Resistorless Current-mode Quadrature Sinusoidal Oscillator Using CDTAs

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***Abstract*- A circuit technique for realizing a current-mode quadrature sinusoidal oscillator using current differencing transconductance amplifiers (CDTAs) as active components is presented in this paper. The proposed circuit employing only three CDTAs and two grounded capacitors can provide two quadrature sinusoidal current outputs with 90° phase difference. The oscillation condition and the oscillation frequency (ω_0) of the proposed circuit can be electronically and orthogonally tuned. Simulation results with PSPICE are used to confirm the presented theory.**

Keywords: Current differencing transconductance amplifier (CDTA), Quadrature oscillator, Current-mode circuit

I. INTRODUCTION

The quadrature sinusoidal oscillator is widely used in analog signal-processing and communication. The quadrature oscillator is employed because it can generate two sinusoidal outputs of identical frequency but of 90° phase shift, as for examples in telecommunications for quadrature mixers and single-sideband generators or for measurement purposes in vector generator or selective volmiters [1]. Several synthesizes of quadrature oscillator circuits have received considerable attention [2]-[4]. However, these earlier quadrature oscillators operate in voltage-mode. Current-mode quadrature sinusoidal oscillator circuits are receiving much attention because of their potential advantages such as wider bandwidth, wider dynamic range, simpler circuitry, and lower power consumption. Considering this fact, a number of current-mode quadrature sinusoidal oscillator realizations using CDTAs were reported in the literature [5]-[8]. all of these quadrature oscillators suffer from the following disadvantages: (i) the oscillation condition and the oscillation frequency are interdependent [7]; (ii) the use of some external passive resistors [5]-[7]; (iii) the use of a large number of CDTAs in circuit realization, namely four CDTAs [8].

In this paper, the resistorless realization of an electronically tunable current-mode quadrature sinusoidal oscillator using only three CDTAs and two grounded capacitors is proposed. Comparing to the recently realization available in [5]-[8], the proposed circuit offers the following advantages: (i) two quadrature sinusoidal output waveforms of 90° phase shift are obtained simultaneously without changing circuit configuration; (ii) the oscillation condition and the oscillation frequency are independently tunable; (iii) the use of only grounded capacitor, which makes the circuit attractive for integration; (iv) low sensitivity. Simulation results verifying the theoretical analysis are also included.

II. CIRCUIT DESCRIPTION

The circuit representation of the CDTA is shown in Fig.1, where p and n are input terminals, z and x are output terminals. The terminal relation of the CDTA can be expressed by the following matrix [9]-[10]:

$$\begin{bmatrix} i_z \\ i_x \\ v_p \\ v_n \end{bmatrix} = \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & g_m & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_p \\ i_n \\ v_z \\ v_x \end{bmatrix} \qquad (1)$$

where g_m is the transconductance gain of the CDTA, and Z_z is an impedance connected at the terminal z. From equation (1), the current through the terminal z (i_z) follows the difference of the currents through the terminals p and n (i_p-i_n), and flows from the terminal z into an outside impedance Z_z. The voltage drop at the terminal z is transferred to a current at the terminal x (i_x) by a transconductance gain (g_m), which is generally controllable by electronic means.

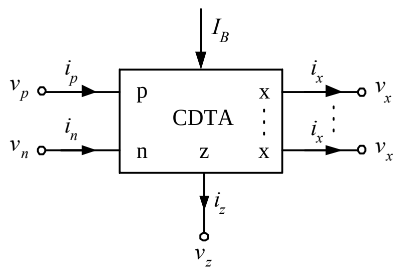

Fig 1 Symbol of the CDTA.

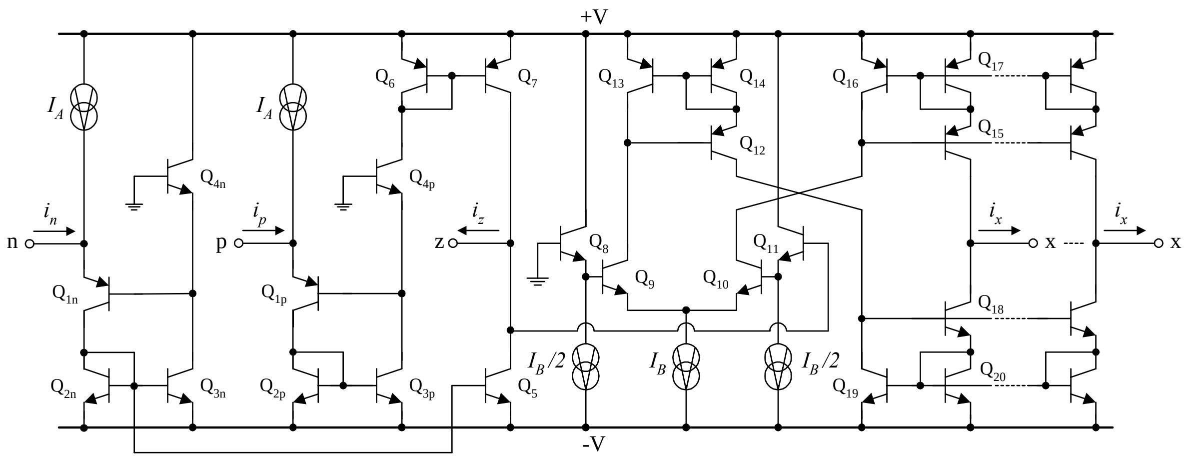

Fig.2 Possible bipolar implementation of the CDTA.

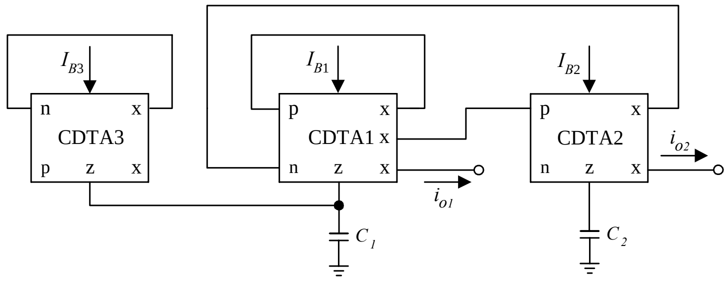

Fig.3 Proposed current-mode quadrature oscillator.

Fig.2 shows the possible bipolar implementation of the CDTA circuit used in this work [11]. It mainly consists of a current subtractor formed by current followers Q_{1p}-Q_{4p} and Q_{1n}-Q_{4n}, and a multiple-output transconductance amplifier Q_8-Q_{20} that converts the voltage drop at the terminal z (v_z) to its corresponding differential output currents i_x. In this case, the transconductance gain g_m is directly proportional to the external bias current I_B, which can be written by:

$$g_m = \frac{I_B}{2V_T} \tag{2}$$

where $V_T \cong 26$ mV at 27°C is the thermal voltage

III. Proposed Circuit

The proposed current-mode quuadrature oscillator is shown in Fig.3, which is based on the use of three CDTAs and two grounded capacitors. From routine calculations for the proposed quadrature oscillator, the characteristic equation of the circuit can be written by:

$$s^2 + s\left(\frac{g_{m3} - g_{m1}}{C_1}\right) + \left(\frac{g_{m1}g_{m2}}{C_1C_2}\right) = 0 \tag{3}$$

From equation (3), the oscillation condition and the oscillation frequency (ω_o) can also be obtained as:

$$g_{m1} = g_{m3} \tag{4}$$

and

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{5}$$

Further, if we setting $C_1 = C_2 = C$ and by substituting equation (2) into equation (4) and (5), the oscillation condition and oscillation frequency can now be rewritten as

$$I_{B1} = I_{B3} \tag{6}$$

and

$$\omega_0 = \frac{1}{2V_TC}\sqrt{I_{B1}I_{B2}} \tag{7}$$

It is interesting to note that the oscillation condition can be electronically controlled by adjusting I_{B3} without taking an effect to ω_o, that is adjusted by I_{B2} and/or C. Therefore, both the oscillation condition and ω_o of the proposed oscillation are orthogonally controlled. From Fig.3, the current transfer function between quadrature outputs i_{o2} and i_{o1} can be expressed as:

$$\frac{i_{o2}}{i_{o1}} = \frac{g_{m2}}{sC_2} \quad (8)$$

Equation (8) shows that the phase difference (ϕ) between i_{o2} and i_{o1} is 90°. This recommends that the currents i_{o1} and i_{o2} are in quadrature.

IV. Non-ideal Effects

By taking into consideration of the non-ideal CDTAs, the relationship of the terminal current and voltage given in equation (1) can be rewritten as:

$$\begin{bmatrix} i_z \\ i_x \\ v_p \\ v_n \end{bmatrix} = \begin{bmatrix} \alpha_p & -\alpha_n & 0 & 0 \\ 0 & 0 & \beta g_m & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_p \\ i_n \\ v_z \\ v_x \end{bmatrix} \quad (9)$$

where α_p = 1- ε_p and ε_p ($|\varepsilon_p|$ << 1) is the current tracking errors from p to z terminals, α_n = 1- ε_n and ε_n ($|\varepsilon_n|$ << 1) is the current tracking errors from n to z terminals, and $\beta = 1 - \varepsilon_v$ and ε_v ($|\varepsilon_v|$ << 1) is the transconductance inaccuracy factor from z to x terminals, respectively. Reanalysis the proposed oscillator circuit of Fig.3 using equation (9) yields the modified characteristic equation as follows:

$$s^2 + s\left(\frac{\alpha_{n3}\beta_3 g_{m3} - \alpha_{p1}\beta_1 g_{m1}}{C_1}\right) + \left(\frac{\alpha_{n1}\alpha_{p2}\beta_1\beta_2 g_{m1} g_{m2}}{C_1 C_2}\right) = 0 \quad (10)$$

where α_{pi}, α_{ni} and β_i are the parameters α_p, α_n and β of i-th CDTA (i = 1, 2, 3), respectively. In this case, the modified oscillation condition and oscillation frequency are:

$$\alpha_{p1}\beta_1 g_{m1} = \alpha_{n3}\beta_3 g_{m3} \quad (11)$$

and

$$\omega_0 = \sqrt{\frac{\alpha_{n1}\alpha_{p2}\beta_1\beta_2 g_{m1} g_{m2}}{C_1 C_2}} \quad (12)$$

The sensitivities with respect to the active and passive of the oscillation can be written as:

$$S^{\omega_0}_{g_{m1},g_{m2}} = -S^{\omega_0}_{C_1,C_2} = \frac{1}{2} \quad (13)$$

$$S^{\omega_0}_{\alpha_{n1},\alpha_{p2},\beta_1,\beta_2} = \frac{1}{2} \quad (14)$$

and

$$S^{\omega_0}_{\alpha_{p1},\alpha_{p3},\alpha_{n2},\alpha_{n3},\beta_3} = 0 \quad (15)$$

It is important to note that the active and passive sensitivities are within unity in magnitude. Thus, the proposed circuit exhibits a low sensitivity performance.

V. Simulation Results

The proposed CDTA-based current-mode quadrature oscillator configuration of Fig.3 has been simulated with PSPICE simulation program. In simulations, the CDTA was performed with the transistor model of PR100N (PNP) and NP100N (NPN) of the bipolar arrays ALA400 from AT&T [12]. The power supply voltages were set equal to ±V = ±3V, and the bias current was I_A = 200 μA.

To obtain the quadrature output waveforms with the oscillation frequency of $f_o = \omega_o/2\pi \cong$ 478 kHz, the active and passive components were chosen as: $I_{B1} = I_{B2} = I_{B3} = I_B$ = 150 μA and $C_1 = C_2$ = 1 nF. Fig.4(a) shows the simulated quadrature output responses i_{o1} and i_{o2}, where the simulated frequency of the oscillation is found to be 470 kHz. Fig.4(b) represents the simulated frequency spectrums of the proposed circuit. In addition, the total harmonic distortion (THD) of the output responses i_{o1} and i_{o2} is approximated to 2.5%.

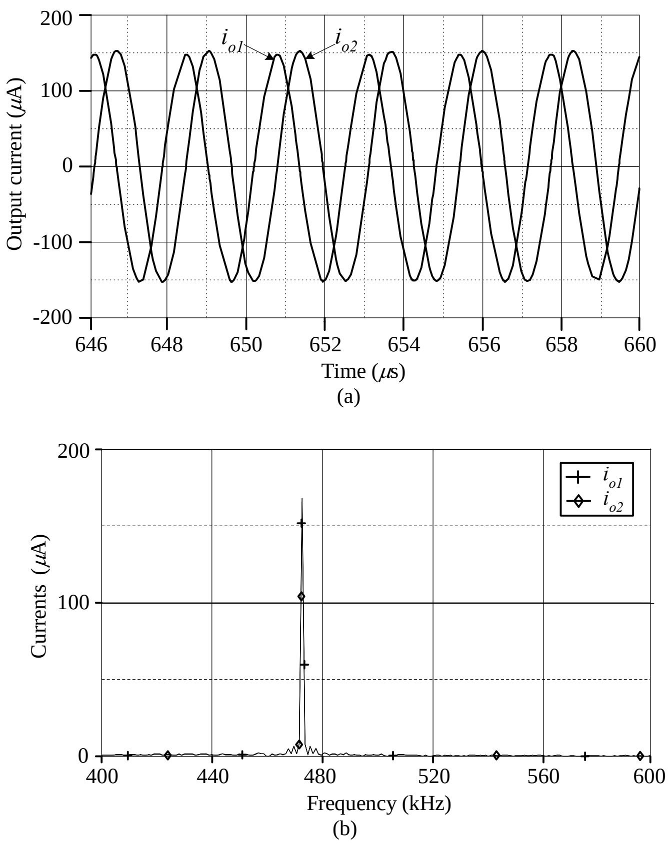

Fig.4 Simulated quadrature output responses i_{o1} and i_{o2} of the proposed oscillator.
(a) output waveforms (b) output spectrums

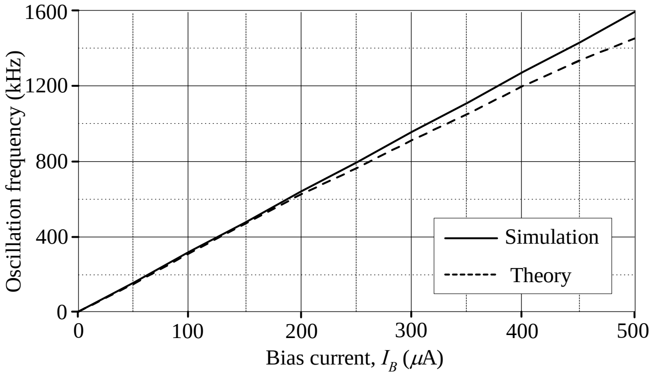

Fig.5 Theory and simulation results of the oscillation frequency (f_0) by varying the bias current I_B

The tunability of the oscillation frequency (f_0) by varying the bias current I_B is shown in Fig.5. It is obvious that the simulated responses are found to be in good agreement with the theoretically predicted behaviour. The deviation between the theoretical calculated with equation (7) and simulated values are less than 2.5%, 5.6% and 8.8% for I_B within the ranges of 100-200 μA, 200-400 μA and 400-500 μA, respectively. However, this influence can easily be minimized by simply adjusting I_B of the CDTAs.

VI. CONCLUSIONS

The resistorless realization of current-mode quadrature oscillator using three CDTAs and two grounded capacitors has been proposed in this paper. The proposed quadrature oscillator circuit offers the following advantages:

(i) Realization of two quadrature sinusoidal output waveforms of 90^o phase shift is obtained simultaneously, without changing circuit configuration.

(ii) Independent current-control of the oscillation condition and the oscillation frequency.

(iii) Using only grounded capacitors for its realization, which is suitable for integration.

(iv) Low passive and active sensitivities.

PSPICE simulations are given to verify the theoretical analysis.

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