Current/voltage-mode third order quadrature oscillator employing two multiple outputs CCIIs and grounded capacitors

Jiun-Wei Horng
Department of Electronic Engineering Chung Yuan Christian University, Chung-Li, 32023, Taiwan
E-mail: jwhorng@cycu.edu.tw

Received 4 November 2010; revised 26 April 2011; accepted 3 May 2011

A new quadrature oscillator circuit using two multiple outputs second-generation current conveyors (CCIIs), three grounded capacitors and three resistors is presented. Two high output impedance current-mode signals and two voltage-mode signals each pair with 90° phase difference are available in the proposed circuit. The oscillation condition and oscillation frequency are independently controllable through grounded resistors. The use of only grounded capacitors makes the proposed circuit attractive for integrated circuit implementation.

Keywords: Quadrature oscillator, Current conveyors, Current-mode, Voltage-mode

1 Introduction

A quadrature oscillator is used because the circuit provides two sinusoids with 90° phase difference, as for example in telecommunications for quadrature mixers and single-sideband generators or for measurement purposes in vector generators or selective voltmeters. Therefore, quadrature oscillators constitute an important unit in many communication and instrumentation systems. The quadrature oscillators generate voltage-mode signals. Several current-mode sinusoidal oscillators were proposed in the literature. However, the current-mode high output impedance sinusoidal oscillators do not provide another high output impedance quadrature current output. Moreover, the current-mode quadrature oscillators require additional current followers for sensing and taking out the quadrature outputs therein and the use of these additional current followers with the virtual grounded inputs may result in floating capacitors realization for what is originally described as grounded capacitors realization. Horng proposed a current-mode high output impedance quadrature oscillator using two differential voltage current conveyors, two resistors and two capacitors. However, the oscillation condition and oscillation frequency cannot be independently tuned. Because the high-order network has high accuracy and high quality factor, it gives good frequency response with low distortion. Maheshwari and Khan proposed a third order quadrature oscillator that generates both voltage-mode and current-mode quadrature signals in the same circuit configuration by using four current controlled current conveyors and three capacitors.

In this paper, a new third order quadrature oscillator circuit using two multiple outputs second-generation current conveyors (CCIIs), three grounded capacitors and three resistors is presented. Two high output impedance sinusoid current-mode signals and two voltage-mode signals each pair with 90° phase difference are available in the proposed circuit. The oscillation condition and oscillation frequency are independently controllable through grounded resistors. The use of only grounded capacitors makes the proposed circuit attractive for integrated circuit implementation. The proposed circuit employs less active components with respect to the previous quadrature oscillator.

2 Circuit Description

The circuit symbol of the multiple outputs CCII is shown in Fig. 1 which shows two types of output terminals, the positive outputs represented by terminal $z+$ and the negative by terminal $z−$. The terminal characteristic of the multiple outputs CCII can be described by the following matrix equation:

$$
\begin{bmatrix}
i_v \\
v_x \\
i_{z+} \\
... \\
i_{zm} \\
i_{z-}
\end{bmatrix} = 
\begin{bmatrix}
0 & 0 & 0 & ... & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & ... & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & ... & 0 & 0 & 0 & 0 \\
... & ... & ... & ... & ... & ... & ... & ... \\
0 & 1 & 0 & ... & 0 & 0 & 0 & 0 \\
0 & -1 & 0 & ... & 0 & 0 & 0 & 0 \\
... & ... & ... & ... & ... & ... & ... & ... \\
0 & -1 & 0 & ... & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
v_y \\
i_z \\
v_{z+} \\
... \\
v_{zm} \\
v_{z-}
\end{bmatrix} \quad \text{(1)}
$$
The proposed quadrature oscillator is shown in Fig. 2. The characteristic equation of the circuit can be expressed as:

\[ s^3C_1C_2C_3R_1R_2R_3 + s^2(C_1 + C_2)C_3R_3 + sC_3R_3 + 1 = 0 \]  

...(2)

The oscillation condition and oscillation frequency can be obtained as:

\[ R_3 = \frac{C_1C_2R_2}{(C_1 + C_2)C_3} \]  

...(3)

\[ \omega_o = \frac{1}{\sqrt{C_1C_2C_3R_2}} \]  

...(4)

The oscillation frequency can be adjusted by the grounded resistor \( R_1 \). The oscillation condition can be independently adjusted by the grounded resistor \( R_3 \). Fig. 2 employs only grounded capacitors. The use of grounded capacitors is particularly attractive for integrated circuit implementation\(^1\). The passive sensitivities of this sinusoidal oscillator are all low and obtained as:

\[ S_{oC_1C_2R_1R_3}^{\omega_o} = -\frac{1}{2} \]

From Fig. 2, the voltage transfer function from \( V_{o2} \) to \( V_{o1} \) is:

\[ \frac{V_{o2}(s)}{V_{o1}(s)} = -\frac{1}{sC_1R_1} \]  

...(5)

The phase difference, \( \phi \), between \( V_{o2} \) and \( V_{o1} \) is:

\[ \phi = 90^\circ \]  

...(6)

ensuring the voltages \( V_{o2} \) and \( V_{o1} \) to be in quadrature.

From Fig. 2, the current transfer function from \( I_{o2} \) to \( I_{o1} \) is:

\[ \frac{I_{o2}(s)}{I_{o1}(s)} = -\frac{1}{sC_3R_3} \]  

...(7)

The phase difference, \( \phi \) between \( I_{o2} \) and \( I_{o1} \) is:

\[ \phi = 90^\circ \]  

...(8)

ensuring the currents \( I_{o2} \) and \( I_{o1} \) to be in quadrature.

Thus, the proposed circuit configuration can provide both voltage-mode and current-mode quadrature signals, simultaneously. Because the output impedances of the currents \( I_{o1} \) or \( I_{o2} \) are very high, the two output terminals, \( I_{o1} \) and \( I_{o2} \), can be directly connected to the next stage, respectively. The resistors \( R_1 \) and \( R_3 \) are connected to the two \( x \) terminals of the CCII(1) and CCII(2), respectively. This design offers another feature of a direct incorporation of the parasitic resistance (\( R_2 \)) as a part of the main resistance. From Eqs (5) and (7), the magnitudes of \( V_{o2} \) and \( V_{o1} \) or \( I_{o2} \) and \( I_{o1} \) need not be the same. For the applications needing equal magnitude quadrature outputs, other amplifying circuits are needed.
3 Effect of the CCII Parasitic Elements on the Proposed Circuits

A non-ideal multiple outputs CCII model\(^{18,19}\) is shown in Fig. 3. It is shown that the real multiple outputs CCII have parasitic resistors and capacitors from the y and z terminals to the ground, and also, a series resistor at the input terminal x. The values of the parasitic impedances\(^{19}\) are

\[
\begin{align*}
R_x &= 60 \, \Omega, \\
R_y &= 7 \, \text{M}\Omega, \\
R_{z1} &= R_{z2} = 3 \, \text{M}\Omega, \\
C_y &= 8 \, \text{pF}, \\
C_{z1} &= C_{z2} = 14 \, \text{pF}.
\end{align*}
\]

The \(\alpha_k(s)\) (k = 1, 2) and \(\beta(s)\) represent the frequency transfers of the internal current and voltage followers of the multiple outputs CCII, respectively. They can be approximated by first order low pass functions, which can be considered to have a near unity value for frequencies much less than their corner frequencies\(^{18,19}\). Taking into account the non-ideal multiple outputs CCII model of Fig. 3 in Fig. 2 and assuming the circuit is working at frequencies much less than the corner frequencies of \(\alpha_k(s)\) and \(\beta(s)\), namely,

\[
\alpha_k(s) = 1 - \varepsilon_1\quad\text{and}\quad\varepsilon_1 (|\varepsilon_1| <\ll 1)\quad\text{denotes the current tracking error and}
\]

\[
\beta(s) = 1 - \varepsilon_2\quad\text{and}\quad\varepsilon_2 (|\varepsilon_2| <\ll 1)\quad\text{denotes the voltage tracking error of the multiple outputs CCII.}
\]

The characteristic equation of Fig. 2 becomes:

\[
s^3C_1'C_2'C_3'R_1'R_2'R_3'R_4'R_{31} + s^2R_1'R_1'[C_1'C_2'C_3'R_4'R_{31}] + C_1'C_2'C_3R_2R_4R_{31} + C_2'C_3R_2R_4R_{31} + C_1'C_2'C_3R_2R_4R_{31} + C_2'C_3R_2R_4R_{31} + \ldots \quad(9)
\]

where

\[
\begin{align*}
C_1' &= C_1 + C_{z1} + C_{z2}, \quad C_2' = C_2 + C_{y}, \\
C_3' &= C_3 + C_{z1} + C_{z2}, \quad R_1' = R_1 + R_{z1}, \\
R_2' &= R_2 + R_{z1}, \quad R_4 = R_{z1} / R_{y}, \\
R_3' &= R_3 / R_{z1}.
\end{align*}
\]

The modified oscillation condition and oscillation frequency are:

\[
\omega_o = \sqrt{\frac{C_1'C_3'R_1'R_3'R_{31} + C_2'C_3'R_2R_4R_{31} + C_1'C_2'C_3'R_2R_4R_{31}}{C_1'C_2'C_3'R_1'R_2R_3R_{31}}} \quad(10)
\]

Eqs (10) and (11) are coupled due to the parasitic impedances, especially because \(R_4, R_5\) and \(R_{y1}\) are finite. This fact implies that the adjustment of the oscillation frequency affects the oscillation condition \([R_1'\text{ appears in both Eqs (10) and (11)].\) Nevertheless, the oscillation condition can be tuned by varying \(R_3'\) after adjusting the oscillation frequency by means of \(R_1'.\)

4 Simulation Results

PSPICE simulations were carried out to demonstrate the feasibility of the proposed circuit in Fig. 2 using 0.18 \(\mu\text{m, level 3 MOSFET from TSMC.}\) The multiple outputs CCII was realized by the CMOS implementation\(^{20}\) in Fig. 4. The aspect ratios of the MOS transistors are shown in Table 1. The multiple current outputs can be easily implemented by simply adding output branches.

---

The figure captions are as follows:

Fig. 3 — Non-ideal multiple outputs CCII model

Fig. 4 — Implementation of multiple outputs CCII
Table 1 — Aspect ratios of the MOS in Fig. 4.

<table>
<thead>
<tr>
<th>MOS transistor</th>
<th>W/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, M2</td>
<td>36/0.9</td>
</tr>
<tr>
<td>M3</td>
<td>63/0.9</td>
</tr>
<tr>
<td>M4, M5</td>
<td>54/0.9</td>
</tr>
<tr>
<td>M6</td>
<td>72/0.9</td>
</tr>
<tr>
<td>M7~M16</td>
<td>18/0.9</td>
</tr>
</tbody>
</table>

Table 2 — Total harmonic distortion analysis of \( V_{o1} \) in Fig. 2

<table>
<thead>
<tr>
<th>Harmonic number</th>
<th>Frequency (Hz)</th>
<th>Fourier component</th>
<th>Normalized component</th>
<th>Phase (Deg)</th>
<th>Normalized Phase (Deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.110E+05</td>
<td>3.881E-01</td>
<td>1.000E+00</td>
<td>8.995E+01</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>2</td>
<td>4.220E+05</td>
<td>4.598E-03</td>
<td>1.185E-02</td>
<td>-1.065E+02</td>
<td>-2.864E+02</td>
</tr>
<tr>
<td>3</td>
<td>6.330E+05</td>
<td>7.949E-03</td>
<td>2.048E-02</td>
<td>-4.279E+01</td>
<td>-3.126E+02</td>
</tr>
<tr>
<td>4</td>
<td>8.440E+05</td>
<td>7.812E-04</td>
<td>2.015E-03</td>
<td>-8.872E+01</td>
<td>-4.985E+02</td>
</tr>
<tr>
<td>5</td>
<td>1.055E+06</td>
<td>9.002E-04</td>
<td>1.374E-02</td>
<td>-1.312E+02</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.266E+06</td>
<td>6.577E-04</td>
<td>1.695E-02</td>
<td>-4.279E+01</td>
<td>-6.554E+02</td>
</tr>
<tr>
<td>7</td>
<td>1.477E+06</td>
<td>3.852E-01</td>
<td>1.000E+00</td>
<td>-1.321E+02</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>8</td>
<td>1.688E+06</td>
<td>7.852E-03</td>
<td>2.038E-02</td>
<td>-4.061E+01</td>
<td>-3.048E+02</td>
</tr>
<tr>
<td>9</td>
<td>1.899E+06</td>
<td>6.374E-03</td>
<td>1.655E-02</td>
<td>-6.079E+01</td>
<td>-3.355E+02</td>
</tr>
<tr>
<td>10</td>
<td>1.055E+06</td>
<td>2.739E-03</td>
<td>7.110E-03</td>
<td>-1.140E+01</td>
<td>-6.110E+02</td>
</tr>
<tr>
<td>11</td>
<td>1.266E+06</td>
<td>3.124E-03</td>
<td>8.111E-03</td>
<td>-1.854E+01</td>
<td>-6.791E+02</td>
</tr>
<tr>
<td>12</td>
<td>1.477E+06</td>
<td>1.867E-03</td>
<td>4.847E-03</td>
<td>-7.782E+01</td>
<td>-7.484E+02</td>
</tr>
<tr>
<td>13</td>
<td>1.688E+06</td>
<td>1.431E-03</td>
<td>3.714E-03</td>
<td>1.093E+01</td>
<td>-7.849E+02</td>
</tr>
<tr>
<td>14</td>
<td>1.899E+06</td>
<td>1.429E-03</td>
<td>3.711E-03</td>
<td>-1.173E+03</td>
<td>1.046E+03</td>
</tr>
<tr>
<td>DC component</td>
<td>7.810769E-03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total harmonic distortion: 2.394199E+00 PERCENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 — Total harmonic distortion analysis of \( I_{o1} \) in Fig. 2

<table>
<thead>
<tr>
<th>Harmonic number</th>
<th>Frequency (Hz)</th>
<th>Fourier component</th>
<th>Normalized component</th>
<th>Phase (Deg)</th>
<th>Normalized Phase (Deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.110E+05</td>
<td>3.852E-01</td>
<td>1.000E+00</td>
<td>1.321E+02</td>
<td>0.000E+00</td>
</tr>
<tr>
<td>2</td>
<td>4.220E+05</td>
<td>7.852E-03</td>
<td>2.038E-02</td>
<td>-4.061E+01</td>
<td>-3.048E+02</td>
</tr>
<tr>
<td>3</td>
<td>6.330E+05</td>
<td>6.374E-03</td>
<td>1.655E-02</td>
<td>-6.079E+01</td>
<td>-3.355E+02</td>
</tr>
<tr>
<td>4</td>
<td>8.440E+05</td>
<td>2.739E-03</td>
<td>7.110E-03</td>
<td>-1.140E+01</td>
<td>-6.110E+02</td>
</tr>
<tr>
<td>5</td>
<td>1.055E+06</td>
<td>3.124E-03</td>
<td>8.111E-03</td>
<td>-1.854E+01</td>
<td>-6.791E+02</td>
</tr>
<tr>
<td>6</td>
<td>1.266E+06</td>
<td>1.867E-03</td>
<td>4.847E-03</td>
<td>-7.782E+01</td>
<td>-7.484E+02</td>
</tr>
<tr>
<td>7</td>
<td>1.477E+06</td>
<td>1.431E-03</td>
<td>3.714E-03</td>
<td>1.093E+01</td>
<td>-7.849E+02</td>
</tr>
<tr>
<td>8</td>
<td>1.688E+06</td>
<td>1.429E-03</td>
<td>3.711E-03</td>
<td>-1.173E+03</td>
<td>1.046E+03</td>
</tr>
<tr>
<td>DC component</td>
<td>6.058814E-03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total harmonic distortion: 2.951148E+00 PERCENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5 — (a) Simulated output waveforms of voltage-mode signals in Fig. 2; (b) Simulated output waveforms of current-mode signals in Fig. 2.

Fig. 6 — Simulation results of the oscillation frequency of Fig. 2, which is obtained by varying the value of the resistor \( R_1 \).

5 Conclusions

A new quadrature oscillator using two multiple outputs CCIIs, three resistors and three grounded capacitors is presented. This quadrature oscillator provides the following advantages: (i) two voltage-mode and two current-mode sinusoidal output signals each pair with 90° phase difference are obtained simultaneously; (ii) the output impedances of the current-mode signals are very high; (iii) the oscillation condition and oscillation frequency are independently controllable through grounded resistors; (iv) the use of only grounded capacitors; (v) a direct incorporation of the parasitic resistances at the x terminals of the CCIIs (\( R_x \)) as a part of the main resistances. The proposed circuit employs less active components with respect to the previous quadrature oscillator

References