High-output impedance Current-mode Quadrature Oscillator with Frequency Control via Electronic Method Using Current Controlled CTTAs

Trakarn Thasangkha1*
1Department of Teacher Training in Electronic Engineering, Faculty of Industrial Education, Rajamangala University of Technology Isan Khonkaen Campus, Khonkaen, 40000
E-mail: trakan.ts@gmail.com*

Abstract
This article presents a current-mode quadrature sinusoidal oscillator employing current controlled current through transconductance amplifiers (CC-CTTAs). The oscillation frequency and oscillation condition can be electronically/orthogonally controlled via correspondent input bias currents. The circuit description is very simple, consisting of merely 3 CC-CTTAs and 2 grounded capacitors. Without any external resistors and 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 7.2mW at ±1.5 V supplies.

Keywords: current-mode, oscillator

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

Presently, the current-mode circuit design technique has been established as an important topic in analogue signal processing. This is owing to that the current-mode structure provides potential advantages such as wide dynamic range, inherent wide bandwidth, low power consumption and simpler structures [2-3].

Several implementations of the quadrature oscillator using different high-performance active building blocks such as, operational transconductance amplifiers (OTAs) [4-5], current conveyors [6], four terminal floating nullors (FTFNs) [7-8], current follower [9-10], current controlled current differenting buffered amplifiers (CCCDBAs) [11], current controlled current differencing transconductance amplifiers (CCCDTAs) [12-13], fully-differential second-generation current conveyor (FDCCII) [14], and differencing voltage current conveyor (DVCCs) [15], have been reported.

Unfortunately, these reported circuits suffer from one or more of following weaknesses:

a) Excessive use of the passive elements, especially external resistors [6, 7, 15].
b) Lack of electronic adjustability [6-10, 15].
c) Output impedances are not high [5-7, 9-13].
d) Use of a floating capacitor, which is not convenient to further fabricate in IC [15].
e) The oscillation conditions and oscillation frequencies cannot be independently controllable [4, 9-10].

The current through transconductance amplifier (CTTA) is a reported active component, especially suitable for a class of analog signal processing [16]. It is really a current-mode element whose input and output signals are currents. In addition, it can offer advantageous features such as high-slew rate, higher speed, wide bandwidth and simple implementation. However, the CTTA cannot be controlled by the parasitic resistance at input port so when it is used in some circuits, it must unavoidably require some external passive components, especially the resistors. This makes it not appropriate for IC implementation due to occupying more chip area and consuming more power consumption.

The aim of this paper is to propose a novel current mode quadrature oscillator emphasizing on use of a modified version of CTTA, which is newly named Current Controlled Current through Transconductance Amplifier (CC-CTTA). The features of proposed circuit are that: The oscillation condition can be adjusted independently from the oscillation frequency by electronic method. The circuit construction consists of 3 CC-CTTAs and 2 grounded capacitors. Moreover, the output currents have high impedance, which facilitates cascading in current mode. The PSPICE simulation results are also...
shown, which are in correspondence with the theoretical analysis.

2. Principle of Operation

2.1 Basic Concept of CC-CTTA

Since the proposed circuit is based on CC-CTTA, a brief review of CC-CTTA is given in this section. Generally, CC-CTTA properties are similar to the conventional CTTA, except that CC-CTTA has finite input resistance: \( R_i \) at the input terminals. This parasitic resistance can be controlled by the bias current \( I_A \) and transconductance \( g_m \) can be controlled by the bias currents \( I_B \) as shown in Eq. (1).

\[
\begin{pmatrix}
I_n \\
V_p \\
I_z \\
I_{x+} \\
I_{x-}
\end{pmatrix} =
\begin{pmatrix}
-1 & 0 & 0 & 0 & 0 \\
0 & R_i & 1 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & g_m & 0 \\
0 & 0 & 0 & -g_m & 0
\end{pmatrix}
\begin{pmatrix}
I_p \\
V_x \\
V_z \\
V_{x+} \\
V_{x-}
\end{pmatrix}
\]

(1)

where

\[
R_i = \frac{V_T}{2I_A}
\]

(2)

\[
g_m = \frac{I_A}{2V_T}
\]

(3)

\( V_T \) is the thermal voltage. The symbol and the equivalent circuit of the CC-CTTA are illustrated in Figs. 1 (a) and (b), respectively.

2.2 Proposed Current-Mode Quadrature Oscillator

The completed proposed current-mode quadrature oscillator circuit employing CC-CTTA is displayed in Fig. 2.

From the circuit as the CC-CTTA properties and routine analysis, the following system characteristic equation can be obtained.

\[
\frac{s^2C_1^2 + sC_1g_{m1}R_{3}}{g_{m1}g_{m2}} + \frac{1}{2 - \frac{1}{g_{m3}R_{3}}} + 1 = 0
\]

(4)

For easy consideration, we set \( C = C_1 = C_2 \) and \( g_m = g_{m1} = g_{m2} \). From the CC-CTTA properties in section II.A and routine analysis, the following system characteristic equation can be obtained

\[
\frac{s^2C_1^2 + sC_1g_{m1}R_{3}}{g_{m1}g_{m2}} + \frac{1}{2 - \frac{1}{g_{m3}R_{3}}} + 1 = 0
\]

(5)

From Eq. (5), the frequency condition and the oscillation frequency of this system can be obtained as

\[
g_{m3}R_{3} = 2
\]

(6)

and

\[
\omega_0 = \frac{g_m}{C}
\]

(7)

Figure 2. Circuit diagram of the proposed circuit

Substituting the intrinsic resistances and transconductance as depicted in Eqs. (2) and (3), respectively, it yields

\[
\frac{I_{B3}}{8I_A} = 1
\]

(8)

and

\[
\omega_0 = \frac{I_A}{2V_T C}
\]

(9)

It should be noted from Eqs. (8) and (9) that the oscillation condition can be adjusted independently from the oscillation frequency by varying \( I_A \) and \( I_{B3} \), while the oscillation frequency can be adjusted by varying \( I_A \). The active and passive sensitivities of the quadrature oscillator are all low and can be obtained as

\[
S_{C,x}^{\omega} = -1, \quad S_{I_A}^{\omega} = 1.
\]

3. Simulation Results

To prove the performances of the proposed circuit, the PSPICE simulation was performed for examination. The PNP and NPN transistors employed
in the proposed circuit were simulated by respectively using the parameter of the NR200N and PR200N bipolar transistors of ALA400 transistor array from AT&T [17].

Fig. 3 depicts internal circuit description of the CC-CCTA used in the simulations. The CC-CCTAs were biased with ±1.5V supply voltages, where \( I_{B1} = I_{B2} = 50 \mu A, I_{E1} = I_{E2} = 150 \mu A, I_{L1} = 20 \mu A, I_{L3} = 160 \mu A, \) and \( C_1/C_2 = 1 \) nF.

Fig. 4 show simulated quadrature output waveforms during initial state, while the simulation result of quadrature outputs waveform during a steady state at 389 kHz frequency as show in Fig. 5, and Fig. 6 shows the simulated output spectrum at 389 kHz frequency. It is found that the total harmonic distortion (THD) is about 0.967%. Fig. 7 show simulated quadrature output waveforms at high frequency.

Fig. 8 shows the simulated output spectrum at 4.011 MHz frequency. The THD is about 1.39%. Fig. 9 depicts the plots of the simulated and theoretical oscillation frequency versus bias currents in the proposed circuit for various capacitances.

FIGURE 3. Internal circuit description of the CC-CCTA.

FIGURE 4. The simulation result of output waveforms during initial state.

FIGURE 5. The simulation result of quadrature outputs during a steady state at 389 kHz frequency.

FIGURE 6. The simulation result of output spectrum at 389 kHz frequency.

FIGURE 7. The simulation result of quadrature outputs during a steady state at 4.011 MHz frequency.

FIGURE 8. The simulation result of output spectrum at 4.011 MHz frequency.

FIGURE 9. The oscillation frequencies against bias currents in the proposed circuit for various capacitances.
the bias currents, \( I_B \), where \( C_1 \) and \( C_2 \) are identical values of 1nF, 10nF and 50nF. It is seen that the simulation results are in accordance with the theoretical analysis as shown in Eq. (9).

4. Conclusions
A current-mode quadrature oscillator based on CC-CTTA has been presented. The features of the proposed circuit are that: oscillation frequency an oscillation condition can be orthogonally adjusted via input bias current; the proposed circuit, due to high output impedances, the power consumption is approximately 7.2mW at 398 kHz frequency, enables easy cascading in current mode; it consists of 3 CC-CTTAs and 2 grounded capacitors, which is convenient to fabricate. The PSPICE simulation results agree well with the theoretical anticipation.

References