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Second Order Current-mode Quadrature Oscillators Using OTAs

***Abstract**. This article presents new current-mode quadrature oscillator circuits using OTA which are designed from block diagram. The proposed circuits consist of three OTAs and two grounded capacitors. The circuits have high output impedance appropriate for cascade connection application in current mode technique which is capable to directly drive load. The oscillators use only grounded capacitor which is very appropriate for further development into an integrated circuit. In addition, the condition of oscillation can be adjusted orthogonally from the frequency of oscillation. The results of PSPICE simulation program are corresponding to the theoretical analysis.*

Streszczenie.** W artykule opisano nowy prądowy generator wykorzystujący OTA – operacyjny transkonduktancyjny wzmacniacz. Układ składa się z trzech wzmacniaczy i dwóch uziemionych kondensatorów. Obwód ma dużą impedancję wyjściową **Oscylator prądowy drugiego rzędu wykorzystujący wzmacniacze transkonduktancyjne

Keywords: Current-mode; quadrature oscillator; OTA.
Słowa kluczowe: oscylator, wzmacniacz transkonduktancyjny, wyjście prądowe.

Introduction

The oscillator is important in electrical and electronic engineering. These circuit have been worldwide implemented like in communication system measuring tool systems, and signal processing. According to recent research reviews on designing current-mode quadrature oscillator circuit using active building block, the most recommended qualifications for an appropriate circuit design are functioning without additional external resistor, using grounded capacitors, consisting of high output impedance and being able to be controlled by electronic method, for instance.

Quadrature oscillator (QO) is one of oscillator which provides two sinusoidal signals with 90 degrees phase difference. Some applications for quadrature signals are employed in telecommunications for single-sideband modulators and quadrature mixers [1]. In the recent years electronic circuit design have been presented in current mode technique. It is stated that the circuit 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 [2]-[3]. From literature survey, it is found that several implementations of oscillator and quadrature oscillator circuits using operational transconductance amplifier (OTA) have been reported [10]-[39]. It was reported that circuits suffer from one more of weaknesses. For example: the oscillation condition and oscillation frequency are not independently controllable. The proposed circuit uses floating capacitor which is not convenient for further fabrication in integrated circuit [6]. The external resistore is excessively used and the proposed circuits consists of large number of passive components.

In this study, it presents the new current mode quad rature oscillator based on OTA. The oscillator circuits use three OTA and two grounded capacitors. The proposed oscillators have high output impedance which is good for cascade connection application in current-mode technique which is capible to directly drive load [3], [7]-[9]. The proposed circuit use only capacitor without external resistor which is convinient for further fabrication in integreted circuit [4]-[5]. In addition, the proposed circuits are desinged based on block diogram which are easy and coveninient for designing. The proposed quadrature oscillators are compared with previously published oscillators and quadrature oscillators based on OTA; the results are shown in Table 1.

Proposed Circuit

Basic Concept of OTA

Operational transconductance amplifier (OTA) is widely implicated in current-mode circuit as filter and oscillator circuits. The output current of an OTA is given by:

$$I_O = g_m (V_+ - V_-)\,. \tag{1}$$

g_m is the transconductance of the OTA. The g_m can be tuned by external input bias current. The symbol and the equivalent circuit of OTA are illustrated in Figs. 1 and 3, respsctively. For BJT OTA, the transconductance can be expressed as

$$g_m = \frac{I_B}{2V_T}\,. \tag{2}$$

V_T is the thermal voltage. The bipolar junction transistor implementation of the internal construction of OTA can be shown in figure 3.

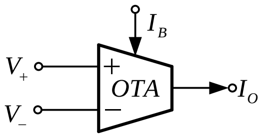


Fig. 1. Symbol of OTA

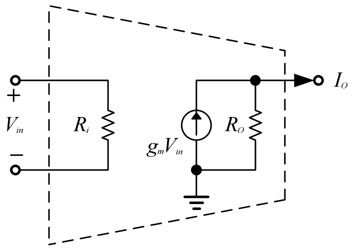


Fig. 2. Equivalent circuit of OTA

Proposed Current-mode Quadrature Oscillators

The block diagram of oscillators is shown in Fig. 4. From block diagram in Fig. 4, the realization of proposed current-mode quadrature oscillators is achieved in Fig. 5, the characteristic equation of the proposed circuits can be written in Eq. (3).

$$s^2 + g_{m1}\frac{g_{m2}C_2 - g_{m3}C_1}{g_{m2}C_1C_2}s + \frac{g_{m1}g_{m3}}{C_1C_2} = 0\,, \tag{3}$$

Table I. Comparison between various oscillator circuits using OTA

Ref.	Active element	Number of active element	Independent control for CO and FO	Grounded C only	Number of R+C	Current-mode QO output
[10]	OTA	2	Yes	Yes	1+2	No
[11]	OTA	4	No	Yes	0+2	Yes
[12]	OTA	3	No	Yes	0+2	No
[13]	OTA	4	Yes	No	8+2	No
[14]	OTA	4	No	Yes	11+3	No
[15]	OTA	2 (Fig. 2a)	No	No	0+3	No
		3 (Fig. 2b)	Yes	Yes	0+2	No
		4 (Fig. 2(c,d))	Yes	Yes	0+2	No
		4 (Fig. 2e)	Yes	No	0+4	No
[16]	OTA	2	Yes	No	1+2	No
[17]	OTA	2	Yes	Yes	4+2	Yes
[18]	OTA	3	Yes	Yes	0+2	No
[19]	OTA	2	Yes	Yes	1+2	No
[20]	OTA	4	Yes	Yes	0+2	No
[21]	OTA	2 (Fig.10)	Yes	No	1+2	No
[22]	OTA	4 (Fig. 2a)	Yes	Yes	0+2	No
		4 (Fig. 2b)	Yes	Yes	0+2	No
		2 (Fig. 2c)	No	No	0+3	No
		4 (Fig. 2d)	Yes	No	0+4	No
[23]	OTA	2 (Fig. 4)	No	No	0+3	No
		3 (Fig. 5)	Yes	Yes	0+2	No
		4 (Fig. 6(a,b))	Yes	Yes	0+2	No
		4 (Fig. 7)	Yes	Yes	0+2	No
[24]	OTA	1 (Fig. 4(1,2))	Yes	Yes	3+2	Yes
		1 (Fig. 4(3,4,5))	Yes	Yes	4+2	Yes
[25]	OTA	3	Yes	Yes	0+2	No
[26]	OTA	2	No	No	0+2	No
[27]	OTA	2 (Fig. 4a)	No	Yes	0+1	No
		2 (Fig. 4b)	No	No	1+0	No
[28]	OTA	3 (Fig. 5a)	Yes	Yes	0+2	No
		4 (Fig. 5b)	Yes	Yes	0+2	No
		6 (Fig. 6(a,b))	Yes	Yes	0+2	No
[29]	OTA	3 (Fig. 2a)	Yes	Yes	0+2	No
		4 (Fig. 2b)	Yes	Yes	0+2	No
		6 (Fig. 2c)	Yes	Yes	0+2	No
[30]	OTA	3 (Fig. 2(a,b,c,d))	Yes	Yes	0+2	No
		3 (Fig. 3(a,b))	Yes	No	0+2	No
[31]	OTA	6 (Fig. 1(a,b,c))	Yes	Yes	0+2	No
		5 (Fig. 1(d,e,i))	Yes	Yes	0+2	No
		3 (Fig. 1f)	Yes	Yes	0+2	No
		4 (Fig. 1(g,h))	Yes	Yes	0+2	No
[32]	OTA	4	Yes	Yes	1+2	No
[33]	DDCC+OTA	1+2	Yes	Yes	1+2	No
[34]	OTA	4	Yes	Yes	0+4	No
[35]	CCII+OTA	1+3	Yes	No	0+2	No
[36]	OTA	4	No	Yes	0+2	No
[37]	OTA	4	Yes	Yes	0+4	No
[38]	OTA	2	No	Yes	0+2	No
[39]	OTA	4	Yes	Yes	0+2	Yes
Proposed QOs	OTA	3	Yes	Yes	0+2	Yes

CO: condition of oscillation, FO: frequency of oscillation, QO: quadrure oscillator

From Eq. (3), the condition of oscillations and frequency of oscillation are written as formula.

(4) $$CO: \; g_{m2} = g_{m3}, \quad C_2 = C_1,$$

and

(5) $$FO: \; \omega_{osc} = \sqrt{\frac{g_{m1} g_{m3}}{C_1 C_2}}.$$

By substituting the transconductance as depicted in Eq. (2), the condition of oscillation and frequency of oscillation are written as Eqs. (6) and (7).

(6) $$I_{B2} = I_{B3}, \quad C_2 = C_1,$$

and

(7) $$f_{osc}:\ \omega_{osc}=\sqrt{\frac{I_{B1}I_{B3}}{C_1C_2}}\,.$$

From Eqs. (6) and (7), it can be found that the condition of oscillation can be adjusted independently from the frequency of oscillation by varying I_{B2} and I_{B3} while the oscillation frequency can be adjusted by I_{B1}. From circuit in Fig. 5, the functions of the output signal I_{O1} and I_{O2} is formula.

(8) $$\frac{I_{o2}(s)}{I_{o1}(s)}=\frac{g_{m3}}{sC_2}\,.$$

For sinusoidal steady state, Eq. (8) becomes

(9) $$\frac{I_{o2}(j\omega_{osc})}{I_{o1}(j\omega_{osc})}=-\frac{jg_{m3}}{\omega_{osc}C_2}\,.$$

From Eq. (9), the phase difference θ between I_{O1} and I_{O2} can be written as formula.

(10) $$\theta=-90^o\,.$$

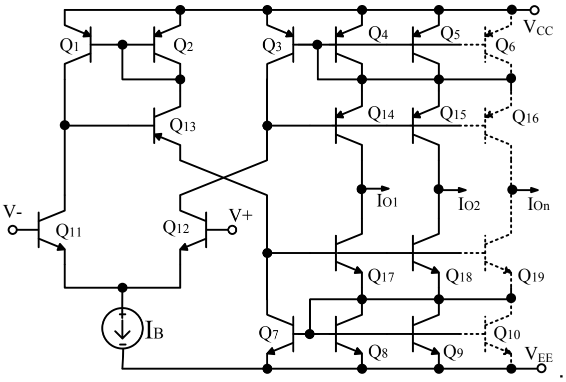


Fig. 3. Internal construction of OTA

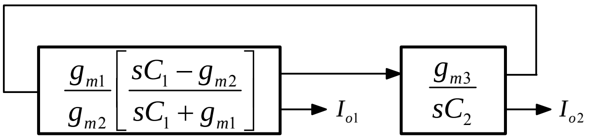


Fig. 4. Block diagram of quadrature oscillators

According to Eq. (10), the oscillators can provide two sinusoidal output current signals with 90^0 phase difference. Sensitivity of oscillator circuits can be expressed as

(11) $$S_{I_{B1}}^{\omega_0}=S_{I_{B3}}^{\omega_0}=\frac{1}{2},\quad S_{C_1}^{\omega_0}=S_{C_2}^{\omega_0}=-\frac{1}{2}$$

Analysis of Non-Ideal Case

For non-ideal case, the characteristic equation of OTA can be writtenin as

(12) $$I_O=g_m(\rho_pV_+-\rho_nV_-)\,.$$

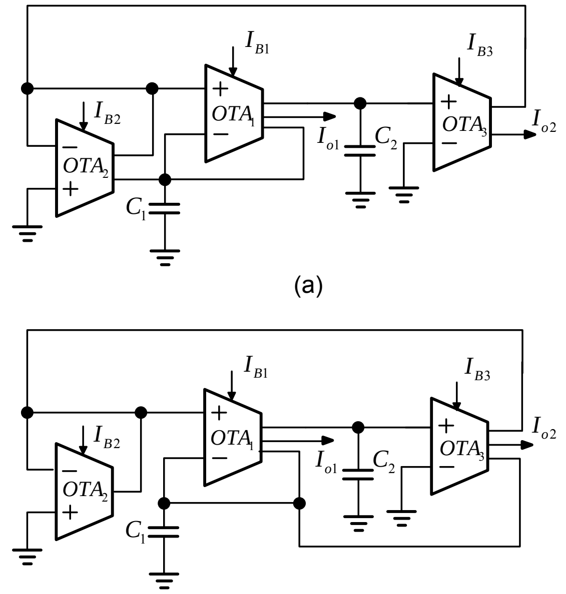
Parameters ρ is the transferred value. It is deviating from one, depending on the value of intrinsic impedances and temperatures. OTA should be carefully designed to reduce the errors. In this case, the characteristic equation, the condition of oscillation and the frequency of oscillation are as follows:

(13) $$\left\{\begin{aligned}&s^2+g_{m1}\frac{\rho_{n1}\rho_{n2}g_{m2}C_2-\rho_{p1}\rho_{p3}g_{m3}C_1}{\rho_{n2}g_{m2}C_1C_2}s\\&+\frac{\rho_{n1}\rho_{p3}g_{m1}g_{m3}}{C_1C_2}\end{aligned}\right\}=0\,,$$

(14) $$\rho_{n1}\rho_{n2}g_{m2}C_2=\rho_{p1}\rho_{p3}g_{m3}C_1\,,$$

and

(15) $$\omega_{osc}=\sqrt{\frac{\rho_{n1}\rho_{p3}g_{m1}g_{m3}}{C_1C_2}}\,.$$



(a)

(b)

Fig. 5. Proposed current-mode quadrature oscillators

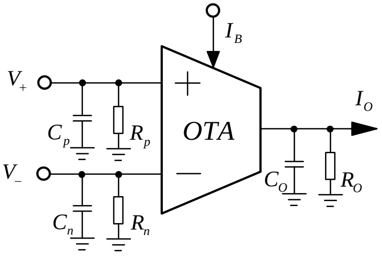


Fig. 6: Parasitic resistances and capacitances of OTA

Analysis of the Parasitic Resistances and Capacitances

The parasitic resistances and capacitances of the OTA can be shown in Fig. 6. In this case, the characteristic equation, the CO and the FO from Eqs. (3) to (5) becomes

(16) $$\left\{\begin{aligned}&s^3C'C''C'''+s^2(C'C''G'''+C'C'''G''\\&+C''C'''G'+g_{m1}C'C'''+g_{m2}C''C''')\\&+s(C'G''G'''+C''G'G'''+C'C''C'''\\&+g_{m1}C'G'''+g_{m1}C'''G'+g_{m2}C''G''\\&+g_{m2}C'''G''+g_{m1}g_{m2}C'''+g_{m2}g_{m3}C'\\&-g_{m1}g_{m3}C'')+C'C''G'''+g_{m1}C'G'''\\&+g_{m2}G''G'''+g_{m1}g_{m2}G'''\\&+g_{m2}g_{m3}G'-g_{m1}g_{m3}G''+g_{m1}g_{m2}g_{m3}\end{aligned}\right\}=0\,,$$

(17) $$\begin{aligned}&C'C''C'''(C'C''G'''+C'C'''G''+C''C'''G'\\&+g_{m1}C'C'''+g_{m2}C''C''')=(C'G''G'''+C''G'G'''\\&+C'C''C'''+g_{m1}C'G'''+g_{m1}C'''G'+g_{m2}C''G''\\&+g_{m2}C'''G''+g_{m1}g_{m2}C'''+g_{m2}g_{m3}C'-g_{m1}g_{m3}C'')\,,\\&(C'C''G'''+g_{m1}C'G'''+g_{m2}G''G'''+g_{m1}g_{m2}G'''\\&+g_{m2}g_{m3}G'-g_{m1}g_{m3}G''+g_{m1}g_{m2}g_{m3})\end{aligned}$$

and

$$\omega_{osc} = \sqrt{\frac{\begin{bmatrix} C^{'}C^{''}G^{'''} + g_{m1}C^{'}G^{'''} + g_{m2}G^{''}G^{'''} \\ +g_{m1}g_{m2}G^{'''} + g_{m2}g_{m3}G^{'} - g_{m1}g_{m3}G^{''} \\ +g_{m1}g_{m2}g_{m3} \end{bmatrix}}{\begin{bmatrix} (C^{'}C^{''}G^{'''} + C^{'}C^{'''}G^{''} + C^{''}C^{'''}G^{'} \\ +g_{m1}C^{'}C^{'''} + g_{m2}C^{''}C^{'''}) \end{bmatrix}}}. \quad (18)$$

Where

Circuit 5 (a):

$$\begin{aligned} C^{'} &= C_{o2} + C_{o3} + C_{p1} + C_{n2} \\ C^{''} &= C_1 + C_{o1} + C_{o2} + C_{n1} \\ C^{'''} &= C_2 + C_{o1} + C_{p3} \\ G^{'} &= G_{o2} + G_{o3} + G_{p1} + G_{n2} + g_{m1}, \\ G^{''} &= G_{o1} + G_{o2} + G_{n1} \\ G^{'''} &= G_{o1} + G_{p3} \end{aligned}$$

Circuit 5 (b):

$$\begin{aligned} C^{'} &= C_{o2} + C_{o3} + C_{p1} + C_{n2} \\ C^{''} &= C_1 + C_{o1} + C_{o3} + C_{n1} \\ C^{'''} &= C_2 + C_{o1} + C_{p3} \\ G^{'} &= G_{o2} + G_{o3} + G_{p1} + G_{n2} + g_{m1}. \\ G^{''} &= G_{o1} + G_{o3} + G_{n1} \\ G^{'''} &= G_{o1} + G_{p3} \end{aligned}$$

Simulation Results

To verify the theoretical prediction of the proposed oscillators the PSPICE simulation was built (for example, proposed quadrature oscillator in Fig. 5(a)) with C_1=C_2=1nF, I_{B1}=I_{B3}=200μA, and I_{B2}=188μA. 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 [40]. The circuit was biased with ±1.5V supply voltages. This yields oscillation frequency of 520.260 kHz, where the calculated value of this parameter from Eq. (7) yields 612.134 kHz (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. Figs. 7 and 8 show the simulated quadrature output waveforms during initial state and steady state, respectively. Fig. 9 shows the simulation result of output spectrum. The results of the total harmonic distortion (THD) of I_{O1} and I_{O2} are about 5.559%. Additionally, the phase difference of the output current I_{O1} and I_{O2} are about 90.1 degrees.

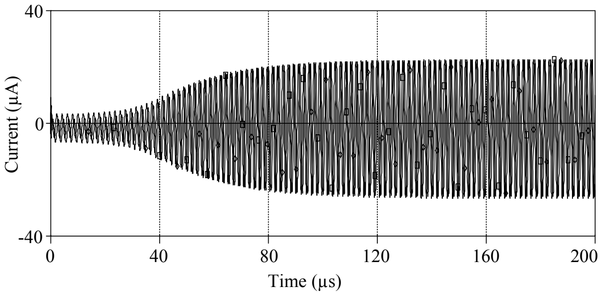


Fig. 7. Output waveforms during initial state

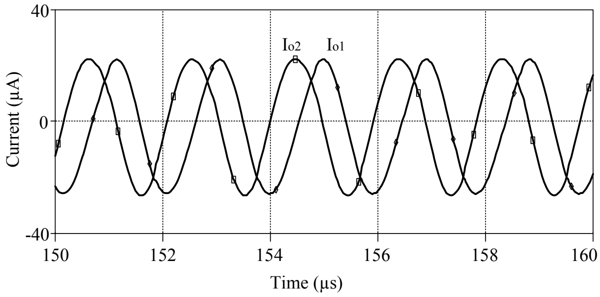


Fig. 8. Quadrature output waveforms in steady state

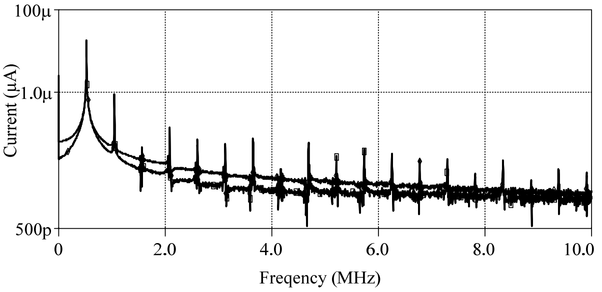


Fig. 9. Output frequency spectrum

Conclusion

The proposed current-mode quadrature oscillators consist of three OTAs and two grounded capacitors. The condition of oscillation and frequency of oscillation can be electronically and orthogonally controlled by adjusting the bias currents of the OTA. The proposed circuits use only grounded capacitors without any external resistor which is very appropriate to further develop into integrated circuit and have high output impedance that make the circuit able to directly drive load without additional current buffer. PSPICE simulation are included to verify the theoretical analysis. Simulated and theoretical results are in close agreement.

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