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Three Oscillator Families Using the Current Feedback Op-Amp

Drei Familien von Oszillatoren unter Verwendung stromrückgekoppelter Operationsverstärker

Abstract
Three alternative voltage-mode oscillator families using the current feedback op-amp are given. Each family includes three different oscillator circuits, each of them employs a second order RC circuit, two resistors and a single current feedback op-amp (CFOA). Two families employ voltage feedback and the third family employs current feedback. The third family is generated from the recently reported unity gain inverting current mode all-pass filters. This family is suitable for realizing current-mode oscillators using a two-output current conveyor instead of the CFOA. PSpice simulation results for the current-mode oscillators are given.

Übersicht
Drei alternative Familien von Oszillatoren vom Spannungstyp mit stromrückgekoppelten Operationsverstärkern werden vorgestellt. Jede Familie umfaßt drei unterschiedliche Oszillatoren mit jeweils einer RC-Schaltung zweiter Ordnung, zwei Widerständen und einem stromrückgekoppelten Operationsverstärker (CFOA). Zwei Familien haben Stromrückkopplung, *die dritte Spannungsrückkopplung. Letztere entstand aus den kürzlich veröffentlichten* invertierenden Allpaßfiltern vom Stromtyp. Die dritte Familie umfaßt auch Oszillatoren vom Stromtyp unter Verwendung von Stromübertragern mit zwei Ausgängen, anstatt von CFOA. Simulationsergebnisse mit PSpice für die Oszillatoren vom Stromtyp werden vorgestellt.

Für die Dokumentation
Oszillatoren / Operationsverstärker / Spannungsrückkopplung / Stromrückkopplung

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1. Introduction

The current feedback op-amp (CFOA) is a very powerful building block in analog signal processing [1]. Recently several oscillator circuits using a single CFOA have been introduced in the literature [2-6]. The four Wien oscillators reported in [2] employ a CFOA together with four impedance branches, alternating in different positions. The oscillators reported in [5] employ five or more impedance branches between the available nodes of the single CFOA circuit.

One of the objectives of this paper is to classify a class of the single CFOA oscillators which employs the resistors and capacitors in the form of a second order, three port RC network N. It is found that there are three alternative oscillator families based on using the same number of circuit components. Each family includes three different oscillators which can be made equivalent according to two design constraints within the RC network. The first two oscillator families are based on using voltage feedback and the third oscillator family is based on using current feedback. The second oscillator family includes oscillators which are a generalization of the minimum component oscillators reported in [7, 8]. The third oscillator family is generated from the recently reported current-mode all-pass circuits [9, 10]. The third family can also be used as current-mode oscillators, if a two-output current conveyor (CCII) is used instead of the CFOA. PSpice simulation results for the three current-mode oscillator circuits are included.

2. The first oscillator family

Fig. 1 represents the general configuration of the first oscillator family [3], which employs the CFOA as a voltage controlled voltage source (VCVS). The characteristic equation of this oscillator family is

$$KT_{21}(s)=1 \tag{1}$$

where K is the gain of the VCVS given by:

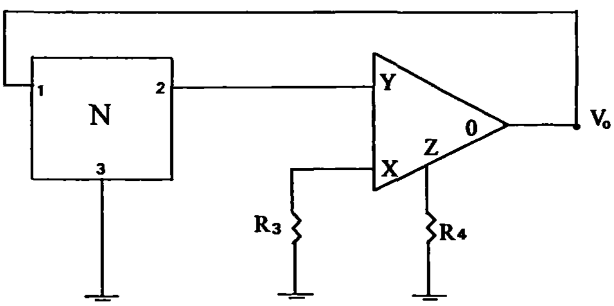

Fig. 1: The generalized configuration of the first oscillator family

$$K=\frac{R_4}{R_3}. \tag{2}$$

$T_{21}(s)$ is the transfer function of the RC bandpass network N:

$$T_{21}(s)=\frac{H\omega_o s}{s^2+\frac{\omega_o}{q}s+\omega_o^2} \tag{3}$$

where $q < 1/2$ and $Hq < 1$.

Three alternative realizations of the network N are shown in **Fig. 2**. The condition of oscillation and the frequency of oscillation for each of the three circuits are summarized in **Table 1**. It is seen that the equal R, equal C design of the network N results in three equivalent oscillator circuits, (assuming ideal CFOAs). The effect of the parasitic capacitance Cz of the CFOA on the performance of this family of oscillators has been reported in [3].

3. The second oscillator family

The second generalized oscillator configuration is shown in **Fig. 3**. In this case the CFOA together with R_3 and R_4 act as a voltage attenuator to provide a voltage αV_o to terminal 1 of the network N, where α is given by

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Table 1

Family No	Fig. No.	Condition of Oscillation	Design Equations	ω_0	Ref.
I	2a	$\frac{R_4}{R_3}=1+\frac{R_1}{R_2}+\frac{C_2}{C_1}$			3
	2b	$\frac{R_4}{R_3}=1+\frac{R_1}{R_2}\left(1+\frac{C_2}{C_1}\right)$	$\frac{C_1}{C_2}=\frac{R_1}{R_2}=1$ and $\frac{R_4}{R_3}=3$	$\frac{1}{\sqrt{C_1C_2R_1R_2}}$	3
	2c	$\frac{R_4}{R_3}=1+\frac{C_2}{C_1}\left(1+\frac{R_1}{R_2}\right)$			3
II	4a	$\frac{R_3}{R_3+R_4}=\frac{R_1}{R_2}+\frac{C_2}{C_1}$			2
	4b	$\frac{R_3}{R_3+R_4}=\frac{2+\frac{R_1}{R_2}\left(1+\frac{C_1}{C_2}\right)}{2+\frac{C_1}{C_2}}$	$\frac{C_1}{C_2}=\frac{R_2}{R_1}=3$ and $\frac{R_3}{R_4}=2$	$\frac{1}{\sqrt{C_1C_2R_1R_2}}$	New
	4c	$\frac{R_3}{R_3+R_4}=\frac{2+\frac{C_2}{C_1}\left(1+\frac{R_2}{R_1}\right)}{2+\frac{R_2}{R_1}}$			New
III	7a, 8a	$\frac{R_3}{R_4}=1+2\left(\frac{R_1}{R_2}+\frac{C_2}{C_1}\right)$			New
	7b, 8b	$\frac{R_3}{R_4}=1+2\frac{R_1}{R_2}\left(1+\frac{C_2}{C_1}\right)$	$\frac{C_1}{C_2}=\frac{R_1}{R_2}=1$ and $\frac{R_3}{R_4}=5$	$\frac{1}{\sqrt{C_1C_2R_1R_2}}$	New
	7c, 8c	$\frac{R_3}{R_4}=1+2\frac{C_2}{C_1}\left(1+\frac{R_1}{R_2}\right)$			New

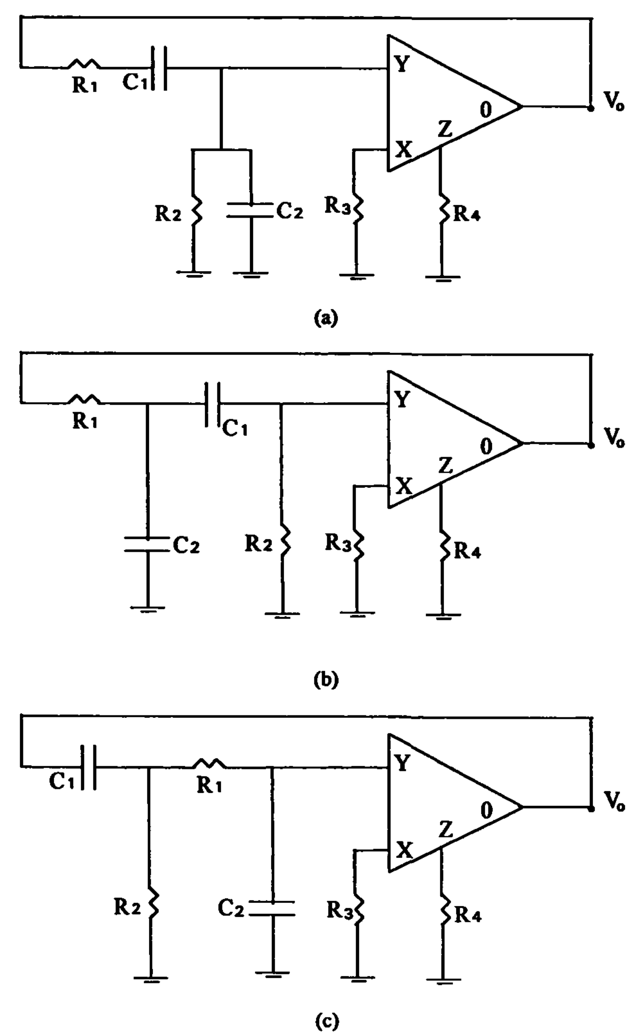


Fig. 2: The three oscillator circuits of the first family

$$\alpha=\frac{R_3}{R_3+R_4}. \tag{4}$$

Fig. 4 represents the three oscillator circuits which belong to the generalized configuration of Fig. 3. It should be noted that the oscillator circuit of **Fig. 4(a)** has been reported in [2], whereas those of **Figs. 4(b)** and **(c)** are generalizations of the minimum component oscillators using the CCII and reported in [7, 8]. The condition of oscillation and the frequency of oscillation are given in Table 1. It is seen that the three oscillator circuits are equivalent if and only if,

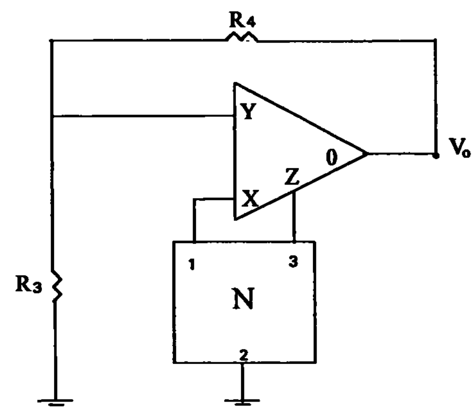


Fig. 3: The generalized configuration of the second oscillator family

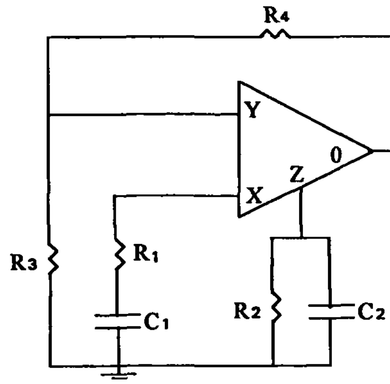
$$C_1=3C_2 \text{ and } R_2=3R_1 \tag{5}$$

In this case the condition of oscillation reduces to

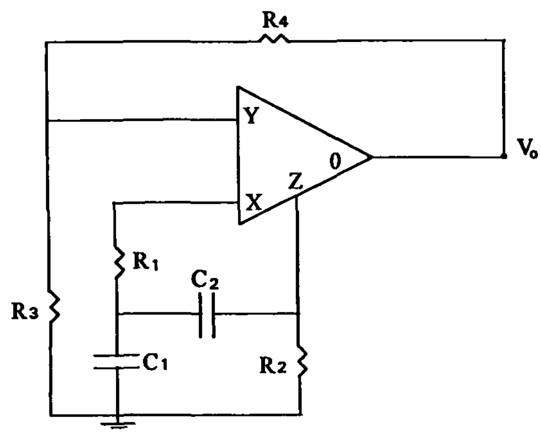
$$\alpha=\frac{2}{3}. \tag{6}$$

4. The third oscillator family

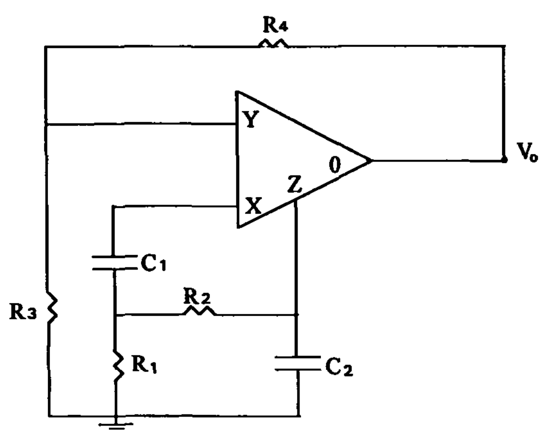
This new oscillator family differs completely from the previous two families as it employs current feedback instead of voltage feedback. This oscillator family is generated from unity gain second order inverting all-pass filters as shown in **Fig. 5(a)**. It is well known that voltage-mode as well as current-mode second order, unity gain inverting all-pass filters can be realized using a single CFOA [1], or a single current conveyor (CCII) [9]. **Fig. 5(b)** represents a recently reported current-mode all-pass filter [9] which is suitable for generating oscillator circuits according to the block diagram shown in Fig. 5(a). In general, the current transfer function of the second order inverting all-pass filter can be expressed as:



(a)



(b)



(c)

Fig. 4: The three oscillator circuits of the second family

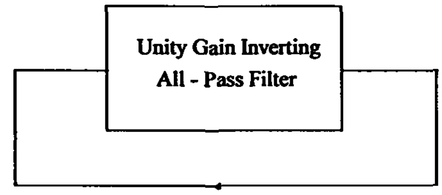
$$Ti(s) = -\frac{s^2 - \frac{\omega_o}{q}s + \omega_o^2}{s^2 + \frac{\omega_o}{q}s + \omega_o^2}. \qquad (7)$$

According to the block diagram shown in Fig. 5(a), the characteristic equation is given by:

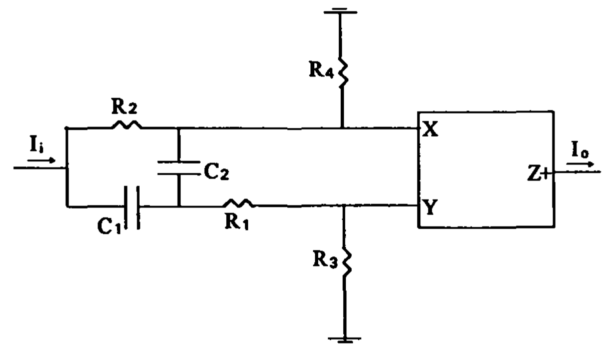
$$Ti(s) = 1 \qquad (8)$$

which is reduced to

$$s^2 + \omega_o^2 = 0 \qquad (9)$$

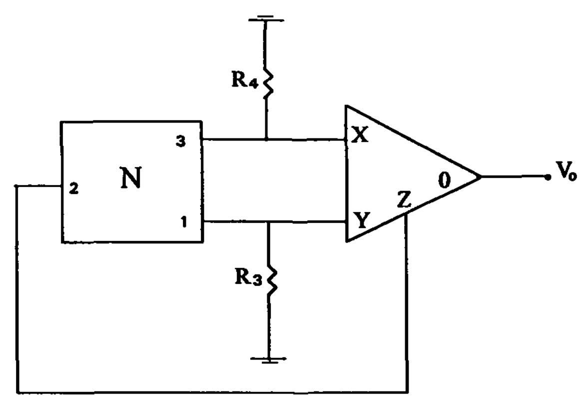


(a)

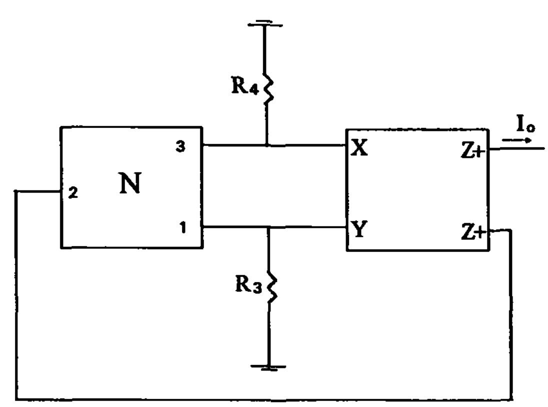


(b)

Fig. 5: Unity gain inverting all-pass filter
(a) The block diagram representing the generation of the third oscillator family
(b) A current-mode unity gain inverting all-pass filter [9]



(a)



(b)

Fig. 6: The generalized configuration of the third oscillator family
(a) Voltage-mode oscillator using CFOA
(b) Current-mode oscillator using CCII

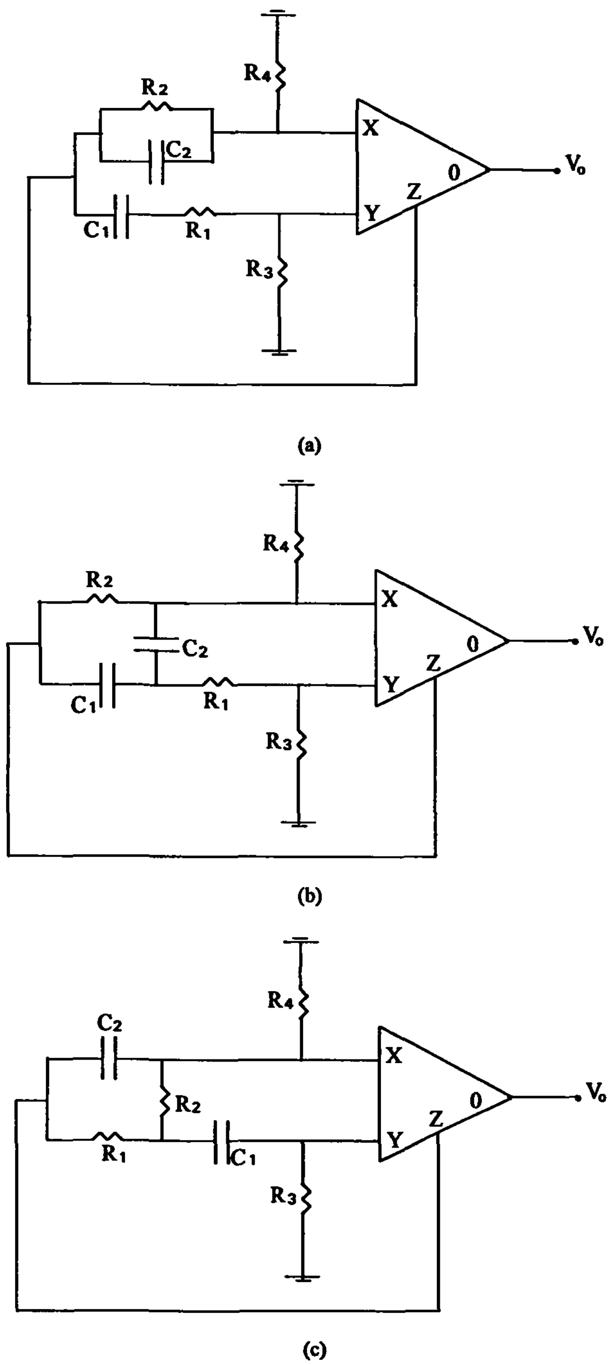


Fig. 7: The three voltage-mode oscillators of the third family
(a), (b), (c) see text

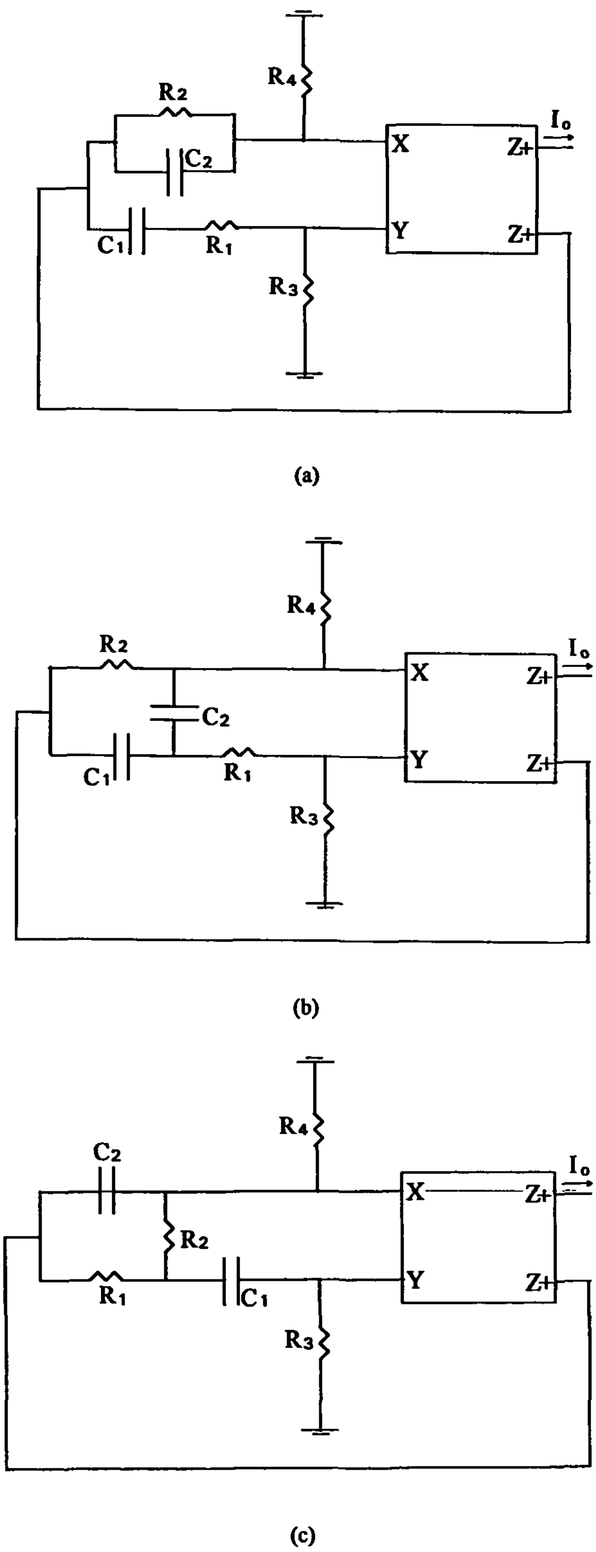


Fig. 8: The three current-mode oscillators of the third family
(a), (b), (c) see text

The above equation represents the characteristic equation of an oscillator of angular frequency ω_0.

The family of oscillators considered in this section can provide a voltage output or a current output as shown in **Fig 6**. The general configuration shown in **Fig. 6(a)** is based on using a CFOA with a current feedback from port Z to port 2 of the network N and provides a voltage output. Similarly **Fig. 6(b)** represents the current-mode oscillator based on using a two-output CCII.

Fig. 7 shows the three voltage oscillator circuits based on using the CFOA. It should be noted that the circuit of **Fig. 7(a)** is based on the all-pass circuit reported in [10], whereas those of **Figs. 7(b)** and (c) are based on the all-pass circuits given in [9]. The condition of oscillation for each circuit is given in Table 1. It can be shown that the equal *R*, equal *C* design of the network N results in an equivalence of the three oscillator circuits. in this case the condition of oscillation is reduced to:

$$\frac{R_3}{R_4} = 5. \qquad (10)$$

Three new current mode oscillators that belong to the same family are shown in **Fig. 8**. In this case a two-output CCII is used as the active element instead of the CFOA. The conditions of oscillation and the frequency of oscillation are the same as given in Table 1.

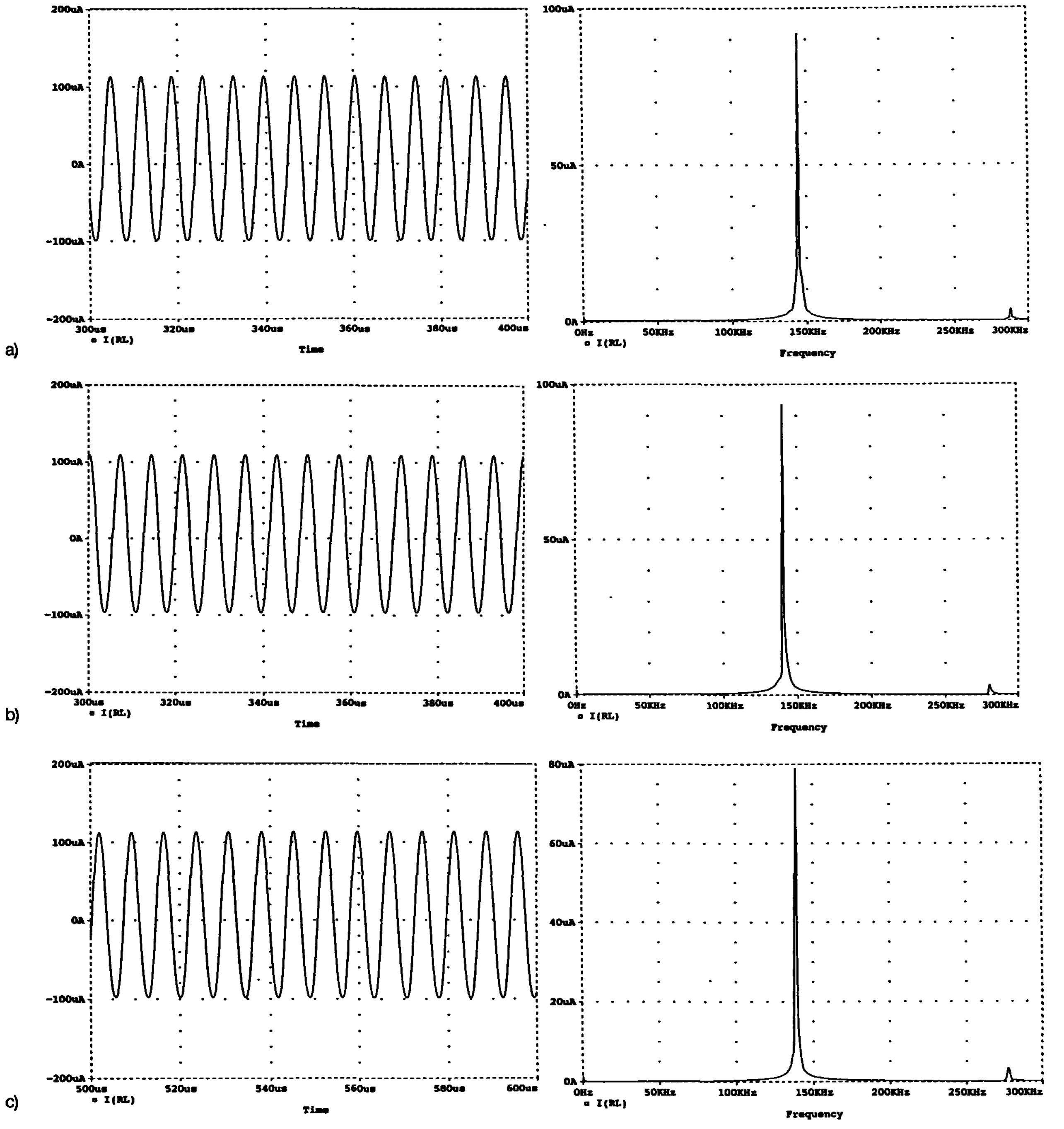


Fig. 9 (a) The output current waveform and the frequency spectrum of the oscillator of Fig.8(a)
(b) The output current waveform and the frequency spectrum of the oscillator of Fig.8(b)
(c) The output current waveform and the frequency spectrum of the oscillator of Fig.8(c)

5. Simulation results

Although the three oscillator circuits of each family are theoretically equivalent, their practical performance however differs slightly from each other due to the nonideal CFOA. In order to demonstrate the above statement, and to limit the amount of simulations included in the paper, only the current mode oscillators are considered in this section.

PSpice simulations have been carried out using a two output CCII, based on a generalization of the CCII+ given in [11]. The supply voltages used equal to ±5 V, and the load resistor was taken as 1 kΩ. The oscillator circuit components taken are as follows,

$R_1 = R_2 = 1$ kΩ, $C_1 = C_2 = 1$ nF and $R_4 = 1$ kΩ

The magnitude of the resistor R3 which adjusts the circuit for oscillation for each of the three circuits are given by 5.23 kΩ, 5.45 kΩ and 5.13 kΩ respectively. The output current waveform and the frequency spectrum for each of the three circuits are given in **Figs. 9(a)**, **(b)** and **(c)** respectively. From the simulations it is seen that there is a slight difference in the oscillation frequency of the three oscillator circuits.

6. Conclusions

Three alternative voltage-mode oscillator families using the current feedback op-amp are given. Each family includes three different oscillator circuits, each of them employs a second order RC circuit, two resistors and a single current feedback op-amp (CFOA). Two families employ voltage feedback and the third family employs current feedback. The third family is generated from the recently reported unity gain inverting current mode all-pass filters. The third family is suitable for realizing current-mode oscillators using a two-output current conveyor instead of the CFOA.

It is worth noting that it is not possible to realize single op-amp oscillators based on the configuration of Fig. 5(a). This is due to the fact that a unity gain inverting all-pass filter can not be realized using a single op-amp [12]. The above application demonstrates one major advantage of the CFOA over the conventional op-amp.

PSpice simulation results to demonstrate the performance of the three theoretically equivalent current mode oscillators are given.

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