Third-Order Voltage-Mode Quadrature Oscillator Using DDCC and OTAs

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Abstract. This article presents a 3rd voltage-mode quadrature oscillator using differential different current conveyor (DDCC) and operational transconductance amplifier (OTA) as active elements. The proposed circuit is realized from a non-inverting lossless integrator and an inverting second order low-pass filter. The oscillation condition and oscillation frequency can be electronically/orthogonally controlled via input bias currents. The circuit description is very simple, consisting of merely 1 DDCC, 2 OTAs, 1 grounded resistor and 2 grounded capacitors. Using only grounded elements, the proposed circuit is then suitable for IC architecture. The PSPICE simulation results are depicted, and the given results agree well with the theoretical anticipation. The power consumption is approximately 1.86mW at ±1.25V supply voltages.

Keywords: Oscillator, DDCC, OTA

1. Introduction

An oscillator is an important basic building block, which is frequently employed in electrical engineering applications. Among the several kinds of oscillators, a quadrature oscillator is widely used because it can offer sinusoidal signals with 90° phase difference, for example, in telecommunications for quadrature mixers and single-sideband [1].

Several implementations of second order quadrature oscillators using different high-performance active building blocks, such as, OTAs [2], current conveyors [3], four-terminal floating nullors (FTFN) [4-5], current follower [6], current differencing buffered amplifiers (CDBAs) [7], current differencing transconductance amplifiers (CDTAs) [8], fully-differential second-generation current conveyor (FDCCII) [9], and differencing voltage current conveyor (DVCCs) [10], have been reported. Recently, it has been proved that the third order oscillator provides good characteristic with lower distortion than second order oscillator [11-12]. From our literature found that the third order oscillator employing CCCIIs [11], OTAs [12-13], CDTAs [14], have been proposed.

The aim of this paper is to propose a third order voltage-mode oscillator, based on DDCC and OTAs. The features of the proposed circuits are that: the oscillation condition can be adjusted independently from the oscillation frequency by electronic method. The circuit construction consists of 1 DDCC, 2 OTAs, 1 grounded resistor and 2 grounded capacitors. The PSPICE simulation results are also shown, which are in correspondence with the theoretical analysis.

2. Circuit Principle

2.1. Basic concept of DDCC
The electrical behaviors of the ideal DDCC are represented by the following hybrid matrix [15]:

\[
\begin{bmatrix}
V_x \\
I_{y1} \\
I_{y2} \\
I_{y3} \\
I_x
\end{bmatrix} = \begin{bmatrix}
0 & 1 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
V_x \\
V_{y1} \\
V_{y2} \\
V_{y3} \\
I_z
\end{bmatrix}.
\] (1)

The symbol and the equivalent circuit of the DDCC are illustrated in Figs. 1(a) and (b), respectively.

2.2. Basic concept of OTA
An ideal operational transconductance amplifier (OTA) has infinite input and output impedances. The output current of an OTA is given by

\[I_o = g_m(V_\text{in} - V_\text{o}),\] (2)

where \(g_m\) is the transconductance of the OTA. This \(g_m\) can be tuned by external input bias current (\(I_{\text{ib}}\)). For a CMOS OTA, the transconductance can be expressed as

\[g_m = \sqrt{kI_{\text{b}}} k = \mu C_{\text{ox}} \left( \frac{W}{L} \right).\] (3)

Here \(k\) is the physical transconductance parameter of the MOS transistor. The symbol and the equivalent circuit of the OTA are illustrated in Figs. 2(a) and (b), respectively.

2.3. General structure of 3rd oscillator
The oscillator is designed by cascading an inverting second order low-pass filter and the lossless integrators as systematically shown in Fig. 3 [13]. From block diagram in Fig. 3, we will receive the characteristic equation as

\[s^3 + bs^2 + as + ck = 0.\] (4)

From Eq. (4), the oscillation condition (OC) and oscillation frequency (\(\omega_{\text{osc}}\)) can be written as
\[ OC : ab = ck \text{ and } \omega_{oc} = \sqrt{a} . \]  

From Eq. (5), if \( a = c \), the oscillation condition and oscillation frequency can be adjusted independently, which are the oscillation condition can be controlled by \( k \) and \( b \), while the oscillation frequency can be tuned by \( a \).

2.4. Proposed 3\textsuperscript{rd} voltage-mode quadrature oscillator

As mentioned in last section, the proposed oscillator is based on the inverting second order low-pass filter and the lossless integrators. In this section, these circuits will be described. The inverting second order low-pass filter based on DDCC and OTA is shown in Fig. 4(a). The voltage transfer function of this circuit can be written as

\[ T(s) = \frac{V_{LP}}{V_m} = \frac{-g_{m1}}{s^2 + s \left( \frac{1}{C_1R} + \frac{g_{m1}}{C_1C_2R} \right)} . \]  

From Eq. (6), the parameters \( a, b \) and \( c \) can be expressed as

\[ a = c = \frac{g_{m1}}{C_1C_2R} \text{ and } b = \frac{1}{C_1R} . \]  

Fig. 4(b) shows the lossless integrator using OTA. Considering the circuit in Fig. 4(a) and using OTA properties, we will receive

\[ \frac{V_o}{V_m} = \frac{k}{s}, \text{ where } k = \frac{g_{m2}}{C_3} . \]  

The completed 3\textsuperscript{rd} voltage-mode quadrature oscillator is shown in Fig. 5. The oscillation condition (OC) and oscillation frequency (\( \omega_{oc} \)) can be written as

\[ \frac{1}{C_1R} = \frac{g_{m2}}{C_3} \text{ and } \omega_{oc} = \frac{g_{m1}}{\sqrt{C_1C_2R}} . \]  

If \( g_{m1} = \sqrt{k_1I_{B1}} \), \( g_{m2} = \sqrt{k_2I_{B2}} \) and \( C_1 = C_2 = C_3 = C \), the oscillation condition and oscillation frequency can be rewritten as

\[ \frac{1}{R} = \sqrt{k_2I_{B2}} \text{ and } \omega_{oc} = \frac{1}{C} \sqrt{\frac{(k_1I_{B1})^{\frac{1}{2}}}{R}} . \]  

It is obviously found that, from Eq. (10), the oscillation condition and oscillation frequency can be adjusted independently, which are the oscillation condition can be controlled by setting \( R \) and \( I_{B2} \), while the oscillation frequency can be tuned by setting \( I_{B1} \). From the circuit in Fig. 5, the voltage transfer function from \( V_{o1} \) to \( V_{o2} \) is
\[
\frac{V_{o2}(s)}{V_{i1}(s)} = \frac{g_{m2}}{sC_3}.
\]

For sinusoidal steady state, Eq. (11) becomes

\[
\frac{V_{o2}(j\omega)}{V_{i1}(j\omega)} = \frac{g_{m2}}{sC_3} e^{-j\phi}.
\]

The phase difference \(\phi\) between \(V_{o1}\) and \(V_{o2}\) is \(\phi = -90^\circ\) ensuring that the voltages \(V_{o2}\) and \(V_{o1}\) are in quadrature.

Fig. 5: Proposed 3\textsuperscript{rd} quadrature oscillator.

3. Simulation Results

To investigate the theoretical analysis, the proposed filter in Fig. 5 is simulated by using the PSPICE simulation program. Internal constructions of DDCC and OTA used in simulation are respectively shown in Fig. 6(a) and (b). The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0.25\(\mu\)m TSMC CMOS technology [16]. The transistor aspect ratios of PMOS and NMOS transistor are indicated in Table I. The circuit was biased with \(\pm1.25V\) supply voltages, \(V_{BB}=-0.6V, C_1=C_2=C_3=0.1nF, \ I_{B1}=65\mu A, \ I_{B2}=70\mu A\) and \(R=0.75k\Omega\). This yields simulated oscillation frequency of 1.69MHz. Fig. 7(a) shows simulated quadrature output waveforms. Fig. 7(b) shows the simulated output spectrum, where the total harmonic distortion (THD) is about 1.75%. The power consumption is approximately 1.86mW.

![Internal constructions of (a) DDCC (b) OTA.](image)

**Fig. 6: Internal constructions of (a) DDCC (b) OTA.**

**TABLE I. DIMENSIONS OF THE TRANSISTORS**

<table>
<thead>
<tr>
<th>Transistor</th>
<th>W ((\mu m))</th>
<th>L ((\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M4, M19-M20</td>
<td>3</td>
<td>0.25</td>
</tr>
<tr>
<td>M5-M8</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>M9-M10</td>
<td>10</td>
<td>0.25</td>
</tr>
<tr>
<td>M11-M15</td>
<td>5</td>
<td>0.25</td>
</tr>
<tr>
<td>M16</td>
<td>4.4</td>
<td>0.25</td>
</tr>
<tr>
<td>M17-M18</td>
<td>16</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Fig. 7: (a) Output voltage waveforms (b) Spectrum.

4. Conclusions

A 3rd voltage-mode quadrature oscillator based on DDCC and OTAs has been presented. The features of the proposed circuit are that: oscillation frequency an oscillation condition can be orthogonally adjusted via input bias current; it consists of 1 DDCC, 2 OTAs, 1 grounded resistor and 2 grounded capacitors, which is convenient to fabricate. The PSPICE simulation results agree well with the theoretical anticipation.

5. References