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° 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.

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 (DCC) [2] and the Dual-X Second Generation Current Conveyor DXCCII [14] are combined and hence renamed as DD-DXCCII [26, 27]. Keeping this in consideration, the port relationships of DD-DXCCII are now characterized as:

\[
\begin{bmatrix}
I_{\text{T}1} \\
I_{\text{T}2} \\
I_{\text{T}3} \\
V_{X+} \\
V_{X-} \\
I_{Z+} \\
I_{Z-}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & -1 & 1 & 0 & 0 & 1 & 0 \\
-1 & 1 & -1 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
V_{T1} \\
V_{T2} \\
V_{T3} \\
I_{X+} \\
I_{X-} \\
V_{Z+} \\
V_{Z-}
\end{bmatrix}
\]

(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_{35} - 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_{13} 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

<table>
<thead>
<tr>
<th>Refs</th>
<th>Single Active Element</th>
<th>Type of Active Element</th>
<th>No. of Resistors</th>
<th>No. of Capacitors</th>
<th>All Grounded Passive Components</th>
<th>No. of Current Outputs</th>
<th>No. of Voltage Outputs</th>
<th>Orthogonal/Independent controlling</th>
<th>Designed Frequency of Oscillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>No</td>
<td>CC</td>
<td>2G</td>
<td>2G</td>
<td>Yes</td>
<td>-</td>
<td>2</td>
<td>NA</td>
<td>-</td>
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<tr>
<td>4</td>
<td>No</td>
<td>OTA</td>
<td>-</td>
<td>2F, 1G</td>
<td>No</td>
<td>-</td>
<td>2</td>
<td>No</td>
<td>300kHz</td>
</tr>
<tr>
<td>5</td>
<td>No</td>
<td>OTA</td>
<td>-</td>
<td>2G</td>
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<td>1</td>
<td>2</td>
<td>Yes</td>
<td>10KHz</td>
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<tr>
<td>6</td>
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<td>3G</td>
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<td>-</td>
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<td>-</td>
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<td>-</td>
<td>1</td>
<td>Yes</td>
<td>2MHz</td>
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<td>8</td>
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<td>Yes</td>
<td>-</td>
<td>2</td>
<td>No</td>
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<td>1</td>
<td>-</td>
<td>Yes</td>
<td>NA</td>
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<tr>
<td>10</td>
<td>Yes</td>
<td>CF+</td>
<td>3F</td>
<td>3G</td>
<td>No</td>
<td>2</td>
<td>-</td>
<td>No</td>
<td>NA</td>
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<td>11</td>
<td>No</td>
<td>OA &amp; OTA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
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<td>12</td>
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<td>FTFN</td>
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<td>NO</td>
<td>2</td>
<td>-</td>
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<td>13</td>
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<td>16</td>
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<td>CCCII</td>
<td>-</td>
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<td>2</td>
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<td>Yes</td>
<td>FDCI1</td>
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<td>20</td>
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<td>2G</td>
<td>3G</td>
<td>Yes</td>
<td>3</td>
<td>3</td>
<td>Yes</td>
<td>1.7MHz</td>
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<td>ZC-CG-CDBA</td>
<td>3F</td>
<td>2G</td>
<td>No</td>
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<td>DVCC</td>
<td>2G</td>
<td>2G</td>
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<td>3</td>
<td>2</td>
<td>No</td>
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<tr>
<td>23</td>
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<td>3F, 2G</td>
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<td>No</td>
<td>2</td>
<td>-</td>
<td>Yes</td>
<td>6.9KHz</td>
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<tr>
<td>24</td>
<td>No</td>
<td>DXCCI1</td>
<td>1F, 1G</td>
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<td>-</td>
<td>2</td>
<td>No</td>
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<td>25</td>
<td>No</td>
<td>DVCC</td>
<td>3F</td>
<td>3G</td>
<td>No</td>
<td>-</td>
<td>4</td>
<td>Yes</td>
<td>2.5MHz</td>
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<td>Proposed</td>
<td>Yes</td>
<td>DD-DXCCII</td>
<td>3G</td>
<td>2G</td>
<td>Yes</td>
<td>2</td>
<td>2</td>
<td>Yes</td>
<td>26.54MHz</td>
</tr>
</tbody>
</table>


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

\[ s^2 + s \left( \frac{1}{C_1R_1} + \frac{1}{C_2R_2} - \frac{1}{C_1R_1} \right) + \frac{1}{C_1C_2R_1R_2} = 0 \]  

(2)

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

$$I_{o2} = j\omega C_1 R_1 I_{o1}$$  \hspace{1cm} (5)

$$V_{o1} = j\omega C_2 R_2 V_{o3}$$  \hspace{1cm} (6)

$$V_{o1} = -V_{o2}$$  \hspace{1cm} (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.

**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:

$$S_Y = \frac{Y \partial X}{X \partial Y}$$  \hspace{1cm} (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 ($\omega_o$) are given as below

$$S_{\omega_o}^c = S_{\omega_o}^a = S_{\omega_o}^o = -\frac{1}{2}$$  \hspace{1cm} (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 ($\beta_i$ where $i \in \{1, 2, 3, 4, 5, 6\}$) and current transfer gains ($\alpha_i$ where $j \in \{1, 2\}$). The relationship of the terminal voltages and currents can be rewritten as:

$$\begin{bmatrix}
I_{T1} \\
I_{T2} \\
I_{T3} \\
V_{x+} \\
V_{x-} \\
I_{z+} \\
I_{z-}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\beta_1 & -\beta_2 & \beta_3 & 0 & 0 & 0 & 0 \\
-\beta_4 & \beta_5 & -\beta_6 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
V_{T1} \\
V_{T2} \\
V_{T3} \\
I_{x+} \\
I_{x-} \\
V_{z+} \\
V_{z-}
\end{bmatrix}$$  \hspace{1cm} (10)

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

$$s^2 + \left[ \frac{1}{C_1 R_1} + \frac{\alpha_3 \beta_6}{C_2 R_2} - \frac{\alpha_1 \beta_2}{C_2 R_2} \right] + \frac{\alpha_2 (\alpha_1 \beta_3 \beta_4 R_5 + \beta_5 R_2 - \alpha_1 \beta_3 \beta_2 R_5)}{C_1 C_4 R_4 R_5} = 0$$  \hspace{1cm} (11)

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

$$\text{FO: } \alpha_o = \sqrt{\frac{\alpha_2 (\alpha_1 \beta_3 \beta_4 R_5 + \beta_5 R_2 - \alpha_1 \beta_3 \beta_2 R_5)}{C_1 C_4 R_4 R_5}}$$  \hspace{1cm} (12)

$$\text{CO: } \frac{1}{C_1 R_1} + \frac{\alpha_3 \beta_6}{C_2 R_2} \geq \frac{\alpha_1 \beta_2}{C_2 R_2}$$  \hspace{1cm} (13)

Furthermore, by using equation (8), the sensitivities of active ($\beta_i$ where $i \in \{1, 2, 3, 4, 5, 6\}$) and passive components ($R_i, R_2, R_3, C_1$ and $C_2$) with respect to $\omega_o$ are again analyzed and given as follows:

$$S_{\omega_o}^c = -\frac{1}{2} \left[ \frac{\alpha_1 \beta_3 \beta_4 R_5 + \alpha_2 \beta_5 R_2 - \alpha_1 \beta_3 \beta_2 R_5}{\alpha_2 (\alpha_1 \beta_3 \beta_4 R_5 + \beta_5 R_2 - \alpha_1 \beta_3 \beta_2 R_5)} \right]$$  \hspace{1cm} (14)
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 $\omega_o$ 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 ($R_{Y1}$, $R_{Y2}$, $R_{Y3}$, $R_X$, $R_Z$, 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 $R_Y$. 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

$$S^2 + S \left( \frac{1}{C_1' R_1'} + \frac{1}{C_2' R_2'} - \frac{1}{C_3' R_3'} \right) + \frac{1}{C_1' C_2' R_1' R_2'} = 0$$

(22)

The modified frequency of oscillation is given as

$$\omega_o = \sqrt{\frac{1}{C_1' C_2' R_1' R_2'}}$$

(23)

where,

$$R'_i = R_i / / R_{Y1} / / R_{Y2} / / R_{Y3}$$

$$C'_i = C_{Y1} + C_{Y2} + C_{Y3} + C_{Z+} + C_{Z-}$$

$$R'_i = R_i + R_{X+} + R_{X-}$$

$$R'_i = R_i + R_{X+} + R_{X-}$$

$S_{R_1}^\alpha = \frac{1}{2} \left[ \frac{\alpha \alpha \beta \beta R_1 - \alpha \alpha \beta \beta R_1}{\alpha \alpha \beta \beta R_1} \right]$$

(15)

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 $R_Y$ represent the parasitic resistances appearing at the X+ and X- terminals, respectively.

**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 $C_1 = 3pF$, $R_1 = R_3 = 2k\Omega$, $R_2 = 1k\Omega$. 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. 7 and Fig. 8, 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>
<thead>
<tr>
<th>Transistors</th>
<th>W (μm) / L (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M4, M11-M14, M27-M30</td>
<td>3.6/0.18</td>
</tr>
<tr>
<td>M1-M14</td>
<td>11.51/0.18</td>
</tr>
<tr>
<td>M2-M4</td>
<td>2.88/0.18</td>
</tr>
<tr>
<td>M27-M30</td>
<td>0.89/0.18</td>
</tr>
<tr>
<td>M39</td>
<td>16.9/0.18</td>
</tr>
<tr>
<td>M37-M30</td>
<td>5.22/0.18</td>
</tr>
<tr>
<td>M30</td>
<td>3.6/0.18</td>
</tr>
</tbody>
</table>
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, AD844s [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 trans-conductance 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 $C_1 = C_2 = 100\text{pF}$, $R_1 = R_3 = 2k\Omega$, $R_2 = 1k\Omega$. 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.

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...
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.

REFERENCES

