The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2018

Volume 4, Pages 67-73

IConTES 2018: International Conference on Technology, Engineering and Science

# A Novel Third Order Quadrature Oscillator

**Ihsan KARACAN**
Iskenderun Technical University

**Ahmet GOKCEN**
Iskenderun Technical University

**Abstract**: In this work, a third-order quadrature oscillator circuit is presented using an inverting current feedback operational amplifier (ICFOA), an active element that has attracted considerable attention in recent years. The topology consists of two ICFOA, three capacitors and three resistors. The proposed quadrature oscillator topology obtained by, a second-order low-pass filter with voltage mode, and a voltage-mode integrator with a cascaded closed loop. It has been observed that the implemented system works with the PSPICE simulation program and it overlaps with the theoretical results. The theoretical cut-off frequency is 1.326MHz and the cut-off frequency measured after the simulation is 1.350MHz. In the simulation, 0.35µm MOSIS parameter set and ICFOA CMOS structure are used. The proposed third order quadrature oscillator power consumption is 7.8mW.

**Keywords:** Analog integrated circuits, Quadrature oscillators, Inverting current feedback operational amplifier

## Introduction

Oscillators are one of the most important basic circuit blocks frequently used in electrical and electronics engineering applications. Among the sinusoidal oscillators, quadrature oscillators are frequently used in communication circuits, control and measurement systems because they can give two signals with $90^o$ phase difference from two different outputs (Horng et al., 2005). In the literature, several different active elements such as differential current transconductance amplifier (CDTA) (Horng, Lee & Wu, 2010), operational transresistance amplifier (OTRA) (R.Pandey, N.Pandey & Paul, 2012), second generation current conveyor (CCII) (Horng et al., 2007), differential voltage current conveyor (DVCC) (Chaturvedi & Maheshwari, 2013) based quadrature oscillators are available.

The presence of opposing input terminals of the inverted second generation current conveyor (ICCII) element makes this active element an important element for analog circuit designs (Ibrahim, 2004; Minaei, 2006; Soliman, 2008). However, the lack of a low impedance output lead creates disadvantages for voltage mode circuits. To this end, the application of voltage buffering to the high impedance output terminal of the inverting second generation current conveyor element results in low impedance output stage. This new result is called inverting current feedback operational amplifier (ICFOA) (Sözen, Gökçen, Kilinç & Çam, 2011). This new element is more suitable for voltage mode circuits due to its low impedance output.

In this work, a new third order quadrature oscillator design based on an ICFOA is presented. The presented structure is obtained by forming a closed loop by connecting the ICFOA based second order low pass filter and ICFOA based integrator with cascade connection. By the third order quadrature oscillator circuit, a sinusoidal waveform with $90^o$ phase difference signal can be obtained. Since the output of this quadrature oscillator circuit structure has low impedance, the synthesized circuit can be connected without additional circuit as a cascade. Thus, there is no difficulty in adapting to analogue signal processing circuits.

This work is organized as follows. In Section II, the function of ICFOA is briefly described and then the working principle of the proposed third order quadrature oscillator circuit is presented. The suitability of the



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presented circuit is verified by PSPICE simulation program in the Section III. It is seen that the results of simulation are closely related to the theoretical propositions. The results are also explained in Section IV.

## Circuit Description

The ICFOA circuit diagram is shown in Fig.1. The operation of the ICFOA can be characterized by the following equations;

$$\begin{aligned} I_y &= 0 \\ V_x &= -V_y \\ I_z &= \pm I_x \\ V_w &= V_z \end{aligned} \tag{1}$$

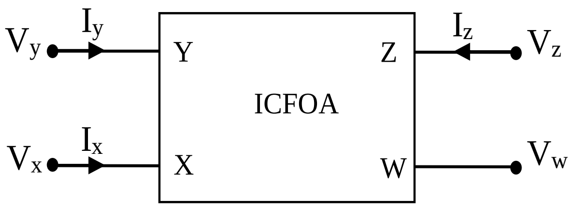


Figure 1. Circuit symbol of the ICFOA

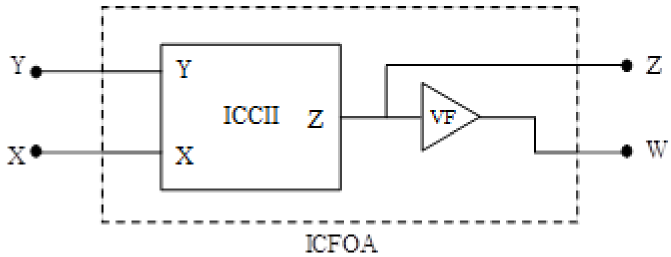


Figure 2. ICFOA implementation using an ICCII and a voltage buffer

The positive or negative sign in the Eq.(1) Iz = ± Ix indicates that the inverted current is the feedback amplifier with the feedback ICFOA (+) or ICFOA (-). ICFOA can be obtained using an ICCII and a voltage buffer (VF) as shown in Fig. 2. The CMOS structure of ICFOA can be obtained by cascading CMOS ICCII and VF (Ibrahim, 2002; Chiu, 1996; Manetakis, 1996).

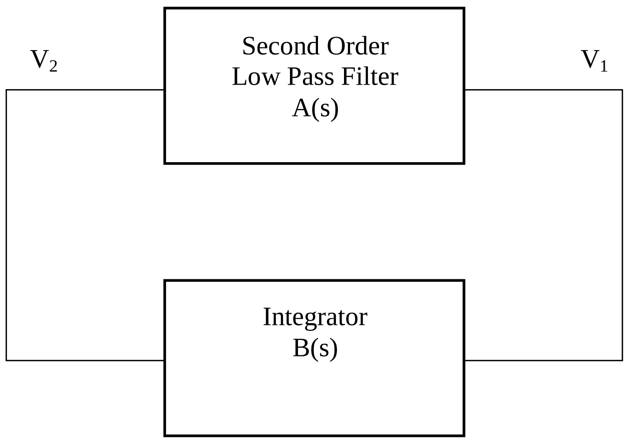


Figure 3. Block structure of quadrature oscillator

The general structure of the third order quadrature oscillator is shown in Fig.3. A second-order low-pass filter with transfer function A(s) and the integrator with transfer function B(s) is connected cascade by closed loop. The gain of this closed-loop implementation is A(s).B(s). The quadrature oscillator equation is given in Eq.(2).

$$A(s).B(s) = \frac{-a_3}{s(a_0 s^2 + a_1 s + a_2)} \cdot \tag{2}$$

The equations A(s) and B(s) expressed in Eq. (2) are as follows;

$$A(s) = \frac{1}{a_0 s^2 + a_1 s + a_2} \quad ve \;\; B(s) = -\frac{a_3}{s} \tag{3}$$

To obtain a continuous oscillation, the characteristic equation can derivate as below.

$$a_0 s^3 + a_1 s^2 + a_2 s + a_3 = 0 \tag{4}$$

The oscillation condition (CO) and the oscillation frequency (FO) are determined from Eq. (4).

$$CO: \; a_0 a_3 = a_1 a_2 \tag{5}$$

$$FO: \omega_0 = \sqrt{\frac{a_3}{a_1}} = \sqrt{\frac{a_2}{a_0}} \tag{6}$$

If this structure is formed and the condition is fulfilled, two sinusoidal signals with $90^o$ phase difference are obtained.

The proposed third order quadrature oscillator circuit consists of a second order low pass filter and integrator implemented with ICFOA as shown in Figs. 4 (a) and (b),respectively (Gökçen, Göçmen & Çam, 2012).

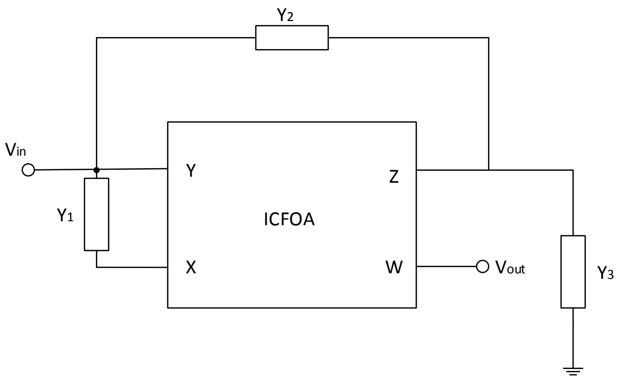


Figure 4(a).Second order lowpass filter

If the admittances are chosen as; $Y_1 = \frac{1}{\frac{1}{G_1} + \frac{1}{sC_1}}$ , $Y_2 = G_2 = 2G_1$ , $Y_3 = sC_3$ the second-order low-pass filter equation can be obtained as below.

$$A(S) = \frac{2G_1 G_1}{s^2 C_1 C_3 + s(2C_1 G_1 + C_3 G_1) + 2G_1 G_1} \tag{7}$$

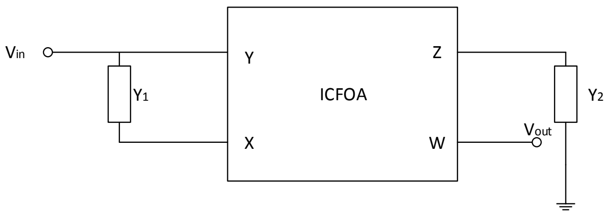


Figure 4(b). ICFOA based integrator

The admittances can be taken as $Y_1 = G_4 \quad Y_2 = sC_4$ and the integrator equation derived as ;

$$B(s) = \frac{-2G_4}{sC_4} \tag{8}$$

As a result of mathematical operations, the proposed function of the circuit is obtained as in Eq. (7).

$$s^3C_1C_3C_4 + s^2(2C_1C_4G_1 + C_3C_4G_1) + s2C_4G_1^2 + 4G_1^2G_4=0 \tag{9}$$

The third order quadrature oscillator circuit obtained when the required admittance values are used is shown in Fig. 5.

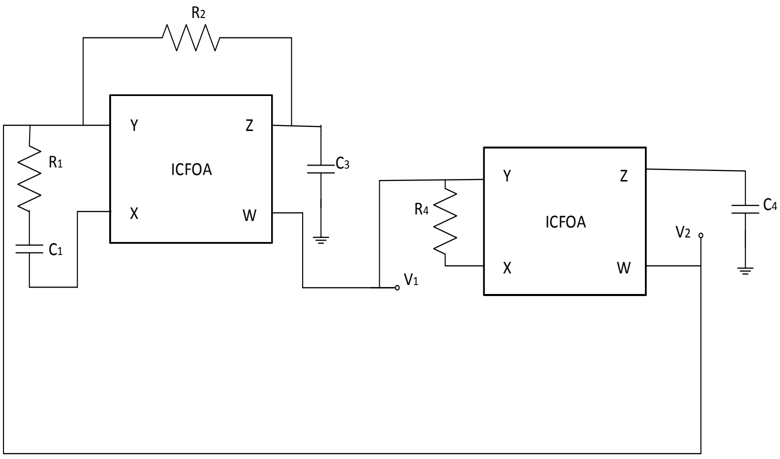


Figure 5. Third order quadrature oscillator circuit

The oscillation condition can be found from the characteristic function in Eq. (7).

$$CO : 2C_1C_3G_4 = (2C_1 + C_3)C_4G_1 \tag{10}$$

If $C_1 = C_4$ ,$2C_1 = C_3$ ve $G_1 = G_4$ are selected in Eq.(8) the oscillation frequency can be calculated as below.

$$FO : \omega_0 = \sqrt{\frac{G_1^2}{C_1^2}} \tag{11}$$

$$f_0 = \frac{1}{2\pi R_1 C_1} \tag{12}$$

## Simulation Results

The proposed third-order quadrature oscillator circuit is verified by the PSPICE simulation program using the CMOS structure of ICFOA. The CMOS implementation of ICFOA (+) is shown in Fig.6. This realization has been achieved by connecting the grounded differential current conveyor (DDCC) elements $Y_1$ and $Y_3$ with a voltage buffer (Ibrahim, 2002; Chiu, 1996; Manetakis, 1996). In the simulation, 0.35µm CMOS model parameter set is used. When the proposed quadrature oscillator circuit is selected as $R_1 = R_4 = 4K$, $R_2 = 2K$, $C_1 = C_4 = 30pF$, $C_3$=60pF the theoretical cut-off frequency is obtained as 1.326MHz. The measured cut-off frequency in the simulation is 1.350MHz.

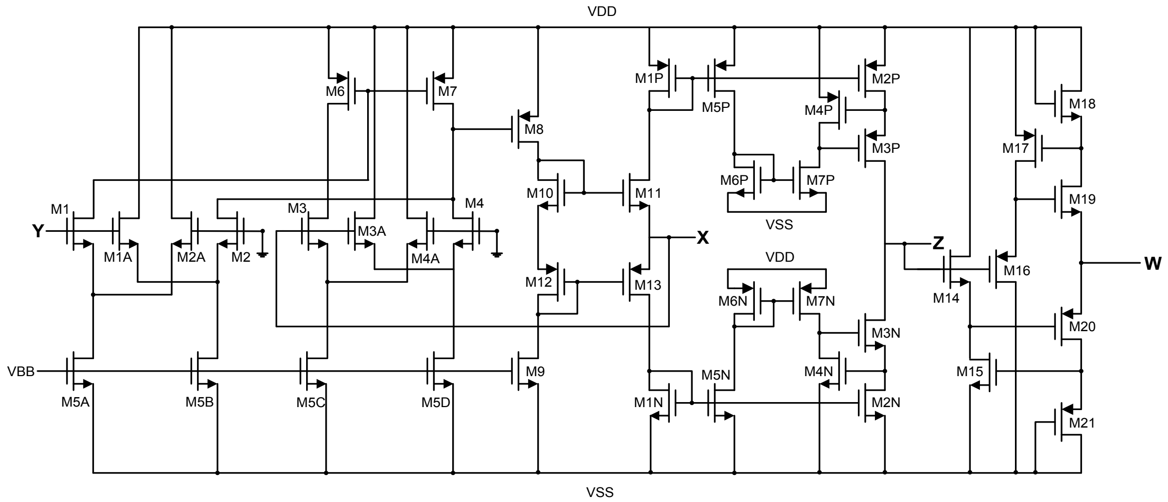


Figure 6. CMOS implementation of ICFOA

Fig. 7 and Fig. 8 show the output waveforms of the third-order quadrature oscillator circuit, the transient and the steady-state responses generated by the PSPICE simulation program, respectively.

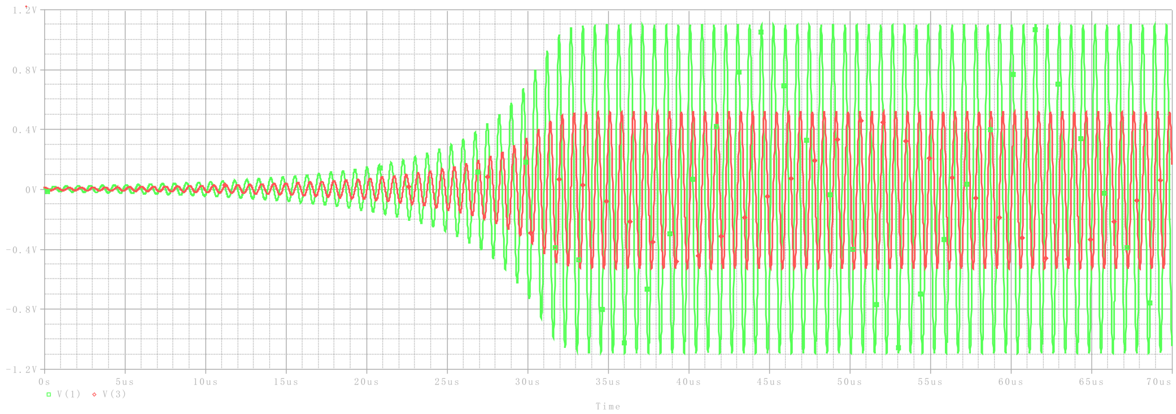


Figure 7. Transient waveform of the third order quadrature oscillator

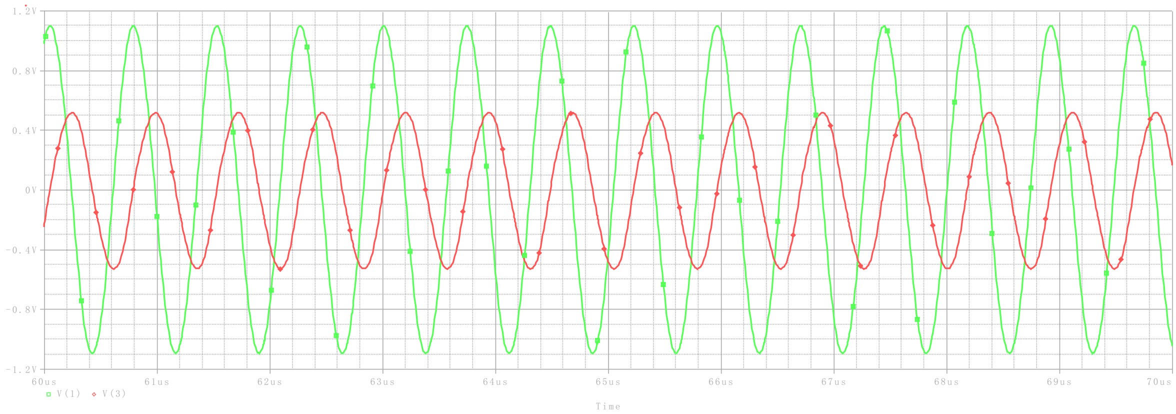


Figure 8. Steady state time waveform of the third order quadrature oscillator

The frequency response of the proposed third order quadrature oscillator circuit is shown in Fig.9. The Lissajous curve of the proposed third order quadrature oscillator is depicted in Fig.10.

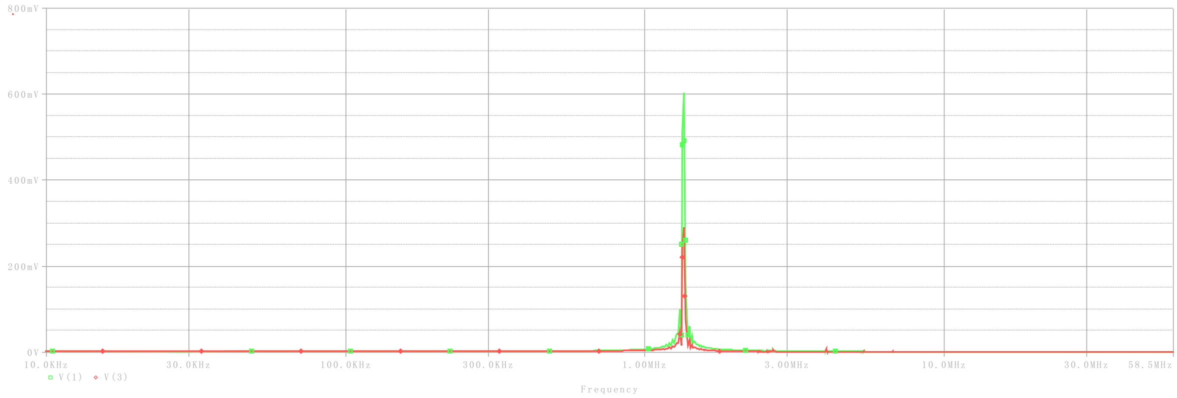


Figure 9. Frequency waveform of the third order quadrature oscillator

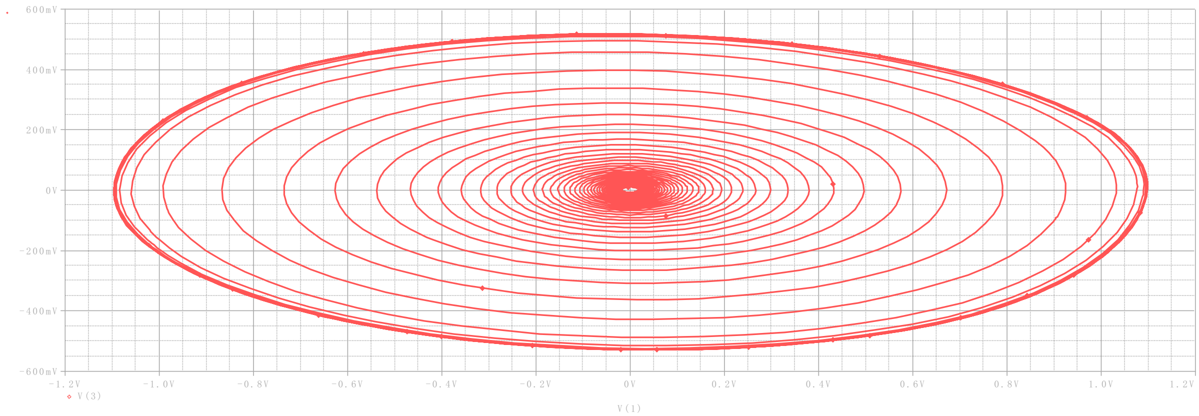


Figure 10. Lissajous waveform of the third order quadrature oscillator

## Conclusion

In this work, a third order quadrature oscillator based on voltage mode ICFOA is presented. To demonstrate the workability of the quadrature oscillator, a PSPICE simulation was performed using the ICFOA CMOS structure and 0.35μm CMOS process parameters. As a result of the theoretical analysis, the cut-off frequency is 1.326MHz and the cut-off frequency measured after the simulation is 1.350MHz. The power consumption of the power is 7.8mW. The simulated result confirms the theoretical results. The output of this quadrature oscillator circuit can be connected as a cascade without requiring an additional circuit since the output of the quadrature oscillator circuit has low impedance.

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## Author Information

**Ihsan Karacan**
The Graduate School of Engineering and Science,
Iskenderun Technical University,
Hatay / Turkey

**Ahmet Gokcen**
Computer Engineering, Iskenderun Technical University,
Hatay / Turkey
Contact E-mail: *ahmet.gokcen@iste.edu.tr*