Explicit-Current-Output Quadrature Oscillator Using Second-Generation Current Conveyor Transconductance Amplifier

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Abstract. *This paper presents a novel quadrature sinusoidal oscillator using second-generation current conveyor transconductance amplifier as an active building block. The proposed circuit employs only a single second-generation current conveyor transconductance amplifier, four passive components. The proposed circuit offers the advantages of independent control of the condition of oscillation and frequency of oscillation, availability of two explicit quadrature current outputs and two quadrature voltages, use of all-grounded passive elements and low active and passive sensitivities. The workability of the proposed circuit is confirmed by SPICE simulations.*

Keywords

Single-element-controlled oscillators (SECOs), single-resistance-controlled oscillators (SRCOs), quadrature oscillators, second-generation current conveyor transconductance amplifier (CCII-TA).

1. Introduction

The application and advantages in the realization of RC sinusoidal oscillators using current conveyors (CCs) and current-feedback operational amplifiers (CFOAs) have received considerable attention [1]-[10]. Among them, the class of sinusoidal oscillators providing non-interactive (independent) control of the condition of oscillation (CO) and the frequency of oscillation (FO) is of special interest. Single-element-controlled oscillators (SECOs) and single-resistance-controlled oscillators (SRCOs) find numerous applications in communication, control systems, signal processing, instrumentation and measurement systems, see [10] and the references cited therein.

All of the oscillator realizations in [1]-[10], make use of at least five passive components and do not provide any inherent electronic control to either the CO or the FO. In this respect, the use of electronically controlled ABBs are advantageous since they not only provide electronic tunability to the circuit parameters, compensate for the process tolerances, but also reduce the use of external linear resistors. A new SRCO has been proposed by Prasad et al. in [11], where the proposed circuit uses a single current differencing transconductance amplifier (CDTA), only four passive components and yet provides independent CO and FO control. However, the proposed circuit in [11] uses floating passive components (including a floating capacitor), which is not convenient for IC implementation [12].

The purpose of this paper is to present a new sinusoidal oscillator using second-generation current conveyor transconductance amplifier (CCII-TA). The proposed circuit offers the following advantageous features:

- The circuit employs only a single CCII-TA and a bare minimum of four passive components and yet provides non-interactive (independent) control of the CO and the FO. The circuit is canonic and the component count is both necessary and sufficient to provide non-interactive controls of the CO and the FO.
- The circuit uses all-grounded passive components (AGPEs), which is suitable for monolithic integration [13]-[14]. This is because grounded capacitor circuits can compensate for the stray capacitances at their nodes.
- The circuit provides two quadrature current outputs for explicit utilization and presence of two quadrature voltage signals. This makes the circuit suitable to be used in quadrature mixers or other communication systems wherein there is a requirement of multiple sinusoids which are 90° phase shifted, e.g. quadrature mixers and single sideband modulators, see [15] and references cited therein. The presence of explicit-current-outputs (ECOs) had not been investigated previously in [1]-[10].
- The circuit enjoys low active and passive sensitivities.

With all the above stated advantages, the proposed circuit is unique addition to the current repertoire of SECOs and mixed-mode quadrature oscillators (QOs). To verify the workability, the SPICE simulation results of a bipolar transistor implementation of the proposed circuit have been included.

2. Proposed Circuit

The second-generation current conveyor transconductance amplifier (CCII-TA) essentially consists of a multiple-output second-generation current conveyor (MO-CCII) at the front end and a balanced operational transconductance amplifier (BOTA) at the rear-end. This ABB is different from the one proposed by Prokop et al. in [16] and [17], wherein a third-generation current conveyor (CCIII) is present at the input stage. Recently, a practical implementation of a simplified CCII-TA using commercially available active devices has been presented by Jaikla et al. in [18]. The ABB has also been described in section 2.3 of [19]. The CCTA used in this paper is ideally characterized by the following equations

$$I_y = 0, \quad V_x = V_y, \quad I_z = I_{z_1} = I_{z_2} = I_x,$$
$$I_{o+} = -I_{o-} = g_m V_z \tag{1}$$

where g_m represents the transconductance of the BOTA stage. The circuit symbol of CCII-TA is shown in Fig. 1. A possible bipolar implementation of CCII-TA is provided in Fig. 2, where $g_m = \frac{I_{B2}}{2V_T}$, I_{B2} is the input bias current and V_T is the thermal voltage whose value is 26 mV at 27 °C.

The proposed mixed-mode QO using CCII-TA and AGPEs is shown in Fig. 3. The circuit has been derived using the classical methodology of creating three resistor two capacitor based SRCOs as described in [3], [5] and Fig. 3(a), 3(b) of [6]. Using (1) and doing routine circuit analysis yields the following characteristic equation

$$s^2 C_1 C_2 R_1 R_2 + s C_1 (R_1 - R_2) + g_m R_2 = 0. \tag{2}$$

From (2), the condition of oscillation (CO) is

$$\text{CO}: \quad R_2 = R_1, \tag{3}$$

and the frequency of oscillation (FO) is

$$\text{FO}: \quad f_0 = \frac{1}{2\pi}\sqrt{\frac{g_m}{C_1 C_2 R_1}} = \frac{1}{2\pi}\sqrt{\frac{I_{B2}}{2 C_1 C_2 R_1 V_T}}. \tag{4}$$

It is clear from (3) and (4) that CO can be controlled independently of FO by changing R_2 and the FO can be controlled by means varying the transconductance g_m and thus by the bias current I_{B2}. Thus, the circuit provides non-interactive (independent) control of the CO and the FO and could be used as a variable frequency oscillator (VFO). The two marked explicit quadrature current outputs in Fig. 3 are related as

$$I_{o1} = jk' I_{o2}, \quad where \quad k' = \frac{\omega_0 C_1}{g_m}. \tag{5}$$

The two marked quadrature voltages in Fig. 2 are related as

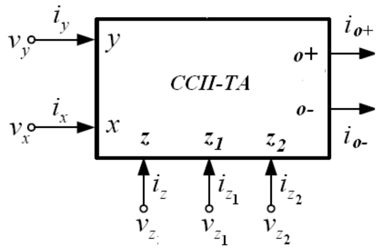

Fig. 1. The circuit symbol of CCII-TA.

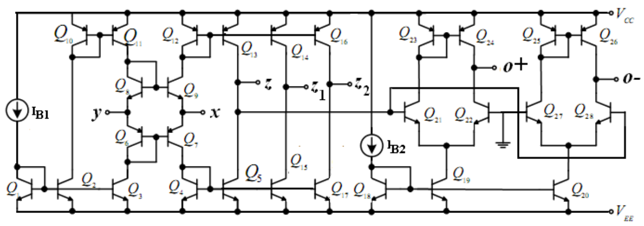

Fig. 2. A possible bipolar implementation of the CCII-TA.

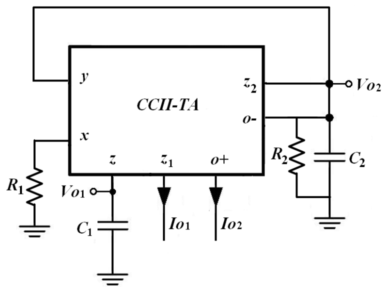

Fig. 3. The proposed mixed-mode quadrature oscillator using CCII-TA.

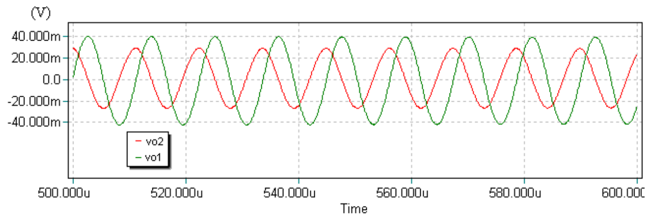

Fig. 4. The steady state time domain waveforms for the quadrature voltages.

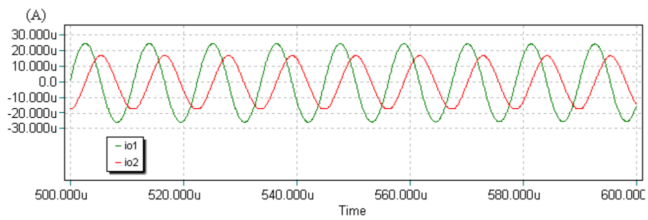

Fig. 5. The steady state time domain waveforms for the quadrature currents.

$$V_{o2} = jk^{''} V_{o1} \quad where \quad k^{''} = \omega_0 C_1 R_1. \qquad (6)$$

It is evident from (5) and (6) that the ratios of the magnitudes of quadrature currents and quadrature voltages given by $k^{'}$ and $k^{''}$ respectively, are operating frequency dependent terms. This feature is present in all previously reported QOs, which generate quadrature signals using inverting or non-inverting integrators. It is worth mentioning that for $k^{'} = k^{''} = 1$ the quadrature signals would have equal magnitudes.

Also, it should be noted that the circuit provides current outputs from high impedance terminals for explicit utilization, but the quadrature voltages are to be buffered before use. The need of external voltage buffers is required for all oscillators that do not incorporate them inside the ABB. For example, all current conveyor based oscillators would require external voltage buffers to provide voltage outputs (this applies to all current conveyors exemplified in Fig. 1 of [19]). Some popular ABBs that eliminate the use of external buffers to provide voltage outputs in oscillators are current-feedback-operational amplifier (CFOA) and current-differencing-buffered amplifier (CDBA) [20], [21].

It is ironical that none of previously reported CFOA based SRCOs in [5]-[10] were investigated for quadrature voltage outputs (although many of them were voltage-mode QOs). The recently proposed CFOA based QO in [20] (claimed to be the first) uses a floating capacitor and thus the circuit is not suitable for monolithic integration. Several realizations of voltage-mode QOs using CDBA are provided in the literature [21], [22], [23]. However, none of the previously reported CFOA or CDBA oscillators, is a current-mode QO, i.e. provides explicit quadrature current outputs. Apart from this, the recently reported oscillator in [24] is a current-mode QO, but cannot provide quadrature voltage signals. To the best of author's knowledge, no oscillator is proposed till date that simultaneously provides explicit quadrature current outputs and buffered voltage outputs, without using external voltage buffers.

2.1 Non-Ideal Analysis

- The proposed QO is analyzed for the CCII-TA non-idealities, namely α which represents the voltage transfer gain from y to x, β, β_1 and β_2 which represent the current transfer gains from x to z, z_1 and z_2, respectively. All of these parasitic voltage/current gains differ from their ideal values of unity by voltage/current tracking errors. Considering them, the modified CO and the FO are given as

$$\text{CO}: \quad \alpha\beta_2 R_2 = R_1 \qquad (7)$$

and

$$\text{FO}: \quad f_0 = \frac{1}{2\pi}\sqrt{\frac{\alpha\beta g_m}{C_1 C_2 R_1}}. \qquad (8)$$

- The non-zero parasitic resistance R_x appears at terminal x and in series with the external resistor R_1. From Fig. 1, it could be derived that $R_x = \frac{V_T}{2I_{B1}}$. For large values of I_{B1} and $R_1 >> R_x$, the non-ideal effects of R_x could be alleviated.
- The parasitic resistance R_z and parasitic capacitance C_z appear between the high-impedance z terminal of the CCII-TA and ground. The parasitic capacitance C_z is absorbed into the external capacitance C_1 as it appears in shunt with it. But the presence of parasitic resistance at terminal z would change the type of the impedance, which should be of a purely capacitive character. This effect could be alleviated by making the operating frequency $\omega_0 > \frac{1}{R_z(C_1+C_z)}$.
- The parasitic resistance R_{z_2} and parasitic capacitance C_{z_2} appear between the high-impedance z_2 terminal of the CCII-TA and ground. Similarly, parasitic resistance R_o and parasitic capacitance C_o appear between the high-impedance $o-$ terminal of the CCII-TA and ground. The parasitic capacitances C_{z_2} and C_o can be absorbed into the external capacitance C_2 as they appear in shunt with it. Since the values of R_{z_2} and R_o are in the order of $M\Omega$, hence an external resistor of value R_2 should be connected at this terminal such that, $R_{z_2}||R_o||R_2 \approx R_2$.

Considering the above stated non-idealities (except for the parasitic resistances), the final expression for the FO is

$$\text{FO}: \quad f_0 = \frac{1}{2\pi}\sqrt{\frac{\alpha\beta g_m}{(C_1+C_z)(C_2+C_{z_2}+C_o)R_1}}. \qquad (9)$$

The sensitivity study indicates that

$$|S^{f_0}_{\alpha,\beta,g_m,R_1}| = \frac{1}{2}, \qquad (10)$$

$$S^{f_0}_{C_1} = -\frac{C_1}{2(C_1+C_z)}, \quad S^{f_0}_{C_z} = -\frac{C_z}{2(C_1+C_z)},$$

$$S^{f_0}_{C_2} = -\frac{C_2}{2(C_2+C_{z_2}+C_o)},$$

$$S^{f_0}_{C_{z_2}} = -\frac{C_{z_2}}{2(C_2+C_{z_2}+C_o)},$$

$$S^{f_0}_{C_o} = -\frac{C_o}{2(C_2+C_{z_2}+C_o)}. \qquad (11)$$

It is evident from (10) and (11) that the magnitude values of all f_0 sensitivities are less than unity and hence the proposed QO exhibits an attractive sensitivity performance. It should also be pointed that the FO would vary with the change in operating temperature, but this, however, should not be considered as a drawback, as the designer has an electronic control over the FO through the bias current. The dependence on the temperature can be reduced if the bias current is made proportional to absolute temperature (PTAT). The design of

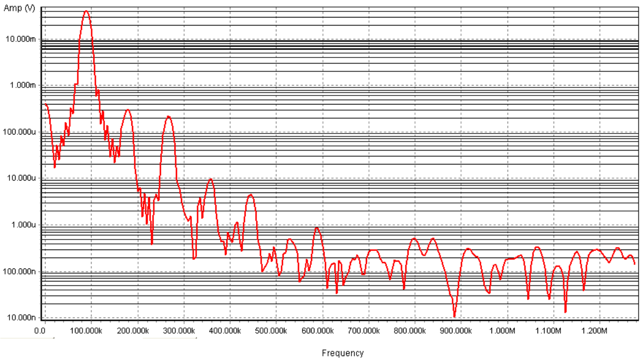

Fig. 6. Simulated FFT spectrum of the V_{o1}.

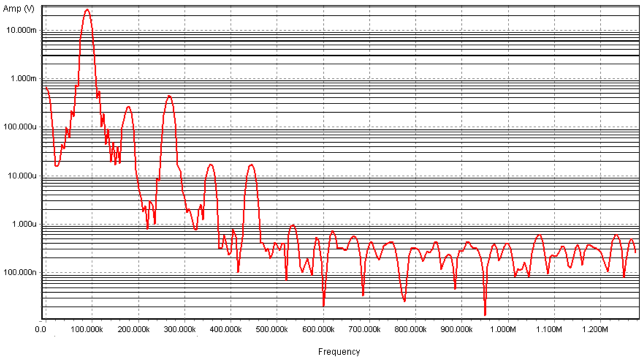

Fig. 7. Simulated FFT spectrum of the V_{o2}.

such QO with temperature insensitive tuning laws is another ongoing study and the results of which will be reported in near future.

Interestingly, the circuit features are similar to another recently proposed oscillator circuit in [25], created using current differencing transconductance amplifier (CDTA). A close investigation of [25] reveals that both the CO and the FO are affected with the change in operating temperature, since V_T term is directly present in both the CO and the FO. This is however not the case here and a suitable measure is to make R_2 greater than R_1, so that even for the change in resistances due to environment changes, the condition $R_2 > R_1$ is still satisfied.

3. Design Example and Simulation Results

The proposed oscillator circuit is simulated in B2SPICE using the bipolar implementation of CCII-TA as shown in Fig. 2. The process parameters for the PR100N and NR100N bipolar transistors of ALA400 transistor array from AT & T [26] have been used with ± 3 V voltage supply. The circuit was designed with $C_1 = C_2 = 1$ nF, $R_1 = 1$ kΩ and the input bias currents values $I_{B1} = 100$ μA and $I_{B2} = 25$ μA. In practice, the value of R_2 is kept slightly larger than R_1 to

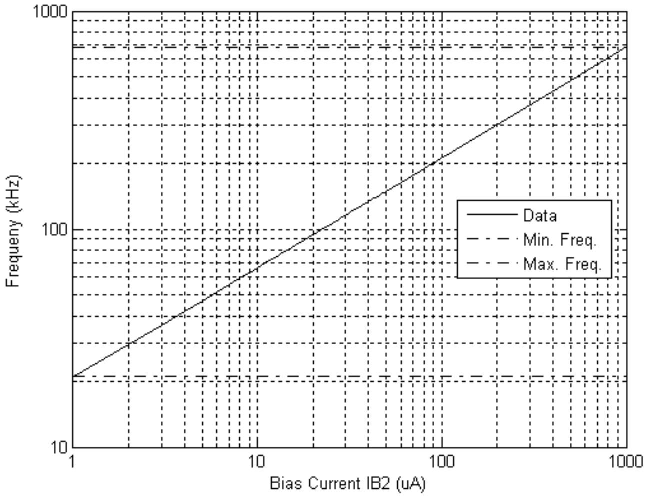

Fig. 8. Electronic tuning of FO with bias current I_{B2}.

start the oscillations. The simulated output waveforms for the quadrature currents I_{o1}, I_{o2} and the quadrature voltages V_{o1} and V_{o2} in steady state are shown in Fig. 4 and Fig. 5, respectively. Fig. 6 and Fig. 7 show the frequency spectrum of the quadrature voltage output waveforms and the value of total harmonic distortion (THD) at both the outputs is less than 3 %. The electronic tuning of the oscillator with the input bias current I_{B2} is shown in Fig. 8, where FO varies from approximately 21 kHz at 1 μA to 682 kHz at 1000 μA and which shows about thirty fold variation in FO for a three decade variation in I_{B2}. Due to the non-availability of the required resources, the experimental results could not be carried out. However, it is expected that the experimental results would agree well with the theoretical and simulated results.

4. Concluding Remarks

A large catalog of sinusoidal oscillators using ABBs is already available in the literature. With the appearance of every new ABB, analog circuit designers start investigating its versatility in creating circuits suitable for the analog signal processing. Sinusoidal oscillators are very important analog circuits and hence, using the modern ABBs to create oscillator circuits always interests the circuit designers. The oscillator circuit proposed in this paper provides many desirable properties that are expected from a modern oscillator. These include non-interactive control of the CO and the FO, availability of two explicit quadrature current outputs, presence of two quadrature voltage signals, use of all-grounded passive elements and low active and passive sensitivities. SPICE simulation results have confirmed the workability of the proposed circuit. It is believed that the proposed oscillator circuit does not serve merely as an application of the new ABB, but rather with its advantageous features prove beneficial to analog circuit designers and researchers in the field. More such interesting oscillator topologies using CCII-TA could also be explored!

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