A Simple Current-mode Quadrature Oscillator Using only Single CDTA

Supawat Lawanwisut*, Dalibor Biolek**, and Montree Siripruchyanan***

*Department of Information and Communication Engineering, Faculty of Industrial Technology, Thammasat Rajabhat University, Lopburi, 15000, Thailand, Email: supawat@tru.ac.th
**Department of Electrical Engineering, Military Academy Brno, Kounicova 65, 612 00 Brno, Czech Republic, Email: dalibor.biolek@unob.cz
***Department of Teacher Training in Electrical Engineering, Faculty of Technical Education, King Mongkut’s University of Technology North Bangkok, Bangsue, Bangkok, 10800, Thailand, Email: mts@kmutnb.ac.th

Abstract—This article presents a simple current-mode quadrature oscillator using single current differencing transconductance amplifier (CDTA) as active element. The oscillation condition and oscillation frequency can be electronically controlled. The circuit description is very simple, consisting of merely 1 CDTA, 1 resistor and 2 capacitors. The proposed circuit is suitable for IC architecture. The PSPICE simulation and experimental results are depicted, and the given results agree well with the theoretical anticipation.

I. INTRODUCTION

A n oscillator is an important basic building block, which is frequently employed in electrical engineering applications. For example, it can be found in communication systems to be a carrier in a modulator, instrumentation and measurement systems to generate a signal employed in sensor application, and etc. 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]. 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].

A reported 5-terminals active element, namely current differencing transconductance amplifier (CDTA) [3], seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters [3–4]. It is really current-mode element whose input and output signals are currents. In addition, output current of CDTA can be electronically adjusted. Besides, the modified version of CDTA whose parasitic resistances at two current input ports can be electronically controlled has been proposed in [5]. This CDTA is called current controlled current differencing transconductance amplifier (CC-CDTA).

From our survey, it is found that several implementations of oscillator employing CDTAs or CC-CDTAs have been reported [6-11]. Unfortunately, these reported circuits suffer from one or more of following weaknesses: use of more than two CDTAs or CC-CDTAs and excessive use of the passive elements which is not convenient to further fabricate in IC, some reported circuits use multiple-output CDTA or CC-CDTA. Consequently, the circuits become more complicated in transistor level.

The purpose of this paper is to introduce a current-mode quadrature oscillator, based on single CDTA. The oscillation condition and oscillation frequency can be adjusted by electronic method. The circuit construction consists of entirely 1 CDTA, 1 resistor and 2 capacitors. The PSPICE simulation and experimental results obtained from commercially available ICs are also shown, which are in correspondence with the theoretical analysis.

II. PRINCIPLE OF OPERATION

A. Current differencing transconductance amplifier (CDTA)

Since the proposed circuit is based on CDTA, a brief review of CDTA is given in this section. The characteristics of the ideal CDTA are represented by the following hybrid matrix

\[
\begin{bmatrix}
V_p \\
V_n \\
I_z \\
I_a
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & g_m & 0
\end{bmatrix}
\begin{bmatrix}
I_p \\
I_n \\
V_a \\
V_z
\end{bmatrix}.
\]

For BJT CDTA, the transconductance can be expressed as
\[ g_m = \frac{I_B}{2V_T}. \] (2)

\[ V_T \text{ and } I_B \text{ are the thermal voltage and input bias current, respectively. In general, CDTA can contain an arbitrary number of } x \text{ terminals, providing currents } I_x \text{ of both directions. The symbol and the equivalent circuit of the CDTA are illustrated in Figs. 1(a) and (b), respectively.} \]

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

**Figs. 1.** CDTA (a) Symbol (b) Equivalent circuit.

**Fig. 2.** Implementation block diagram for quadrature oscillator.

\[ \frac{sC_1 R_n - 1}{sC_1 R_n + 1} I_{O1} + \frac{g_m}{sC_2} I_{O2} \]

\[ \text{(a)} \]

**Fig. 3.** Proposed quadrature oscillator.

\[ I_{O2} = \frac{g_m}{sC_2} I_{O1} \]

Eq. (4) is called the condition of oscillation, this is achieved by setting

\[ C_2 = C_1 \text{ and } g_m = 1/R_n. \] (5)

Then the characteristic equation of the system becomes

\[ s^2 C_1 C_2 R_n + g_m = 0. \] (6)

From Eq. (6), the oscillation frequency of this system can be obtained to be

\[ \omega_o = \frac{g_m}{\sqrt{R_n C_1 C_2}} = \frac{I_B}{2V_T R_n C_1 C_2}. \] (7)

From circuit in Fig. 3, the current transfer function of \( I_{O2} \) to \( I_{O1} \) is

\[ \frac{I_{O2}(s)}{I_{O1}(s)} = \frac{g_m}{sC_2}. \] (8)

Under sinusoidal steady state, Eq. (8) becomes

\[ \frac{I_{O2}(j\omega)}{I_{O1}(j\omega)} = \frac{g_m}{\omega C_2} e^{-j\phi}. \] (9)

The phase difference, \( \phi \), between \( I_{O2} \) and \( I_{O1} \) is

\[ \phi = -90^\circ. \] (10)

ensuring the currents \( I_{O2} \) and \( I_{O1} \) to be in quadrature form. The active and passive sensitivities of the oscillator are all low and can be obtained as

\[ S_{m,R_n}^{1/2}, S_{g_m}^{1/2} = \frac{1}{2}. \] (11)

**B. Proposed Circuit**

The proposed quadrature oscillator is designed by cascading an all-pass filter and a non-inverting lossless integrator as shown in Fig. 2. Using this block diagram, proposed quadrature oscillator based on single CDTA can be implemented as shown in Fig. 3. The characteristic equation of the proposed quadrature oscillator in Fig. 3 can be expressed as

\[ s^2 C_1 C_2 R_n + s(C_2 - C_1 R_n g_m) + g_m = 0. \] (3)

From Eq. (3), it can be seen that the proposed circuit can produce a sinusoidal signal if the oscillation condition is fulfilled:

\[ g_m R = \frac{C_2}{C_1}. \] (4)

**C. Non-ideal case**

In practice, the CDTA is possible to work with nonidealities. Its properties will change to
\[ I_z = \alpha_p I_p - \alpha_n I_n \quad (12) \]

and
\[ I_s = \beta g_m V_z. \quad (13) \]

The parameters: \( \alpha_p \), \( \alpha_n \) and \( \beta \) are the current/voltage transfer values, deviating from one, based on the internal circuit construction. In the non-ideal case, a new analysis of the proposed oscillator circuit in Fig. 2 yields the following characteristic equation
\[ s^2 C_1 C_2 R_m + s \left( C_2 - \alpha_p \beta C_1 R_m g_m \right) + \alpha_p g_m = 0. \quad (14) \]

The oscillation condition and oscillation frequency are changed to be
\[ C_2 / C_1 = \alpha_p \beta R_m g_m \quad (15) \]

and
\[ \omega_o = \frac{\alpha_p \beta g_m}{\sqrt{R_m C_1 C_2}}. \quad (16) \]

The active and passive sensitivities of the oscillator in non-ideal case are expressed as
\[ S_{\omega_0}^{\alpha_p} = -\frac{1}{2}, S_{\omega_0}^{\alpha_n \beta} = \frac{1}{2}. \quad (17) \]

Practically, the \( \alpha_p \), \( \alpha_n \) and \( \beta \) originate from intrinsic resistances and stray capacitances in the CDTA. These errors affect the sensitivity to temperature and high frequency response of the proposed circuit, thus the CDTA should be carefully designed to minimize these errors. Consequently, these deviations should be very small and can be ignored.

I. SIMULATION AND EXPERIMENTAL RESULTS

To prove the performances of the proposed circuit, a PSPICE simulation was performed for examination and verification. The implementation of CDTA was achieved by using the commercially available ICs, namely AD844 (CCII) and LM13600N (OTA), as shown in Fig. 4.

![Fig. 4. Implementation of CDTA based on commercially available ICs.](image)

The circuit was biased with \( \pm 3V \) supply voltages, \( C_1=C_2=1nF, I_{\text{g}}=60\mu A \, (g_m=1.15mS) \) and \( R_m=1k\Omega \). This yields oscillation frequency of 153.15kHz, where the calculated value of this parameter from Eq. (7) yields 170.76kHz (deviated by 10.10%). Figs. 5 and 6 show simulated quadrature output waveforms. Fig. 7 shows the simulated output spectrum, where the total harmonic distortion (THD) is about 3.01%. The experimental response is also illustrated in Fig. 8, which is the dropped voltage at \( C_2 \). The oscillation frequency of experimental result is about 159.9kHz, which is deviated from the calculated value by 6.37%.

![Fig. 5. The simulation result of output waveforms during initial state.](image)

![Fig. 6. The simulation result of quadrature outputs.](image)

![Fig. 7. The simulation result of output spectrum.](image)
II. CONCLUSION

A simple quadrature oscillator based on CDTA has been presented. The features of the proposed circuit are that: oscillation frequency an oscillation condition can be electronically adjusted; the proposed consists of only 1 CDTA, 1 resistor and 2 capacitors, which is convenient to fabricate in IC form and practical implementation using the commercially available ICs. The PSPICE simulation and experimental results agree well with the theoretical anticipation.