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New voltage-mode quadrature oscillator employing single DBTA and only grounded passive elements

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Abstract: A new voltage-mode quadrature oscillator employing single differential-input buffered and transconductance amplifier (DBTA), three grounded capacitors, and two grounded resistors is presented. The use of only grounded capacitors and resistors makes the proposed circuit ideal for integrated circuit implementation. Outputs of two sinusoidal signals with 90° phase difference are available in the proposed quadrature oscillator. The oscillation condition and the oscillation frequency are independently adjustable by different grounded passive elements. The passive and active sensitivities of the proposed circuit configuration are low. PSPICE simulation results are given to verify the theoretical analysis.

Keywords: differential-input buffered and transconductance amplifier (DBTA), voltage-mode, quadrature oscillator

Classification: Electron devices, circuits, and systems

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1 Introduction

The quadrature oscillator is a circuit that provides two sinusoids with 90° phase difference and is frequently used in various applications, i.e. in telecommunications for quadrature mixers and single-sideband generators, for measurement purposes in vector generators or selective voltmeters. Therefore, quadrature oscillators constitute an important unit in many communication and instrumentation systems [1, 2, 3, 4]. Recently, an application of current feedback amplifiers (CFAs), operational trans-resistance amplifiers (OTRAs), current differencing buffered amplifiers (CDBAs), unity-gain voltage (VF) and current followers (CF), current differencing transconductance amplifiers (CDTAs) on the realization of voltage-mode (VM) quadrature oscillators have received considerable attention. A number of oscillator solutions using up to three active CFAs are presented in [5] there the active element are used to make all the passive elements grounded. In this way, however, the total power consumption grows. Cascading two all-pass filters employing current conveyors a quadrature sinusoidal oscillator is constructed in [6]. This solution uses other six passive elements, where all are floating. Another solution of quadrature oscillator using CFAs can be found in [7], however the presented circuit employs not only grounded passive elements. In the literature, there can be also found oscillators using the OTRAs. As examples the solutions in [8, 9, 10] can be given. The behaviour of the OTRA, however, leads to the usage of floating passive elements. Other oscillators employing CDBAs, CFs, VFs, or CDTAs can be found in [11, 12, 13, 14]. In case the authors give the value of THD (total harmonic distortion) that is over 2% [8, 11]. Only in [12] the THD is 1.59%. The oscillators discussed, hence, require an excessive number of active and passive elements and are not attractive for integrated circuit implementation [15].

The aim of this letter is to present VM quadrature oscillator with minimal configuration that is ideal for integration. The proposed oscillator consists of single differential-input buffered and transconductance amplifier (DBTA) [16, 17] and only grounded passive elements, which provides quadrature outputs with 90° phase difference. Its oscillation condition and the oscillation frequency are independently adjustable. The properties of the proposed DBTA-based quadrature oscillator are analyzed theoretically and simulated.

2 Circuit description

The schematic symbol of a six-port differential-input buffered and transconductance amplifier (DBTA) [16, 17] is shown in Fig. 1 (a). It has been defined by the modification of the universal voltage conveyor (UVC) [18, 19, 20]. Using standard notation, the relationships between port currents and voltages of a DBTA are following:

$$v_p = v_y,\ v_n = v_y,\ i_y = 0,\ i_z = i_p - i_n,\ v_w = v_z,\ i_x = g_m v_z. \tag{1}$$

The proposed voltage-mode quadrature oscillator using single DBTA,

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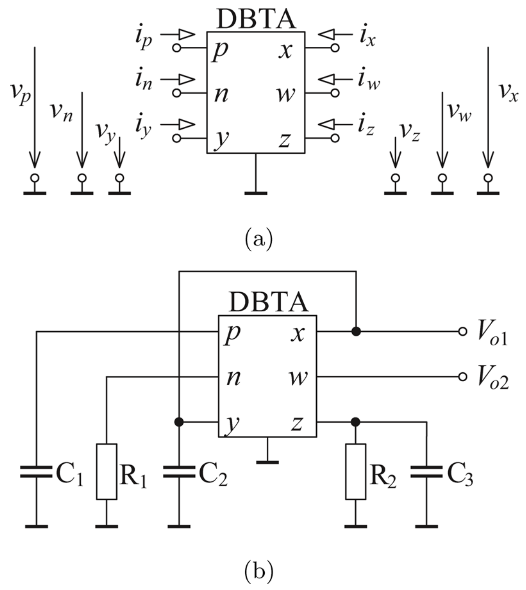

Fig. 1. (a) Schematic symbol of DBTA, (b) proposed DBTA-based voltage-mode quadrature oscillator.

three grounded capacitors, and two grounded resistors is shown in Fig. 1 (b).

The characteristic equation of the circuit can be expressed as:

$$s^2 C_2 C_3 + s(C_2 G_2 - C_1 g_{\mathrm{m}}) + G_1 g_{\mathrm{m}} = 0. \tag{2}$$

The oscillation condition and oscillation frequency ω_0 of this circuit can be obtained as:

$$C_1 R_2 = \frac{C_2}{g_{\mathrm{m}}}, \tag{3}$$

$$\omega_0 = \sqrt{\frac{g_{\mathrm{m}}}{C_2 C_3 R_1}}. \tag{4}$$

It should be noted that the condition of oscillation (3) can be controlled by adjusting the value of the resistor R_2 and/or the capacitor C_1 without affecting the oscillation frequency ω_0 (4). Analogously, oscillation frequency ω_0 can be adjusted by controlling the value of the resistor R_1 and/or the capacitor C_3 without affecting the oscillation condition. This means that the oscillation condition and condition frequency ω_0 are independently adjustable by different grounded resistor and/or capacitor. The use of grounded capacitors is particularly attractive for integrated circuit implementation [15]. Here can be mentioned that by replacing appropriate resistor with FET-based voltage-controlled resistor (VCR) [21], the oscillation condition and the condition frequency ω_0 of this solution can be adjusted electronically, which is also a particular advantage of the proposed circuit.

From Fig. 1 (b), the voltage transfer function between two quadrature outputs V_{o1} and V_{o2} can be expressed as:

$$\frac{V_{o2}}{V_{o1}} = -\frac{g_{\mathrm{m}}}{sC_2}, \tag{5}$$

where the phase difference of $\phi = 90°$, ensuring the voltage V_{o1} and V_{o2} to be in quadrature.

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3 Non-ideal effects

Taking into account the non-idealities of DBTA, relationships of the terminal currents and voltages given in (1) can be rewritten as:

$$v_p = \beta_p v_y,\ v_n = \beta_n v_y,\ i_y = 0,\ i_z = \alpha_p i_p - \alpha_n i_n,\ v_w = \gamma v_z,\ i_x = g_m v_z, \quad (6)$$

where $\beta_j = 1 - \varepsilon_{vj}$, $\alpha_j = 1 - \varepsilon_{ij}$ for $j = p, n$ and $\gamma = 1 - \varepsilon_v$. Here, ε_{vj} and ε_v ($|\varepsilon_{vj}|$, $|\varepsilon_v| \ll 1$) denote voltage tracking errors and ε_{ij} ($|\varepsilon_{ij}| \ll 1$) denote current tracking errors of DBTA, respectively. The characteristic equation becomes:

$$s^2 C_2 C_3 + s(C_2 G_2 - \alpha_p \beta_p C_1 g_m) + \alpha_p \alpha_n \beta_n G_1 g_m = 0. \quad (7)$$

In this case, the modified oscillation condition and oscillation frequency ω_0 can be expressed as:

$$\alpha_p \beta_p C_1 R_2 = \frac{C_2}{g_m}, \quad (8)$$

$$\omega_0 = \sqrt{\frac{\alpha_p \alpha_n \beta_n g_m}{C_2 C_3 R_1}}. \quad (9)$$

It should be noted from (8) and (9) that the oscillation condition and oscillation frequency ω_0 of the proposed quadrature oscillator are slightly altered by the effects of the DBTA current- and voltage-tracking errors. However, they can still be controlled independently.

The active and passive sensitivities of the quadrature oscillator parameters are:

$$S^{\omega_0}_{\alpha_p,\alpha_n,\beta_n,g_m} = -S^{\omega_0}_{C_2,C_3,R_1} = \frac{1}{2}. \quad (10)$$

From Eq. (10) it is evident that the circuit has optimum sensitivity performance in the sense that all values are equal to 0.5 in magnitude.

4 Simulation results

In order to confirm the above given theoretical analysis, the proposed DBTA-based quadrature oscillator in Fig. 1 (b) has been simulated using PSPICE software. In simulations, the DBTA circuit was constructed with three commercially available current feedback amplifiers (CFAs) AD844 ICs of Analog Devices [22, 23], as shown in Fig. 2 (a). Note that, the OTA [3] in the structure [16, 17] of the DBTA is replaced by ^{3}CFA, where the transconductance g_m is defined by resistor R_K [24]. The model parameters of AD844 were taken from the built-in library (AD844A/AD), and the supply voltages were taken as ±12 V. To obtain the sinusoidal output waveform with the oscillation frequency of $f_0 = \omega_0/2\pi \cong 15.92$ kHz, the following passive component values have been chosen: $R_1 = R_2 = 10\,\text{k}\Omega$, $R_K = 1/g_m = 10\,\text{k}\Omega$ and $C_1 = C_2 = C_3 = 1\,\text{nF}$, where $R_2 \cong 10.5\,\text{k}\Omega$ was designed to be larger than $R_K = 1/g_m$ to ensure the oscillations would start.

The simulated sinusoidal outputs V_{o1} and V_{o2} of the proposed quadrature oscillator is shown in Fig. 2 (b). From the simulation results, the oscillation frequency of $f_0 \cong 15.61$ kHz is obtained, which agrees very well with the

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theoretical analysis. Fig. 2 (c) shows the simulated frequency spectrum of the outputs V_{o1} and V_{o2}. The total harmonic distortion (THD) is equal to 1.63%. The control of f_0 via resistor R_1 without affecting the oscillation condition is shown in Fig. 3.

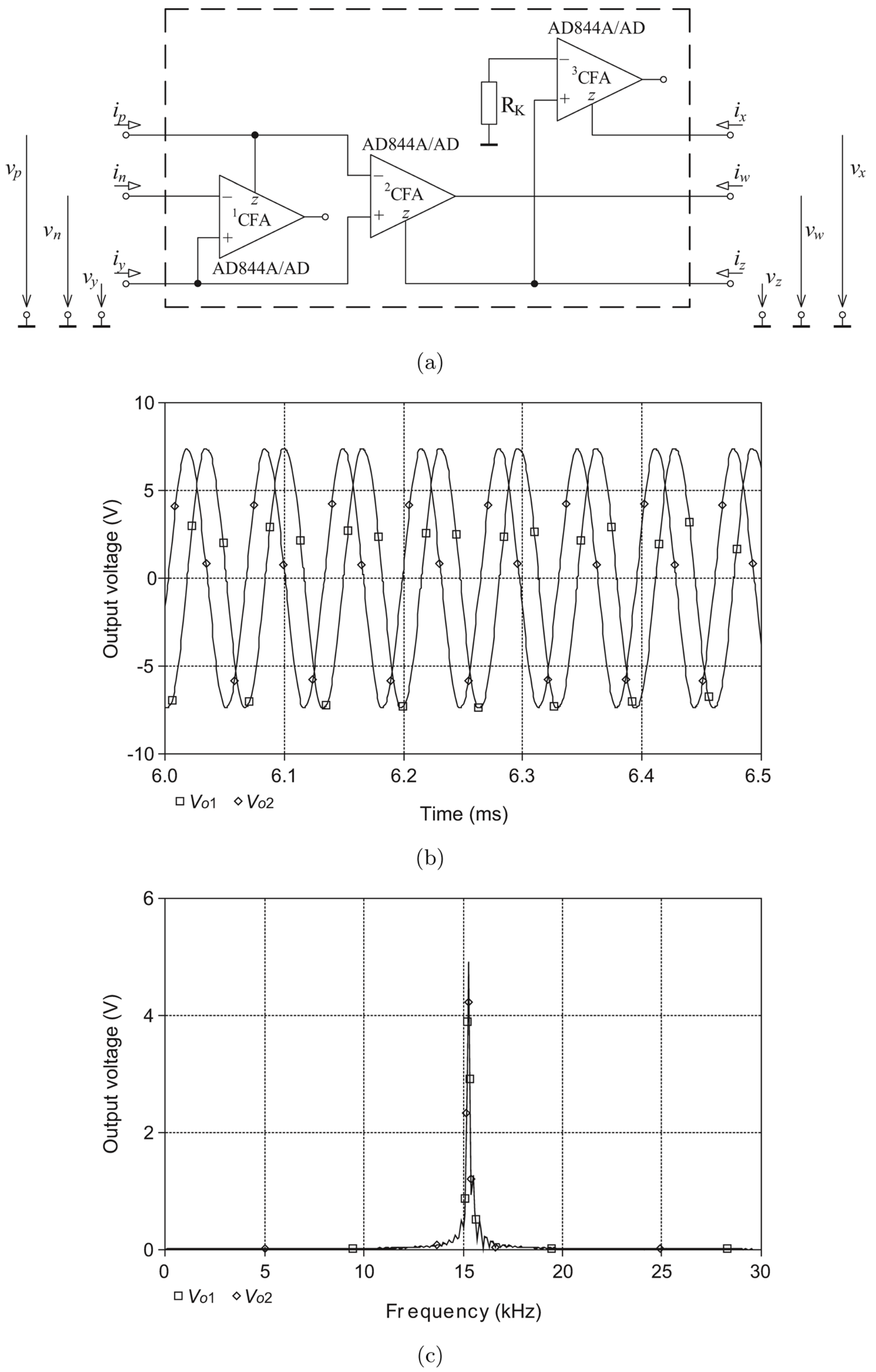

Fig. 2. (a) Possible implementation of DBTA using three CFAs (AD844s); The simulated quadrature outputs V_{o1} and V_{o2} of the proposed oscillator: (b) output waveforms, (c) output spectrums.

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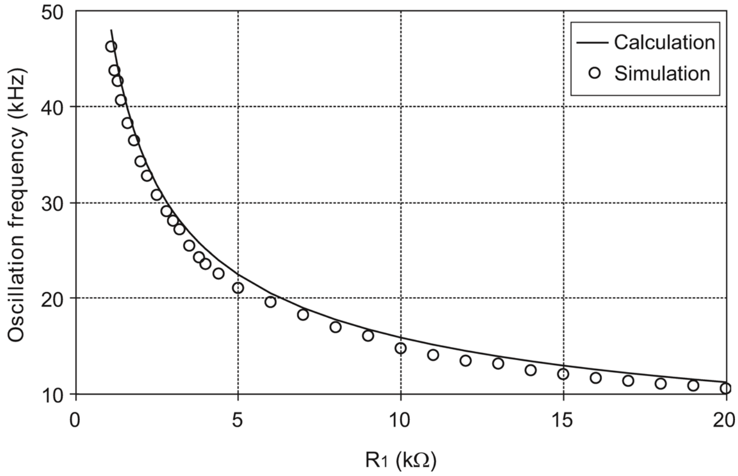

Fig. 3. Calculation and simulation results of the oscillation frequencies by varying the value of the resistor R_1.

5 Conclusion

In this letter, the first voltage-mode quadrature oscillator using the novel versatile active function block for analog signal processing, namely the differential-input buffered and transconductance amplifier (DBTA), has been demonstrated. The proposed oscillator consists of single DBTA, three grounded capacitors and two grounded resistors. The use of only grounded passive elements makes the proposed circuit attractive for integrated circuit implementation. The circuit can provide two quadrature outputs with 90° phase difference. Its oscillation condition and oscillation frequency can be controlled separately via different grounded resistor and/or capacitor. In addition, the sensitivities of the proposed circuit are low. The possible realization of the DBTA using three commercially available AD844 ICs of Analog Devices has been shown. PSPICE simulation results are in good agreement with the theoretical analysis and support the feasibility of the proposed circuit.

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