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Novel Oscillators using Current and Voltage Followers

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ABSTRACT: *Two novel oscillator circuits with both voltage and current outputs are proposed. The two oscillators are related to each other by the adjoint network theorem. Each oscillator employs a current follower and a voltage follower, and has the advantage of independent control on the frequency of oscillation and the condition of oscillation. A new minimum R,C oscillator with voltage and current outputs is also given. Two new two-resistor two-capacitor, current-mode and voltage-mode oscillators are also included. PSpice simulation results illustrating the performance of the oscillator circuits are included.*

Introduction

The use of current followers and voltage followers as basic building blocks offer several advantages in analog signal processing (**1, 2**). Many voltage-mode oscillators using voltage followers are available in the literature (**3**). These oscillators can be easily converted using the adjoint network theorem (**4**) to realize current-mode oscillators employing current followers.

The purpose of this paper is introduce a new oscillator circuit, which employs both current and voltage followers and has the following advantages:

1. a current output as well as a voltage output are available,
2. the current output is taken from the Z terminal of the current conveyor which has a very high output impedance,
3. the voltage output is taken from the op amp output and can thus be used without additional voltage buffer,
4. the condition of oscillation is adjusted by varying a single resistor without affecting the frequency of oscillation,
5. the frequency of oscillation is controlled by a single grounded capacitor without affecting the condition of oscillation.

Applying the adjoint network theorem (**4**) to the proposed oscillator circuit results in an equivalent oscillator. A two-resistor, two-capacitor oscillator with both voltage and current outputs is also given. Two novel two-resistor, two-capacitor current-mode and voltage-mode oscillators are generated from this generalized configuration. The current-mode oscillator employs two-opposite polarity current conveyors and the voltage-mode oscillator employs two current feedback op amps.

The Proposed Oscillators

The oscillator circuits considered in this paper are based on using a voltage follower (VF) and a current follower (CF). Figure 1(a) represents the well-known symbol of the VF, which is defined by the hybrid matrix equation

$$\begin{bmatrix} I_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ I_2 \end{bmatrix}. \tag{1}$$

Two alternative realizations of the VF are shown in Fig. 1(b) and (c) and are based an using the conventional op amp (OA) and the current conveyor (CCII), respectively.

The noninverting CF which is the dual of the VF, is described by the matrix equation

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}. \tag{2a}$$

Fig. 2(a) and (b) represent two alternative realizations of the noninverting CF using a CCII− and two CCII+, respectively.

The realization of a balanced-output CF using a two-output CCII (see (**5**)) is shown in Fig. 2(c), and is described by the matrix equation

$$\begin{bmatrix} V_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \\ V_3 \end{bmatrix}. \tag{2b}$$

The proposed generalized oscillator circuit is shown in Fig. 3(a). The circuit employs a VF and a two-output CF which is realized using a two-output CCII. The characteristic equation can be expressed as

$$Y_3(Y_1 + Y_2 + Y_4) = Y_1 Y_2. \tag{3}$$

Two oscillator circuits with independent frequency control and condition of oscillation are realizable based on the circuit of Fig. 3(a).

Realization I

Figure 3(b) represents the first proposed oscillator circuit. From Eq (3), and taking

$$Y_1 = \frac{1}{R_1},\ Y_2 = \frac{sC_2}{sC_2R_2+1},\ Y_3 = \frac{sC_3}{sC_3R_3+1},\ Y_4 = sC_1, \tag{4}$$

the condition of oscillation and the radian frequency of oscillation are obtained as

$$R_3 = R_1\left(1 + \frac{C_1}{C_2}\right) + R_2, \tag{5a}$$

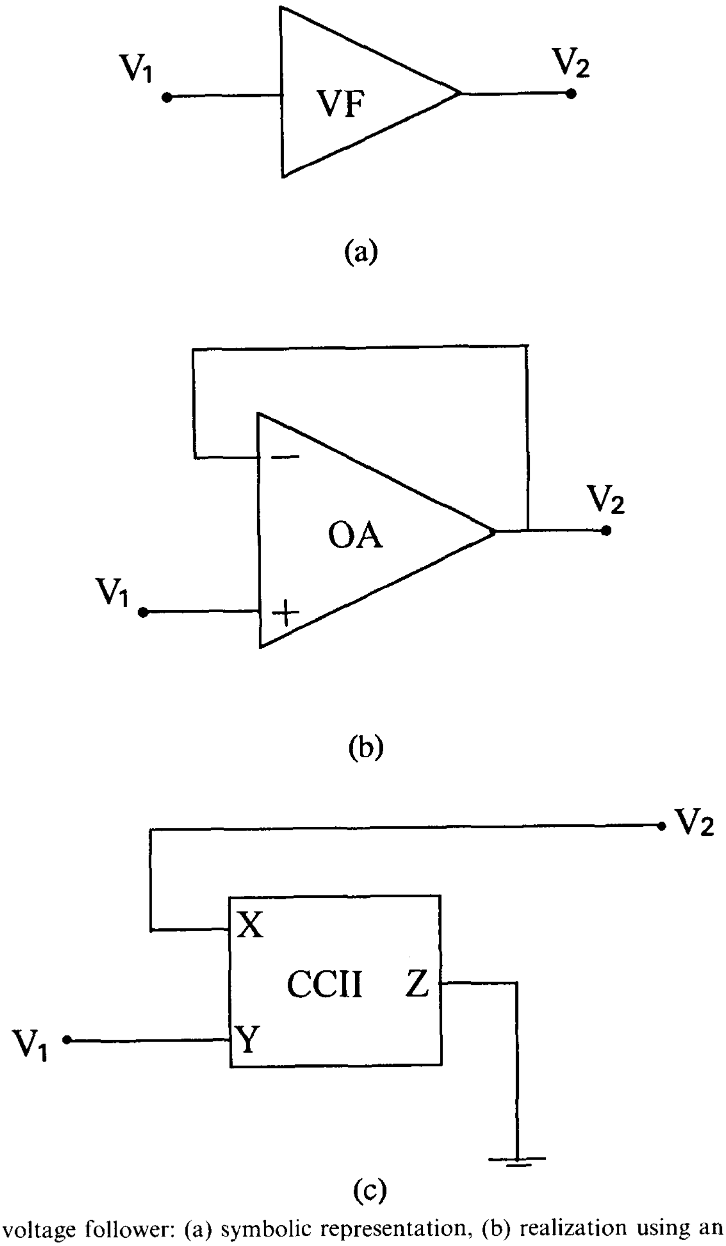


FIG. 1. The voltage follower: (a) symbolic representation, (b) realization using an op amp, (c) realization using a CCII.

$$\omega_0 = \sqrt{\frac{1-C_2/C_3}{C_1C_2R_1R_2}}. \tag{5b}$$

It is seen that R_3 controls the condition of oscillation without affecting the frequency

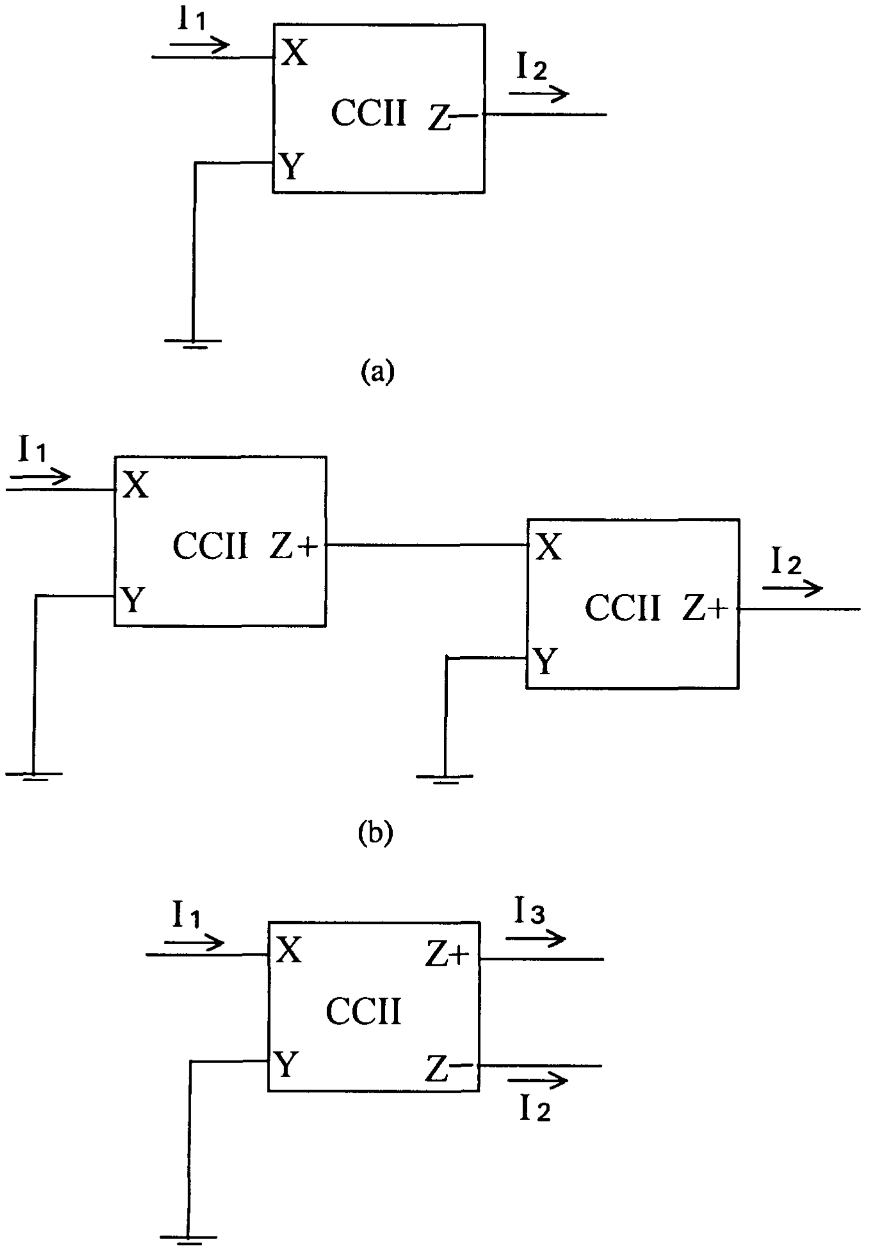
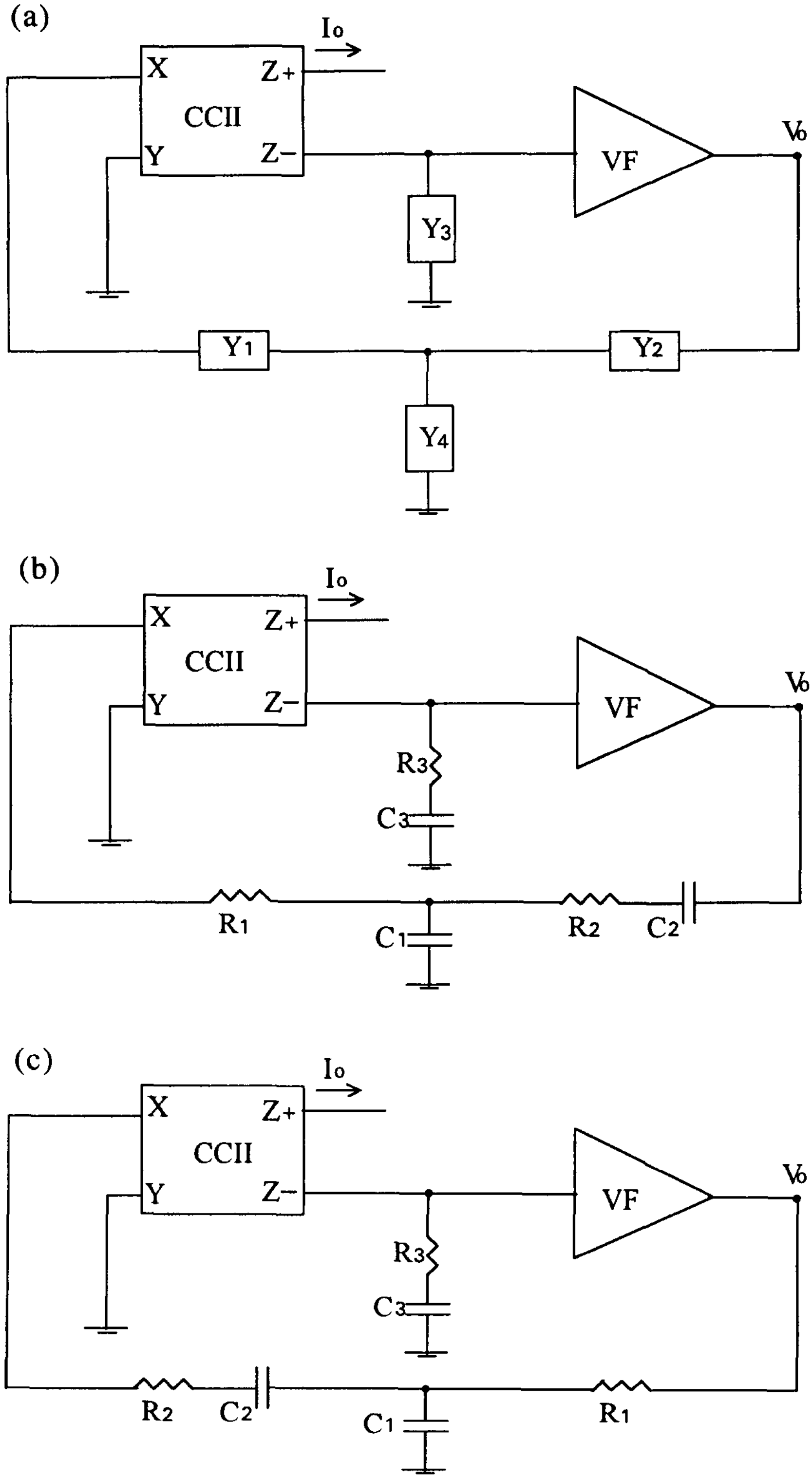


FIG. 2. (a) Realization of a noninverting CF using a CCII-, (b) realization of a noninverting CF using a two CCII+, (c) realization of a balanced-output CF using a two-output CCII.

FIG. 3. (a) The follower-based generalized oscillator circuit, (b) the first proposed oscillator circuit, (c) the second proposed oscillator circuit.


(a)
Io
X
Z+
CCII
Y
Z−
VF
Vo
Y3
Y1
Y2
Y4
(b)
Io
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CCII
Y
Z−
VF
Vo
R3
C3
R1
C1
R2
C2
(c)
Io
X
Z+
CCII
Y
Z−
VF
Vo
R3
C3
R2
C2
C1
R1

of oscillation, which can be adjusted by tuning the grounded capacitor C_3 without disturbing the condition of oscillation.

Realization II

Figure 3(c) represents the second proposed oscillator circuit which is generated from the circuit of Fig. 3(b) by interchanging the R_1 and the R_2-C_2 branches. As seen from Eq (3), the characteristic equation remains the same when Y_1 and Y_2 are interchanged, and thus the two circuits of Fig. 3(b) and (c) are equivalent and Eq (5a) and Eq (5b) apply to the circuit of Fig. 3(c). It is worth noting that the oscillator circuits of Fig. 3(b) and (c) can be generated from each other using the adjoint network theorem (**4**).

The Minimum R,C Oscillators

It is well known that a minimum *R,C* oscillator is one which employs two-resistor and two-capacitor. Three voltage-mode minimum *R,C* oscillator circuits using the CCII+ acting as a negative impedance converter (NIC) have been introduced in the literature (**6, 7**). The $2R+2C$ oscillator circuit given in (**6**) is obtained directly from the Huelsman filter (**8**) by grounding the input port and realizing the NIC using a CCII+. It can also be shown that the oscillators given in (**7**) can be generated from the Sallen–Key lowpass and highpass filters (**9**).

The three $2R+2C$ oscillators employing a current controlled current source (CCCS) and given in Table 1 of (**10**) (realizations 1, 8 and 9) have been previously reported by Bhattacharyya *et al.* (**11**) (realizations a, b, and c of Fig. 8). To realize the required CCCS whose gain is larger than 1 and using a CCII, an additional op amp plus two resistors are needed as illustrated in (**12**); thus the oscillator circuit is not minimal in R any more. Therefore, it seems that there is no $2R+2C$ current-mode oscillator using CCIIs that is available in the literature, to this author's knowledge.

In this section, a novel $2R+2C$ oscillator with both voltage and current outputs is introduced. Figure 4(a) represents the proposed oscillator, which is generated from the generalized circuit of Fig. 3(a) with

$$Y_1 = sC_1,\ \ Y_2 = \frac{1}{R_1},\ \ Y_3 = sC_2 + \frac{1}{R_2},\ \ Y_4 = 0. \tag{6}$$

The condition of oscillation and the radian frequency of oscillation are given by

$$\frac{R_1}{R_2} + \frac{C_2}{C_1} = 1,\ \ \omega_0 = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}. \tag{7}$$

This attractive $2R+2C$ oscillator has both a voltage output and a current output. Two additional $2R+2C$ oscillators generated from this generalized oscillator are given next. The first is a current-mode oscillator and the second is a voltage-mode oscillator.

Figure 4(b) represents the $2R+2C$ current-mode oscillator, where the second CCII is used as a VF from port Y to port X. Since port Z is free, it is used as the output current port.

Figure 4(c) represents the voltage-mode minimum *R,C* oscillator which employs two

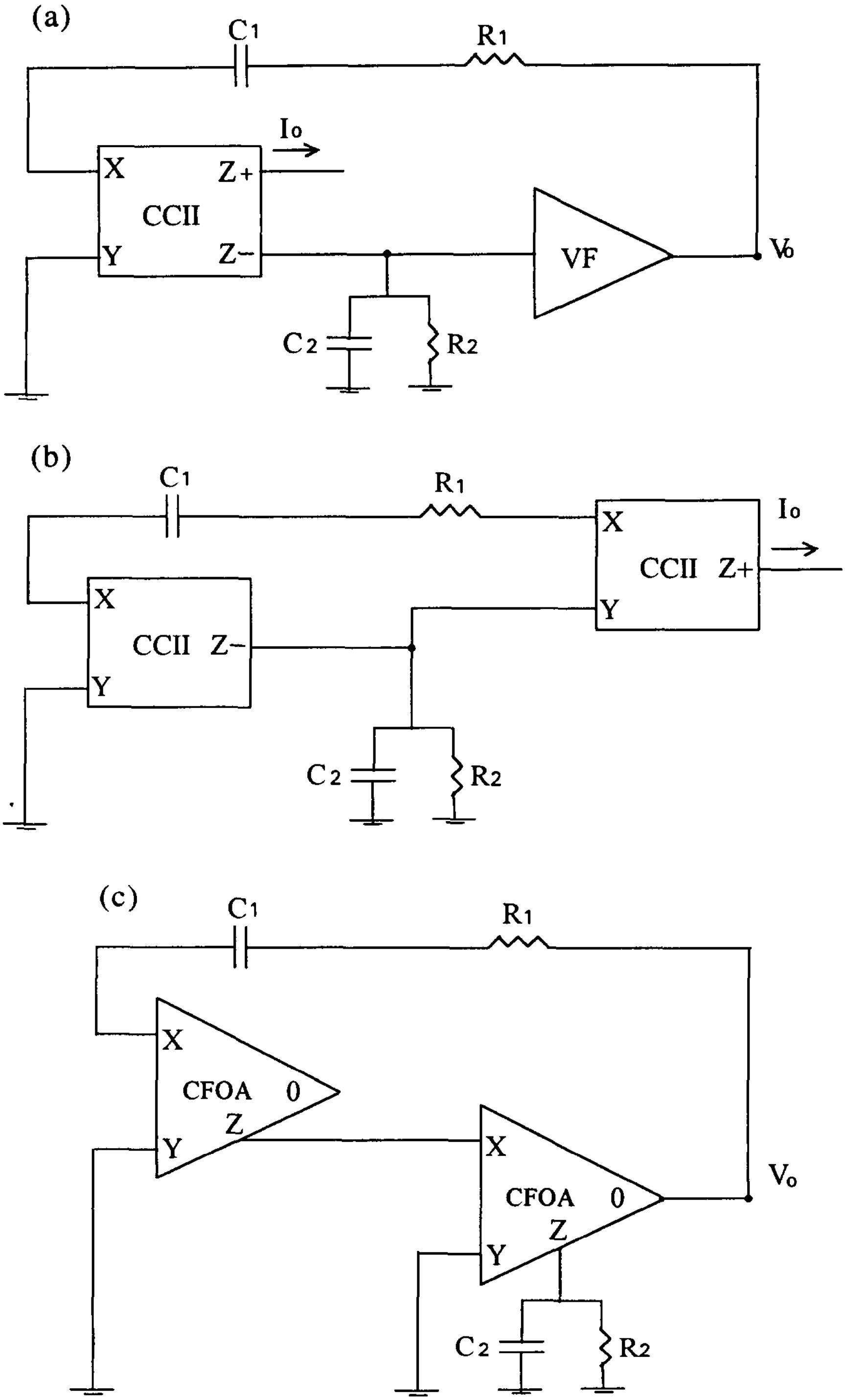

FIG. 4. (a) The $2R+2C$ oscillator circuit, with voltage and current outputs, (b) the $2R+2C$ current-mode oscillator using two CCIIs, (c) the $2R+2C$ voltage-mode oscillator using two CFOAs.

current feedback op amps (CFOAs) (**13**). In this case the X port of the first CFOA and the Z port of the second CFOA serve as the input and output ports of the noninverting CF. The VF on the other hand is obtained from port Z to port 0 of the second CFOA.

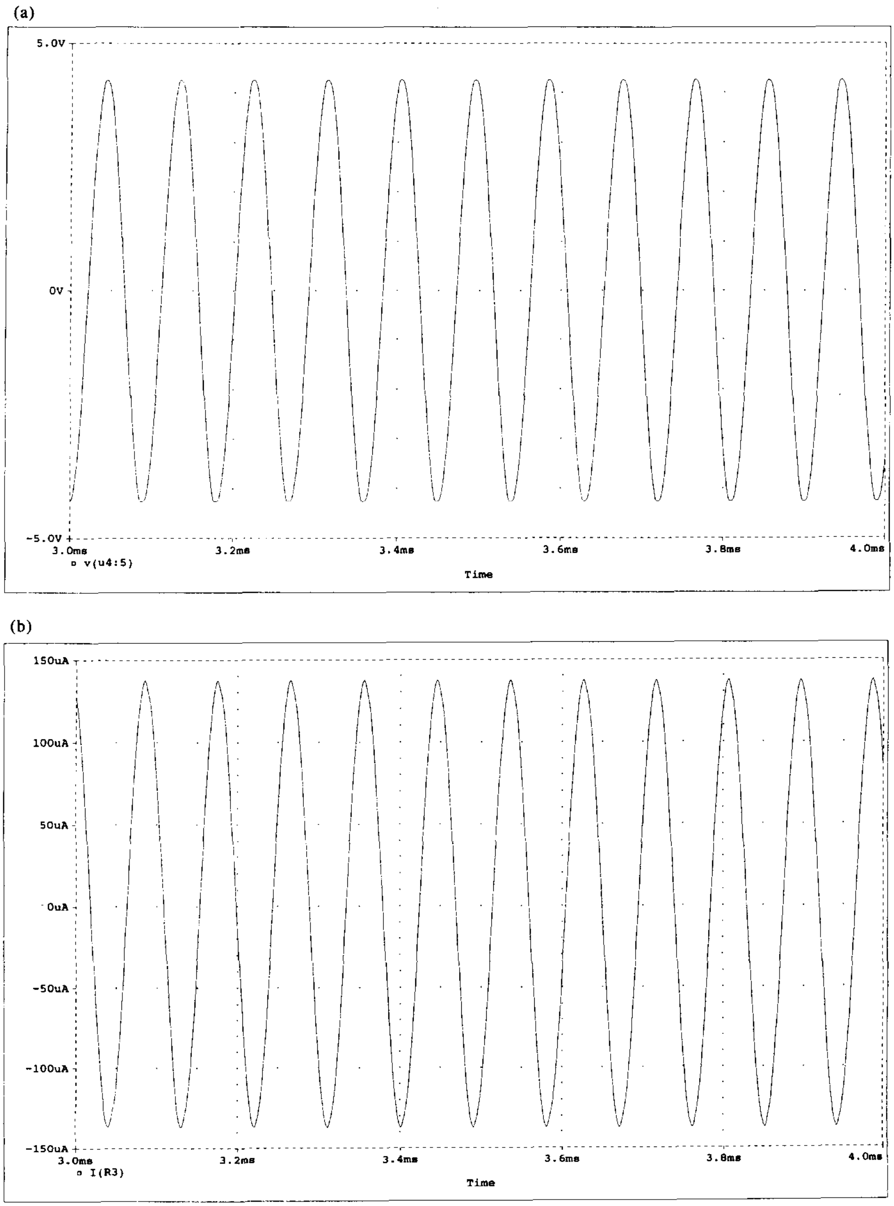

FIG. 5. (a) The voltage waveform of the oscillator of Fig. 3(b), (b) the current waveform of the oscillator of Fig. 3(b), (c) the frequency spectrum of the oscillator of Fig. 3(b).

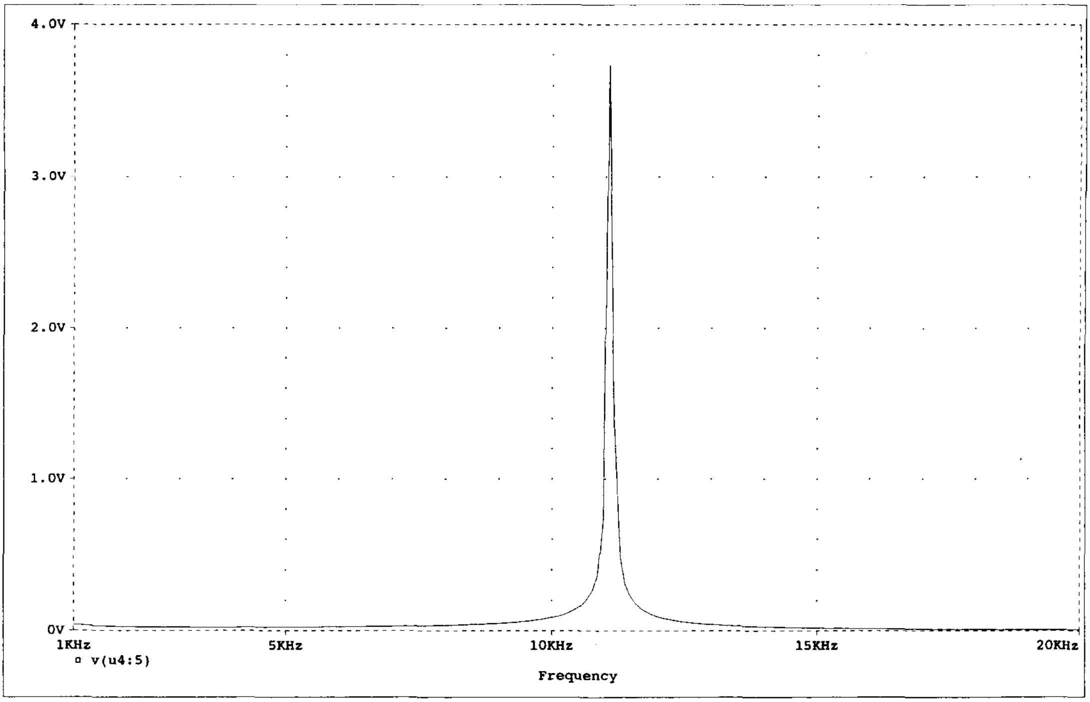

FIG. 5—*continued.*

Simulation Results

PSpice simulations for the oscillator of Fig. 3(b) was performed using the TL082 op amp to realize the VF and two AD844 A/AD to realize the CF both biased with ± 9 V, and taking $C_1 = C_2 = 1$ nF, $C_3 = 2\,nF$, $R_1 = R_2 = 10\,\text{k}\Omega$. To start oscillations, R_3 was taken to be 30.8 kΩ.

Figure 5(a) represents the output voltage waveform and Fig. 5(b) represents the current waveform. Figure 5(c) represents the frequency spectrum from which it is seen that $f_0 = 11.02$ kHz which is slightly less than the theoretical value of 11.25 kHz. It should be noted that the amplitude is limited by the nonlinearities of the active devices and the magnitude of the bias voltage. A simple circuit to control the amplitude of oscillation can be added to the oscillator circuit if desirable (**14**).

The PSpice simulations of the oscillator of Fig. 4(a) was performed, taking $C_1 = 2$ nF, $C_2 = 1$ nF, $R_1 = 1\,\text{k}\Omega$ and $R_2 = 2\,\text{k}\Omega$. To start oscillations, R_2 was increased to 2.2 kΩ. Figure 6(a) represents the output voltage waveform and Fig. 6(b) represents the frequency spectrum, from which it is seen that $f_0 = 75.09$ kHz which is very close to the theoretical value of 75.87 kHz.

Conclusion

A generalized oscillator circuit which employs a VF and CF is given. The oscillator has both a voltage output and a current output. The special case of a minimum passive

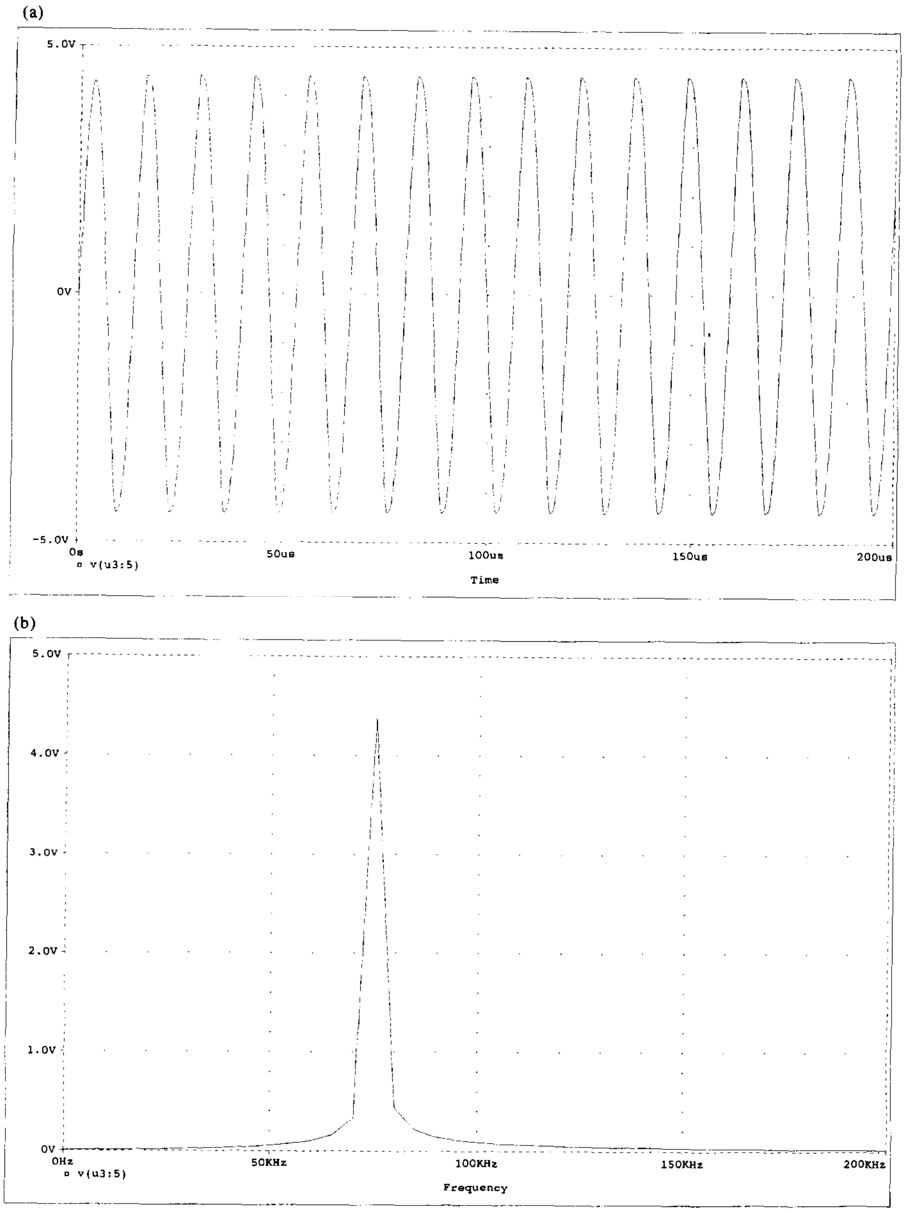

FIG. 6. (a) The voltage waveform of the oscillator of Fig. 4(a), (b) the frequency spectrum of the oscillator of Fig. 4(a).

component oscillator is considered, and three attractive $2R+2C$ oscillators are given. PSpice simulations are included to verify the performance of the proposed oscillators.

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References

(1) Lidgey, F. J., Current followers. *Wireless World*, pp. 40–43, 1984.

(2) Lidgey, F. J. and Toumazou, C., Accurate current follower. *Electronics & Wireless World*, pp. 17–19, 1985.

(3) Senani, R., Network transformations for incorporating nonideal simulated immittances in the design of active filters and oscillators. *IEE Proc. Pt. G*, 1987, **134**, 158–166.

(4) Roberts, G. W. and Sedra A. S., A general class of current amplifier-based biquadratic filter circuits. *IEEE Trans. Circuits Systems*, 1992, **39**, 257–263.

(5) Elwan, H. O. and Soliman A. M., A novel CMOS current conveyor realization with an electronically tunable current-mode filter suitable for VLSI. *IEEE Trans. Circuits Systems*, 1996, **43**, 663–670.

(6) Svoboda, J. A., Current conveyors, operational amplifiers and nullors. *IEE Proc. Pt. G*, 1989, **136**, 317–322.

(7) Abuelmaatti, M. T., Two minimum component CCII based RC oscillators. *IEEE Trans. Circuits Systems*, 1987, **34**, 980–981.

(8) Huelsman, L. P., Optimum sensitivity active RC bandpass filter. *Electron. Lett.*, 1965, **1**, 226.

(9) Budak, A., *Passive and Active Network Analysis and Synthesis*. Houghton Mifflin, 1974.

(10) Chen, J. J., Chen, C. C., Tsao, H. W. and Liu S. I., Current-mode oscillators using single current follower. *Electron. Lett.*, 1991, **27**, 2056–2059.

(11) Bhattacharyya, B. B., Sundaramurthy, M. and Swamy M. N., Systematic generation of canonic sinusoidal RC active oscillators. *IEE Proc. Pt. G*, 1981, **128**, 114–126.

(12) Carlosena, A. and Moschytz G. S., Design of variable gain current conveyors. *IEEE Trans. Circuits Systems*, 1994, **41**, 79–81.

(13) *Analog Devices, Linear Products Data Book*. Norwood, MA, 1990.

(14) Mahmoud, S. A. and Soliman, A. M., A new CMOS realization of the differential difference amplifier and its application to a MOS-C oscillator. *Internat. J. Electronics*, in press.