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A New Four-Phase Quadrature Oscillator using Single DO-CFTA with Current Control

***Abstract**.This article presents a four-phase current-mode quadrature oscillator based on dual current follower transconductance amplifier (DO-CFTA). It uses single DO-CFTA and two grounded capacitors without additional external resistors. In addition, the condition and frequency of oscillation can be adjusted by electronic method by adjusting the bias currents of the DO-CFTA. It has high output impedance appropriate for cascade connection in current mode technique. Moreover, the oscillator uses only grounded capacitors, it is considerably appropriate for further developing into an integrated circuit. The results of PSPICE simulation program are corresponding to the theoretical analysis.*

Streszczenie.** WQ artykule opisano czterofazowy generator wykorzystujący trankonduktancyjny wzmacniacz DO-CFTA. Układ wykrzystuje pojedynczy wzmacniacz i dwa uziemione kondensatory bez zewnetrznych rezystorów. Generator może być strojony przez prąd pomocniczy wzmacniacza. Symulacje w programie PSPICE potwierdziły teoretyczne założenia. **Czterofazowy kwadraturowy generator wykrzystujący transkonduktancyjny wzmacniacz DO-CFTA

Keywords: Four phase; quadrature oscillator; current-mode; DO-CFTA.
Słowa kluczowe: układ DO-CFTA, czterofazowy generator, wzmacniacz transkonduktancyjny.

Introduction

The oscillator is important in electrical and electronic engineering. These circuits have been worldwide implemented like in communication system measuring tool systems, and signal processing. Quadrature oscillator (QO) is one of the oscillators that 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 designs 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].

According to recent research reviews on designing current-mode quadrature oscillator circuits 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 condition of oscillation and frequency of oscillation can be controlled by electronic method, and etc. In addition, a lot of papers have introduced oscillator circuits using single active element. The circuits using single active element can reduce the power consumption and the circuit construction was not difficult. From literature survey, it is found that several implementations of oscillator circuits employing single active element have been reported [3, 7-32]. Unfortunately, these reported circuits suffer from one more of weaknesses. For example, the proposed circuits use floating passive components [3, 9, 14, 17, 22, 28, 30-31], which are not convenient for further fabrication in integrated circuits [4]. The proposed circuits use more than two passive components and the external resistors are excessively used [3, 7-11, 13-14, 17-32], meanwhile, the circuit cannot be electronically adjusted. Moreover, the proposed oscillator circuits were designed based on current-mode technique cannot provide high output impedance [12, 21-22, 27, 32] and some of proposed circuits cannot give four-phase quadrature signals [3, 7-24, 26-32]. In addition, the circuits cannot present in current-mode technique [8, 10, 12, 25-28].

The purpose of this paper is to present the current-mode quadrature oscillator circuits based on DO-CFTA. The oscillator circuit uses single DO-CFTA and two grounded capacitors. The condition and frequency can be adjusted by electronic method. The oscillator can provide four phase quadrature output signals and it has high output impedance appropriate for cascade connection application in current mode technique which is capable of directly driving load. The circuit uses only grounded capacitors without additional external resisters. This qualification is convenient to for further fabrication in integrated circuits [5-6]. In addition, the proposed oscillator is designed based on block diagram which are easy and convenient for designing. Accordingly, the results of PSPICE simulation program are in correspondence with the theoretical analysis.

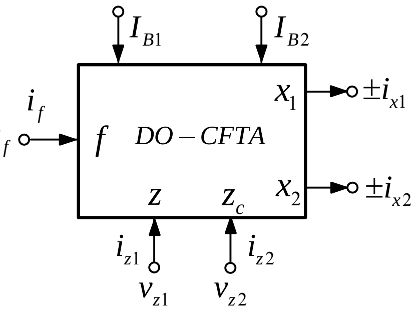


Fig. 1. Symbol of DO-CFTA

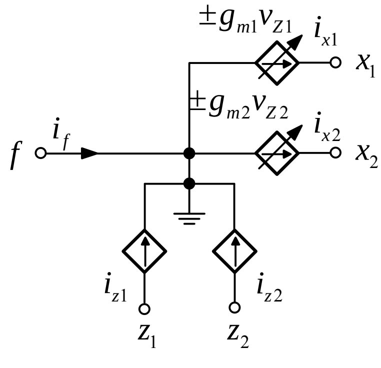


Fig. 2. Equivalent circuit of DO-CFTA

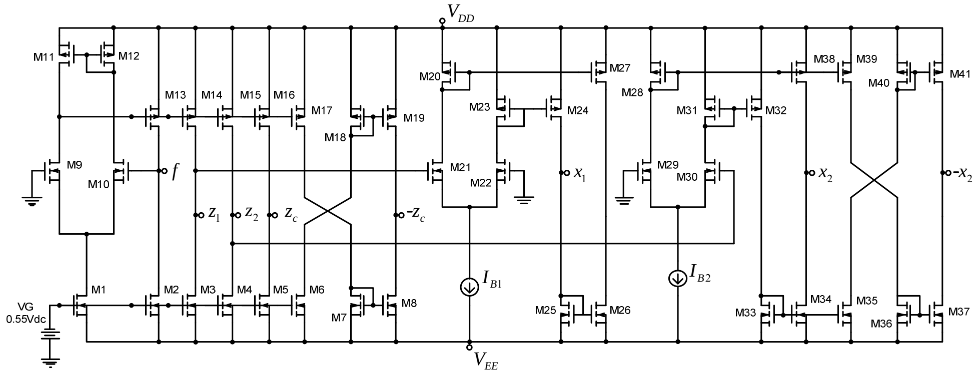


Fig. 3. Internal construction of DO-CFTA

Proposed Circuit

Basic Concept of DO-CFTA

The DO-CFTA is an application form current follower transconductance amplifier (CFTA) [34]. The characteristics of DO-CFTA are represented by the following hybrid matrix:

(1) $$\begin{bmatrix} v_f \\ i_{z1}, i_{z2}, i_{zc} \\ i_{x1} \\ i_{x2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & g_{m1} & 0 \\ 0 & 0 & 0 & g_{m2} \end{bmatrix} \begin{bmatrix} i_f \\ v_{x1}, v_{x2} \\ v_{z1} \\ v_{z2} \end{bmatrix}.$$

In some applications, the z terminal of DO-CFTA can be extended to utilize the current through z terminal which is called z_c (z-copy). For CMOS technology the transconductance (g_m) can be written in Eq. (2). The symbol and equivalent circuit of the DO-CFTA are illustrated in Figs. 1 and 2, respectively. The CMOS internal construction of DO-CFTA is shown in Fig. 3.

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

where

$$k_1 = \mu_n C_{ox} \left(\frac{W}{L}\right)_{21,22}, \quad k_2 = \mu_n C_{ox} \left(\frac{W}{L}\right)_{29,30}.$$

k_1 and k_2 are the physical parameter of CMOS transistor. μ_n is the average electron mobility in the channel, C_{ox} is the gate-oxide capacitance per unit area, W is the effective channel width and L is the effective channel length.In addition, the mobility are dependent on temperature and the doping level but is almost constant for a wide range of normally used doping level.

Table 1. Dimension of CMOS transistors

Transistor	W(µm)	L(µm)
M1-M8	12	1
M9-M10	2	1
M11-M19	20	1
M20, M28	5	1
M21-M22, M29-M30	40	1
M23, M31	5.25	1
M24-M27, M32-M41	6	1

Proposed Four-phase Quadrature Oscillator

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 circuit can be written in Eq. (3).

(3) $$s^2 + \frac{g_{m1}C_2 - g_{m2}C_1}{C_1 C_2} s + \frac{g_{m1} g_{m2}}{C_1 C_2} = 0.$$

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

(4) $$CO: \; g_{m1} = g_{m2}, \quad C_2 = C_1,$$

and

(5) $$FO: \; \omega_{osc} = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}}.$$

It is found from Eq. (4) and Eq. (5) that if $k_1 = k_2 = k$, the CO and FO are as follows:

(6) $$CO: \; I_{B1} = I_{B2}, \quad C_2 = C_1,$$

and

(7) $$FO: \; \omega_{osc} = \sqrt{\mu_n C_{ox} \left(\frac{W}{L}\right)_{21,22,29,30} \frac{\left(I_{B1} I_{B2}\right)^{\frac{1}{2}}}{C_1 C_2}}.$$

From Eqs. (6) and (7), it can be found that the CO and the FO can be electronically adjusted by varying I_{B1} and I_{B2}. From the circuit in Fig. 5, the functions of the output signal i_{o1}, i_{o2}, i_{o3} and i_{o4} are as follow:

(8) $$\frac{i_{o4}(s)}{i_{o1}(s)} = \frac{g_{m2}}{sC_2},$$

(9) $$\frac{i_{o4}(s)}{i_{o2}(s)} = -\frac{g_{m2}}{sC_2},$$

(10) $$\frac{i_{o3}(s)}{i_{o2}(s)} = \frac{g_{m2}}{sC_2},$$

and

(11) $$\frac{i_{o3}(s)}{i_{o1}(s)} = -\frac{g_{m2}}{sC_2}.$$

For sinusoidal steady state, Eqs. (8) to (11) becomes

(12) $$\frac{i_{o4}(j\omega_{osc})}{i_{o1}(j\omega_{osc})} = -\frac{jg_{m2}}{\omega_{osc} C_2},$$

(13) $$\frac{i_{o4}(j\omega_{osc})}{i_{o2}(j\omega_{osc})} = \frac{jg_{m2}}{\omega_{osc} C_2},$$

(14) $$\frac{i_{o3}(j\omega_{osc})}{i_{o2}(j\omega_{osc})} = -\frac{jg_{m2}}{\omega_{osc} C_2},$$

and

(15) $$\frac{i_{o3}(j\omega_{osc})}{i_{o1}(j\omega_{osc})} = \frac{jg_{m2}}{\omega_{osc} C_2}.$$

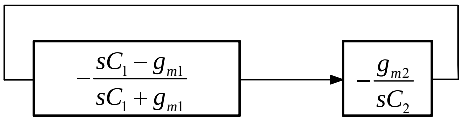


Fig. 4. Block diagram of quadrature oscillator

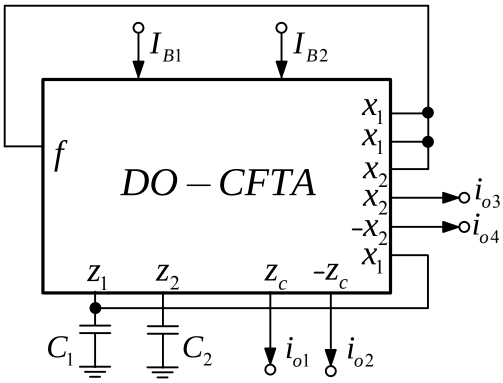


Fig. 5. Proposed current-mode quadrature oscillator

According to Eqs. (12) to (15), the proposed oscillator can provide four phase sinusoidal output current signals with 90^0. Sensitivity of oscillator circuit can be expressed as

$$S_{g_{m1}}^{\omega_{osc}} = S_{g_{m2}}^{\omega_{osc}} = \frac{1}{2}, \quad S_{C_1}^{\omega_{osc}} = S_{C_2}^{\omega_{osc}} = -\frac{1}{2}. \tag{16}$$

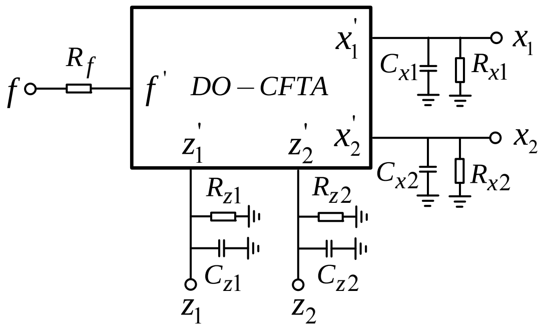


Fig. 6: Parasitic resistances and capacitances of DO-CFTA

Analysis of voltage and current transfer

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

$$\begin{bmatrix} v_f \\ i_{z1}, i_{z2}, i_{zc} \\ i_{x1} \\ i_{x2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ \alpha & 0 & 0 & 0 \\ 0 & 0 & \beta_1 g_{m1} & 0 \\ 0 & 0 & 0 & \beta_2 g_{m2} \end{bmatrix} \begin{bmatrix} i_f \\ v_{x1}, v_{x2} \\ v_{z1} \\ v_{z2} \end{bmatrix}. \tag{17}$$

The parameter α is the current transfer gain from f terminal to z terminal and β is the voltage transfer gain from z terminal to x terminal. In this case, the characteristic equation, the CO and the FO are as follows:

$$s^2 + \frac{\beta_1 \alpha g_{m1} C_2 - \beta_2 g_{m2} C_1}{C_1 C_2} s + \frac{\alpha \beta_1 \beta_2 g_{m1} g_{m2}}{C_1 C_2} = 0, \tag{18}$$

$$CO: \ \beta_1 \alpha g_{m1} C_2 = \beta_2 g_{m2} C_1, \tag{19}$$

and

$$FO: \ \omega_{osc} = \sqrt{\frac{\alpha \beta_1 \beta_2 g_{m1} g_{m2}}{C_1 C_2}}. \tag{20}$$

Analysis of the Parasitic Resistances and Capacitances

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

$$\left\{ \begin{array}{l} s^3 R_f C'C''C''' + s^2\left(C'C'' - R_f g_{m2} C'C'''\right) \\ + s\left(g_{m1}C'' - g_{m2}C'\right) + g_{m1} g_{m2} \end{array} \right\} = 0, \tag{21}$$

$$\begin{aligned} & R_f C'C''C'''\left(C'C'' - R_f g_{m2} C'C'''\right) \\ & = g_{m1} g_{m2}\left(g_{m1}C'' - g_{m2}C'\right) \end{aligned}, \tag{22}$$

and

$$\omega_{osc} = \sqrt{\frac{g_{m1} g_{m2}}{C'C'' - R_f g_{m2} C'C'''}}. \tag{23}$$

where

$$\begin{aligned} C' &= C_{z1} + C_{x1} + C_1 \\ C'' &= C_{z2} + C_2 \\ C''' &= C_{x2} + 2C_{x1} \end{aligned},$$

Simulation Results

To verify the theoretical prediction of the proposed four-phase current-mode quadrature oscillator in Fig. 5, the PSPICE simulation was set $C_1 = C_2 = 0.1\text{nF}$, $I_{B1} = 200\mu\text{A}$ and $I_{B2} = 210\mu\text{A}$, $V_{DD} = 1.5V$ and $V_{EE} = -1.5V$. The CMOS implementation of DO-CFTA and the dimension of the transistors used in simulation are shown in Fig. 3 and Table 1, respectively. The PMOS and NMOS transistors employed in the circuit were simulated by using the parameters of $0.35\mu m$ TSMC CMOS technology [33]. The simulation result found that the frequency is 1.9608MHz, where the calculated value from Eq. (7) about 2.0661MHz. Figs. 7 and 8 demonstrate the simulated output waveforms during initial state and steady state, respectively. Moreover, from the simulation can be found the phase of i_{o1}, i_{o2}, i_{o3} and i_{o4} are about 2.189%, 2.175%, 1.615% and 1.638%, respectively. Fig. 9 shows the simulation result of output spectrum; the results of the harmonics distortion (THD) of i_{o1}, i_{o2}, i_{o3} and i_{o4} are about 2.189%, 2.175%, 1.615% and 1.638%, respectively. The relationship between the generated waveforms of output signals have been verified by Lissagous Figure, shown in Fig. 10. In addition, the stability of proposed oscillator can be proved by using Monte-carlo simulation in which capacitance of C_1, C_2 and transconductance parameter ($\mu_n C_{ox}$) are 5% deviated. The simulation results are shown in Fig. 11.

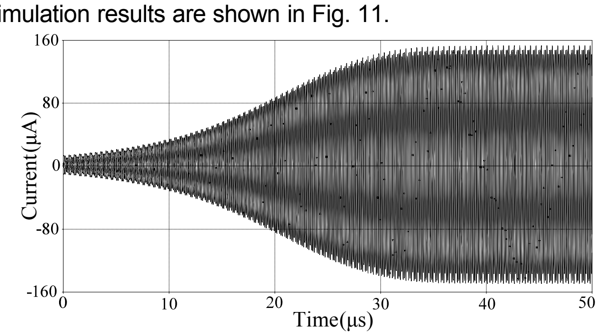


Fig. 7. Output waveforms during initial state

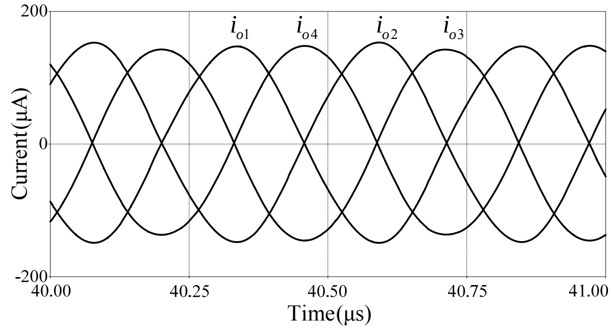


Fig. 8. Quadrature output waveforms in steady state

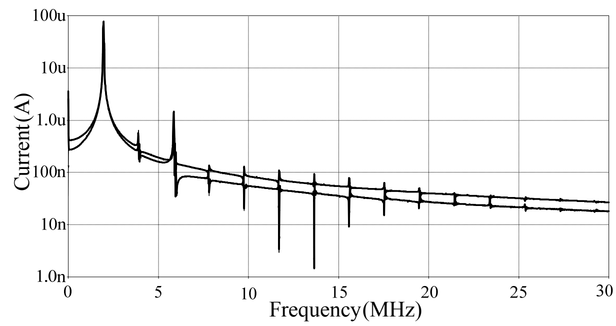
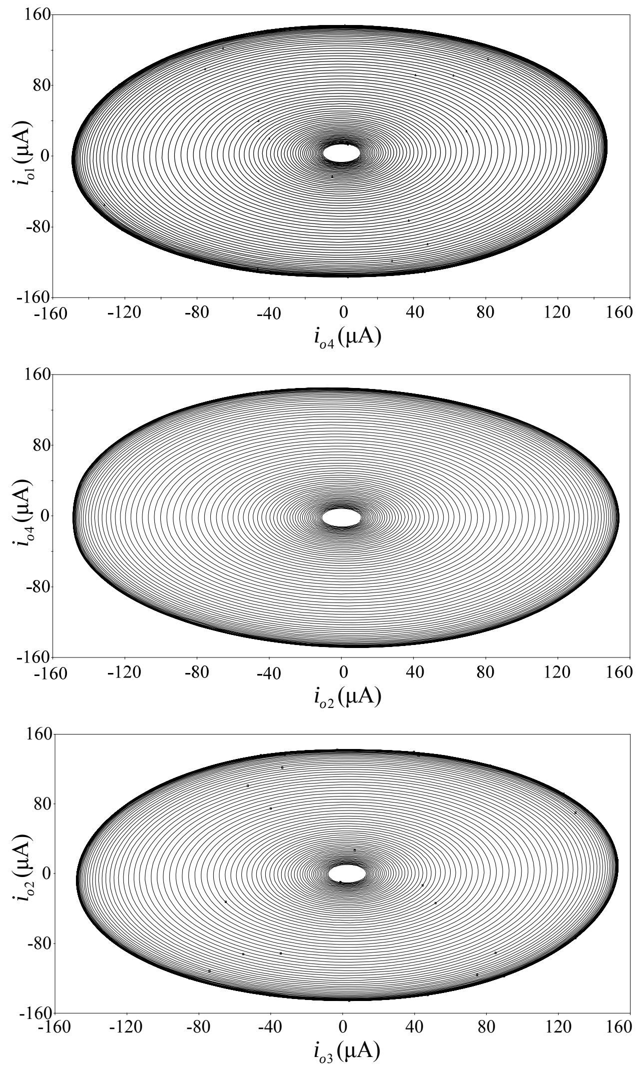


Fig. 9. Spectrum of output signals



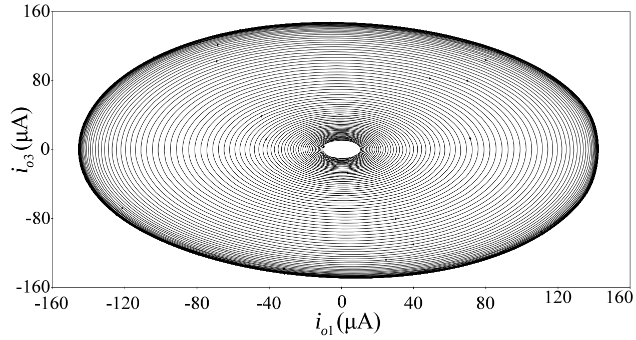


Fig. 10. Lissagous Figure

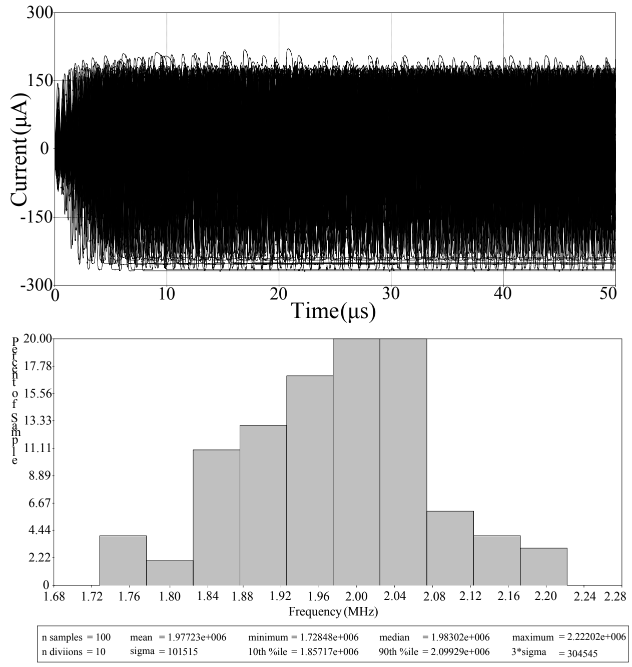


Fig. 11. Monte-Carlo simulation of QO

Conclusion

The four-phase current-mode quadrature oscillator using DO-CFTA has been presented in this paper. The circuit was consisted of single DO-CFTA and two grounded capacitors. The *CO* and *FO* can be electronically controlled by adjusting the bias currents. It is used only grounded capacitors without any external resistor. Additionnally, the outputs of oscillator have high impedance that make the circuit able to directly drive load without additional current buffer. The PSPICE simulation is included to verify the theoretical analysis. Simulated and theoretical results are in close agreement.

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