Original scientific paper

Informacije MIDEM
Journal of Microelectronics,
Electronic Components and Materials
Vol. 46, No. 3(2016), 130 – 135

Dual-Mode Sinusoidal Quadrature Oscillator with Single CCCTA and Grounded Capacitors

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Abstract: In this work, a sinusoidal quadrature oscillator which simultaneously generates voltage and current signal outputs is proposed. It contains only a single current-controlled conveyor transconductance amplifier (CCCTA) and two grounded capacitors. The proposed oscillator has the advantage features of resistorless structure realization, electronic frequency control, availability of two explicit voltage and current quadrature outputs, and low sensitivity figure. Moreover, the parasitic elements existing at the CCCTA terminals are taken into account. The performance of the proposed oscillator circuit was verified using PSPICE simulation with acceptable results.

Keywords: Current-Controlled Conveyor Transconductance Amplifier (CCCTA); Quadrature Oscillator; Resistorless circuits; Voltage-mode and current-mode circuits.

Dvojni sinusni kvadrantni oscillator z enosnim CCCTA in ozemljenimi kondenzatorji

Izvleček: V članku je predstavljen je kvadrantni oscilator, ki vzporedno generira napetostni in tokovni signal. Vsebuje le en tokovno krmiljeno vezje transkonduktančnega ojačevalnika in dva ozemljena kondenzatorja. Predlagano vezje je brez uporov, vsebuje elektronski nadzor frekvence, omogoča dva ločena napetostna in tokovna izhoda in izkazuje nizko občutljivost. Upoštevani so parazitni elementi na CCCTA terminalih. Lastnosti oscilatorja so bile preverjene v PSPICE okolju.

Ključne besede: tokovno krmiljeno vezje transkonduktančnega ojačevalnika; brez uporovno vezje;napetostno in tokovno vezje

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1 Introduction

Sinusoidal quadrature oscillator or two-phase sinusoidal oscillator is a kind of the sinusoidal oscillators that provides explicit two signal outputs with 90° phase shift from the same structure. Accordingly, it performs an essential circuit block employed a wide range of applications in modern electronic and communication systems, control systems, and signal processing. There are many attempts recently in designing sinusoidal quadrature oscillators based on various types of modern active components [1-16]. However, many of them make use of at least two active components [1-12]. Only few circuits can provide both voltage and current quadrature signals from the same configuration [11-14]. These oscillator realizations contains an excessive number of external passive components, i.e., at least four passive components. The recent current-mode quadrature oscillators based on single current differencing transconductance amplifier (CDTA) were introduced in [15-16]. The previous work in [15] employs only one CDTA and three passive components (including two virtually grounded passive components that are floating in the non-ideal sense). In [16], a compact single CDTA-based quadrature oscillator with three external passive components was reported. This circuit requires a floating capacitor, which is not favorable for further integration.

In 2008, the recently defined active circuit element, the so-called current-controlled conveyor transconductance amplifier (CCCTA), was introduced [17]. This device is a modified conception of the current conveyor transconductance amplifier (CCTA) [18], in which its parasitic resistance seen at the x-terminal (R_x) is variable electronically by adjusting an external biasing current. This property provides the advantage of realizing electronically controllable analog function circuits without external passive resistor requirement. Since its introduction, the CCCTA has numerous applications in a class of analog signal processing solutions and circuits [17], [19-21].

This paper presents a sinusoidal oscillator with variable oscillation frequency, able to provide explicitly quadrature voltage and current outputs from the same circuit configuration. The proposed quadrature oscillator employs only one CCCTA and two grounded capacitors. A detailed analysis shows that the oscillator circuit includes low active and passive sensitivities and has good frequency stability. Moreover, the effects of the CCCTA parasitic elements on the oscillator performance are also discussed. Simulation results with PSPICE using standard 0.35-µm BiCMOS process parameters are performed to verify the practical utility and validity of the realized circuit.

2 Principle of the CCCTA and its realization

Basically, the CCCTA can be realized through a cascade connection of second generation current-controlled conveyor (CCCII) and multi-output transconductance amplifier. Fig.1 shows the electrical symbol and equivalent circuit of the CCCTA. It is shown that this device consists of two input terminals (y and x) and two output terminals (z and o±). An ideal property of the CCCTA is described by the following matrix :

$$\begin{bmatrix} i_y \\ v_x \\ i_z \\ i_{o\pm} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} . \begin{bmatrix} i_x \\ v_y \\ v_z \\ v_{o\pm} \end{bmatrix} \tag{1}$$

where R_x represents the parasitic serial resistance at the x-terminal, and g_m denotes the effective small-signal transconductance gain of the CCCTA. As described in eq. (1), the x-terminal has a parasitic resistance R_x, where its value usually depends on an external supplied current. The y-terminal exhibits the high-input impedance terminal, while the z and o-terminals are two types of high-output impedance terminals.

(a)

(b)

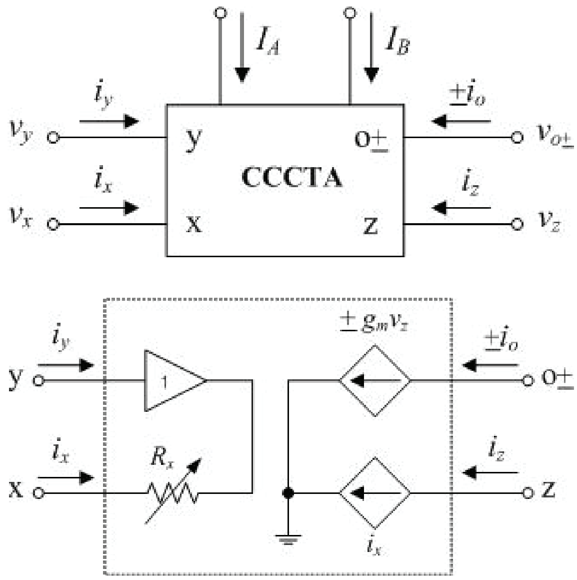


Figure 1: The CCCTA. (a) circuit symbol (b) equivalent circuit.

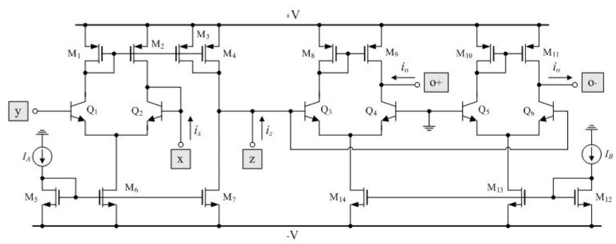


Figure 2: BiCMOS realization of the CCCTA.

One possible realization of the CCCTA in BiCMOS technology is shown in Fig.2 [22]. The circuit is mainly composed of second-generation current-controlled conveyor (Q_1-Q_2, M_1-M_7) and dual-output transconductance amplifier (Q_3-Q_6, M_8-M_{14}). Referring to Fig.2, the parasitic resistance R_x of the CCCTA has been derived as :

$$R_x \cong \frac{2V_T}{I_A} \tag{2}$$

where V_T is the thermal voltage, whose value is approximately 26 mV at 27°C. Note from eq.(2) that the value of R_x depends on the external DC bias current I_A. Assuming transistors Q_3-Q_5 as well as M_8-M_{11} are matched, the expression of g_m can be given by :

$$g_m = \frac{i_o}{v_z} = \frac{I_B}{2V_T} \tag{3}$$

Also note that the g_m-value is controllable electronically and linearly by changing the I_B–value.

3 Proposed dual-mode sinusoidal quadrature oscillator

Fig.3 shows a canonic sinusoidal oscillator that produces voltage and current quadrature outputs explicitly. The circuit constructs from only one CCCTA and two grounded capacitors without needing any external passive resistor. The state-space equations for this configuration is obtained as [23]-[24] :

$$\begin{bmatrix} \dot{v}_1 \\ \dot{v}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{4}$$

where

$$a_{11} = a_{22} = 0, \ a_{12} = -\frac{g_m}{C_1} \text{ and } a_{21} = \frac{1}{R_x C_2} \tag{5}$$

From the above autonomous state-space expression, the characteristic equation of the circuit can be derived as :

$$s^2 - (a_{11} + a_{22})s + (a_{11}a_{22} - a_{12}a_{21}) = 0 \tag{6}$$

The condition of oscillation and the frequency of oscillation (ω_o) from eq.(6) are expressed, respectively, by

$$a_{11} + a_{22} = 0 \tag{7}$$

and

$$\omega_o = \sqrt{a_{11}a_{22} - a_{12}a_{21}} \tag{8}$$

This means that the circuit will oscillate with no oscillation condition at the oscillation frequency of

$$\omega_o = \sqrt{\frac{g_m}{R_x C_1 C_2}} \tag{9}$$

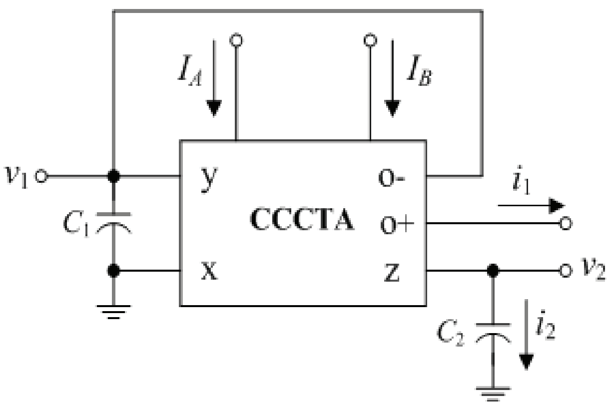


Figure 3: Proposed dual-mode sinusoidal quadrature oscillator.

It is obvious that the ω_o is electronically tunable through the transconductance gain (g_m) and/or parasitic resistance (R_x) of the CCCTA. Thus, the circuit can work as an electronically variable frequency quadrature oscillator.

Considering the proposed configuration of Fig. 3, the two output voltages marked v_1 and v_2 are related as :

$$v_1 = jk_1 v_2 \tag{10}$$

where $k_1 = \omega_o R_x C_2$. Eq.(10) represents a 90°-phase difference between both voltages, showing the quadrature property of the proposed oscillator. Furthermore, in case of $k_1 = 1$, the amplitudes of two quadrature outputs will also be equal. In addition, it is crucial to note that the quadrature output voltages v_1 and v_2 are not in low-impedance levels, hence external voltage buffers are necessary

Also from Fig.3, the relation for two output currents (i_1 and i_2) can be given by the following matrix equation.

$$\begin{bmatrix} \dot{i}_1 \\ \dot{i}_2 \end{bmatrix} = \begin{bmatrix} 0 & -\dfrac{g_m}{C_2} \\ \dfrac{1}{R_x C_1} & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} \tag{11}$$

It is seen that, in this case, the relationship between two quadrature current outputs i_1 and i_2 can be obtain as :

$$i_2 = jk_2 i_1 \tag{12}$$

where $k_2 = \omega_o C_2/g_m$. Clearly, for $k_2 = 1$, two marked explicit quadrature current outputs have equal magnitude. It is also to be noted that the circuit provides the output current i_1 from the high-impedance terminal (terminal o+) but the output current i_2 can be obtained across C_2. Therefore, for explicit dual-mode utilization, an external buffering unit would be required for sensing and taking out the current i_2.

According to eq. (9), the relative sensitivity of ω_o with respect to active and passive components can be obtained as :

$$S_{g_m}^{\omega_o} = \frac{1}{2}, \ S_{R_x}^{\omega_o} = -\frac{1}{2}, \ S_{C_1}^{\omega_o} = -\frac{1}{2} \text{ and } S_{C_2}^{\omega_o} = -\frac{1}{2} \tag{13}$$

All of which are lower than unity in magnitude.

4 Effects of the CCCTA Parasitic Elements

Fig.4 shows the practical model of the CCCTA. As it is seen, there are parasitic resistances and capacitances from terminals y, z and o± to the ground ($R_y//C_y$, $R_z//C_z$ and $R_o//C_o$), and a serial parasitic resistance R_x at the x-terminal. It is further to be noted that the typical values of parasitic resistances R_y, R_z and R_o are in the range of several MΩ, whereas parasitic capacitances C_y, C_z and C_o are within a few fFs. Consider the CCCTA parasitic elements in the proposed oscillator of Fig.3. It is clear that the external grounded capacitors C_1 and C_2 are parallel connected at the terminals y and z, respectively. The effects of parasitic capacitances at corresponding terminals could be adsorbed, as they merge with external capacitance values. Hence, the total impedance at the y-terminal can be approximated to :

$$Z_y \cong \frac{(R_y // R_o)}{(R_y // R_o)C_1 s + 1} \tag{14}$$

For the working frequencies,

$$\omega >> \frac{1}{(R_y // R_o)C_1} = \omega_y \tag{15}$$

Z_y can be further reduced to the value of $1/C_1s$, which is practically not affected by $R_y//R_o$. In a similar way, at the z-terminal, the influence of R_z can also be alleviated for operation at frequencies:

$$\omega >> \frac{1}{R_z C_2} = \omega_z \tag{16}$$

As a result, it can be realized from eqs. (15) and (16) that the frequency range at low frequencies should be selected as [25]:

$$\omega_L >> 10 \times \max\{\omega_y, \omega_z\} \tag{17}$$

Furthermore, it should be considered that there is a high-frequency limitation owing to the parasitic impedances ($R_o//C_o$) in parallel at the terminal o+. Thus, the extra pole introduced at the terminal o+ can be expressed as : $\omega_o \cong 1/(R_oC_o)$. To exhibit the ideal characteristic, the operating frequency range at high frequencies is found as :

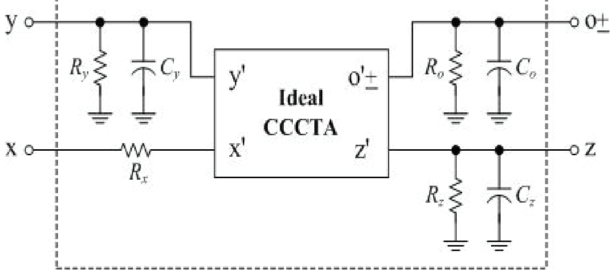


Figure 4: Practical model of the CCCTA including parasitic elements.

$$\omega_H << 0.1 \times \min\{\omega_o\} \tag{18}$$

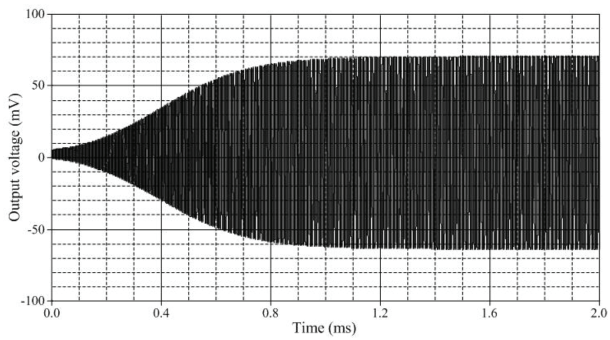
Finally, combining eqs.(17) and (19), the useful frequency range of the proposed oscillator can be defined as :

$$\omega_L << \omega << \omega_H \tag{19}$$

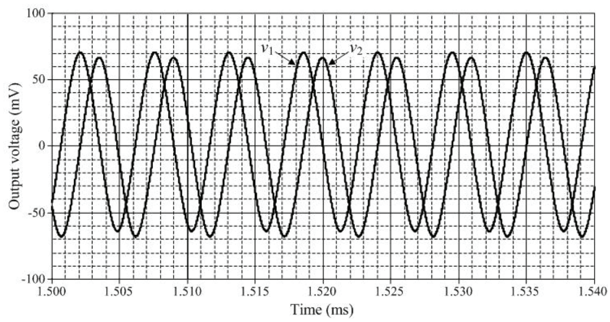
5 Computer Simulation and Performance Verification

The proposed dual-mode sinusoidal oscillator as depicted in Fig.3 was simulated using PSPICE program. In simulation purpose, the CCCTA structure given in Fig.2 was employed with standard 0.35-µm BiCMOS process parameters using supply voltages of +V = -V = 1 V. The aspect ratios (W/L in µm/µm) of the MOS transistors were set to 7/0.7 and 8.5/0.7 for all the NMOS and PMOS transistors respectively.

By choosing $C_1 = C_2 = 0.4$ nF, $I_A = I_B = 25$ µA, the proposed oscillator circuit of Fig.3 was designed to oscillate at $f_o = \omega_o/2\pi \cong 191$ kHz. By performing time-domain analysis, the simulated transient waveforms for quadrature voltage and current outputs of the proposed oscillator are shown in Figs.5 and 6, respectively. As obtained from simulation results, the frequency of oscillation (f_o) was observed as 185 kHz. Fig.7 also shows the simulated fre-

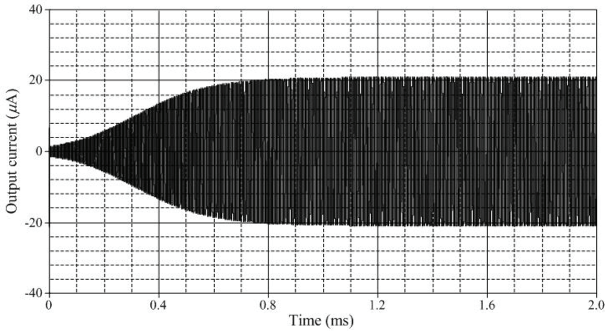


(a)



(b)

Figure 5: Simulated time-doamin responses for *v*1 and *v*2. (a) initial-stage responses, (b) steady-state responses



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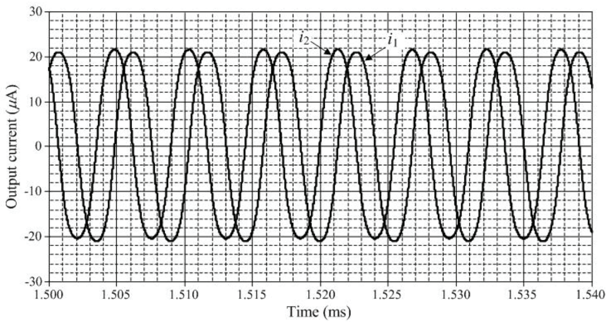
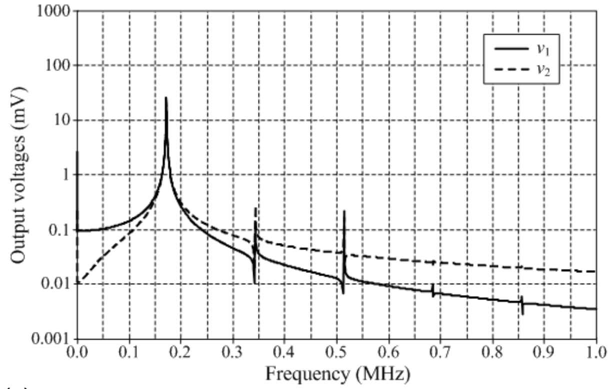
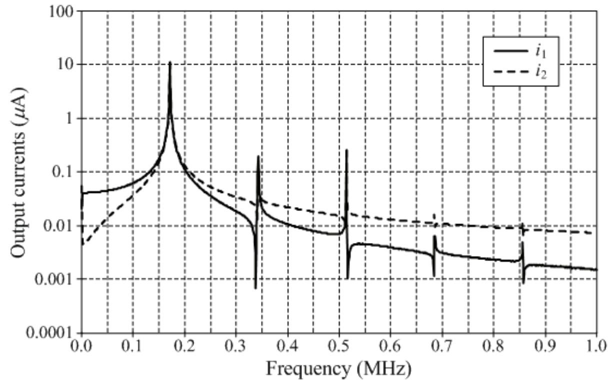


(b)

Figure 6: Simulated time-doamin responses for i_1 and i_2. (a) initial-stage responses, (b) steady-state responses



(a)



(b)

Figure 7: Simulated frequency spectrums of the proposed quadrature oscillator of Fig.3. (a) for v_1 and v_2, (b) for i_1 and i_2

quency spectrums of both voltage and current quadrature output waveforms, and the observed values of total harmonic distortion (THD) at all the outputs were less than 2.89%. To further demonstrate the electronic frequency controllability of the oscillator, the variation of f_o as a function of I_O (= I_A = I_B) is plotted in Fig.8.

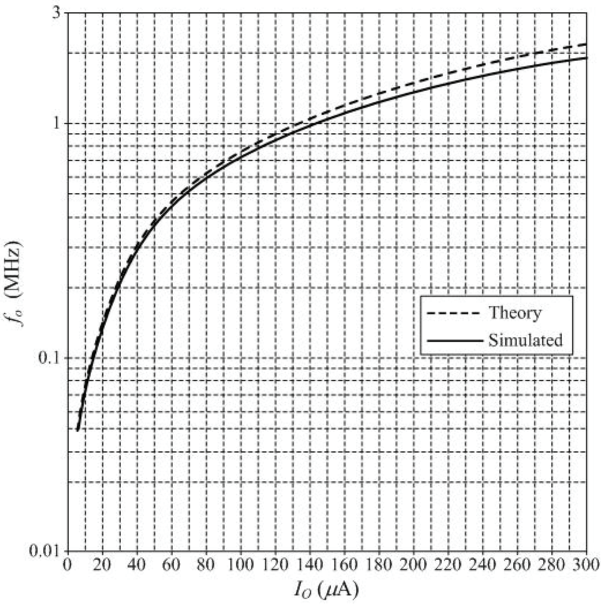


Figure 8: Electronic tuning of f_o with I_O.

6 Concluding Remarks

A generalized scheme to realize a resistorless dual-mode sinusoidal quadrature oscillator using one CC-CTA and only two grounded capacitors is presented. The presented circuit is capable of simultaneously generating two quadrature voltage outputs and two quadrature current outputs. The frequency of oscillation can be made electronically tunable by external DC biasing currents of the CCCTA. Also, the circuit sensitivity study and parasitic element effects were discussed. The circuit performance is verified by PSPICE simulation results.

7 Acknowledgement

This work was supported by the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL).

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Arrived: 02. 07. 2016
Accepted: 01. 09. 2016