Dual Mode Quadrature Oscillator Employing Single Current Controlled Current Conveyor Transconductance Amplifier

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Abstract: This paper presents new realizations of dual mode i.e. both voltage mode and current mode quadrature sinusoidal oscillators using a recently proposed current mode active building block (ABB), namely the current controlled current conveyor transconductance amplifier (CCCCTA). The proposed circuit employs single CCCCTA and four passive grounded elements. The proposed circuits offer two explicit quadrature voltage outputs and two quadrature current outputs. The tuning laws for the condition of oscillation (CO) and the frequency of oscillation (FO) are independently adjustable by the separate bias currents. Non–ideal analyses of the proposed circuits are provided. PSpice simulation results have been included that validate the workability of the proposed circuits.

Keywords: Current controlled current conveyor transconductance amplifier (CCCCTA), Voltage mode (VM), Current mode (CM), Quadrature oscillator, Condition of oscillation (CO), Frequency of oscillation (FO).

I. INTRODUCTION

In recent years designing electronic circuits that can operate from low supply voltages has been gaining an increasing interests due to the fact that the battery operated portable devices require low power dissipation to increase battery life and minimum number of cells to reduce the volume and weight. For this reason the current mode technique is more suitable rather than the voltage mode technique. Also the current mode structures are more favorable because of their advantages such as, larger dynamic range, greater linearity, higher signal bandwidth and simple circuitry [1–2].

Quadrature oscillators (QO) that simultaneously provide two sinusoids, which are 90º phase shifted have become a very important blocks for various communication systems such as in telecommunications for quadrature mixers, in direct conversion receivers, in single sideband generators or for measurement purpose in vector generators or selective voltmeters [3–5].

Now several realizations of voltage mode and current mode quadrature oscillators based on various ABBs have received considerable attention. These include oscillators based on different ABBs like second generation current conveyor (CCII) [6–8], fully differential second generation current conveyor (FDCCII) [9–10], differential difference current conveyor (DDCC) [11], differential input buffered and transconductance amplifier (DBTA) [12], current feedback amplifiers (CFA) [13], current differencing buffered amplifier (CDBA) [14–15] and most recently by current differencing transconductance amplifier (CDTA) [16–18]. Recently a new kind of current mode active building block namely, the current controlled current conveyor transconductance amplifier (CCCCTA) has been introduced. Various researchers have designed new kind of oscillators and filters using this ABB.

The published CCCCTA based oscillators are compared here. Siripruchyanun introduced an oscillator based on a single CCCCTA and two grounded capacitors both in bipolar [2] and in CMOS [19] technology. In both the cases no quadrature output is obtained and the total harmonic distortion (THD) is 2.92% in the first case and 1.07% in the later. Jaikla introduced an oscillator based on a commercially available CCCCTA, one resistor and two grounded capacitors [20]. But no quadrature output is obtained and in this case the THD is about 5.78%. The oscillator proposed by Pissutthipong [21] gives current mode quadrature outputs and in this case the THD is about 2.445%. But a careful observation indicates that most of the circuits can not provide explicit quadrature voltage outputs and quadrature current outputs. These oscillator circuits contain one [2, 9, 10, 12, 16, 19, 20], two [11, 13, 14, 15, 17, 21], or three [6, 8, 18] ABBs and the oscillators in [6, 8, 9, 11, 12, 15] use at least five passive elements. But realizations with one ABB are more acceptable. Also the circuits in [16] employ floating capacitors which is not favorable for monolithic implementation.

In this paper both the voltage mode and current mode quadrature oscillators have been proposed using single CCCCTA and grounded passive components. The CO and FO are independently adjustable by different bias currents. The
grounded passive components make the circuit suitable for monolithic implementation. PSpice simulation results have been included that validate the working of the proposed circuit.

II. CURRENT CONTROLLED CURRENT CONVEYOR TRANSCONDUCTANCE AMPLIFIER

The current controlled current conveyor transconductance amplifier (CCCCTA) is an active block which consists of two principal building blocks, a multiple output current controlled current conveyor at the front end and operational transconductance amplifiers at the rear end. The circuit symbol of the CCCCTA is shown in Fig. 1. A possible bipolar implementation of the CCCCTA is shown in Fig. 2.

\[
\begin{align*}
I_y &= 0 \quad 0 \quad 0 \\
V_x &= R_x \quad 1 \quad 0 \\
I_z &= 1 \quad 0 \quad 0 \\
I_{o1+} &= 0 \quad 0 \quad g_{m1} \\
I_{o1-} &= 0 \quad 0 \quad -g_{m1} \\
I_{o2+} &= 0 \quad 0 \quad g_{m2} \\
\end{align*}
\]

where \(R_x\) represents the parasitic resistance at the X terminal, \(g_{m1}\) and \(g_{m2}\) represent the transconductance gains. For bipolar implementation of the CCCCTA as shown in Fig. 2, the parasitic resistance \(R_x\) and the transconductance gains \(g_{m1}\) and \(g_{m2}\) are given as

\[
R_x = \frac{V_T}{2I_{B1}}, \quad g_{m1} = \frac{I_{B2}}{2V_T}, \quad g_{m2} = \frac{I_{B3}}{2V_T}
\]

where \(V_T\) is the thermal voltage whose value is 26mV at 27ºC. For large value of \(I_{B1}\) the effect of \(R_x\) could be neglected.

III. PROPOSED QUADRATURE OSCILLATOR CIRCUIT

The proposed dual–mode quadrature oscillator circuit using single CCCCTA and grounded passive elements is shown in Fig. 3. Using (1) and doing routine circuit analysis, the characteristic equation can be written as

\[
x^2C_1C_2R_1R_2 + xC_1R_1(1 - g_{m2}R_2) + g_{m1}R_2 = 0
\]
It is seen from (3) that the condition of oscillation (CO) and frequency of oscillation (FO) are given as

\[
CO : R_2 \geq \frac{1}{g_{m2}}
\]

(4)

\[
FO : f_{\text{osc}} = \frac{1}{2\pi \sqrt{C_1 C_2 R_1}}
\]

(5)

It is clear from (4) and (5) that the condition of oscillation and frequency of oscillation are independently adjustable by the transconductance gains \(g_{m2}\) and \(g_{m1}\), respectively and therefore by the bias currents \(I_{B1}\) and \(I_{B2}\), respectively. Also from (5) it is clear that \(R_1\) can be used for electronic tuning of the oscillation frequency. The two marked quadrature voltages in Fig. 3 are related as

\[
V_{\alpha2} = -j k_1 V_{ol} \quad \text{where} \quad k_1 = \frac{\omega_c C_1}{g_{m1}}
\]

(6)

For \(k_1=1\) the two quadrature voltages have equal magnitude. Similarly, the two marked quadrature currents in Fig. 3 are related as

\[
I_{\alpha2} = -j k_2 I_{ol} \quad \text{where} \quad k_2 = \omega_c C_1 R_1
\]

(7)

For \(k_2=1\) the two explicit quadrature current outputs have equal magnitude. It is clear from (6) and (7) that factors \(k_1\) and \(k_2\) are operating frequency dependent terms that is they depend on \(g_{m1}\) and hence temperature dependent. Thus the changing of frequency of oscillation by \(g_{m1}\) simultaneously changes the ratio of the magnitudes of quadrature voltages and quadrature currents. The circuit provides current outputs from high impedance port for explicit utilization but external voltage buffers would be required for the quadrature voltage outputs.

**IV. NON–IDEALITIES AND SENSITIVITY ANALYSIS**

In the non–ideal case, the CCCCTA can be characterized by the following equations [22]

\[
\begin{bmatrix}
I_y \\
V_x \\
I_z \\
I_{z1} \\
I_{o1+} \\
I_{o1-} \\
I_{o2+} \\
I_{o2-}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 \\
R_x & \alpha & 0 & 0 \\
\beta & 0 & 0 & 0 \\
\beta_1 & 0 & 0 & 0 \\
0 & 0 & +\gamma_{1} g_{m1} & 0 \\
0 & 0 & 0 & -\gamma_{2} g_{m2} \\
0 & 0 & +\gamma_{3} g_{m2} & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
V_y \\
V_z \\
V_{o1+} \\
V_{o1-} \\
V_{o2+} \\
V_{o2-}
\end{bmatrix}
\]

(8)

where \(\alpha\) represents the voltage transfer gain from Y terminal to X terminal, \(\beta\) and \(\beta_1\) represent the current transfer gains from X terminal to Z and \(Z_1\) terminals and \(\gamma_{1}, \gamma_{2}\) and \(\gamma_{3}\) represent the current transfer gains from \(Z\) terminal to \(O_{1+}, O_{1-}\), and \(O_{2+}\), terminals, respectively.

The non–zero parasitic resistance \(R_s\) appears in series with the external resistor \(R_1\). Therefore this parasitic resistance \(R_s\) increases the external resistor \(R_1\) as

\[
R'_1 = R_1 + R_s
\]

(9)

The parasitic resistances \(R_2, R_{o1}, R_{o2}\) and parasitic capacitances \(C_{p}, C_{o1}, C_{o2}\) appear between the high output impedance current terminals \(Z, O_{1+}, O_{1-}\), and ground. Since the values of \(R_3\) and \(R_{o2}\) are in the order of \(\Omega\), hence an external resistor \(R_3\) should be connected at this terminal so that \(R_3||R_{o2}=R_2\). The parasitic capacitances \((C_{p}+C_{o2})\) and \(C_{o1}\) are absorbed into the external capacitors \(C_2\) and \(C_1\), respectively, as they appear in shunt with them. Therefore the original capacitances \(C_1\) and \(C_2\) are increased to \(C_1'\) and \(C_2'\) as

\[
C_1' = C_1 + C_{o1}
\]

(10)
\[ C_2' = C_2 + C_z + C_{o2} \]  
(11)

Taking into account the aforementioned non–idealities the modified expression of CO and FO are

\[ CO : R_2 \geq \frac{1}{\gamma_3 g_{m2}} \]  
(12)

\[ FO : f_{osc} = \frac{1}{2\pi} \sqrt{\frac{\alpha \beta \gamma_3 g_{m1}}{(C_1 + C_{o1})(C_2 + C_z + C_{o2})(R_1 + R_x)}} \]  
(13)

The sensitivity of any active network is given as:

\[ S^f_e = \frac{e}{F} \frac{\partial F}{\partial e} \]  
(14)

where \( F \) represents a network function and \( e \) represents the element of variation of the filter. The oscillation frequency is the parameter of interest. Using this definition the active and passive sensitivities are given as:

\[ S^f_x = S^f_y = S^f_{g_{m1}} = \frac{1}{2} \]  
(15)

\[ S^f_{C_1} = -\frac{C_1}{2(C_1 + C_{o1})}, \]  
(16)

\[ S^f_{C_{o1}} = -\frac{C_{o1}}{2(C_1 + C_{o1})}, \]  
(17)

\[ S^f_{C_2} = -\frac{C_2}{2(C_2 + C_z + C_{o2})}, \]  
(18)

\[ S^f_{C_z} = -\frac{C_z}{2(C_2 + C_z + C_{o2})}, \]  
(19)

\[ S^f_{C_{o2}} = -\frac{C_{o2}}{2(C_2 + C_z + C_{o2})}, \]  
(20)

\[ S^f_{R_1} = -\frac{R_1}{2(R_1 + R_x)}, \]  
(21)

\[ S^f_{R_x} = -\frac{R_x}{2(R_1 + R_x)}, \]  
(22)

Therefore it is evident that the circuit exhibits low active and passive sensitivities.

V. RESULTS AND DISCUSSIONS

The proposed oscillator circuit as shown in Fig. 3 has been simulated in PSpice by using the bipolar implementation of the CCCCTA. The circuit is biased with ±1.5 V supply voltages. The passive components were chosen as \( C_1=C_2=220 \) pF, \( R_1=1 \) k\( \Omega \), \( R_2=1 \) k\( \Omega \), \( R_x=130 \) \( \Omega \) (\( I_{B1}=100 \) \( \mu \)A), \( g_{m1}=1 \) mS (\( I_{B2}=50 \) \( \mu \)A) and \( g_{m2}=1 \) mS (\( I_{B3}=50 \) \( \mu \)A). With these values, the condition of oscillation is satisfied. The start up of oscillations and the steady state waveforms for both the quadrature voltages and currents are shown in Fig. 4 and Fig. 5, respectively. The steady state is reached approximately within 30 \( \mu \)s. The frequency spectrums (FFT) for both the voltage mode and current mode are shown in Fig. 6. The total harmonic distortions (THD) for both the voltage mode and current mode structures are nearly 3.61\% and 3.42\%, respectively at the oscillation frequency of 380 kHz. The electronic tuning of the oscillation frequency with the bias current \( I_{B2} \) for different capacitor values is shown in Fig. 7. For practical measurement the CCCCTA can also be constructed using commercially available circuits AD844 and LM13600. It is expected that the experimental results would agree well with the simulated and theoretical results.
Fig. 4 The growing oscillations of quadrature outputs for (a) Voltage mode (b) Current mode
Fig. 5 The steady state time domain waveforms of the quadrature outputs for (a) Voltage mode (b) Current mode

Fig. 6 The FFT spectrum of outputs for (a) Voltage mode (b) Current mode
VI. CONCLUSION

In this paper, a dual mode quadrature sinusoidal oscillator using a single CCCCTA has been proposed, which simultaneously provides two explicit quadrature voltage outputs and current outputs. The oscillator circuit proposed in this paper is attractive because it provides independent adjusting of the oscillation frequency and the oscillation condition. It also uses all grounded passive components, which is advantageous from the viewpoint of integrated circuit manufacturing. Also the circuit provides low total harmonic distortion and low sensitivities. The simulation results are in good agreement with the theoretical anticipation. Since the circuit consists of single CCCCTA and grounded passive components it is thus suitable for monolithic implementation to employ in portable electronic equipments.

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