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A Simple Current-mode Sinusoidal Quadrature Oscillators Using Single DO-CDTA Based-on All-pass Filter

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ABSTRACT

This article presents the current-mode sinusoidal quadrature oscillator circuits based on all-pass filter. The oscillator circuits use only single DO-CDTA and two grounded capacitors, which are able to provide quadrature output signals. The condition of oscillation and frequency of oscillation can be controlled by adjusting the bias currents of the DO-CDTA. The circuits have high output impedance appropriate for cascade connection application in current mode technique, which is capable to directly drive load. The proposed circuits use only grounded capacitors without addition external resistor. This qualification is very appropriate for further development into an integrated circuit. The results of PSPICE simulation program are corresponding to the theoretical analysis.

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INTRODUCTION

The current design of the active building block (ABB) devices begins the role as being used in analog technology and analog signal processing. Therefore, ABB has been developed to be used as a pawn in the designing circuit. Additionally, to help design a circuit and reduce passive devices used in a design process, ABB development has been required to be more qualified for increasing parasitic resistances at input terminal, extended numbers of input and output terminals, etc.

Quadrature oscillator (QO) is one of oscillator which provides two sinusoidal signals with 90 degrees phase difference. Some applications for quadrature signal are employed in telecommunications for single-sideband modulators and quadrature mixers (Khan and Khawaja, 2000). In the last decade, a lot of papers in 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 (Toumazou *et al.*, 1990; Cam *et al.*, 2000).

According to recent research reviews on designing quadrature oscillator circuits based on all-pass filter using active building block, it is found that the most recommended qualifications for an appropriate circuit design: without addition external resistor, using grounded capacitors, circuit has high output impedance, and the pole frequency can be controlled by electronic method, and etc. From literature survey, it is found that several implementations of quadrature oscillators based on first order all-pass filter using active building block devices have been reported. Unfortunately, these reported circuits suffer from one more of weaknesses. For example, the pole frequency cannot be electronically controlled by adjusting the bias current. The proposed circuits use floating capacitor, which is not convenient for further fabrication in integrated circuit (Yuce *et al.*, 2008). The external resistors are excessively used and the proposed circuit consists of large number of passive components, and etc. The quadrature oscillators based on all-pass filter is compared with previously published quadrature oscillators based on all-pass filter; the results are shown in Table 1.

Basic Concept of DO-CDTA:

The Dual-output current differencing trans conductance amplifier (DO-CDTA) is an application for current differencing trans conductance amplifier (CDTA) (Biolek, 2003). The characteristics of the ideal DO-CDTA are represented by the following hybrid matrix:

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$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_{x1} \\ I_{x2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & g_{m1} & 0 \\ 0 & 0 & 0 & 0 & g_{m2} \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_x \\ V_z \\ V_z \end{bmatrix} \tag{1}$$

For CMOS DO-CDTA, the trans conductance can be written in Eq. (2). The symbol and equivalent circuit of the DO-CDTA are illustrated in Figs. 1(a) and (b), respectively. The CMOS internal construction of DO-CDTA is shown in Fig. 2 (Somdunyakanok *et al*., 2009).

$$g_{m1} = \sqrt{k_1 I_{B1}}, \quad g_{m2} = \sqrt{k_2 I_{B2}} \tag{2}$$

where $k_1 = \mu_n C_{ox} \left(W/L \right)_{11,12}$ and $k_2 = \mu_n C_{ox} \left(W/L \right)_{19,20}$

Here k is the physical parameter of CMOS transistor. μ_n is the mobility of the carrier, C_{ox} is the gate-oxide capacitance per unit area, W is the effective channel width and L is the effective channel length.

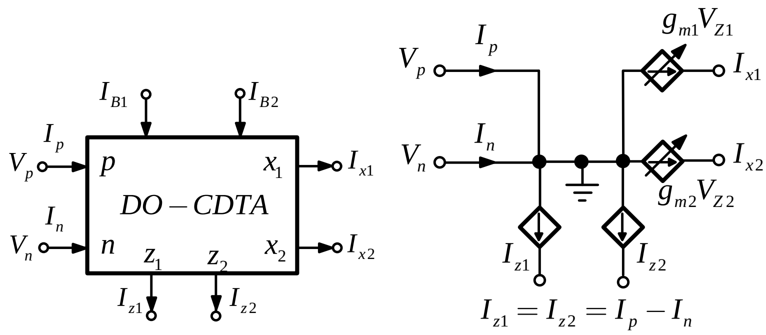

Fig. 1: DO-CDTA (a) Symbol (b) Equivalent Circuit

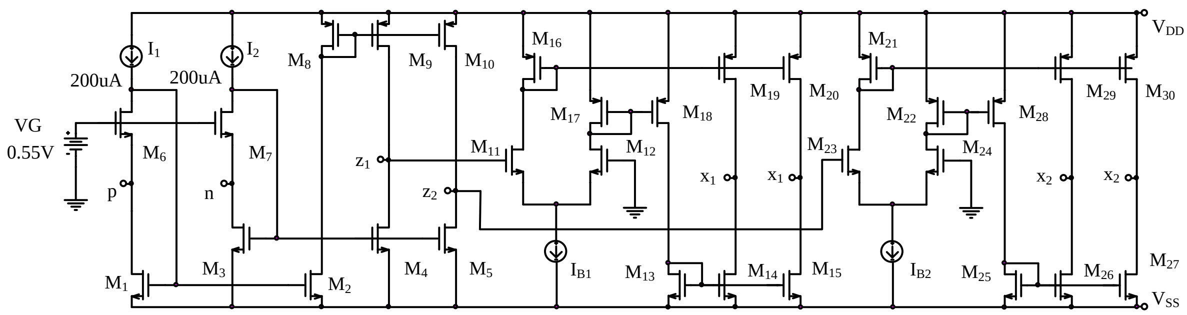

Fig. 2: Internal Construction of DO-CDTA

Proposed Current-mode Quadrature Oscillators:

The proposed quadrature oscillator circuits are shown in Figs. 3(a) and (b). The oscillators consist of single DO-CDTA and 2 grounded capacitors. The characteristic equation of the proposed circuits can be written in (3)

$$s^2 + s\frac{g_{m1}C_2 - g_{m2}C_1}{C_1 C_2} + \frac{g_{m1}g_{m1}}{C_1 C_2} = 0 \tag{5}$$

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

$$g_{m1} = g_{m2}, \quad C_2 = C_1 \tag{6}$$

and

$$\omega_{osc} = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{7}$$

It is found from (4) and (5), the condition of oscillation and frequency of oscillation are as follows:

$$I_{B1} = I_{B2}, \quad C_2 = C_1 \tag{8}$$

and

$$\omega_{osc} = \sqrt{\frac{\sqrt{k_1 I_{B1}}\sqrt{k_2 I_{B2}}}{C_1C_2}} \tag{9}$$

From circuits in Figs. 3(a) and (b), the current transfer functions can be written as

$$\frac{I_{o2}(s)}{I_{o1}(s)} = \frac{g_{m2}}{sC_2} \tag{10}$$

For sinusoidal steady state, (8) becomes

$$\frac{I_{o2}(j\omega)}{I_{o1}(j\omega)} = \frac{g_{m2}}{\omega_{osc}C_2}e^{-j90^0} \tag{11}$$

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

$$\phi = -90^0 \tag{12}$$

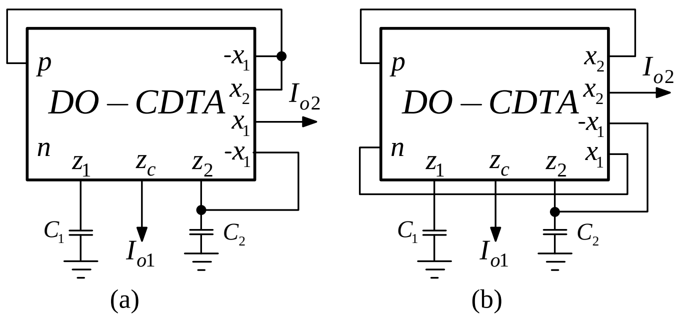

Fig. 3: Proposed Quadrature Oscillators

It is seen from (10) that the proposed current-mode quadrature oscillators can provide 2 sinusoidal signal output currents with 90^0 phase difference. Sensitivities of the active and passive of oscillator circuits are shown in (11).

$$S^{\omega_{osc}}_{C_1,C_2} = -\frac{1}{2}, \quad S^{\omega_{osc}}_{g_{m1},g_{m2}} = \frac{1}{2} \tag{13}$$

Analysis of Non-Ideal Case and Parasitic Component:

For non-ideality case, the characteristic equation of DO-CDTA in (1) is written as

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_{x1} \\ I_{x2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \alpha_p & -\alpha_n & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta_1 g_{m1} & 0 \\ 0 & 0 & 0 & 0 & \beta_2 g_{m2} \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_x \\ V_z \\ V_z \end{bmatrix} \tag{14}$$

The parameters α_p, α_n, β_1 and β_2 are the voltage/current transfer deviated from one, depending on the value of intrinsic impedances and temperatures. Consequently, these errors affect the sensitivity of temperature

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and the high frequency response of the proposed circuits. In non-ideal case the characteristic equation, the condition of oscillation and the frequency of oscillation from (3)-(5) are as follows:

Circuit 3(a):

$$s^2 + s\frac{\alpha_p\beta_1 g_{m1}C_2 - \alpha_p\beta_2 g_{m2}C_1}{C_1C_2} + \frac{\alpha_p\beta_1\beta_2 g_{m1}g_{m2}}{C_1C_2} = 0 \quad (15)$$

$$\alpha_p\beta_1 g_{m1}C_2 = \alpha_p\beta_2 g_{m2}C_1 \quad (16)$$

and

$$\omega_{osc} = \sqrt{\frac{\alpha_p\beta_1\beta_2 g_{m1}g_{m2}}{C_1C_2}} \quad (17)$$

Circuit 3(b):

$$s^2 + s\frac{\alpha_n\beta_1 g_{m1}C_2 - \alpha_p\beta_2 g_{m2}C_1}{C_1C_2} + \frac{\alpha_p\beta_1\beta_2 g_{m1}g_{m2}}{C_1C_2} = 0 \quad (15)$$

$$\alpha_n\beta_1 g_{m1}C_2 = \alpha_p\beta_2 g_{m2}C_1 \quad (16)$$

and

$$\omega_{osc} = \sqrt{\frac{\alpha_p\beta_1\beta_2 g_{m1}g_{m2}}{C_1C_2}} \quad (17)$$

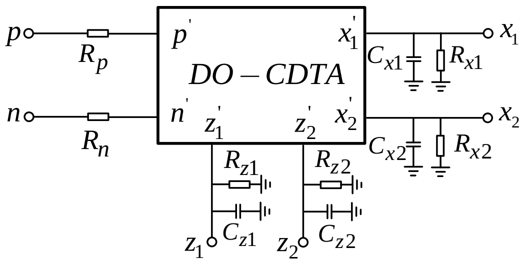

Fig. 4: Parasitic Resistances and Capacitances of the DO-CDTA

In addition, the influence of parasitic terminal impedances of DO-CDTA will be also considered. The parasitic resistances and capacitances of the DO-CDTA can be shown in Fig. 4. If the parasitic resistances at the z and x terminals are much greater than the parasitic resistances at p and n terminals $(R_z, R_x \gg R_p, R_n)$, in this case, the characteristic equation, the condition of oscillation and the frequency of oscillation of the current-mode quadrature oscillators, from (3)-(5) are represented as follows:

$$s^2 + s\frac{g_{m1}(C_2 + C_{z2} + C_{x1}) - g_{m2}(C_1 + C_{z1})}{(C_1 + C_{z1})(C_2 + C_{z2} + C_{x1})} + \frac{g_{m1}g_{m1}}{(C_1 + C_{z1})(C_2 + C_{z2} + C_{x1})} = 0 \quad (18)$$

$$g_{m1}(C_2 + C_{z2} + C_{x1}) = g_{m2}(C_1 + C_{z1}) \quad (19)$$

and

$$\omega_{osc} = \sqrt{\frac{g_{m1}g_{m1}}{(C_1 + C_{z1})(C_2 + C_{z2} + C_{x1})}} \quad (20)$$

Table 1: Comparison Between Various Oscillator Based-on First Order All-pass Filter.

Ref	Active element	Number of active element	Electronically control for CO and FO	Grounded C only	Number of R+C	Current-mode output
(Biolek *et al*., 2010)	VD-DIBA	2	Yes	Yes	0+2	No
(Bumrongchoke *et al*., 2010)	CDTA	1	Yes	Yes	1+2	Yes
(Cakir *et al*., 2005)	OTRA	3 (2 buffer)	No	No	7+2	No
(Chaturvedi *et al*., 2012)	DDCC	4	No	Yes	2+2	No
(Horng, 2005)	CCII	3	No	Yes	3+3	No
(Jaikla *et al*., 2008)	CDTA	1	Yes	No	1+2	Yes
(Jin *et al*., 2012)	CDTA	3	Yes	No	1+2	Yes
(Kacar *et al*., 2007)	DVCC	3	No	Yes	3+2	Yes
(Keskin *et al*., 2006a)	CDBA	2	No	No	4+4	No
(Keskin *et al*., 2006b)	CDTA	2	Yes	No	4+2	Yes
(Khan *et al*., 2007)	MOCCII	4	No	Yes	2+2	Yes
(Kiling *et al*., 2004)	OTRA	2	No	No	6+2	No
(Minaei *et al*., 2010)	DVCC	3	No	Yes	2+2	No
(Minhaj, 2009)	CCII	3	No	Yes	3+3	No
(Na Songkla *et al*., 2012)	CCCII	3	Yes	Yes	0+2	Yes
(Pandey *et al*., 2012)	DVCCTA	2	Yes	Yes	2+2	Yes
(Prommee *et al*., 2007)	OTA	2	Yes	Yes	4+2	Yes
(Sozen *et al*., 2011)	ICCII	2	No	Yes	2+2	No
(Tanaphatsiri *et al*., 2008)	CCCDTA	2	Yes	No	0+2	No
(Un *et al*., 2007)	CCII	2	No	No	5+3	Yes
(Un *et al*., 2008)	CCII	2	No	No	4+2	Yes
(Uygur *et al*., 2006)	CDTA	2	Yes	No	2+2	Yes
(Vosper *et al*., 1996)	CCII	3	No	Yes	5+2	No
Proposed Oscillator	DO-CDTA	1	Yes	Yes	0+2	Yes

CO: condition of oscillation
FO: frequency of oscillation

Table 2: Dimensions of CMOS Transistors.

Transistor	W(μm)	L(μm)
M1-M10	20	1
M11-M12, M23-M24	40	1
M13-M15, M25-M27	3	1
M16, M21	5.5	1
M17, M22	5.35	1
M18-M20, M28-M30	6.2	1

Simulation Results:

To verify the theoretical prediction of the proposed current-mode quadrature oscillators in Fig. 3, (for example, proposed quadrature oscillator in Fig. 3(a)) the PSPICE simulation was built with $C_1 = C_2 = 0.2\text{nF}$ and $I_{B1} = I_{B2} = 200\mu A$. The CMOS implementation of the internal construction of DO-CDTA used in simulation is shown in Fig. 2. The PMOS and NMOS transistors employed in the proposed circuit were simulated by using the parameters of $0.35\mu m$ TSMC CMOS technology (Yuce *et al*., 2006). The ratio of dimension of the transistors PMOS and NMOS is shown in Table 2.

The circuit was biased with $\pm 1.5V$ supply voltages. This yields oscillation frequency of 925.463 kHz, where the calculated value of this parameter from Eq. (9) yields 1.006 MHz (deviated by 8.005%). In this case, value of the parameter changed because the CMOS implementation used in the circuit deviated from the non-ideal properties and the effect of parasitic elements. Figures 5 and 6 show the simulated quadrature output waveforms during initial state and steady state, respectively. Figure 7 shows the simulation result of output spectrum. The results of the harmonics distortion (THD) of I_{o1} and I_{o2} are about 1.848% and 0.922%, respectively. In addition, the phase difference of the output currents I_{o1} and I_{o2} are approximately 89.70 degrees. The generated waveforms relationship within quadrature circuit has been verified by Lissagous Figure, shown in Fig. 8.

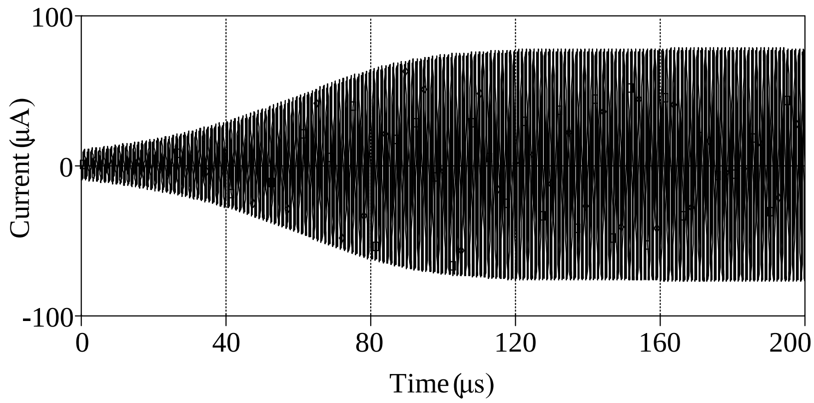

Fig. 5: Simulation Result of Output Waveforms during Initial State.

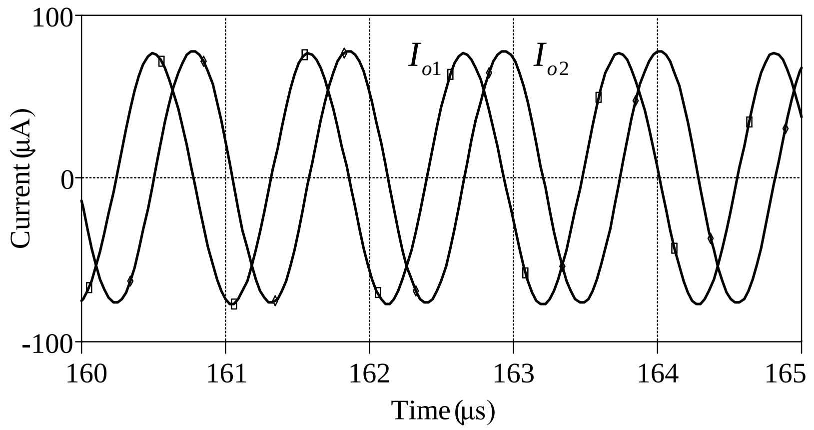

Fig. 6: Quadrature Output Waveforms.

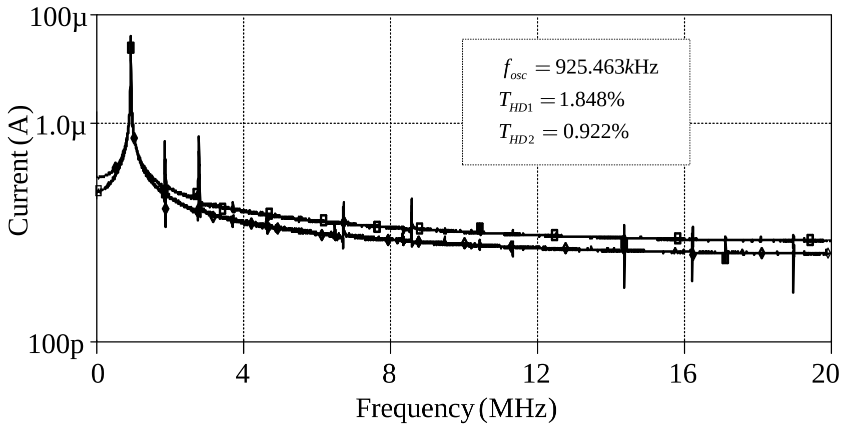

Fig. 7: Output Frequency Spectrum.

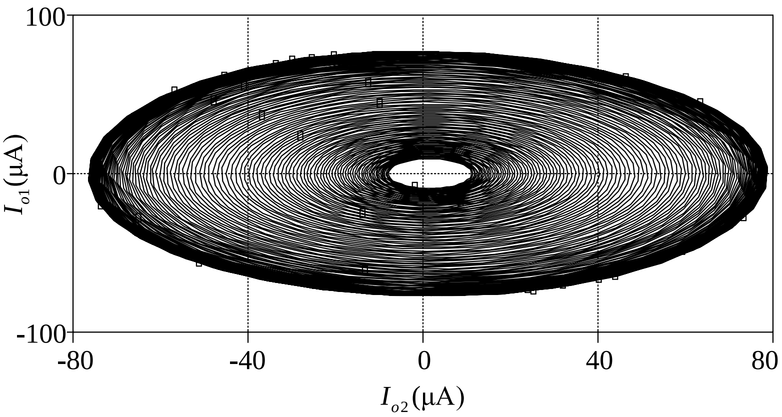

Fig. 8: Lissagous Figure.

Conclusion:

The current-mode quadrature oscillators have been presented in this paper. The proposed circuits is simple construction using only single active element (single DO-CDTA) and two grounded capacitors. In addition, the condition of oscillation and frequency of oscillation can be electronically controlled by adjusting the bias currents of the DO-CDTA. The proposed current-mode quadrature circuits use only grounded capacitors without any external resistor which is very appropriate to further develop into an integrated circuit (Bhushan *et al*., 1967; Soliman, 2008). Moreover, the oscillator circuits have high output impedances that make the circuit able to directly drive load without additional current buffer. PSPICE simulations are included to verify the theoretical analysis. Simulated and theoretical results are in close agreement.

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