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A Resistor-less Current-mode Quadrature Sinusoidal Oscillator Employing Single CCCDTA and Grounded Capacitors

***Abstract**. In this study, a current-mode quadrature sinusoidal oscillator using single current controlled current differencing transconductance amplifier (CCCDTA) and 2 grounded capacitors is proposed. The proposed oscillator can provide 2 sinusoidal output currents with 90° phase difference. The oscillation condition and oscillation frequency can be controlled electronically by adjusting the bias current of the CCCDTA. The oscillator configuration exhibits high output impedance which makes easy to drive loads without using any buffering devices. The use of only grounded capacitors is ideal for integration. The circuit performances are depicted through PSpice simulations, they show good agreement to theoretical assumptions.*

***Streszczenie.** W artykule przestawiono sinusoidalny generator prądowy wykorzystujący wzmacniacz transkonduktancyjny. Generator może mieć dwa wyjścia prądowe z sygnałami przesuniętymi w fazie o 90°. Warunki oscylacji mogą być sterowane p[rzez dobór prądu we wzmacniaczu. Generator ma dużą wyjściową impedancję. Właściwości układu zbadano wykorzystując symulację PSpice. (**Kwadraturowy generator sygnału sinusoidalnego wykorzystujący wzmacniacz transkonduktancyjny i uziemione kondensatory**)*

Keywords: quadrature oscillator; current-mode; CCCDTA.
Słowa kluczowe: generator kwadraturowy, wyjście prądowe, wzmacniacz trankonduktancyjny..

Introduction

Controlled quadrature oscillators are extremely useful circuits for various communication applications, wherein there is a requirement of multiple sinusoids which are 90° phase shifted, e.g. in quadrature mixers and single-sideband modulators [1]. Recently, current-mode circuits have been receiving considerable attention of due to their potential advantages such as inherently wide bandwidth, higher slew-rate, greater linearity, wider dynamic range, simple circuitry and low power consumption [2]

In 2003, a new active building block, namely current differencing transconductance amplifier (CDTA) is introduced to provide new possibilities in the current-mode circuit. CDTA seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analogue 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 which the 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 (CCCDTA). Another CDTA modification, called ZC-CDTA (Z Copy CDTA) is proposed in [6], providing a copy of the current flowing to the z terminal. This copy can be used as an output signal for driving an independent load.

Over the past few years, a number of schemes based on CDTAs or CCCDTAs have been developed to realize sinusoidal oscillators [7-16]. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

a) Excessive use of the passive elements, especially the external resistors [9, 15].
b) Employ more than one CDTA or CCCDTA [8-10, 12-14].
c) Use multiple-output CDTA or CCCDTA (there are two gms in CDTA or CCCDTA) consequently, the circuits become more complicated [7, 16].
d) Some outputs are not high output impedance then the cascade-ability is not directly achieved [7-8, 15].
e) Use of floating capacitor, which is not convenient to further fabricate in IC [9, 11, 15].

The aim of this paper is to introduce a current-mode quadrature sinusoidal oscillator based on single CCCDTA. The features of the proposed circuit are the following:

a) Without external resistor requirement and using only grounded capacitors.
b) Use only one active element.
c) Electronic adjustment of the oscillation condition and oscillation frequency.
d) High-impedance current outputs.

Theory and principle

Basic concept of CCCDTA

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

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_x \end{bmatrix} = \begin{bmatrix} R_p & 0 & 0 & 0 \\ 0 & R_n & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_x \\ V_z \end{bmatrix}. \tag{1}$$

For a BJT CCCDTA, the parasitic resistances (Rp and Rn) and the transconductance (gm) can be expressed to be

$$R_p = R_n = \frac{V_T}{2I_{B1}}, \tag{2}$$

and

$$g_m = \frac{I_{B2}}{2V_T}. \tag{3}$$

V_T is the thermal voltage. IB1 and IB2 are the bias current used to control the parasitic resistances and transconductance, respectively. The symbol and the equivalent circuit of the CCCDTA are illustrated in Figs. 1(a) and (b), respectively. In general, CCCDTA can contain an arbitrary number of z terminals. The internal current mirror provides a copy of the current flowing out of the z terminal to the z_c terminal.

Proposed current-mode quadrature oscillator

The proposed current-mode quadrature oscillator is designed by cascading a first-order all-pass filter and a non-inverting lossless integrator as shown in Fig. 2. Based on this block diagram, the single-CCCDTA quadrature oscillator can be implemented according to Fig. 3. It is found that the proposed circuit uses grounded capacitors unlike the circuit in [11] employing a floating capacitor and one external resistor. In order to utilize the current through the capacitor C_2, an auxiliary z_c terminal is used. Using routine circuit analysis, the characteristic equation can be found as

$$s^2C_1C_2R_n + s\left(C_2 - C_1g_mR_n\right) + g_m = 0 . \tag{4}$$

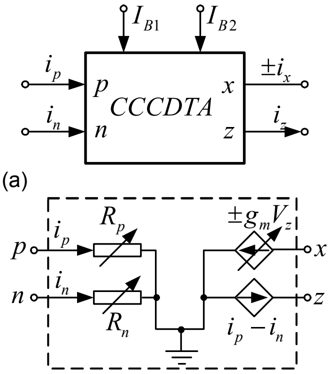

Fig.1. CCCDTA (a) Symbol (b) Equivalent circuit

From Eq. (4), it can obviously be seen that the proposed circuit can be set as an oscillator if

$$C_2 / C_1 = R_ng_m . \tag{5}$$

Eq. (5) is called the condition of oscillation, this is achieved by setting

$$C_2 = C_1 \text{ and } g_m = 1/R_n . \tag{6}$$

The oscillation frequency of this system can be obtained to be

$$\omega_{osc} = \sqrt{\frac{g_m}{R_nC_1C_2}} . \tag{7}$$

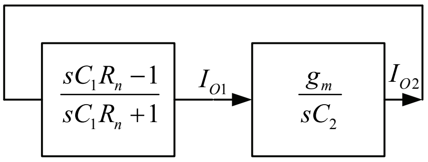

Fig.2. Block diagram of the quadrature oscillator

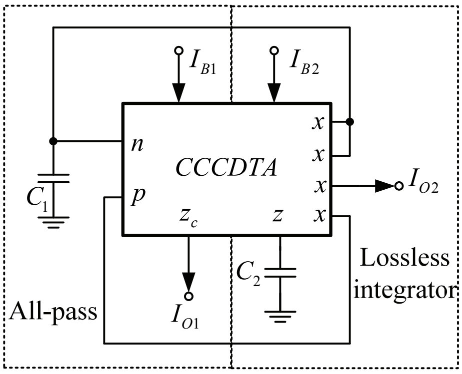

Fig.3. Proposed current-mode quadrature oscillator

It is found from Eqs. (6) and (7) that if $R_n=V_T/2I_{B1}$ and $g_m=I_{B2}/2V_T$, the oscillation condition and oscillation frequency can be electronically adjusted as follows:

$$I_{B2} = 4I_{B1} , \tag{8}$$

and

$$\omega_{osc} = \frac{1}{V_T}\sqrt{\frac{I_{B1}I_{B2}}{C_1C_2}} . \tag{9}$$

From circuit in Fig. 2, the current transfer function of I_{O2} to I_{O1} is

$$\frac{I_{O2}(s)}{I_{O1}(s)} = \frac{g_m}{sC_2} . \tag{10}$$

For sinusoidal steady state, Eq. (10) becomes

$$\frac{I_{o2}(j\omega_{osc})}{I_{o1}(j\omega_{osc})} = \frac{g_m}{\omega_{osc}C_2}e^{-j90^\circ} \tag{11}$$

The phase difference ϕ between I_{o1} and I_{o2} is

$$\phi = -90^\circ, \tag{12}$$

ensuring that the currents I_{o2} and I_{o1} are in quadrature. For the oscillation frequency, with regard to Eq. (7), Eq. (11) gives

$$\frac{I_{o2}(j\omega_{osc})}{I_{o1}(j\omega_{osc})} = \sqrt{g_mR_n\frac{C_1}{C_2}}e^{-j90^\circ} . \tag{13}$$

Taking into account oscillation condition Eq. (6), one can conclude that the oscillator will provide quadrature signals of equal magnitudes. All the active and passive sensitivities of the oscillator are low as shown in (14):

$$S^{\omega_{osc}}_{C_1,C_2,R_n} = -\frac{1}{2}, S^{\omega_{osc}}_{g_m} = \frac{1}{2} \tag{14}$$

Analysis of non-ideal case

For a complete analysis of the circuit, it is necessary to take into account the following non-idealities of CCCDTA,

- Current transfer gains

$$I_z = \alpha_pi_p - \alpha_ni_n, I_x = \beta g_mV_z , \tag{15}$$

where α_p and α_n are the parasitic current transfer gains from p, n terminals to z terminal, respectively. β is the parasitic current gains associated with copies of the current from x terminal. All these gains slightly differ from their ideal values of unity by current tracking errors.

- The parasitic resistances and capacitances appear between the high-impedance z (C_z and R_z) and x (C_x and R_x) terminals of the CCCDTA and ground.

Considering the non-ideal effects, the characteristic equation for the proposed circuit shown in Fig. 2, get modified to

$$\begin{bmatrix} R_pY_3\left(Y_2 + Y_1Y_2 + 2\beta\alpha_ng_m\right) + Y_1Y_2R_n + \\ Y_2 - \beta Y_1g_mR_n + 2\beta\alpha_ng_m - \beta\alpha_pg_m \end{bmatrix} = 0 . \tag{16}$$

where $Y_1 = s\left(C_1 + 2C_x\right) + 2G_x$, $Y_2 = s\left(C_2 + C_z\right) + G_z$ and $Y_3 = sC_x + G_x$. To alleviate the effect of the first term in Eq. (16), the value of R_p should be small which can be set by IB1. In addition, if values of R_x and R_z are high which can be achieved by a good design of CCCDTA (using high performance current mirrors), the characteristic equation in Eq. (16) is as follows:

$$\begin{bmatrix} s^2\left(C_1 + 2C_x\right)\left(C_2 + C_z\right)R_n + s\left(C_2 + C_z\right) - \\ \beta s\left(C_1 + 2C_x\right)g_mR_n + 2\beta\alpha_ng_m - \beta\alpha_pg_m \end{bmatrix} = 0 . \tag{17}$$

Then the oscillation condition and oscillation frequency of the proposed circuit becomes

(18) $$C_2 + C_z = \beta g_m R_n \left(C_1 + 2C_x\right),$$

and

(19) $$\omega_{osc} = \sqrt{\frac{\beta g_m \left(2\alpha_n - \alpha_p\right)}{\left(C_1 + 2C_x\right)\left(C_2 + C_z\right) R_n}}.$$

It is found that parameters; α_p, α_n, β, C_x and C_y will effect both oscillation condition and oscillation frequency. These parameters are dependent on temperature variations. Consequently, these errors affect the sensitivity to temperature and the high frequency response of the proposed circuit, the CCCDTA should be carefully designed to minimize these errors. Moreover, the stray/parasitic capacitance at terminal z and x can be absorbed into the external grounded capacitors as they appear in shunt with them.

Simulation results

To prove the performances of the proposed inductance simulator, the PSpice simulation program was used for the examination. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [17]. Internal construction of CCCDTA used in simulation is shown in Fig. 4. The circuit was biased with ±2.5V supply voltages, C1=C2=1nF, I_{B1}=50μA and I_{B2}=222μA. This yields oscillation frequency of 590.59kHz, where the calculated value of this parameter from Eq. (10) yields 645.25kHz (deviated by 8.47%). Figs. 5 and 6 show simulated quadrature output waveforms. Fig. 7 shows the simulated output spectrum, where the total harmonic distortion (THD) is about 2.94%. The quadrature relationships between the generated waveforms have been verified using Lissagous figure and shown in Fig. 8. The quadrature phase error is less than 5%.

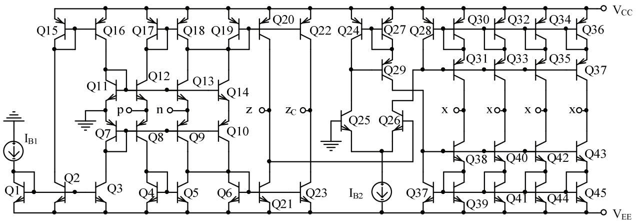

Fig.4. Internal construction of CCCDTA

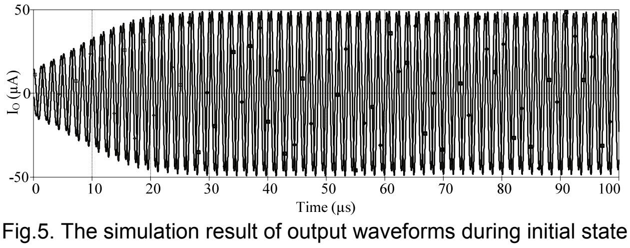

Fig.5. The simulation result of output waveforms during initial state

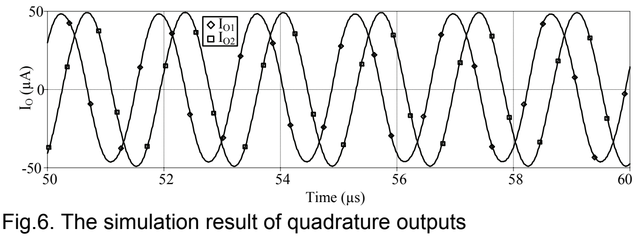

Fig.6. The simulation result of quadrature outputs

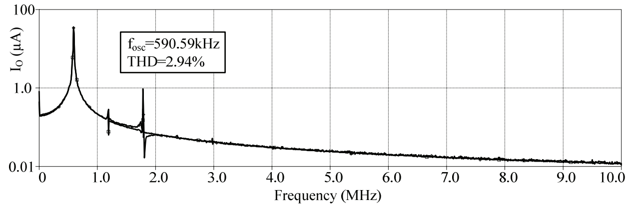

Fig.7. The simulation result of output spectrum

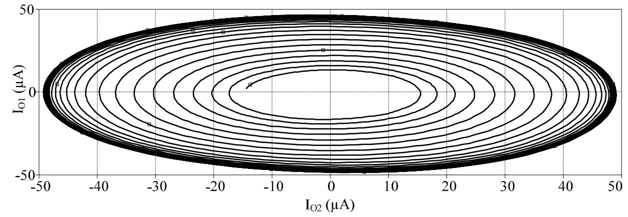

Fig.8. Lissagous figure

Conclusions

A simple current-mode quadrature oscillator based on CCCDTA has been presented. The features of the proposed circuit are that: oscillation frequency an oscillation condition can be electronically adjusted; the proposed oscillator consists of single CCCDTA and 2 grounded capacitors, which is convenient to fabricate. The PSpice simulation results agree well with the theoretical anticipation.

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