An Active-only High-output Impedance Current-mode Quadrature Oscillator Using CCCCTA Based-lossless Differentiators

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Abstract—This article presents a high-output impedance current-mode quadrature sinusoidal oscillator, providing sinusoidal signals, which differ of 90° in phase. The features of the proposed circuit are that; oscillation frequency can be electronically controlled; it can provide the quadrature signal, which is free from the preset of oscillation condition. In addition, since the proposed circuit comprises only active elements, which are 2 CCCCTAs and 2 operational amplifiers, it is very suitable to further develop into an integrated circuit. The PSPICE simulation results are depicted.

Keywords—Quadrature oscillator; CCCCTA; Differentiator; Operational amplifier; Active-only

I. 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 systems [1]. Presently, the current-mode technique has been more popular than the voltage-mode type. This is due to requirements in low-voltage environments such as in portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for this purpose, more so than the voltage-mode one. Presently, there is a growing interest in synthesizing current-mode circuits because of their many potential advantages, such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry, and lower power consumption [2].

The high-output impedance of current-mode oscillators are of great interest because it makes easily able to drive loads and they facilitate cascading without using a buffering device [3-5]. Moreover, circuits that employ only grounded capacitors are advantageous from the point of view of integrated circuit implementation [5-7].

The synthesis and design of analog signal processing circuits using only active elements without any passive element are important in fully integrated circuit (IC) technology. This technique makes circuit becoming smaller chip area, lower power consumption, wider frequency range of operation and programmability [8-11]. The applications can be easily seen in many literatures, for example filter [12], oscillator [13], inductance simulator [14] and etc.

Most of oscillators based on integrator block using different active elements [15-18] have been proposed in the literature. But it is well known that the stage-gain of integrator is declined at high frequency. Consequently, these oscillators cannot oscillate as low frequency because the loop gain is decreased. This means that the re-adjusting of oscillation condition is required at high frequency. To solve the mentioned problem, the oscillator based on differentiator is used to achieve the stability of stage-gain at high frequency [19].

A reported 5-terminals active element, namely Current Conveyor Transconductance Amplifier (CCTA) [20] has been firstly proposed in 2005, it seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters. In addition, its output gain can be adjusted by input bias current. However, the CCTA cannot be controlled by the parasitic resistances at current input port. Recently, Siripruchyanun and Jaikla have proposed the modified-version CCTA, whose parasitic resistances at current input port can be controlled by an input bias current. It is newly named Current Controlled Current Conveyor Transconductance Amplifier (CCCCTA) [21]. It seems to be a useful building block, since many circuits and systems can be implemented by employing only single CCCCTA.

The purpose of this paper is to introduce an active-only current-mode quadrature oscillator using CCCCTA-based differentiators. The oscillation frequency can be electronically adjusted without any oscillation condition. The circuit construction consists of 2 CCCCTAs and 2 opamps without any external passive element. Moreover, the output currents have high impedance, which facilitates cascading in current-mode configurations. The PSPICE simulation results are also shown, which are in correspondence with the theoretical analysis.
II. PRINCIPLE OF OPERATION

A. Basic Concept of CCCCTA

Since the proposed circuit is based on CCCCTA, a brief review of CCCCTA is given in this section. Generally, CCCCTA properties are similar to the conventional CCTA, except that input voltages of CCCCTA are not zero and the CCCCTA has finite input resistance at the \( x \) input terminal. This parasitic resistance can be controlled by the bias current \( I_B \) as shown in the following equation [21]

\[
\begin{bmatrix}
I_y \\
V_x \\
I_x \\
V_o
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 \\
R_x & 1 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & g_m & 0
\end{bmatrix}
\begin{bmatrix}
I_y \\
V_x \\
V_y \\
V_o
\end{bmatrix}.
\] (1)

For the CCCCTA implemented by the CMOS technology, the parasitic resistance \( R_x \) and transconductance \( g_m \) can be expressed as

\[
R_x = \frac{1}{\sqrt{8} \beta I_B},
\] (2)

and

\[
g_m = \sqrt{\beta I_B}.
\] (3)

Here \( \beta = \mu C_{ox} (W/L) \) is the physical parameter of CMOS transistor. In general, CCCCTA can contain an arbitrary number of \( o \) terminals, providing currents \( I_o \) of both directions. The symbol and the equivalent circuit of the CCCCTA are illustrated in Figs. 1(a) and (b), respectively.

\[\text{Figure 1. CCCCTA (a) schematic symbol, (b) equivalent circuit.}\]

B. Operational Amplifier

The open-loop gain of a practical internally compensated operational amplifier (OA) is represented by following transfer function

\[
A(s) = \frac{A_0}{s + \omega_{pl}} = \frac{B}{s^2 + \frac{B}{\omega_p}}.
\] (4)

where \( A_0 \) is open-loop DC gain, \( \omega_{pl} \) is the first pole frequency and \( B(= A_0 \omega_{pl}) \) is the gain-bandwidth product of the operational amplifier. For the frequencies \( \omega \ll \omega_{pl} \), (4) is approximately given by [23]

\[
A(s) \approx \frac{B}{s}.
\] (5)

C. Principle of Oscillator

The oscillator is designed by cascading the inverting and non-inverting lossless differentiators as systematically shown in Fig. 2. From the block diagram in Fig. 2, the current transfer function can be expressed as

\[
\frac{I_o(s)}{I_{in}(s)} = T_1(s)T_2(s) = -s^2 \tau_1 \tau_2.
\] (6)

At oscillation situation, the system loop gain is equal to unity. Thus (6) is written to be

\[
s^2 \tau_1 \tau_2 + 1 = 0.
\] (7)

From (7), the oscillation frequency is as follows:

\[
\omega_{osc} = \frac{1}{\sqrt{\tau_1 \tau_2}}.
\] (8)

It can be seen from (8) that the oscillation frequency can be controlled by \( \tau_1 \) or \( \tau_2 \), which is free from the preset of oscillation condition.

\[\text{Figure 2. Systematic diagram of oscillator.}\]

\[\text{Figure 3. Active-only Differentiators for (a) inverting type, (b) non-inverting type.}\]
D. Proposed Current-mode Quadrature Oscillator

As mentioned in the above section, the proposed oscillator is based on the inverting and non-inverting lossless active-only differentiators. The implementations of the active-only inverting and non-inverting lossless differentiators are shown in Figs. 3(a) and (b), respectively. The current transfer functions can be respectively written as follows:

\[
T_1(s) = -\frac{sR_m g_{m1}}{B_1}, \quad (9)
\]

and

\[
T_2(s) = \frac{sR_m g_{m2}}{B_2}, \quad (10)
\]

Substituting the parasitic resistance \(R_p\) and transconductance \(g_m\) as respectively shown in (2) and (3) into (11), the oscillation frequency \(\omega_{osc}\) is given by

\[
\omega_{osc} = \frac{B_1B_2}{R_p g_{m1} g_{m2}}. \quad (11)
\]

It is obviously found that from (12), the oscillation frequency can be electronically adjusted by setting \(I_{B1}, I_{B2}, I_{B3}\) or \(I_{B4}\). From the oscillator in Fig. 4, the current transfer function from \(I_{o1}\) to \(I_{o2}\) is

\[
\frac{I_{o2}(s)}{I_{o1}(s)} = \frac{sR_m g_{m2}}{B_2}. \quad (13)
\]

For sinusoidal steady state, (13) becomes

\[
\frac{I_{o2}(j\omega)}{I_{o1}(j\omega)} = \frac{R_m g_{m2}}{B_2} e^{j\phi}. \quad (14)
\]

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

\[
\phi = 90^\circ, \quad (15)
\]

ensuring that the currents \(I_{o2}\) and \(I_{o1}\) are in quadrature.

III. SIMULATION RESULTS AND DISCUSSION

To prove the performances of the proposed circuit, the PSPICE simulation program was used. The PMOS and NMOS transistors were simulated by using the parameters of a 0.35\(\mu\)m TSMC CMOS technology [22]. Fig. 5 depicts the schematic description of the CCCCTA used in the simulations. The aspect transistor ratios of PMOS and NMOS transistors are listed in Table 1. The circuit was biased with \(\pm 5\)V supply voltages, \(I_{B1}=I_{B3}=300\mu\)A, \(I_{B2}=I_{B4}=50\mu\)A. LM741 opamp with the gain-bandwidth product of \(B=2\pi(1.0027)\times10^6\) rad.s\(^{-1}\) is used. This yields oscillation frequency of 570kHz.

![Figure 5. Internal construction of CCCCTA.](image)

**TABLE I. DIMENSIONS OF CMOS TRANSISTORS**

<table>
<thead>
<tr>
<th>CMOS Transistors</th>
<th>(W(\mu m) / L(\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M4</td>
<td>15/0.5</td>
</tr>
<tr>
<td>M5-M8,M10-M12</td>
<td>6/1</td>
</tr>
<tr>
<td>M9</td>
<td>5.4/1</td>
</tr>
<tr>
<td>M13-M14</td>
<td>0.5/0.5</td>
</tr>
<tr>
<td>M15-M16</td>
<td>1.5/1</td>
</tr>
<tr>
<td>M17-M18,M20-M21,M23</td>
<td>5/0.5</td>
</tr>
<tr>
<td>M19,M22</td>
<td>1/0.5</td>
</tr>
<tr>
<td>M24-M29</td>
<td>2/1</td>
</tr>
</tbody>
</table>

Figs. 6 and 7 show simulated quadrature output waveforms. Fig. 7 confirms that the output currents are in quadrature as analyzed in (14). Fig. 8 shows the simulated output spectrum, where the total harmonic distortion (THD) is about 6.68%. Fig. 6 shows the simulation results of output waveforms during initial state.

![Figure 6. The simulation results of output waveforms during initial state.](image)
9 depicts the plots of the simulated oscillation frequencies relative to the bias currents, \( I_{B1} \) and \( I_{B3} \), where \( I_{B2}=I_{B4} \) are identical values of 50\( \mu \)A, 100\( \mu \)A and 200\( \mu \)A.

![Figure 7](image-url)

**Figure 7.** The simulation results of output waveforms during steady state.

![Figure 8](image-url)

**Figure 8.** The simulation result of output spectrum.

![Figure 9](image-url)

**Figure 9.** Oscillation frequencies against bias currents.

IV. CONCLUSION

A current-mode quadrature oscillator based on active-only differentiators has been presented. The proposed circuit consists of only active-elements, which are 2 CCCCTAs and 2 op amps. The oscillation frequency can be electronically tuned via input bias currents, which is free from the preset of oscillation condition. Due to high-output impedances, it enables easy cascading in a current-mode architecture. As mentioned advantages, the proposed oscillator is appropriate to fabricate into integrated circuit (IC). The PSPICE simulation results agree well with the theoretical anticipation.

REFERENCES


