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Research Article

Quadrature Oscillators Using Operational Amplifiers

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Two new quadrature oscillator circuits using operational amplifiers are presented. Outputs of two sinusoidal signals with 90° phase difference are available in each circuit configuration. Both proposed quadrature oscillators are based on third-order characteristic equations. The oscillation conditions and oscillation frequencies of the proposed quadrature oscillators are orthogonally controllable. The circuits are implemented using the widely available operational amplifiers which results in low output impedance and high current drive capability. Experimental results are included.

1. Introduction

Quadrature oscillator is used because the circuit provides two sinusoids with 90° phase difference, as, for example, in telecommunications for quadrature mixers and single-sideband generators or for measurement purposes in vector generators or selective voltmeters. Therefore, quadrature oscillators constitute an important unit in many communication and instrumentation systems [1–7].

Recently, several multiphase oscillators based on operational amplifiers were proposed [6–11]. Two-integrator loop technique was developed to realize quadrature oscillators using operational amplifiers [6]. In 1993 [7], Holzel proposed a new method for realizing quadrature oscillator, which consists of two all-pass filters and one inverter using operational amplifiers. Several multiphase oscillators using operational amplifiers were proposed in [8–11]. However, the quadrature output voltages cannot be obtained from [8–10]. The multiphase sinusoidal oscillator in [11] was constructed by cascading several first-order all-pass networks and unity-gain inverting networks. However, the block diagram of the quadrature oscillators in [11] was the same with [7].

In this paper, two new quadrature oscillator circuits using operational amplifiers are proposed. Outputs of two sinusoidal signals with 90° phase difference are available in each proposed circuit configuration. Both proposed quadrature oscillators are based on third-order characteristic equations. The oscillation conditions and oscillation frequencies of the proposed quadrature oscillators are orthogonally controllable. The circuits are implemented using the widely available operational amplifiers which results in low output impedance, high current drive capability (enabling the systems to drive a variety of loads), simplicity, and low cost.

2. Circuit Description

Figure 1 shows the first proposed quadrature oscillator circuit. The characteristic equation of the circuit can be expressed as

$$\begin{aligned} &s^3 C_1 C_2 C_3 R_1 R_2 R_3 R_4 R_5 + s^2 C_3 R_3 R_4 R_5 (C_1 R_1 + C_2 R_2) \\ &\quad + sC_3 R_3 R_4 R_5 + R_1 R_2 = 0. \end{aligned} \tag{1}$$

At $s = j\omega$, by equating the real and imaginary parts with zero, the oscillation condition and oscillation frequency can be obtained as

$$R_3 R_4 R_5 = \frac{C_1 C_2 R_1{}^2 R_2{}^2}{C_3 (C_1 R_1 + C_2 R_2)}, \tag{2}$$

$$\omega_o = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}. \tag{3}$$

From (2) and (3), the oscillation condition and oscillation frequency can be orthogonally controllable.

From Figure 1, the voltage transfer function from V_{o2} to V_{o1} is

$$\frac{V_{o2}}{V_{o1}} = -\frac{1}{sC_3R_4}. \tag{4}$$

The phase difference, ϕ, between V_{o2} and V_{o1} is

$$\phi = 90^\circ \tag{5}$$

ensuring the voltage V_{o2} and V_{o1} to be in quadrature. Because the output impedance of the operational amplifier is very small, the two output terminals, V_{o1} and V_{o2}, can be directly connected to the next stage, respectively.

The passive sensitivities of the quadrature oscillator in Figure 1 are all low and obtained as

$$S^{\omega_o}_{C_1,C_2,R_1,R_2} = -\frac{1}{2}. \tag{6}$$

Figure 2 shows the second proposed quadrature oscillator circuit. The characteristic equation of the circuit can be expressed as

$$\begin{aligned} &s^3C_1C_2C_3C_4C_5R_1R_2R_3 + s^2C_3C_4C_5R_3(C_1R_1 + C_2R_2) \\ &\quad + sC_3C_4C_5R_3 + C_1C_2 = 0. \end{aligned} \tag{7}$$

At $s = j\omega$, by equating the real and imaginary parts with zero, the oscillation condition and oscillation frequency can be obtained as

$$R_3 = \frac{{C_1}^2{C_2}^2R_1R_2}{C_3C_4C_5(C_1R_1 + C_2R_2)}, \tag{8}$$

$$\omega_o = \frac{1}{\sqrt{C_1C_2R_1R_2}}. \tag{9}$$

From (8) and (9), the oscillation condition and oscillation frequency can be orthogonally controllable.

From Figure 2, the voltage transfer function from V_{o2} to V_{o1} is

$$\frac{V_{o2}}{V_{o1}} = -\frac{1}{sC_3R_3}. \tag{10}$$

The phase difference, ϕ, between V_{o2} and V_{o1} is

$$\phi = 90^\circ \tag{11}$$

ensuring the voltage V_{o2} and V_{o1} to be in quadrature. Because the output impedance of the operational amplifier is very small, the two output terminals, V_{o1} and V_{o2}, can be directly connected to the next stage, respectively.

The passive sensitivities of the quadrature oscillator in Figure 2 are all low and obtained as

$$S^{\omega_o}_{C_1,C_2,R_1,R_2} = -\frac{1}{2}. \tag{12}$$

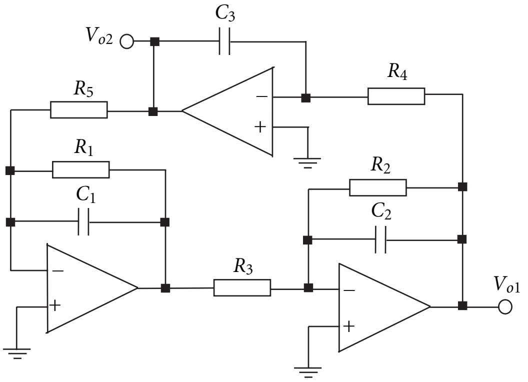

Figure 1: The first proposed quadrature oscillator circuit.

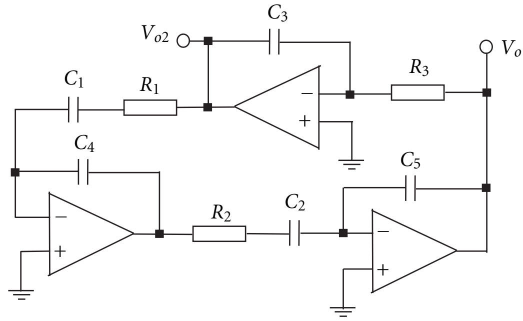

Figure 2: The second proposed quadrature oscillator circuit.

3. Experimental Results

The quadrature oscillator in Figure 1 was constructed using LF351s. Figure 3 represents the quadrature sinusoidal output waveforms of Figure 1 with $C_1 = C_2 = C_3 = 1$ nF, $R_1 = R_2 = R_4 = R_5 = 10\,\mathrm{k\Omega}$, $R_3 = 4.563\,\mathrm{k\Omega}$, and the power supply ±10 V. Figure 4 shows the experimental results of the oscillation frequency of Figure 1 by varying the value of R ($R = R_1 = R_2 = R_4 = R_5$) with $C_1 = C_2 = C_3 = 1$ nF, and R_3 was varied with R by (2) to ensure the oscillations will start.

The quadrature oscillator in Figure 2 was constructed using LF351s. Figure 5 represents the quadrature sinusoidal output waveforms of Figure 2 with $C_1 = C_2 = C_3 = C_4 = C_5 = 1$ nF, $R_1 = R_2 = 10\,\mathrm{k\Omega}$, $R_3 = 4.767\,\mathrm{k\Omega}$, and the power supply ±10 V. Figure 6 shows the experimental results of the oscillation frequency of Figure 2 by varying the value of R ($R = R_1 = R_2$) with $C_1 = C_2 = C_3 = C_4 = C_5 = 1$ nF, and R_3 was varied with R by (8) to ensure the oscillations will start.

4. Conclusions

Two new quadrature oscillator circuits based on operational amplifiers are presented. The proposed quadrature oscillators provide the following advantages: (i) two sinusoidal output signals of 90° phase difference are obtained simultaneously in each configuration; (ii) the oscillation conditions and oscillation frequencies are orthogonally controllable; (iii) the output terminals have the advantages of low output

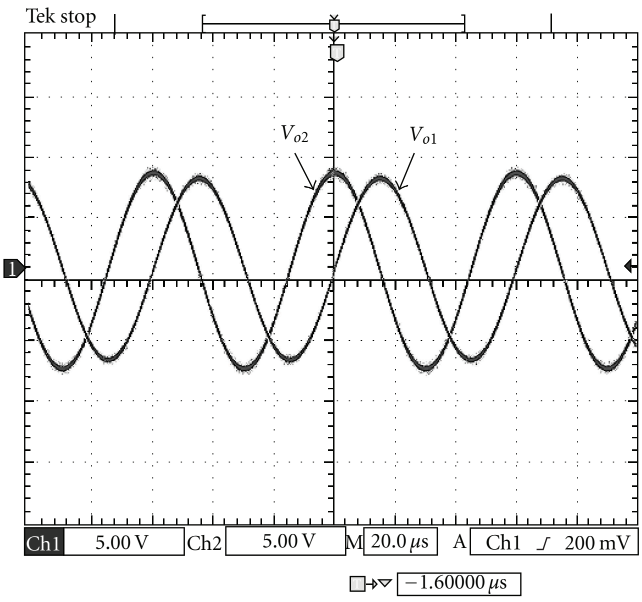

FIGURE 3: The experimental quadrature output waveforms of Figure 1.

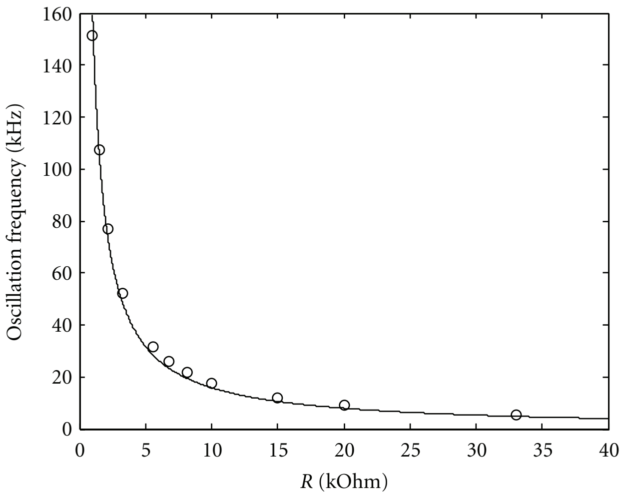

FIGURE 4: Experimental results of the oscillation frequency of Figure 1, which is obtained by varying the value of R; o o o, experimental results; —, ideal curve.

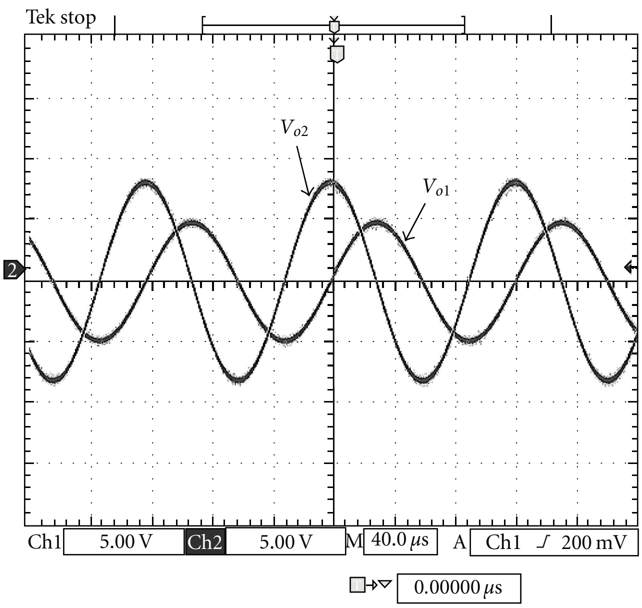

FIGURE 5: The experimental quadrature output waveforms of Figure 2.

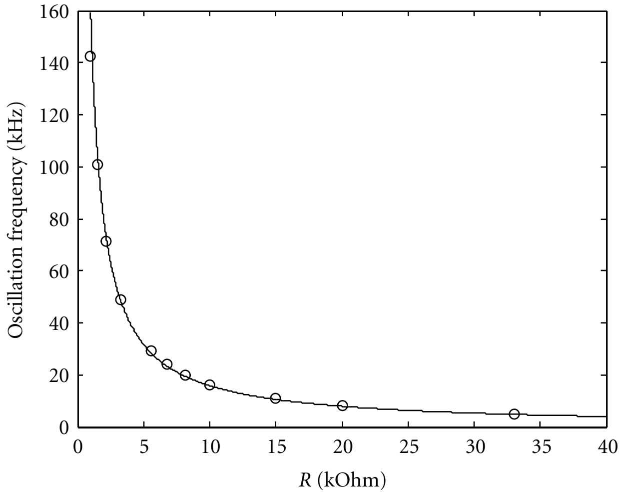

FIGURE 6: Experimental results of the oscillation frequency of Figure 2, which is obtained by varying the value of R; o o o, experimental results; —, ideal curve.

impedances and high current drive capability; (iv) simplicity and low cost; (v) the passive sensitivities are low.

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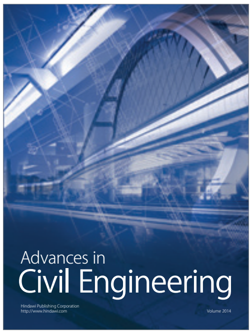
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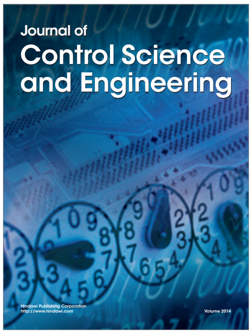
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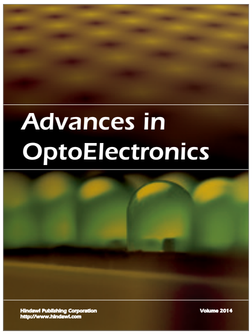
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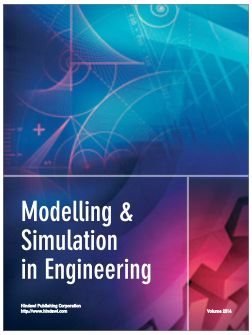
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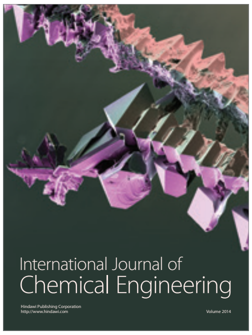
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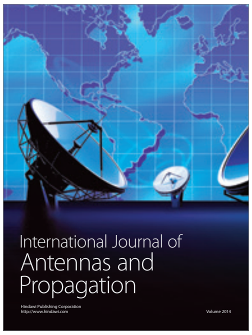
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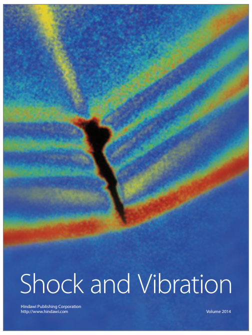
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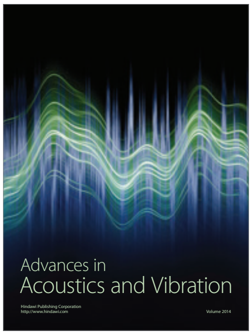
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