Saksit SUMMART[1], Chanchai THONGSOPA[1], Winai JAIKLA[2]

Suranaree University of Technology (1), King Mongkut's Institute of Technology Ladkrabang (2)

OTA Based Current-mode Sinusoidal Quadrature Oscillator with Non-interactive Control

***Abstract**. The current-mode quadrature oscillator with non-interactive 2 current control for both of condition of oscillation (CO) and frequency of oscillation (FO) using 4 operational transconductance amplifiers (OTAs) and 2 grounded capacitors is presented. The proposed oscillator provides 2 sinusoidal output currents with 90º phase difference. It also provides high output impedances that make the circuit can directly drive load without additional current buffers. The condition of oscillation and the frequency of oscillation can be electronically/independently controlled by adjusting the bias current of the OTA. The use of only grounded capacitors without any external resistor is ideal for integration.*

***Streszczenie.** Opisano układ generator prądowego ze sterowaniem warunków oscylacji i częstotliwości oscylacji. W układzie wykorzystano 4 wzmacniacze transkonduktancyjne i dwie uziemione pojemności. (**Prądowy generator sinusoidalny bazujący na wzmacniaczach transkonduktancyjnych**)*

Keywords: non-interactive control; quadrature oscillator; current-mode; OTA.
Słowa kluczowe: generator prądowy, wzmacniacz trankonduktancyjny..

Introduction

Today electronics industry has been remarkably developed especially in terms of parts and devices. Various kinds of electronic device have been used to create a wide range of signal processing circuits, starting from a vacuum type to a semiconductor which is in the form of discrete and later in a form of integrated circuit or so called IC. Likely, in terms of circuit design, new and distinguished techniques and methods have continuously been introduced to create up-to-date circuits with more ease and convenience for use and applications. Thus, these techniques help improve the existing circuits for better performance, more resolution and more accuracy so as to gain high frequency response by designing a circuit with simplest structure. The circuit can then be simply and cost-effectively developed to an integrated circuit.

In the field of electric and electronic engineering, oscillators play an important role and have been widely applied in various aspects such as communications systems, instrumentation, measurement and signal processing, etc. The concept of oscillator design has been mainly on the requirement of multiple sinusoids which are 90◦ phase shifted, called quadrature signal, for easy implementation with other circuits for example in the design of SSB modulator [1], etc. From the past, there have been attempts to synthesis the sine wave oscillator in both forms of current and voltage mode. In the last decade, there has been a necessity to reduce voltage consumption in the circuit to support the wireless devices that run on compact batteries. Such requirement calls for the development of current- mode circuit designs due to their potential advantages such as inherently wide bandwidth, higher slew-rate, greater linearity, wider dynamic range, simple circuitry and low power consumption [2-5]. From literature survey, it is found that several implementations of oscillator employing OTAs have been reported [6-31]. The proposed quadrature oscillators (QO) using OTAs are compared with previously published QOs of [6-31] and the results are shown in Table 1.

The aim of this paper is to propose the current-mode quadrature oscillator, based on OTAs. The oscillation condition and oscillation frequency can be independently adjusted by electronic method and non-interactive dual-current control for both the condition of oscillation and the frequency of oscillation. The circuit construction consists of 4 OTAs and 2 grounded capacitors. The PSpice simulation results are also shown, which are in correspondence with the theoretical analysis.

Proposed Circuit

Basic Concept of OTA

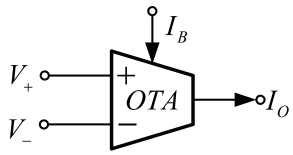
An ideal operational transconductance amplifier (OTA) has infinite input and output impedances. The output current of an OTA is given by

(1) $$I_O = g_m(V_+ - V_-),$$

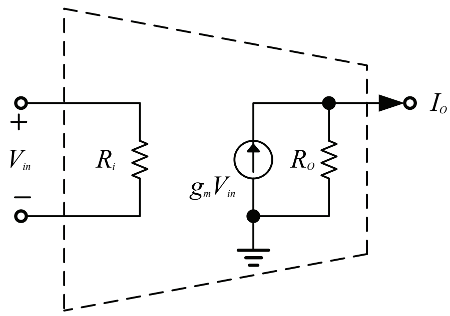
where g_m is the transconductance of the OTA. This g_m can be tuned by external input bias current (I_B). For a BJT OTA, the transconductance can be expressed as

(2) $$g_m = \frac{I_B}{2V_T}.$$

V_T is the thermal voltage. The symbol and the equivalent circuit of the OTA are illustrated in Figs. 1(a) and (b), respectively.



(a)



(b)

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

Ref	Active element	Number of active element	Non-interactive dual current control for CO and FO	Grounded C only	Number of R+C	Current-mode QO output
[6]	OTA	2	No	Yes	1+2	No
[7]	OTA	4	No	Yes	0+2	Yes
[8]	OTA	3	No	Yes	0+2	No
[9]	OTA	4	No	No	8+2	No
[10]	OTA	4	No	Yes	12+3	No
[11]	OTA	4	No	Yes	0+2	No
[12]	OTA	2	No	No	1+2	No
[13]	OTA	2	No	Yes	4+2	Yes
[14]	OTA	3	No	Yes	0+2	No
[15]	OTA	2	No	Yes	1+2	Yes
[16]	OTA	3	No	Yes	0+2	Yes
[17]	OTA	2	No	No	1+2	No
[18]	OTA	4 (Fig. 2a)	Yes	Yes	0+2	No
		4 (Fig. 2b)	No	Yes	0+2	No
		2 (Fig. 2c)	No	No	0+3	No
		4 (Fig. 2d)	No	No	0+4	No
[19]	OTA	2 (Fig. 4)	No	No	0+3	No
		5 (Fig. 4)	No	Yes	0+2	No
		6 (Fig. 4)	Yes	Yes	0+2	No
		7 (Fig. 4)	No	Yes	0+2	No
[20]	OTA	1 (Fig. 4(1,2))	No	Yes	3+2	Yes
		1 (Fig. 4(3,4,5))	No	Yes	4+2	Yes
[21]	OTA	3	No	Yes	0+2	No
[22]	OTA	2	No	No	0+2	No
[23]	OTA	2 (Fig. 4a)	No	Yes	2+1	No
		2 (Fig. 4b)	No	No	3+0	No
[24]	OTA	3 (Fig. 5a)	No	Yes	0+2	No
		4 (Fig. 5b)	Yes	Yes	0+2	No
		6 (Fig. 6a)	No	Yes	0+2	No
		6 (Fig. 6b)	Yes	Yes	0+2	No
[25]	OTA	3 (Fig. 2a)	No	Yes	0+2	No
		4 (Fig. 2b)	Yes	Yes	0+2	No
		6 (Fig. 2c)	Yes	Yes	0+2	No
[26]	OTA	3 (Fig. 2(a,b,c,d))	No	Yes	0+2	No
		3 (Fig. 3(a,b))	No	Yes	0+2	No
[27]	OTA	4	No	Yes	5+1	No
[28]	OTA	4	No	Yes	1+2	No
[29]	DDCC+OTA	1+1	No	Yes	1+2	No
[30]	OTA	4	Yes	Yes	0+4	No
[31]	CCII+OTA	1+3	No	No	0+2	No
Proposed QO	OTA	4	Yes	Yes	0+2	Yes

CO: condition of oscillation
FO: frequency of oscillation

Tab. 1. Comparison between various QOs using OTA

Proposed Current-mode Quadrature Oscillator

The proposed quadrature oscillator is shown in Fig. 2. It consists of 4 OTAs and 2 grounded capacitors without resistors. The output currents I_{O1} and I_{O2} are high output impedance that is easy to drive external load without loading effect. Using (1), the characteristic equation is written as

(3) $$s^2 + s\left(\frac{g_{m3} - g_{m4}}{g_{m3}C_1}\right) + \frac{g_{m1}g_{m2}}{C_1C_2} = 0 .$$

From Eq. (3), the condition of oscillation and frequency of oscillation are as follows:

(4) OC: $g_{m3} = g_{m4}$,

(5) $$\omega_{osc} = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} .$$

It is found from Eqs. (4) and (5) that if $g_{mi} = I_{Bi} / 2V_T$, the CO and FO are written as

(6) OC: $I_{B3} = I_{B4}$,

and

(7) $$\omega_{osc} = \frac{1}{2V_T}\sqrt{\frac{I_{B1}I_{B2}}{C_1C_2}} .$$

It can be seen that the CO can be adjusted independently from the FO by varying I_{B3} and I_{B4} while the oscillation frequency can be adjusted by I_{B1} and I_{B2}. Moreover, it should be remarked that the proposed circuit enables non-interactive dual-current control for both the condition of oscillation and the frequency of oscillation (CO is tuned by I_{B3} and I_{B4}, FO is tuned by I_{B1} and I_{B2}). From circuit in Fig. 3, the current transfer function of I_{O2} to I_{O1} is

$$\frac{I_{O2}(s)}{I_{O1}(s)} = \frac{g_{m2}}{sC_2}. \tag{8}$$

For sinusoidal steady state, Eq. (8) becomes

$$\frac{I_{o2}(j\omega_{osc})}{I_{o1}(j\omega_{osc})} = \frac{g_{m2}}{\omega_{osc} C_2} e^{-j90^\circ}. \tag{9}$$

The phase difference ϕ between I_{O1} and I_{O2} is

$$\phi = -90^\circ. \tag{10}$$

It is seen from Eq. (10) that the proposed oscillator can provide 2 sinusoidal signal output currents with 90° phase difference. Sensitivities of the oscillator of the circuit are shown in Eq. (11)

$$S_{C_1,C_2}^{\omega_{osc}} = -\frac{1}{2},\ S_{g_{m1},g_{m2}}^{\omega_{osc}} = \frac{1}{2} \tag{11}$$

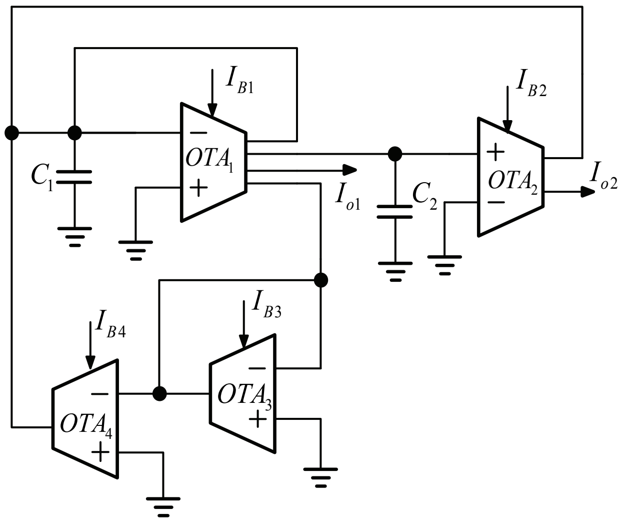


Fig.2. Proposed current-mode quadrature oscillator

Results of Computer Simulation

To verify the theoretical prediction of the proposed current-mode quarature oscillator in Fig. 2, the Pspice simulation was built with $C_1=C_2=1nF$, $I_{B1}=I_{B2}=300\mu A$ and $I_{B3}=I_{B4}=15\mu A$. The BJT implementation of the internal construction of OTA 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 [32].The circuit was biased with ±1.5V supply voltages. This yields oscillation frequency of 778.530kHz, where the calculated value of this parameter from Eq. (7) yields 918.201kHz (deviated by 15.211%). The power consumption of the circuit is about 5.41mW. Figs. 4 and Fig. 5 show the simulated quadrature output waveforms. It is found that the phase difference of I_{O1} and I_{O2} is 90° as shown in Eq. (10). Fig. 6 shows the simulated output spectrum, where the total harmonic distortion (THD) of I_{o1} and I_{o2} are about 0.694% and 0.310%, respectively. The electronic tuning of the oscillation frequency (FO) with the bias current $I_{B1}=I_{B2}$ for different capacitor values is shown in Fig. 7.

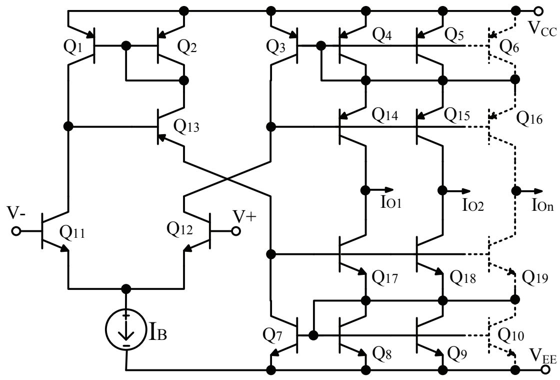


Fig.3. Internal construction of OTA

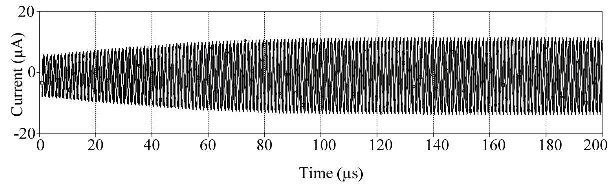


Fig.4. The simulation result of output waveforms during initial state

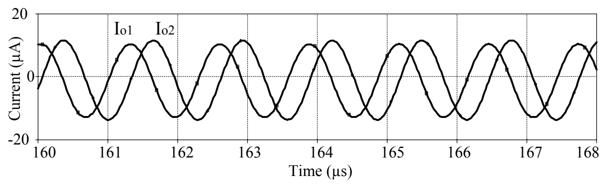


Fig.5. The quadrature output waveforms

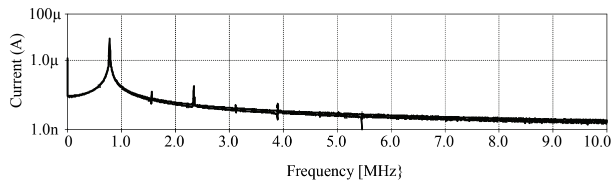


Fig.6. Output frequency spectrum

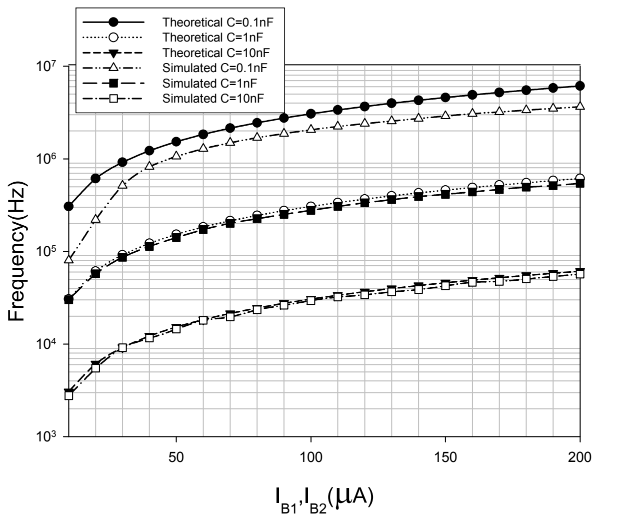


Fig. 7. Oscillation frequencies against bias currents for various capacitances when $I_{B1}=I_{B2}$

Conclusions

A current-mode quadrature oscillator has been presented. The frequency of oscillation and condition of oscillation can be electronically adjusted with non-interactive dual-current control for both the condition of oscillation and the frequency of oscillation. The proposed oscillator consists of OTAs and grounded capacitors without any resistors, which is ideal for ICs. PSpice simulations are included to verify the theoretical analysis. Simulated and theoretical results are in close agreement.

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Authors*: Saksit Summart, Studying Engineering (doctoral's degree), School of Telecommunication Engineering, Suranaree University of Technology, 111 Suranaree Road, Maung, Nakhonrachasima, 30000, Thailand, E-mail: ton_3555@hotmail.com, Asst. Prof. Dr. Chanchai Thongsopa, , School of Telecommunication Engineering, Suranaree University of Technology,E-mail: chan@sut.ac.th, 111 Suranaree Road, Maung, Nakhonrachasima, 30000, Winai Jaikla, Department of Engineering Education, Faculty of Industrial Education, King Mongkut's Institute of Technology Ladkrabang, Bangkok, 10520, Thailand E-mail: winai.ja@hotmail.com*.

The correspondence address is:

e-mail: ton_3555@hotmail.com