CURRENT-MODE FOUR-PHASE QUADRATURE OSCILLATOR USING CURRENT DIFFERENCING TRANSCONDUCTANCE AMPLIFIER BASED FIRST-ORDER ALLPASS FILTER

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Key words: Allpass filter, Current mode, Current differencing transconductance amplifiers, Quadrature oscillator (QO).

In this paper, a CMOS current-mode four-phase quadrature oscillator using current differencing transconductance amplifier (CDTA)-based new first-order allpass filter is proposed. The proposed circuit structure is very simple. It contains only one resistor, two capacitors and three CDTAs. It can provide four quadrature current outputs, and the steady state oscillation is achieved after less than 1μs. Additionally, as all the output impedances of the four-phase quadrature oscillator are high, the proposed oscillator circuit can be connected directly to the next stage without any impedance matching requirements. PSPICE simulation results are included to confirm the theory.

1. INTRODUCTION

Oscillator and Filter are the very important blocks in analog signal proceesing systems [1–4]. During the past few years, in active oscillator and filter design, the current-mode approach [5] has become more popular due to its advantages of providing larger dynamic range, wider bandwidth, lower power consumption and simpler configurations over the voltage-mode counterparts, especially for the high-frequency operation. Many current-mode active elements have been reported, such as operational transconductance amplifier (OTA) [6–7], current conveyor [8–9], current operational amplifier [10–11], current differencing buffered amplifier (CDBA) [12–13] and current differencing transconductance amplifiers (CDTA).

In 2003, Biolek proposed the current differencing transconductance amplifier [14–15]; after that, great interest has been devoted to analyze and develop this block [16]. The CDTA is a synthesis of the well-know advantages of the current

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differencing buffered amplifier (CDBA) [17]. It is a really current-mode element whose input and output are current form. As a result, a variety of CDTA applications have, also, been considered by various researchers [18–23].

Considering these facts, in this paper, a CMOS current-mode four-phase quadrature oscillator using current differencing transconductance amplifier (CDTA)-based new first-order allpass filter is proposed. The proposed circuit has following advantages: (a) its structure is very simple, it contains only one resistor, two capacitors and three CDTAs; (b) a new first-order allpass filter is proposed and used in the oscillator; (c) it can provide four quadrature current outputs, the steady state of the oscillator are achieved less than 1µs; (d) as all the output impedances of the four-phase quadrature oscillator are high, the proposed oscillator circuit can be connected directly to the next stage without any impedance matching requirements.

2. **BASIC PRINCIPLE**

2.1. THE SYMBOL OF CDTA AND THE REALIZATION OF THE CIRCUIT

Fig. 1a denotes the symbol of CDTA, Fig. 1b is the equivalent circuit of the CDTA. The terminal relation of the CDTA can be characterized by the following set of equations [24]:

$$v_p = v_n = 0\,, \qquad i_z = i_p - i_n\,,$$
$$i_x + = g_m v_z = g_m Z_z i_z\,, \qquad i_x - = -g_m v_z = -g_m Z_z i_z\,, \tag{1}$$

where p and n are input terminals, z and x are output terminals, g_m is the transconductance gain, and Z_z is an external impedance connected at the terminal z. From equation (1), the current 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 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 electronically controllable by an external bias current.

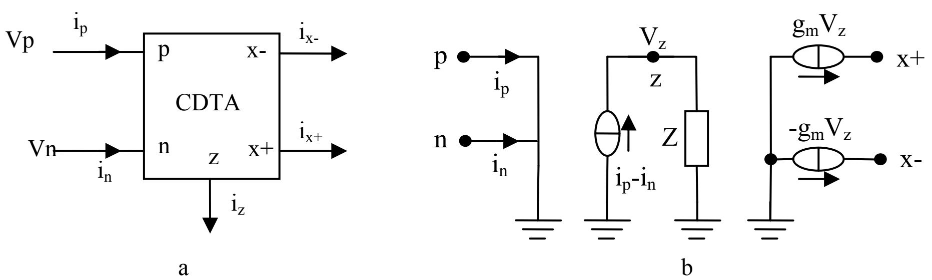

Fig. 1 – Symbol and ideal model of CDTA.

The possible CMOS realization of the CDTA used in this work is shown in Fig. 2 [24].

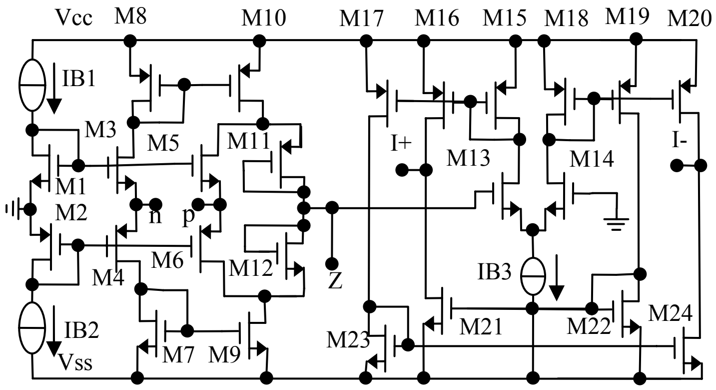

Fig. 2 – CMOS-based CDTA in this work [24].

The circuit consists of a current differencing circuit M1-M12, and a transconductance amplifier M13-M24. The current differencing circuit part (M1-M12) realizes the function of “$i_z = i_p - i_n$”; the transconductance amplifier (M13-M24) realizes the function of “$i_x = g_m * (i_p - i_n) = g_m V_z$, and the transconductance gain (g_m) of the transconductance amplifier can be set by IB3.

2.2. THE CDTA-BASED CURRENT-MODE FIRST-ORDER ALLPASS FILTER

Allpass (AP) filters are widely used in analogue signal processing in order to shift the phase while keeping the amplitude constant, to produce various types of filter characteristics and to implement high-Q frequency selective circuits [24].

The new CDTA-based AP filter is shown in Fig. 3. It consists of two CDTAs and one capacitance and one resistor.

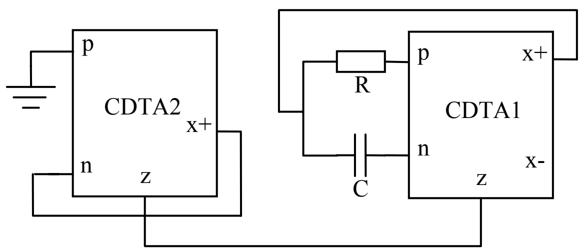

Fig. 3 – Proposed CDTA-based first-order allpass filter.

From routine calculations for the new first-order allpass filter, the current transfer function for the allpass filter of Fig. 3 is:

$$H(s) = \frac{I_{out}}{I_{in}} = \frac{g_{m1}}{g_{m2}} \frac{1 - sRC}{1 + sRC}. \tag{2}$$

The pole frequency (ω_0) and the phase response (φ) can be found as:

$$\omega_0 = \frac{1}{RC}, \tag{3}$$

$$\varphi(\omega) = -2\arctan(\omega RC). \tag{4}$$

Equation (4) shows that the allpass filter can provide phase shifting 0–180^{o} by adjusting the values of *R* and *C*.

2.3. THE PROPOSED CDTA-BASED CURRENT-MODE QO CIRCUIT

The proposed current-mode QO circuit using CDTAs is realized by cascading the new allpass filter of Fig. 3 and a CDTA-based lossless integrator (CDTA3 and C2); the resulting circuit is shown in Fig. 4. The circuit consists of three CDTAs, one capacitance and one resistor, and it is very simple.

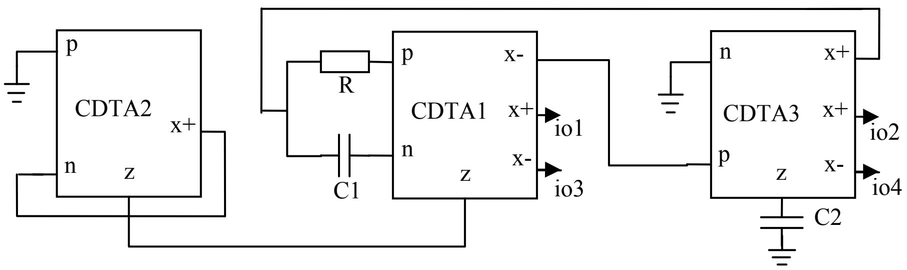

Fig. 4 – Proposed current-mode QO with the CDTA-based first-order allpass filter.

By routine circuit analysis using equation (1), the characteristic equation of the proposed quadrature oscillator in Fig. 4 can be expressed as:

$$s^2 + \frac{g_{m2}C_2 - g_{m1}g_{m3}C_1R}{g_{m2}RC_1C_2} + \frac{g_{m1}g_{m3}}{g_{m2}RC_1C_2} = 0. \tag{5}$$

From equation (5), the oscillation condition and the oscillation frequency (ω_0) can respectively be obtained as:

$$g_{m2}C_2 = g_{m1}g_{m3}C_1R\,, \tag{6}$$

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m3}}{g_{m2}RC_1C_2}}\,. \tag{7}$$

From the circuit of Fig.4, the current transfer function between $i_{01}$and i_{02} is:

$$i_{02} = -\left(\frac{g_{m3}}{sC_2}\right)i_{01}\,. \tag{8}$$

The phase difference between i_{01} and i_{02} is equal to:

$$\Phi = 90^{\circ}\,, \tag{9}$$

which results in two-quadrature outputs. Also, by based on the multiple-output CDTA, the circuit provides an inverted version of the output currents $i_{01}$and i_{02}. Thus, the relations of all the output currents can be expressed as:

$$i_{01} = -i_{03} \quad \text{and} \quad i_{02} = -i_{04}\,. \tag{10}$$

This means that the circuit can provide four-quadrature current outputs.

3. SENSITIVITY ANALYSIS

The incremental sensitivity is an important performance criterion of any active network. The relative sensitivity of a parameter F to a circuit parameter x_i is defined by:

$$S_{xi}^{F} = \frac{x_i}{F}\frac{\mathrm{d}F}{\mathrm{d}x_i}. \tag{11}$$

Using this definition, it is easy to show from equation (7) that the sensitivities of ω_0 to the variation in active and passive element values are given by:

$$S_{g_{m1},g_{m3}}^{\omega_0} = \frac{1}{2}, \quad S_{g_{m2}}^{\omega_0} = -\frac{1}{2}, \quad S_{R,C_1,C_2}^{\omega_0} = -\frac{1}{2}. \tag{12}$$

From the above calculations, it can be seen that the proposed oscillator circuit exhibits attractive performance with active and passive sensitivities are constant and less than unity.

4. SIMULATION RESULTS

The performance of the proposed circuits is verified using Pspice. The CDTA is realized as shown in Fig. 2. The supply voltages used are $V_{DD} = -V_{SS} = 2.5$V, and the bias currents $I_{B1} = I_{B2} = 100$ µA.

The output waveforms obtained from the proposed quadrature oscillator structure of Fig. 4 are shown in Figs. 5, 6 and 7. The simulated frequency of the oscillation is found to be 3.4 MHz, the amplitude of the output currents is 200 µA, and the steady state oscillations are achieved after less than 1 µs. The frequency spectrums of the proposed quadrature oscillator are shown in Fig. 8, the total harmonic distortion (THD) in the output waveforms i_{01}, i_{02}, i_{03} and i_{04} are varying from 2% to 5%.

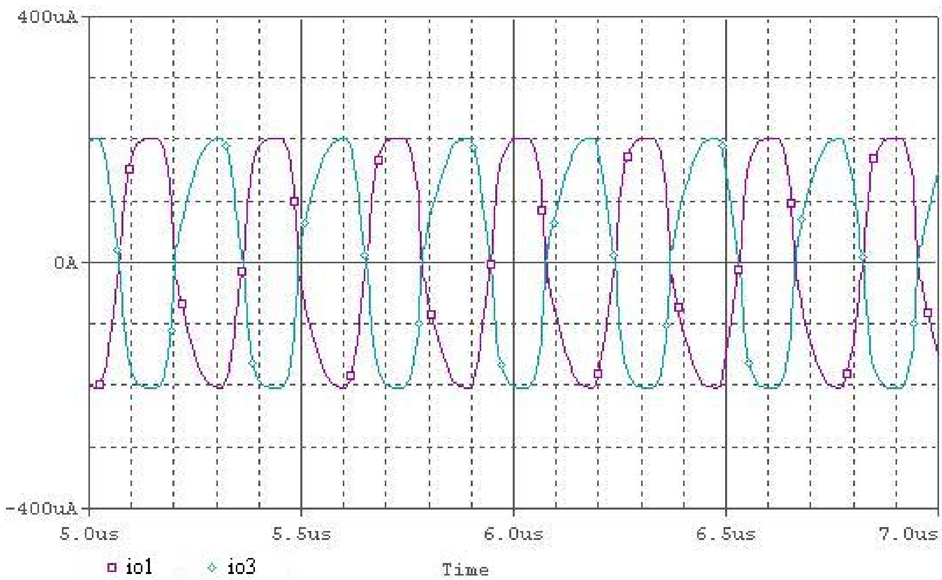

Fig. 5 – Simulated i_{01} and i_{03} of the oscillator.

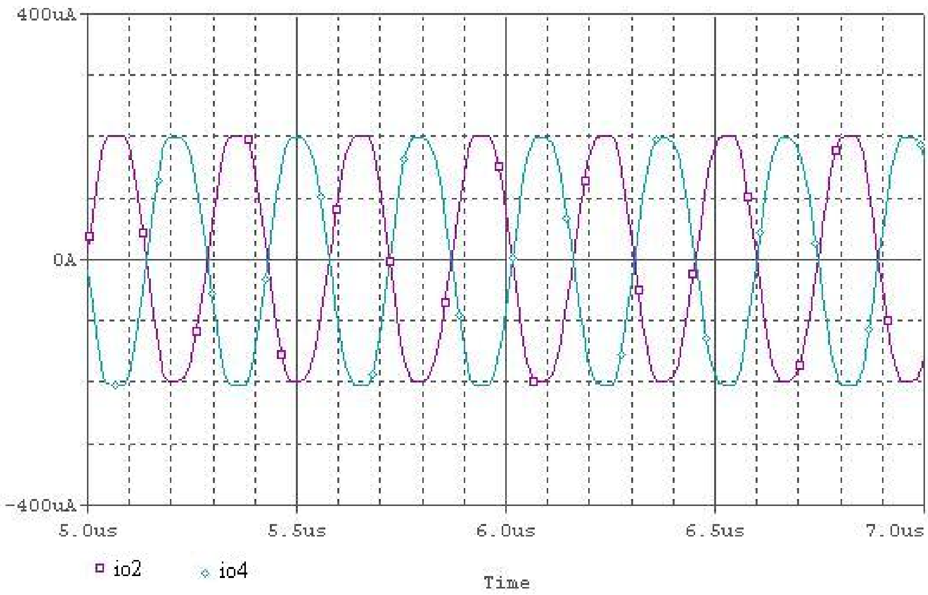

Fig. 6 – Simulated i_{02} and i_{04} of the oscillator.

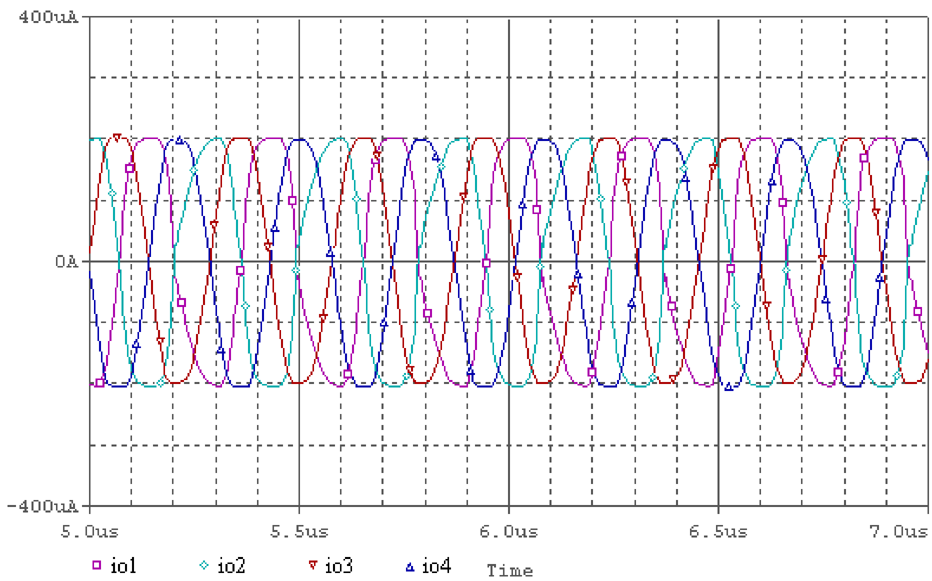

Fig. 7 – Simulated i_{01}, i_{02}, i_{03} and i_{04} of the oscillator.

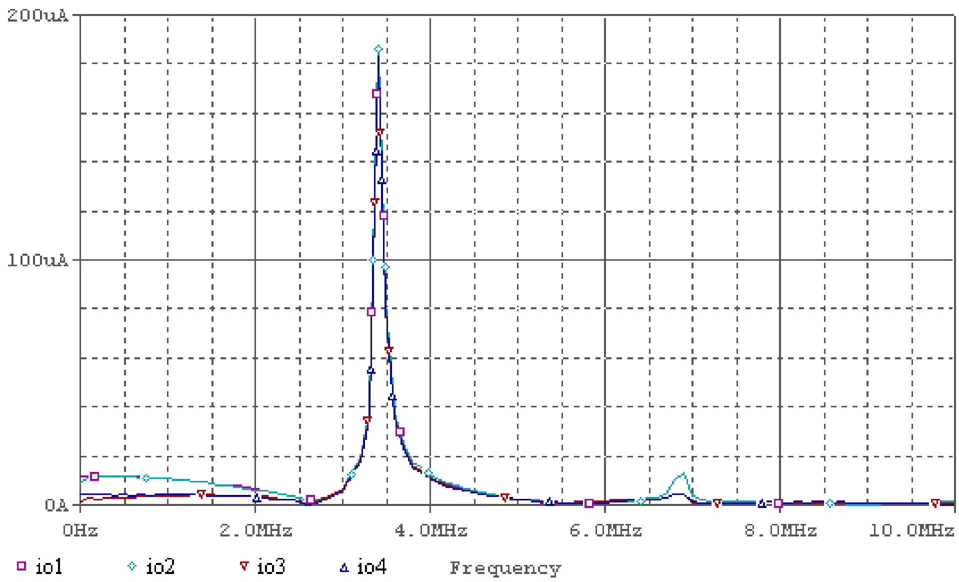

Fig. 8 – Simulated frequency spectrums of the oscillator.

5. **CONCLUSIONS**

A CMOS current-mode four-phase quadrature oscillator using current differencing transconductance amplifier (CDTA)-based new first-order allpass filter has been proposed in this paper. The proposed circuit has the following advantages: (a) its structure is very simple, it contains only one resistor, two capacitors and three CDTAs; (b) a new first-order allpass filter is proposed and used in the oscillator; (c) it can provide four quadrature current outputs, the steady state of the oscillator is achieved after less than 1μs; (d) as all the output impedances of the four-phase quadrature oscillator are high, the proposed oscillator circuit can be connected directly to the next stage without any impedance matching requirements.

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