{X-}, R_{Z+} and R_{Z-}) and parasitic capacitances (C_{Y1}, C_{Y2}, $C_{Y3,}$ C_{Z+} and C_{Z-}) as shown in Fig. 4. From the proposed circuit of versatile quadrature oscillator, it can be seen that two external resistors are connected at X+ and X- terminals. It is to be noted that current conveyors with resistive termination at X port is appropriate with a view to absorb X-terminal parasitic resistances i.e. R_{X+} and R_{X-}. It is also worth mentioning that the parasitic resistances and capacitances appearing at the high input impedance terminals (Y_1, Y_2 and Y_3) and high output impedance terminals (Z+ and Z-) are absorbed into the external resistors and capacitors as they are shunt with them. The modified characteristic equation with parasitic effects is given below

$$s^2 + s\left(\frac{1}{C_1'R_1'} + \frac{1}{C'R_3'} - \frac{1}{C_1'R_2'}\right) + \frac{1}{C_1'C'R_1'R_3'} = 0 \quad (22)$$

The modified frequency of oscillation is given as

$$\omega_o = \sqrt{\frac{1}{C_1'C'R_1'R_3'}} \quad (23)$$

where,

$$R_1' = R_1 // R_{Y1} // R_{Y3} // R_{Z-}$$
$$C_1' = C_1 + C_{Y1} + C_{Y3} + C_{Z-}$$
$$R_2' = R_2 + R_{X+}$$
$$R_3' = R_3 + R_{X-}$$
$$C' = C_2' // R' =$$
$$\left(C_2 + C_{Y2} + C_{Z+}\right) // \left(R_{Y2} // R_{Z+}\right)$$

where, R_{Y1}, R_{Y2} and R_{Y3} are the parasitic resistances and C_{Y1}, C_{Y2} and C_{Y3} are the parasitic capacitances at the Y_1, Y_2 and Y_3 terminals, respectively, R_{Z+} and R_{Z-} are the parasitic resistances and C_{Z+} and C_{Z-} are the parasitic capacitances at the Z_+ and Z_- terminals, respectively, and R_{X+} and R_{X-} represent the parasitic resistances appearing at the X+ and X- terminals, respectively.

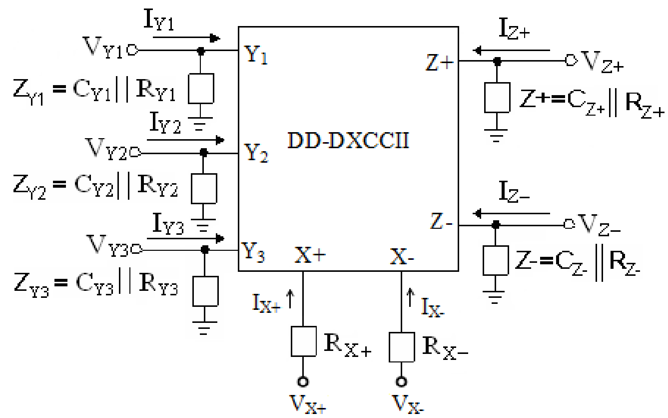

Fig. 4. Parasitic Model of DD-DXCCII

IV. Simulation Results

The performance of the proposed quadrature oscillator is verified using PSPICE with 0.18µm process parameters. The proposed circuit is designed with the frequency of oscillation at 26.54MHz by considering the passive component values as C_1 = C_2 = 3pF, R_1 = R_3 = 2kΩ, R_2 = 1kΩ. The CMOS implementation of DD-DXCCII as shown in Fig. 1 (b) is used. The list of aspect ratios is shown in Table 2. The supply voltages are taken as $V_{DD} = -V_{SS} = 1V$ and the biasing voltage as $V_{BB} = -0.65V$. The simulated FO for the proposed oscillator is found to be 26.18MHz, which is very close to the theoretical value. The two current outputs along with their Fourier spectrum are shown in Fig. 5 and Fig. 6, respectively. Similarly, three voltage outputs and their Fourier spectrum are shown in Fig. 7 and Fig. 8, respectively. The THD for the current and voltage outputs is found to be within 2%, which is low, keeping in view the frequency of operation.

TABLE II:
ASPECT RATIOS (W/L) USED IN Fig. 1 (b)

Transistors	W (µm) / L (µm)
M_1-M_4, M_{15}-M_{20}, M_{25}-M_{26}	1.44/0.18
M_{11}-M_{14}	11.51/0.18
M_3, M_6-M_{10}	2.88/0.18
M_{21}-M_{24}	0.29/0.18
M_{29}	16.19/0.18
M_{27}-M_{28}	5.22/0.18
M_{30}	3.6/0.18

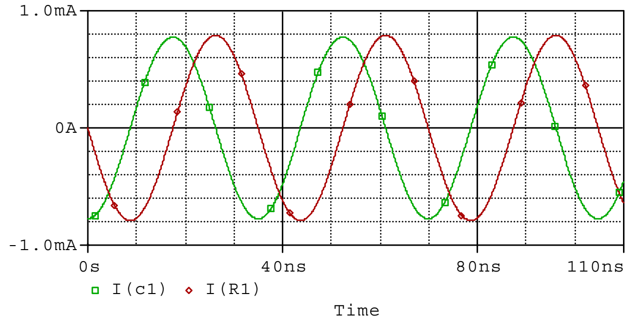

Fig. 5. Two quadrature current outputs at 26.54MHz

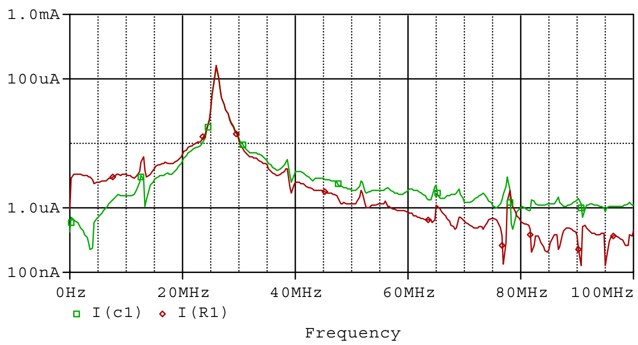

Fig. 6. Fourier spectrum of two current outputs

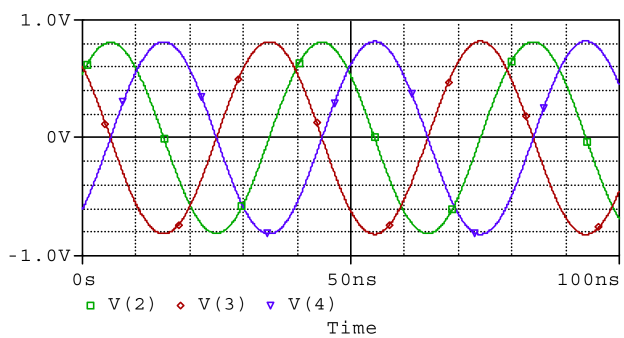

Fig. 7. Three quadrature voltage outputs at 26.54MHz

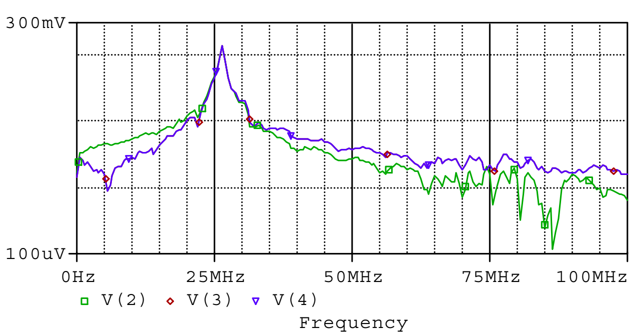

Fig. 8. Fourier spectrum of three voltage outputs

V. Practical Aspects

A. Possible Experimental Setup

The current mode active elements along with DD-DXCCII (at which the new proposed circuit is based on) are not commercially available. The catalogue of such type of active elements is exhaustive, ranging from CCI, CCII, CCIII, CCCII, DVCC, DDCC, DXCCII etc. However, such active elements have been successfully realized using commercially available integrated circuits (ICs) for instance, LM13600, AD-844s [24, 25, 28, 29]. This may apply equally well to DD-DXCCII and its possible realization using commercially available ICs, like LM13600 and AD844s is shown in Fig. 9. It is well known that an AD844 can realize a second generation current conveyor with additional buffered Z output and LM13600 is the standard single-output operational transconductance amplifier (OTA). Moreover, it does provide a possible solution to the need of experimental setups. After verifying the proposed circuit of quadrature oscillator by its CMOS implementation, its verification with OTAs and AD844 realization was also carried out. The supply voltages used were ±10V. The bias current I_B used is 500μA. The circuit was tested with $C_1 = C_2 = 100$pF, $R_1 = R_3 = 2$kΩ, $R_2 = 1$kΩ. The quadrature voltage and current outputs are shown in Fig. 10 and Fig. 11, respectively. The measured oscillation frequency is 794KHz which is quite near to the designed value of 796.17KHz.

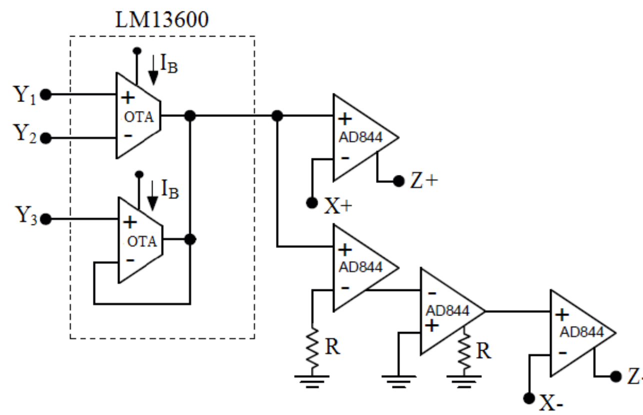

Fig. 9. Possible realization of proposed quadrature oscillator using AD844 and LM13600

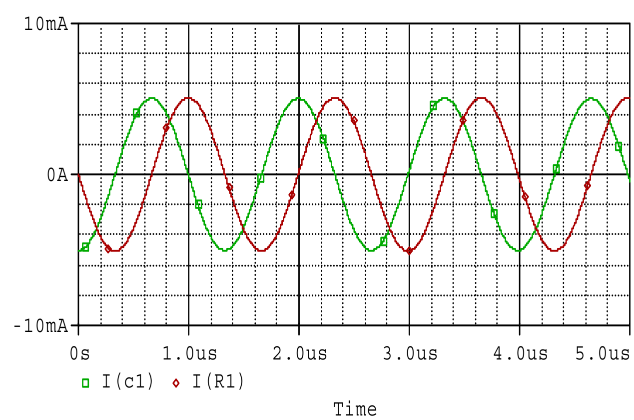

Fig. 10. Two quadrature current outputs at 794KHz

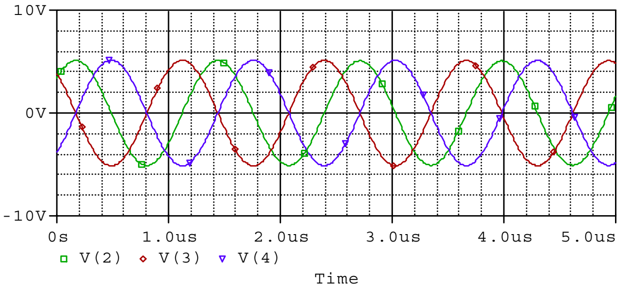

Fig. 11. Three quadrature voltage outputs at 794KHz

B. Output current sensing

It may further be noted that the output currents are through passive elements. Moreover, the impedance level may also not be desirable and even frequency dependent (where the output is through a capacitor). The purpose may be fulfilled with additional current sensing elements in form of current followers. It is a well known fact that current conveyor itself can be used to realize an accurate current follower. This will lead to high impedance current output but at the cost of un-grounded passive components. All these concerns are quite obvious, but keeping in view the simplicity and other advantages of the proposed circuit, this may not be seen as a drawback of the proposed work. Other available work also suffers from similar current sensing problems [10, 12, 13, 22, 23] as compared to many others which actually show high impedance current output(s) [6, 9, 11, 15-21]. However, the use of current follower would make the passive elements virtually grounded instead of being physically grounded.

VI. Conclusion

In this paper, a new versatile quadrature oscillator is proposed. The proposed circuit is very simple and contains only single DD-DXCCII as active element. It employs all grounded passive components, which is ideal for IC implementation. The proposed circuit provides two quadrature current outputs and three quadrature voltage outputs simultaneously from the same configuration. The proposed circuit enjoys good active and passive sensitivities. However, due to a variety of features along with circuit simplicity, FO and CO is not independently adjustable. Non-ideal and parasitic study is also discussed. Simulations results are further given to confirm the presented theory. Possible experimental setup for DD-DXCCII using commercial available ICs is further discussed.

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