

Design of Current-mode Sinusoidal Quadrature Oscillator Using CCCII

Winai Jaikla, and Supayotin Na Songkla

Abstract—This paper presents the design of current-mode quadrature oscillator using second generation current controlled current conveyors (CCCII) as active element. The oscillator has high output impedance, electronic and independent control on oscillation condition and on oscillation frequency. It consists of 3 CCCII, two grounded capacitors and one electronic resistor. The proposed circuit is suitable for integrated circuit (IC) architecture. PSpice simulation result is included to demonstrate the practicality of the oscillator circuit.

Index Terms—Quadrature oscillator, CCCII, Current-mode

I. INTRODUCTION

THE quadrature oscillator, which provides 2 sine waves with 90 degree phase difference, are important in electrical and electronic applications, for example in telecommunications for quadrature mixers and single-sideband generators or for measurement purposes in vector generators or selective voltmeters [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]. The literature surveys show that a lot of attention has thus been given to oscillators utilizing the different high-performance active building blocks, such as, four-terminal floating nullors (FTFN) [3-4], current conveyors [5], OTAs [6-7], current follower [8-9], differencing voltage current conveyor (DVCCs) [10], current controlled current differencing buffered amplifiers (CCDCBAs) [11], current controlled current differencing transconductance amplifiers (CCCDTAs) [12-14] and fully-differential second-generation current conveyor (FDCCII) [15], have been reported. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Excessive use of the passive elements, especially external resistors [3-4, 5, 10].
- Lack of electronic adjustability [3-4, 5, 8-9, 10].
- Output impedances are not high [5, 8-13, 15].
- Use of a floating capacitor, which is not convenient to further fabricate in IC [10].
- The oscillation condition and oscillation frequency cannot be independently controllable [6, 8-9, 14].

The CCII is a reported active component, especially suitable for a class of analog signal processing [15]. The fact that this device can operate in both current and voltage-modes, provides flexibility and enables a variety of circuit designs. In addition, it can offer advantageous features such as high-slew rate, higher speed, wide bandwidth and simple implementation [16-17]. However, the CCII can not control the parasitic resistance at X (R_x) port so when it is used in some circuits, it must unavoidably require some external passive components, especially the resistors. This makes it not appropriate for IC implementation due to occupying more chip area, high power dissipation and without electronic controllability. On the other hand, the introduced second-generation current-controlled conveyor (CCCII) [18] has the advantage of electronic adjustability over the CCII. Also, the use of multiple-output current conveyors is found to be useful in the derivation of current-mode circuit with high output impedance using a reduced number of active components [19-20].

The authors in this paper propose a novel current-mode quadrature oscillator using CCCII that overcomes all the aforementioned drawbacks. The proposed circuit provides the following advantageous features:

- Availability of quadrature explicit-current-outputs (ECOs) from high-output impedance terminals. The ECOs can also be flown into external loads to give quadrature voltage outputs. ECOs also facilitate cascading with other current-mode circuits without requiring the use of external current-followers.
- The proposed circuit employs only grounded capacitors and which is advantageous from the point of view of integrated circuit implementation as grounded capacitor circuits can compensate for the stray capacitances at their nodes.
- The circuit is governed by independent oscillation conditions and oscillation frequencies tuning laws. The tuning laws are completely decoupled and none of the term appearing in the oscillation conditions is present in the oscillation frequencies and vice versa. This enables non-interactive dual control for both the oscillation conditions and the oscillation frequencies. Thus, the circuit can be used as electronically-controlled variable frequency oscillator.

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II. THEORY AND PRINCIPLE

A. Basic Concept of CCCII

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

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_X & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}. \quad (1)$$

If the CCCII is realized using CMOS technology, R_x can be respectively written as

$$R_x = \sqrt{\frac{1}{kI_B}}; k = 8\mu_n C_{ox} \left(\frac{W}{L}\right)_{10-11} = 8\mu_n C_{ox} \left(\frac{W}{L}\right)_{12-13}. \quad (2)$$

Here k is the physical transconductance parameter of the MOS transistor. I_B is the bias current used to control the intrinsic resistance at x port. In general, CCCII can contain an arbitrary number of z terminals; provide both directions of currents I_Z . As an example, the symbol and the equivalent circuit of the CCCII with a pair of $z+$ and $z-$ terminals are illustrated in Fig. 1(a) and (b), respectively. The internal construction of CMOS CCCII is shown in Fig. 2.

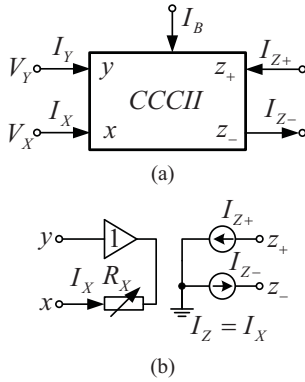


Fig. 1. CCCII (a) Symbol (b) Equivalent circuit

B. Proposed Current-Mode Quadrature Oscillator

The proposed current-mode oscillator circuit is shown in Fig. 3. It is seen that proposed circuit consists of 3 CCCII, 2 grounded capacitors and 1 electronic resistor (R_k) which is easy to fabricate in monolithic chip. The transresistance of the electronic resistor circuit can be expressed as [21]

$$R_k = \frac{V_{in}}{I_{in}} = \frac{L}{2\mu C_{ox} W (V_{DD} - V_T)}, \quad (3)$$

where V_T denotes the threshold voltage.

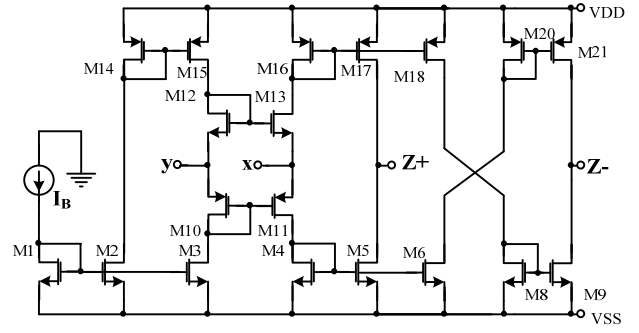


Fig. 2. Schematic of the CMOS CCCII

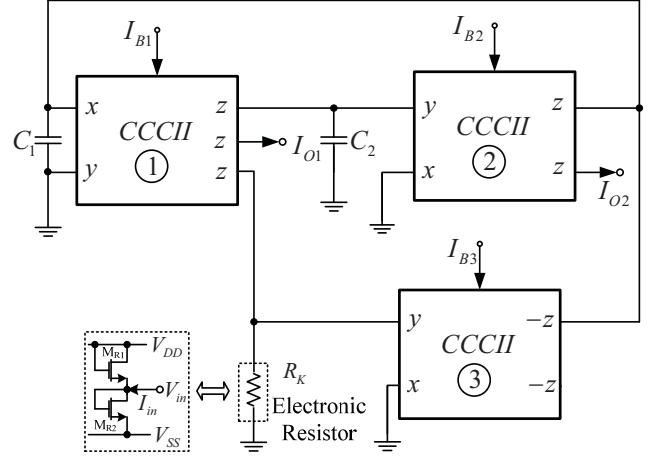


Fig. 3. Proposed current-mode quadrature oscillator

Using routine circuit analysis, the characteristic equation can be found as

$$s^2 C_1 C_2 R_{x1} R_{x2} + s C_2 R_{x2} \left(1 - \frac{R_k}{R_{x3}}\right) + 1 = 0. \quad (4)$$

From Eq. (4), it can be seen that the proposed circuit can produce oscillations if the oscillation condition is fulfilled:

$$R_k \leq R_{x3}. \quad (5)$$

If the above oscillation condition is satisfied the circuit produces oscillations with frequency of

$$\omega_{osc} = \sqrt{\frac{1}{R_{x1} R_{x2} C_1 C_2}}. \quad (6)$$

From Eqs. (5) and (6), if the parasitic resistance is controlled by input bias current as shown in Eq. (2), it can be seen that the oscillation condition can be adjusted independently from the oscillation frequency by varying I_{B3} and R_k while the oscillation frequency can be adjusted by I_{B1} and I_{B2} . Thus both condition of oscillation and frequency of oscillation have dual control for tuning. From circuit in Fig. 3, the relationship between the explicit-current-outputs can be found as

$$\frac{I_{o2}(s)}{I_{o1}(s)} = \frac{1}{sR_{x2}C_2}. \quad (7)$$

For sinusoidal steady state, Eq. (7) becomes

$$\frac{I_{o2}(j\omega_{osc})}{I_{o1}(j\omega_{osc})} = \frac{1}{\omega_{osc}R_{x2}C_2} e^{-j90^\circ}. \quad (8)$$

It is evident from (8) that all the explicit-current-outputs are shifted by 90° from each other and thus the oscillator can be used as quadrature oscillator.

III. ANALYSIS OF NON-IDEAL CASE

For a complete analysis of the proposed oscillator, it is necessary to take into account the following non-idealities of CCCII:

A. Voltage and Current Tracking Errors

In this non-ideal case, the CCCII can be characterized by

$$\begin{bmatrix} i_y \\ V_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta & R_x & 0 \\ 0 & \pm\alpha & 0 \end{bmatrix} \begin{bmatrix} V_y \\ i_x \\ V_z \end{bmatrix}, \quad (9)$$

where α denotes the current tracking error and β denotes the voltage tracking error of a CCCII. Taking into account tracking errors, the characteristic equation becomes

$$s^2C_1C_2R_{x1}R_{x2} + sC_2R_{x2} \left(1 - \beta_3\alpha_1\alpha_3 \frac{R_k}{R_{x3}} \right) + \beta_2\alpha_1\alpha_2 = 0. \quad (10)$$

From (10), the oscillation condition and oscillation frequency become

$$1 = \beta_3\alpha_1\alpha_3 \frac{R_k}{R_{x3}}, \quad (11)$$

$$\omega_{osc} = \sqrt{\frac{\beta_2\alpha_1\alpha_2}{C_1C_2R_{x1}R_{x2}}}. \quad (12)$$

It is found (11) and (12) that parameters; α and β will affect both oscillation condition and oscillation frequency. To alleviate effects of these errors, the CCCII should be carefully designed to minimize these errors for example using high performance current mirror.

B. Parasitic Resistances and Capacitances

The parasitic resistances and capacitances appear between the high-impedance y (R_y and C_y) and z (R_z and C_z) terminals of the CCCII and ground. If $R_{y1}, R_{z1} \gg R_{xi}$, the characteristic equation becomes

$$\left\{ \begin{array}{l} s^3 (C_1 + C_{z2} + C_{z3})(C_2 + C_{z1} + C_{y2})(C_{z1} + C_{y3})R_{x1}R_{x2}R_{x3} + \\ s^2 (C_2 + C_{z1} + C_{y2})(C_1 + C_{z2} + C_{z3})G_kR_{x1}R_{x2}R_{x3} + \\ s^2 (C_2 + C_{z1} + C_{y2})(C_{z1} + C_{y3})R_{x2}R_{x3} + \\ s (C_2 + C_{z1} + C_{y2})G_kR_{x2}R_{x3} + \\ s (C_{z1} + C_{y3})R_{x3} - s (C_2 + C_{z1} + C_{y2})R_{x2} + G_kR_{x3} \end{array} \right\} = 0. \quad (13)$$

(13) is format of third order oscillation. In this case, the oscillation condition and oscillation frequency become

$$\left\{ \begin{array}{l} (C_2 + C_{z1} + C_{y2})^2 (C_1 + C_{z2} + C_{z3})(C_{z1} + C_{y3}) \left[(C_1 + C_{z2} + C_{z3})G_kR_{x1}R_{x2}R_{x3} + \right] R_{x1}R_{x2}R_{x3} = \\ \left[(C_2 + C_{z1} + C_{y2})G_kR_{x2}R_{x3} + (C_{z1} + C_{y3})R_{x3} - (C_2 + C_{z1} + C_{y2})R_{x2} \right] G_kR_{x3} \end{array} \right\}. \quad (14)$$

and

$$\omega_{osc} = \sqrt{\frac{G_kR_{x3}}{(C_2 + C_{z1} + C_{y2}) \left[(C_1 + C_{z2} + C_{z3})G_kR_{x1}R_{x2}R_{x3} + (C_{z1} + C_{y3})R_{x2}R_{x3} \right]}}. \quad (15)$$

It is found (14) and (15) that the parasitic capacitance $C_{z2} + C_{z3}$ and $C_{z1} + C_{y2}$ are absorbed into the external capacitance C_1 and C_2 , respectively as they appear in shunt with them [22]. To alleviate the effects of the parasitic capacitances the operating frequency ω_{osc} should be chosen such that :

$$\omega_{osc} > \max \left[\frac{1}{(C_1 + C_{z2} + C_{z3})(R_{x1} // R_{z1} // R_{z2})}, \frac{1}{(C_2 + C_{z1} + C_{y2})(R_{z1} // R_{y2})} \right]. \quad (16)$$

IV. RESULTS OF COMPUTER SIMULATION

The working of the proposed circuit has been verified using PSpice simulation program. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a $0.25\mu\text{m}$ TSMC CMOS technology [23]. The aspect ratios of PMOS and NMOS transistor are listed in Table 1. Fig. 2 depicts schematic description of the CCCII used in the simulations. The circuit was biased with $\pm 1.25\text{V}$ supply voltages, $C=200\text{pF}$, $I_{B1}=I_{B2}=100\mu\text{A}$ and $I_{B3}=60\mu\text{A}$. Fig. 4 show simulated quadrature output waveforms, I_{O1} and I_{O2} and 1.25MHz .

TABLE I
DIMENSIONS OF THE TRANSISTORS

Transistor	W (μm)	L (μm)
M1-M9	5	0.5
M10-M11	16	0.25
M12-M13	8	0.25
M14-M21	15	0.5
MR1-MR2	3.8	0.5

Fig. 5 shows the simulated output spectrum, where the total harmonic distortion (THD) is about 1.243%. The quadrature relationships between the generated waveforms have been verified using Lissagous figure and shown in Fig. 6. The quadrature phase error is less than 3%. The electronic tuning of the oscillation frequency with the bias current I_B ($I_{B1}=I_{B2}=I_B$) for different capacitor values ($C_1=C_2=C$) is shown in Fig. 7.

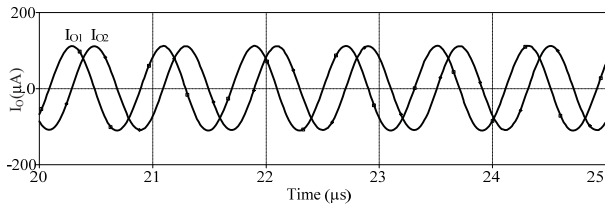


Fig. 4. Current outputs of the proposed oscillator.

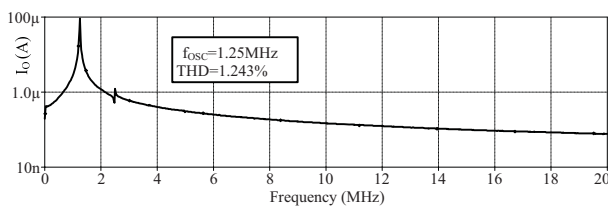


Fig. 5. Spectrum of signal in Fig. 4.

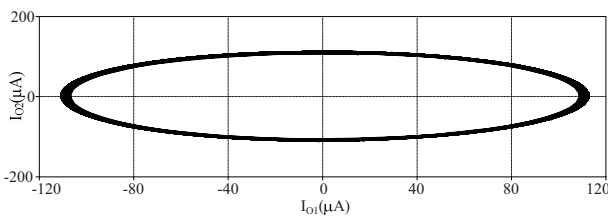


Fig. 6. Lissagous figure.

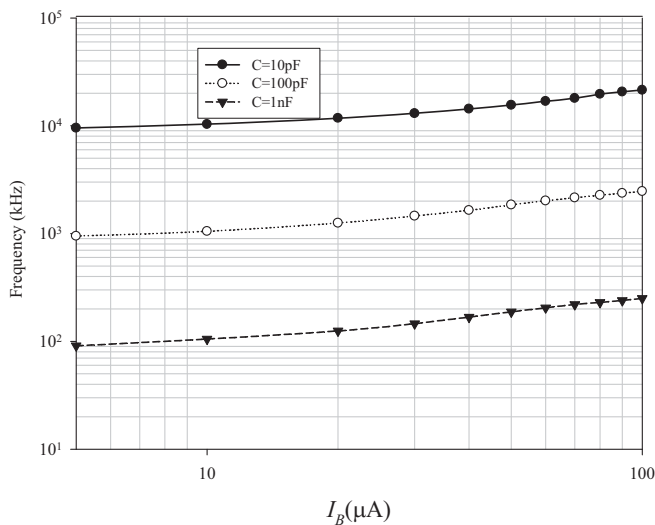


Fig. 7. Simulated oscillation frequency versus I_B for different capacitances C .

V. CONCLUSIONS

An electronically tunable current-mode quadrature oscillator based on CCCIs has been presented. The features of the proposed circuit are that: oscillation frequency and oscillation condition can be electronically/independently tuned; the proposed oscillator consists of merely 3 CCCIs, 1 electronic resistor and 2 grounded capacitors, non-interactive dual-current control of both the condition of oscillation and frequency of oscillation and availability of four quadrature explicit-current-outputs from high-output impedance terminals. PSpice simulation results agree well with the theoretical anticipation.

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REFERENCES

- [1] I. A. Khan and S. Khawaja, "An integrable gm-C quadrature oscillator," *Int. J. Electronics*, vol. 87, no. 1, pp.1353-1357, 2000.
- [2] C. Toumazou, F.J. Lidgey and D.G. Haigh, *Analogue IC design: the current-mode approach*, Peter Peregrinus, London, 1990.
- [3] M. T. Abuelma'atti and H. A. Al-Zaher, "Current-mode sinusoidal oscillators using single FTFN," *IEEE Trans. Circuits and Systems-II: Analog and Digital Signal Proc.*, vol. 46, pp. 69-74, 1999.
- [4] U. Cam, A. Toker, O. Cicekoglu, and H. Kuntman, "Current-mode high output impedance sinusoidal oscillator configuration employing single FTFN," *Analog Integrated Circuits and Signal Proc.*, vol. 24, pp. 231-238, 2000.
- [5] M. T. Abuelma'atti and A.A. Al-Ghumaiz, "Novel CCI-based single-element-controlled oscillators employing grounded resistors and capacitors," *IEEE Trans. on Circuits and Systems-I: Fundamental Theory and Applications*, vol. 43, pp. 153-155, 1996.
- [6] S. Minaei and O. Cicekoglu, "New current-mode integrator, all-pass section and quadrature oscillator using only active elements," *1st IEEE Int'l Conf. Circuits and Systems for Communications*, vol. 26-28, pp.70-73, 2002.
- [7] K. Kumwachara and W. Surakamponorn, "An integrable temperature-insensitive gm-RC quadrature oscillator," *Int. J. Electronics*, vol. 90, no. 1, pp.599-605, 2003.
- [8] J. J. Chen, C.C. Chen, H.W. Tsao, and S.I. Liu, "Current-mode oscillators using single current follower," *Electronics Letters*, vol. 27, pp. 2056-2059, 1991.
- [9] M.T. Abuelma'atti, "Grounded capacitor current-mode oscillator using single current follower," *IEEE Trans. Circuits and Systems-I: Fundamental Theory and Applications*, vol. 39, pp. 1018-1020, 1992.
- [10] J. W. Horng, "Current-mode quadrature oscillator with grounded capacitors and resistors using two DVCCs," *IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences*, vol. E86-A, pp. 2152-2154, 2003.
- [11] W. Jaikla and M. Siripruchyanun, "A Versatile quadrature oscillator and universal biquad filter using CCCDBAs," *Proceedings of ECTI con 2006*, Ubon-ratchathani, Thailand, pp.501-504, May 2006.
- [12] W. Jaikla and M. Siripruchyanun, "A versatile quadrature oscillator and universal biquad filter using dual-output current controlled current differencing transconductance amplifier," *The Proceedings of ISCIT 2006*, Bangkok, Thailand, pp. 1072-1075, 2006.
- [13] W. Jaikla and M. Siripruchyanun, "CCCDTAs-based versatile quadrature oscillator and universal biquad filter," *The Proceedings of ECTI con 2007*, Chiang Rai, Thailand, pp. 1065-1068, 2007.

- [14] R. Keawon, W. Jaikla, "A resistor-less current-mode quadrature sinusoidal oscillator employing single CCCDTA and grounded capacitors," *Przegląd Elektrotechniczny (Electrical Review)*, vol. 8, pp. 138-141, 2011.
- [15] J. W. Horng, C. L. Hou, C. M. Chang, H. P. Chou, C. T. Lin and Y. H. Wen, "Quadrature oscillators with grounded capacitors and resistors using FDCCIs," *ETRI Journal*, vol. 28, pp. 486-494, 2006.
- [16] K. C. Smith and A. Sedra, "The current conveyor-a new circuit building block," *IEEE Proc.* vol. 56, 1368-1369, 1968.
- [17] A. Sedra and K. C. Smith, K. "A second-generation current conveyor and its applications," *IEEE Trans. Circuit Theory*, 17, 132-134, 1970.
- [18] A. Fabre, O. Saaid, F. Wiest and C. Boucheron, "Current controllable bandpass filter based on translinear conveyors," *Electron. Lett.* vol. 31, 1727-1728, 1995.
- [19] K. Ikeda and Y. Tomita, "Realization of current-mode biquadratic filter using CCIs with current followers," *Electronics and Communications in Japan*. vol. 77, 99-107, 1994.
- [20] A. M. Soliman, "New current mode filters using current conveyors," *Int. J. Electron. Commun. (AEU)*, vol. 51, 275-278, 1997.
- [21] Z. Wang, "2-MOSFET transresistor with extremely low distortion for output reaching supply voltages," *Electronics Letters*, vol. 26, p. 951-952, 1990.
- [22] W. Jaikla, A. Lahiri "Resistor-less current-mode four-phase quadrature oscillator using CCCDTAs and grounded capacitors," *Int. J. Electron. Commun. (AEU)*, In Press, doi:10.1016/j.aeue.2011.07.001, Available online 15 August 2011
- [23] P. Prommee, K. Angkeaw, M. Somdunyanok, K. Dejhan, "CMOS-based near zero-offset multiple inputs max-min circuits and its applications," *Analog Integr. Circuits Signal Process.* vol. 61, 93-105, 2009.

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