A CURRENT-MODE SINUSOIDAL QUADRATURE OSCILLATOR USING SINGLE CCCFTA

Thanaset Thosdeekoraphat[1], Chanchai Thongsopa[1], Worawut Boonpeang[1], Supawat Kochapradit[1], Charinsak Saetiaw[2], and Saksit Summart[3]

[1]School of Electronics Engineering, Suranaree University of Technology, Thailand

[2]Rajamangala University of Technology Isan, Khon-Kean Campus, Thailand

[3] Department of Computer Technology, North Eastern Technological College, Thailand

Thanaset@sut.ac.th

ABSTRACT This article presents a current-mode quadrature oscillator using current controlled current follower transconductance amplifier (CCCFTA). The proposed circuit consisting of only few devices which are single active element and 2 grounded capacitors; it has a simple construction that is easy for designing a current-mode quadrature oscillator. In addition, the condition of oscillation and frequency of oscillation can be controlled electronically by adjusting the bias current. The proposed circuit uses only grounded capacitors without any external resistor which is beneficial from the point of view of integrated circuit fabrication. Moreover, the simulation results by PSPICE program are shown corresponding with the theoretical analysis.

1. INTRODUCTION

Quadrature oscillator is one type of oscillator which provides sinusoidal signals with 90^0 phase difference. Some applications for quadrature signal, it is used in telecommunications for single-sideband modulators and quadrature mixers (Khan & Khawaja, 2000). In the last decade, a lot of papers in electronic circuit design have been presented in current-mode technique using the current-mode building block. It is stated that the circuits designed from current-mode technique can provide the advantages such as larger dynamic range, inherently wide bandwidth, higher slew-rate, greater linearity and low power consumption (Toumazou, et al., 1990).

From literature survey, it is found that several implementations of quadrature oscillator using active building block have been reported. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Excessively use the passive elements, especially external resistors (Bumrongchoke, et al., 2010).
- Cannot be electronic adjustability (Bumrongchoke, et al., 2010), (Jin & Wang, 2012).
- Low Output impedance (Jaikla & Siripruchyanan, 2007), (Jaikla & Siripruchyanan, 2012).
- Used a floating capacitor, which is not convenient to future fabricate in IC (Jin & Wang, 2012).
- Employ more than one active element (Biolek, et al., 2006), (Jaikla & Siripruchyanan, 2007).

The aim of this paper is to propose the current-mode quadrature oscillator, based on CCCFTA (Herencsar, et al., 2009). The condition of oscillation and frequency of oscillation can be adjusted by electronic method. The proposed circuit consists of single CCCFTA and 2 grounded capacitors.

2. BASIC CONCEPT OF CCCFTA

The ideal properties of CCCFTA are represented by the following hybrid matrix:

$$\begin{bmatrix} v_f \\ i_z, i_{zc} \\ i_x \end{bmatrix} = \begin{bmatrix} R_f & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} i_f \\ v_x \\ v_z \end{bmatrix} \tag{1}$$

R_f is the parasitic resistances at f port, respectively. These resistances are tuned by I_{B1}. V_T is the thermal voltage; g_m is the transconductances which can be controlled by I_{B2}. The symbol and the equivalent circuit of the CCCFTA are illustrated in Figs. 1 and 2, respectively. The BJT internal construction of CCCFTA is shown in Fig. 3. For a BJT CCCFTA, the transconductance and parasitic resistance can be expressed as

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

and

$$R_f = \frac{V_T}{2I_{B1}} \tag{3}$$

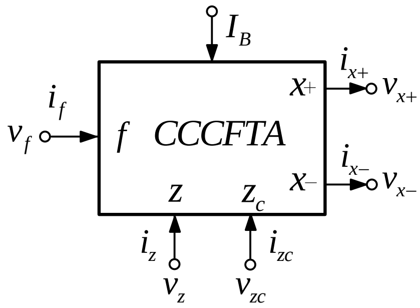

Fig. 1 Symbol of CCCFTA

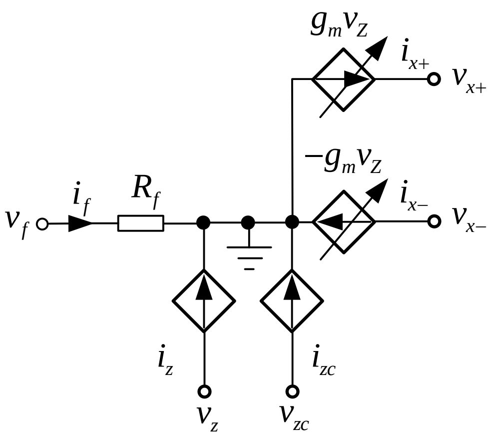

Fig. 2 Equivalent circuit of CCCFTA

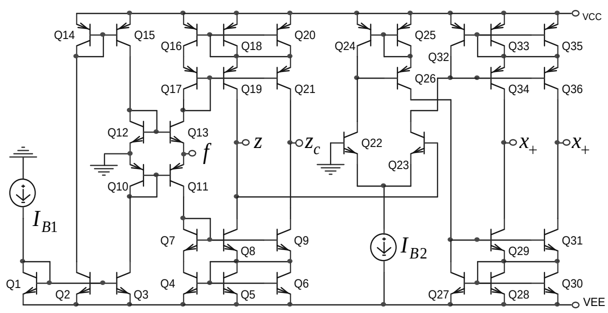

Fig. 3 Internal construction of CCCFTA

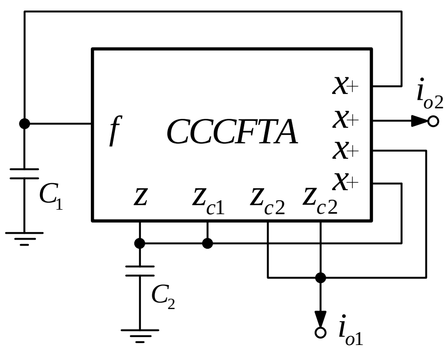

Fig. 4 Proposed current-mode quadrature oscillator

3. PROPOSED CURRENT-MODE QUADRATURE OSCILLATORS

The proposed current-mode oscillator circuit can be shown in Fig. 4. It is seen that the proposed circuit use only single CCCFTA and 2 grounded capacitors without additional external resistor. From Fig. 4 the characteristic equation of the proposed circuits can be written in (4).

$$s^2 + s\frac{C_2 - g_m R_f C_1}{R_f C_1 C_2} + \frac{g_m}{R_f C_1 C_2} = 0 \tag{4}$$

From (4), the condition of oscillations and frequency of oscillation are as follows:

$$1 - g_m R_f, \quad C_2 = C_1 \tag{5}$$

and

$$\omega_{osc} = \sqrt{\frac{g_m}{R_f C_1 C_2}} \tag{6}$$

By substituting the transconductance in (2) and parasitic resistances in (3) as depicted, the condition of oscillation and frequency of oscillation are written in (5) and (6), respectively.

$$4I_{B1} = I_{B2}, \quad C_2 = C_1 \tag{7}$$

and

$$\omega_{osc} = \frac{1}{V_T}\sqrt{\frac{I_{B1} I_{B2}}{C_1 C_2}} \tag{8}$$

From (7) and (8), the condition of oscillation and frequency of oscillation can be adjusted by varying bias current of CCCFTA. From circuit in Fig. 4, the functions of the relation of the output signal i_{o1} and i_{o2} are defined as:

$$\frac{I_{o2}(s)}{I_{o1}(s)} = \frac{g_{m3}}{sC_2} \tag{9}$$

For sinusoidal steady state, (9) becomes

$$\frac{I_{o2}(j\omega_{osc})}{I_{o1}(j\omega_{osc})} = -\frac{jg_{m2}}{\omega_{osc} C_2} \tag{10}$$

From (10), the phase difference θ between i_{o1} and i_{o2} can be written as

$$\theta = -90^0 \tag{11}$$

According to (11), the proposed quadrature oscillator can provide two sinusoidal output current signals with 90 degrees phase difference. Sensitivity of oscillator can be expressed as

$$S_{I_{B1}}^{\omega_{osc}} = S_{I_{B2}}^{\omega_{osc}} = \frac{1}{2}, \quad S_{C_1}^{\omega_{osc}} = S_{C_2}^{\omega_{osc}} = -\frac{1}{2} \tag{12}$$

4. ANALYSIS OF NON-IDEAL CASE

For non-ideal case, the characteristic equation of CCCFTA in (1) is written as

$$\begin{bmatrix} v_f \\ i_z \\ i_{zc} \\ i_x \end{bmatrix} = \begin{bmatrix} R_f & 0 & 0 & 0 \\ \alpha & 0 & 0 & 0 \\ 0 & \gamma & 0 & 0 \\ 0 & 0 & \pm\beta g_m & 0 \end{bmatrix} \begin{bmatrix} i_f \\ i_z \\ v_z \\ v_x \end{bmatrix} \tag{13}$$

In non-ideal case, the characteristic equation, the condition of oscillation and the frequency of oscillation are as follows:

$$\left\{ s^2 + s\frac{C_2 - \beta g_m R_f C_1}{R_f C_1 C_2} + \frac{\beta g_m[\alpha(1+\gamma)-1]}{R_f C_1 C_2} \right\} = 0 \tag{14}$$

$$C_2 = \beta g_m R_f C_1 \tag{15}$$

and

$$\omega_{osc} = \sqrt{\frac{\beta g_m[\alpha(1+\gamma)-1]}{R_f C_1 C_2}} \tag{16}$$

5. SIMULATION RESULTS

To verify the theoretical prediction of the proposed first order filter in Fig. 4, the PSPICE simulation was built with $C_1 = C_2 = 0.5$nF, $I_{B1} = 50\mu$A, and $I_{B2} = 200\mu$A. The BJT implementation of the internal construction of CCCFTA used in simulation is shown in Fig. 3. 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 (Frey, 1993). The circuit was biased with ± 1.25V supply voltages. This yields oscillation frequency of 1.0421MHz, where the calculated value of this parameter from (8) yields 1.2242MHz (deviated by 15.008%). In this case, value of the parameter changed because the BJT implementation used in the circuit deviated from the non-ideal properties and the effect of parasitic elements. Figs. 5 and 6 show the simulated quadrature output waveforms during initial state and steady state, respectively. Fig. 7 shows the simulation result of output spectrum. In addition, Fig. 8 shows the quadrature relationships between the generate waveform by Lissagous figure. Tables 1 and 2 show the results of the total harmonic distortion (THD), from this table the THD of i_{o1} and i_{o2} are about1.307% and 1.023%, respectively. Additionally, the phase difference of the output current i_{o1} and i_{o2} are about 91.82 degrees.

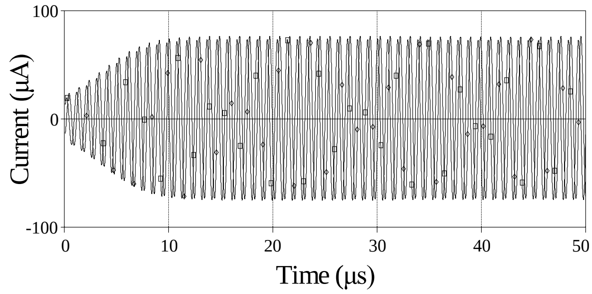

Fig. 5 Output waveforms during initial state

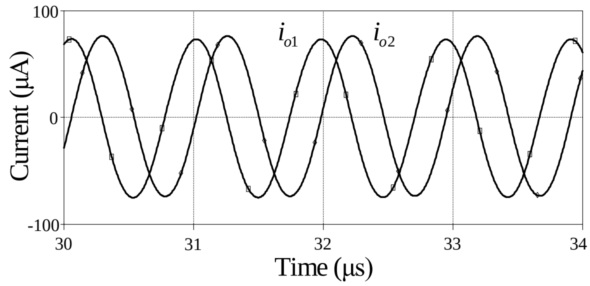

Fig. 6 Output waveforms in steady state

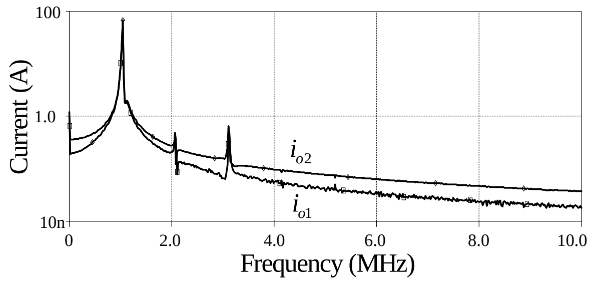

Fig. 7 Output frequency spectrum

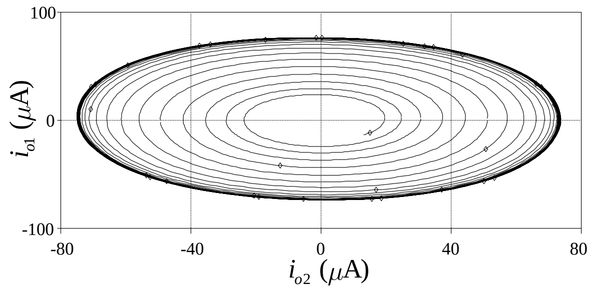

Fig. 8 Lissagous figure

Table 1 Total harmonic distortion analysis of i_{o1}.

Harmonic no.	Frequency (Hz)	Fourier Component (A)	Phase (Degrees)
1	1.042×10^6	7.450×10^{-5}	-1.028×10^1
2	2.084×10^6	3.689×10^{-7}	1.545×10^2
3	3.126×10^6	8.752×10^{-7}	-8.028×10^0
4	4.168×10^6	1.266×10^{-7}	7.702×10^0
5	5.211×10^6	1.112×10^{-7}	-4.214×10^0
6	6.253×10^6	8.390×10^{-8}	1.823×10^1
7	7.295×10^6	8.009×10^{-8}	1.876×10^1
8	8.337×10^6	4.376×10^{-8}	6.714×10^0
9	9.379×10^6	4.092×10^{-8}	1.065×10^1
10	1.042×10^7	4.225×10^{-8}	5.595×10^0
DC component = -7.697111×10^{-7}			
Total harmonic distortion = 1.307699%			

Table 2 Total harmonic distortion analysis of i_{o2}.

Harmonic no.	Frequency (Hz)	Fourier Component (A)	Phase (Degrees)
1	1.042×10^6	7.450×10^{-5}	-1.028×10^1
2	2.084×10^6	3.689×10^{-7}	1.545×10^2
3	3.126×10^6	8.752×10^{-7}	-8.028×10^0
4	4.168×10^6	1.266×10^{-7}	7.702×10^0
5	5.211×10^6	1.112×10^{-7}	-4.214×10^0
6	6.253×10^6	8.390×10^{-8}	1.823×10^1
7	7.295×10^6	8.009×10^{-8}	1.876×10^1
8	8.337×10^6	4.376×10^{-8}	6.714×10^0
9	9.379×10^6	4.092×10^{-8}	1.065×10^1
10	1.042×10^7	4.225×10^{-8}	5.595×10^0
DC component = -7.697111×10^{-7}			
Total harmonic distortion = 1.307699%			

6. CONCLUSION

A current-mode quadrature oscillator based on CCCFTA has been presented. The proposed circuit consists of single CCCFTA and 2 grounded capacitors. The circuit use only grounded capacitors without additional external resister. This qualification is suitable for further fabrication to integrated circuit (Bhusan & Newcomb, 1969), (Soliman, 2008). Moreover, the oscillator has high output impedance that make the circuit to be able to directly drive load without additional current buffer. The frequency of oscillation and condition of oscillation can be electronically controlled. PSPICE simulation results are included to verify the theoretical analysis. Simulated and theoretical results are in close agreement.

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Thanaset Thosdeekoraphat received the B.Eng. and M.Eng. degrees in Telecommunication engineering from Suranaree University of Technology in 2006 and 2008, respectively. Ph.D. in Telecommunication engineering (2012), Suranaree University of Technology, Thailand. At present

Lecturer, School of Telecommunication and Electronic Engineering, Suranaree University of Technology, Thailand. Research interests include hyperthermia inductive heating, magnetic shielding system, RF and microwave circuit design, microwave heating, antenna, active antenna and UWB transmitter-receiver design and analysis of impulse signal for UWB communication system. In addition, as a reviewer of the International Journal of Antennas and Propagation.

Chanchai Thongsopa B.Eng. (1'Hons) Electronics Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand, M.Eng. (Electrical and Communications Engineering), Kasetsart University, Thailand and D.Eng. (Electrical Engineering), King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand in 1992, 1996 and 2002, respectively. Lecturer, School of Telecommunication and Electronic Engineering. At present Associate Professor in Electronics Engineering Head, School of Electronics Engineering. Experiences & Expert are RF circuit design, active antenna, Microwave heating application in 1992-1997 Researcher at Aeronautical Radio of Thailand Company Design Systems Air Traffic control: Design transmitters VHF-UHF (AM) 25W (on 24 Hour) and Design Transmitters HF (AM) 1KW (on 24 Hour). Furthermore, Researcher at National Electronics and Computer Technology Center (NECTEC) and consultant of SDH project at Telephone Organization of Thailand (TOT) design RF circuit in 1997-2000.

Worawut Boonpeang received the B.Eng. (1'Hons) in Electronic engineering (2013), from Suranaree University of Technology.
He studying Ph.D. degree in electronic engineering (2014), Suranaree University of Technology, Thailand. Research interests include high power switching induction, and microcontroller.

Supawat Kotchapradit received the B.Eng. (1'Hons) in Electronic engineering (2013), from Suranaree University of Technology.
He studying Ph.D. degree in electronic engineering (2014), Suranaree University of Technology, Thailand. Research interests include power electronic, microwave circuit and RF circuit design.

Charinsak SAETIAW received the B.Eng. degrees in Telecommunication Engineering from Suranaree University of Technology, M.Eng. degree in Telecommunication Engineering from Suranaree University of Technology and Ph.D. degree in Telecommunication Engineering of Suranaree University of Technology, Thailand, in 1997, 2007 and 2014, respectively. His research interests include Active antenna and antenna systems for several applications.

Saksit Summart received the B. Tech. Ed. degree in Telecommunication Engineering from Rajamangala Institute of Technology Khon Kaen Campus (RITKK) in 2002 and Master of Tech. Ed. in electrical technology from King Mongkut's University of Technology North Bangkok (KMUTNB) in 2008. Now and Ph.D. degree in Telecommunication Engineering at Suranaree University of Technology (SUT). He has been with Electronic Program, Electronic Division, Northeastern Technology College, Khon Kaen, Thailand since 2007. His research interests include electronic communications, analog signal processing and analog integrated circuit.