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Synthesis of grounded capacitor and grounded resistor oscillators

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Abstract

Three novel oscillators that employ grounded capacitors and grounded resistors and using the current conveyor as the active building block are given. The proposed oscillators are based on modification of the well known two-integrator loop oscillator. The proposed oscillators have the advantages of independent oscillation control by varying a single grounded resistor as well as independent frequency control through another grounded resistor. A novel current mode oscillator using two-output current conveyors is generated from one of the proposed oscillators. The oscillators reported in this paper are suitable for very large-scale integration, by using MOS grounded resistors. PSpice simulations to confirm the excellent performance of each of the proposed oscillators are included. © 1999 The Franklin Institute. Published by Elsevier Science Ltd.

Keywords: Oscillators; Current conveyors

1. Introduction

Several active RC oscillators using the operational amplifier (op amp) are available in the literature [1]. A unified approach to the realization of canonic variable frequency oscillators using op amps has been given by Bhattacharyya and Darkani [2]. Since it is highly desirable to have oscillators with all capacitors grounded, a further comprehensive study for the generation of grounded-capacitor variable frequency oscillators using op amps was completed by the same authors in [3]. Due to the nature of op amp, which necessitates the use of feedback around it, it is of course impossible to have grounded-capacitor, as well as grounded-resistor oscillators using op amps. In the present state of technology, namely very large-scale integration

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(VLSI), it is highly desirable to have grounded-C and grounded-R oscillators. This is of course possible using active devices like the first generation current conveyor (CCI) [4], or the second generation current conveyor (CCII) [5]. The first CCII oscillator introduced in the literature is based on the two-integrator loop [6], and it employs two opposite polarity CCIIs, together with two grounded resistors and two grounded capacitors. The main disadvantage of this oscillator, is that there is no control on the condition of oscillation. Recently there has been a great interest in realizing current conveyor oscillators with grounded C, grounded R and having independent control on the condition of oscillation and on the frequency of oscillation. The oscillators given in [7] and [8] employ combinations of CCI and CCII. The oscillators given in [9] employ two CCI−, and those given in [10] employ two CCII−. The oscillators given in [10] however are not minimal in the number of capacitors since, they employ three or four capacitors.

In this paper, two alternative approaches to modify the two-integrator loop oscillator to achieve independent control on the condition of oscillation and on the frequency of oscillation and using CCIIs only are given. The first modification is based on the addition of a third CCII+ and two resistors, and results in two new oscillator circuits. The second modification is achieved by adding two resistors only to the original circuit, in which the CCII− is realized using two CCII+ s in a new configuration. A novel current mode oscillator using two-output CCIIs is generated from one of the proposed oscillators. The oscillators reported in this paper are suitable for VLSI, by using MOS grounded resistors [11].

2. The two-integrator loop CCII oscillator

Figure 1 represents the well-known two-integrator loop oscillator [6], which employs two opposite polarity CCIIs. The state equations are given by

$$\begin{bmatrix} \frac{dv_1}{dt} \\ \frac{dv_2}{dt} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}, \tag{1}$$

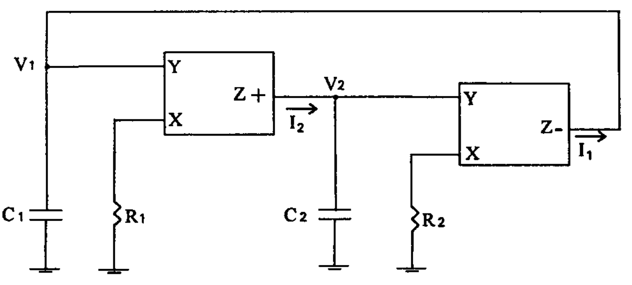


Fig. 1. The two-integrator loop oscillator.

where

$$a_{11} = a_{22} = 0, \quad a_{12} = -\frac{1}{C_1R_2} \quad \text{and} \quad a_{21} = \frac{1}{C_2R_1}. \tag{2}$$

From Eq. (1), the condition of oscillation, and the radian frequency of oscillation are given, respectively, by

$$a_{11} + a_{22} = 0, \tag{3}$$

$$\omega_0 = \sqrt{a_{11}a_{22} - a_{12}a_{21}}. \tag{4}$$

It is seen that, in the ideal case the circuit will oscillate under no condition, and with a radian frequency given by

$$\omega_0 = \frac{1}{\sqrt{C_1C_2R_1R_2}}. \tag{5}$$

This oscillator may also be considered as a loop of two opposite polarity current integrators. The current equations are given by

$$\begin{bmatrix} \dfrac{di_1}{dt} \\ \dfrac{di_2}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\dfrac{1}{C_2R_2} \\ \dfrac{1}{C_1R_1} & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}. \tag{6}$$

If $R_1 = R_2$ and $C_1 = C_2$, the amplitudes of the current waveforms as well as the voltage waveforms will be equal. The two currents may be utilized as outputs of the oscillator, by replacing each of the two single output CCIIs by a two-output CCII [12]. That is this oscillator circuit may be considered as a voltage mode as well as a current mode oscillator.

Since the commercially available CCIIs are of the CCII+ type [13], and since the CCII− is realizable using two CCII+s, therefore the practical realization of the oscillator of Fig. 1 requires three CCII+s. Two alternative realizations of the CCII−, using two CCII+ are shown in Fig. 2. To demonstrate the performance of the two-integrator loop oscillator, PSpice simulations have been carried out using the AD844 from analog devices [13] biased with ±9 V.

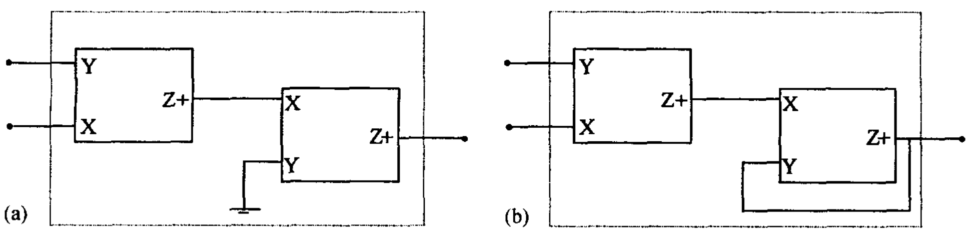


Fig. 2. Two alternative CCII− realizations, using two CCII+.

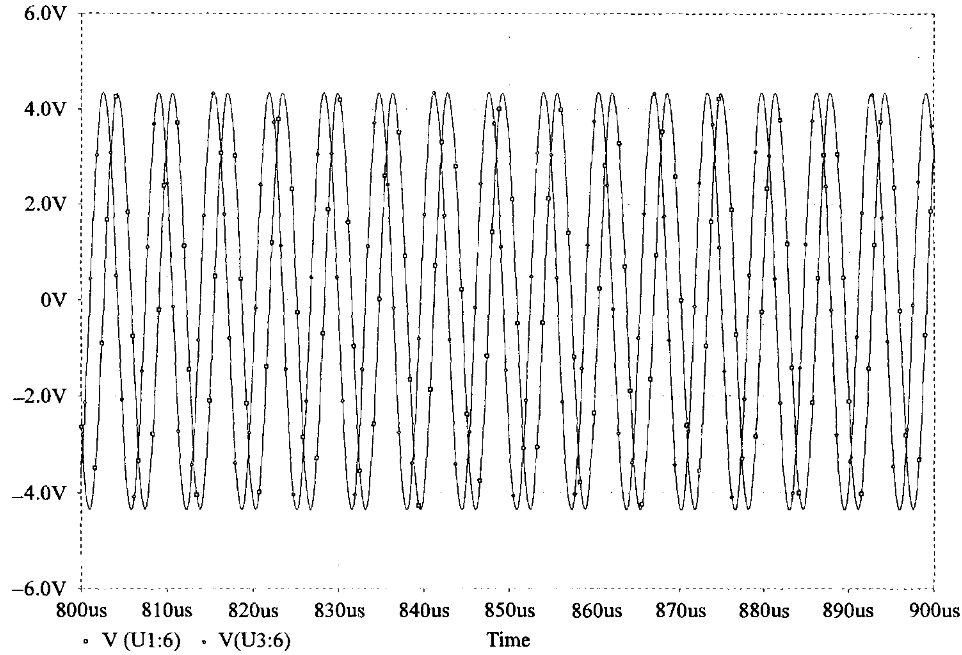


Fig. 3. The voltages V_1 and V_2 waveforms of the oscillator of Fig. 1 using the CCII− of Fig. 2b and with $C_1 = C_2 = 1$ nF and $R_1 = R_2 = 1$ kΩ.

Figure 3 represents the two voltage waveforms obtained at the two CCII outputs, using the CCII− realization of Fig. 2b, and taking $C_1 = C_2 = 1$ nF and $R_1 = R_2 = 1$ kΩ. The simulated frequency was obtained as 153 kHz, which is lower than the theoretical value of 159.15 kHz, due to the R_x and the C_z of the AD844. The amplitudes of the two voltages V_1 and V_2 are equal, and they are 90° out of phase, which agree with the theoretical analysis.

3. The modified CCII oscillators

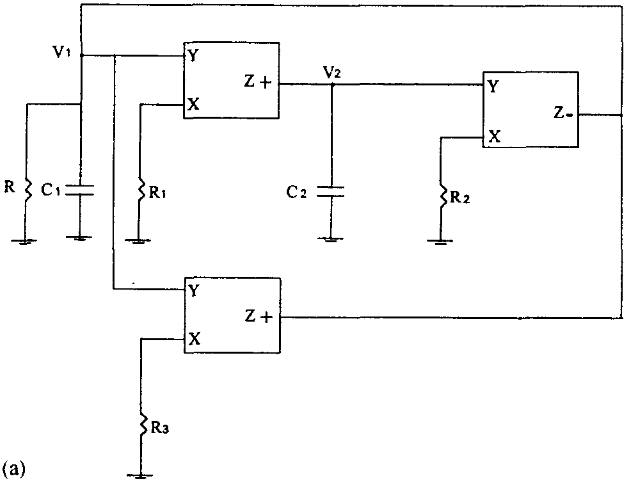
Three equivalent oscillator circuits are generated from the two-integrator loop oscillator. The proposed oscillators have the advantages of independent oscillation control by varying a single grounded resistor as well as independent frequency control through another grounded resistor.

3.1. The first modification

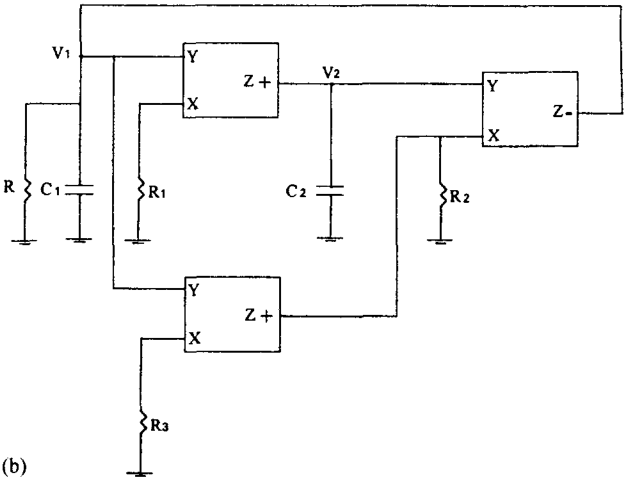
In this subsection two new oscillators are generated from the oscillator circuit of Fig. 1 by using one more CCII+ and two resistors. From Eqs. (3) and (4), it is seen that in order to have independent control on the condition of oscillation and on the frequency of oscillation, either a_{11} or a_{22} must be zero.

Figure 4a represents the first modified oscillator circuit, which is based on the addition of a third CCII+ and the resistors R, R_3 to the circuit of Fig. 1. The state equations in this case are given by:

$$\begin{bmatrix} \dfrac{dv_1}{dt} \\ \dfrac{dv_2}{dt} \end{bmatrix} = \begin{bmatrix} \dfrac{1}{C_1}\left(\dfrac{1}{R_3} - \dfrac{1}{R}\right) & -\dfrac{1}{C_1 R_2} \\ \dfrac{1}{C_2 R_1} & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}. \tag{7}$$



(a)



(b)

Fig. 4. Two equivalent $2C + 4R$ oscillators using four CCII+.

It is seen that the coefficients a_{12}, a_{21} and a_{22} are the same as given by Eq. (2) and thus ω_0 remains as given by Eq. (5). The condition of oscillation is given by

$$R_3 = R. \tag{8}$$

The advantage of this oscillator is that, the grounded resistor R or R_3 can be used to control the condition of oscillation without affecting the frequency of oscillation. On the other hand, the frequency of oscillation is independently controlled by R_1 or R_2 without affecting the oscillation condition.

PSpice simulations have been performed for this oscillator using four AD844 biased with ± 9V and using the circuit of Fig. 2a to realize the CCII−. Figure 5 represents the V_1 and V_2 waveforms obtained with $C_1 = C_2 = 1$ nF, $R_1 = R_2 = R = 1$ kΩ. To start oscillations R_3 was decreased from its theoretical value of 1 to 0.95 kΩ. The simulated frequency was found to be 153.8 kHz.

An equivalent oscillator circuit is shown in Fig. 4b which differs from that of Fig. 4a in one connection only. PSpice simulations have been carried out for this oscillator, and similar results to that shown in Fig. 5 have been obtained.

3.2. The second modification

A new grounded R, grounded C oscillator with independent control on the condition of oscillation and on the frequency of oscillation and using only three

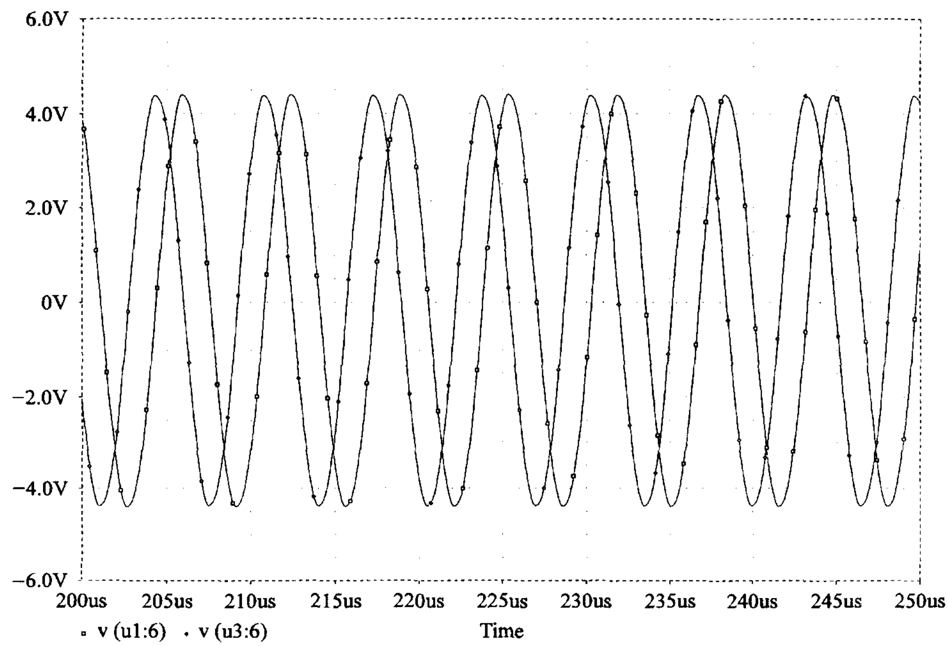


Fig. 5. The voltages V_1 and V_2 waveforms of the oscillator of Fig. 4a, and with $C_1 = C_2 = 1$ nF, $R_1 = R_2 = R = 1$ kΩ and $R_3 = 0.95$ kΩ.

CCII + s is introduced. The proposed oscillator is generated from the circuit of Fig. 1, with the CCII − realized as shown in Fig. 2b, and adding two more resistors, namely R and R_3 to the circuit. The generated three CCII + s oscillator is shown in Fig. 6a. The state equations for this oscillator are the same as given by Eq. (7), and of course the condition of oscillation and the radian frequency of oscillation are given by Eqs. (8) and (5), respectively.

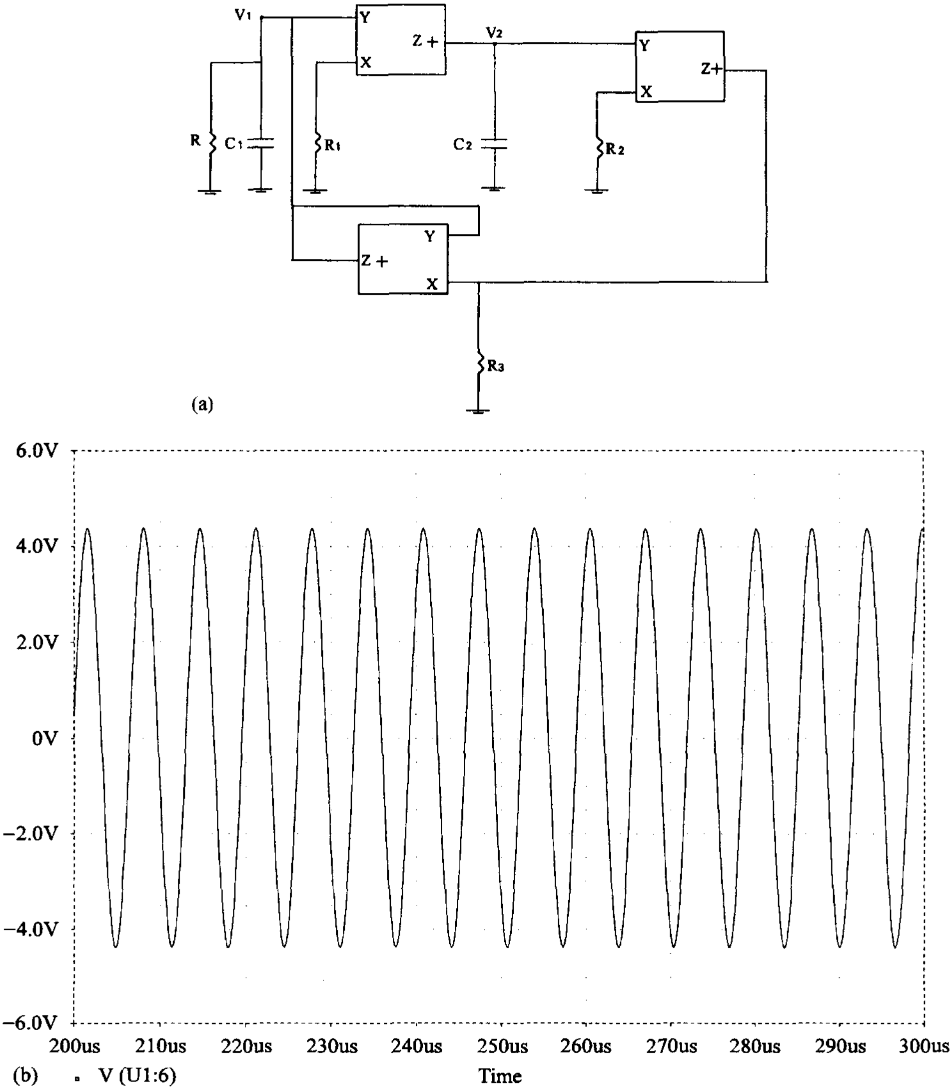


Fig. 6. (a) The $2C + 4R$ oscillator using three CCII +. (b) The voltage V_2 waveform of the oscillator of Fig. 6a, and with $C_1 = C_2 = 1$ nF, $R_1 = R_2 = R = 1$ kΩ and $R_3 = 0.95$ kΩ.

The advantage of this oscillator over the oscillators of Fig. 4, is that it uses three CCII+s instead of two CCII+s and one CCII−.

Fig. 6b represents the voltage V_2 waveform obtained from the PSpice simulations using three AD844 with $C_1 = C_2 = 1$ nF, $R_1 = R_2 = R = 1$ kΩ. To start oscillations R_3 was decreased from its theoretical value of 1 to 0.95 kΩ. The simulated frequency was found to be 156.2 kHz. It is worth noting that the amplitude of the voltage V_1 is slightly lower than that of V_2.

4. The current-mode oscillator

The modified oscillators described in the previous sections employ single output CCIIs. Two of the reported circuits can be modified using a two-output CCII. The modification is based on the degree of freedom available in choosing the magnitude of the resistor R_3 in the oscillator circuits of Fig. 4a and b. If R_3 is taken equal to R_1, the two CCII+, together with the two resistors R_1 and R_3 shown in Fig. 7a can be realized using a two-output CCII with a single resistor as shown in Fig. 7b. This equivalent circuit, can be applied to the oscillators of Fig. 4, as well as to other CCII circuits.

Figure 8a represents the $2C + 3R$ oscillator obtained from Fig. 4b based on using the equivalent CCII circuit of Fig. 7b. In this case, the condition of oscillation is given by

$$R = R_1 \tag{9}$$

The radian frequency remains as given by Eq. (5). It is seen that the resistor R controls the condition of oscillation, and the resistor R_2 controls the frequency of oscillation without disturbing each other. If the single output CCII−, is replaced by a two-output CCII, then the current from the second output ($Z+$) port can be used, resulting in a novel current-mode oscillator.

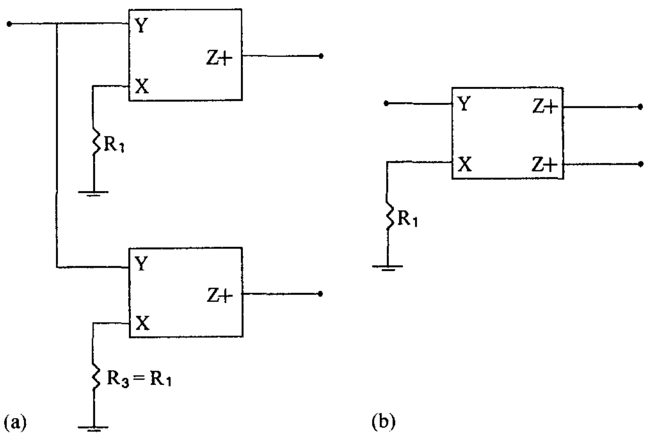
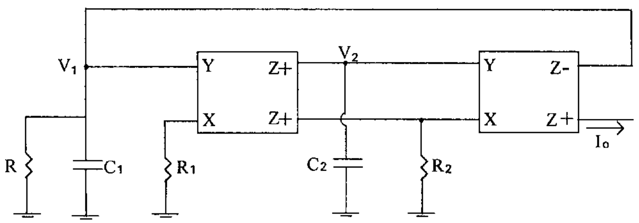


Fig. 7. Two equivalent single-output CCII and two-output CCII circuits.

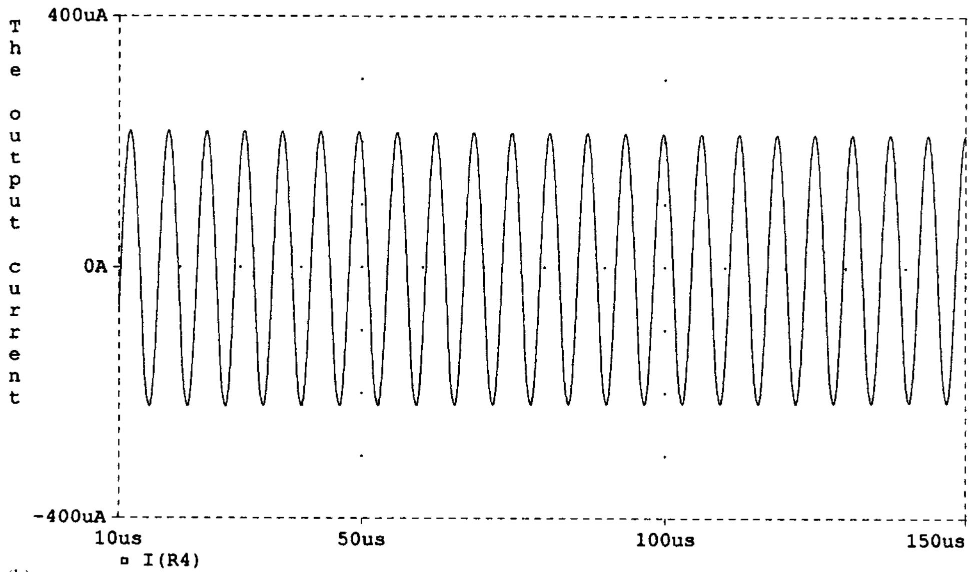
Figure 8b and c represent the PSpice simulated output current waveform and the frequency spectrum obtained using two-outputs CCIIs, based on modification of the single output CCII given in [14], and biased with ± 5V. The load resistance was taken as 10 kΩ, $C_1 = C_2 = 0.1$ nF and $R_1 = R_2 = 10$ kΩ. To start oscillations R was taken equal to 10.13 kΩ. The simulated frequency agrees well with the theoretical value of 159 kHz.

5. VLSI implementation

The proposed oscillators are suitable for VLSI implementation by using MOS grounded resistors [11, 15]. In this section simulations are included for the oscillator of Fig. 8a based on the replacement of the grounded resistors by the CCII MOS circuit shown in Fig. 9a.

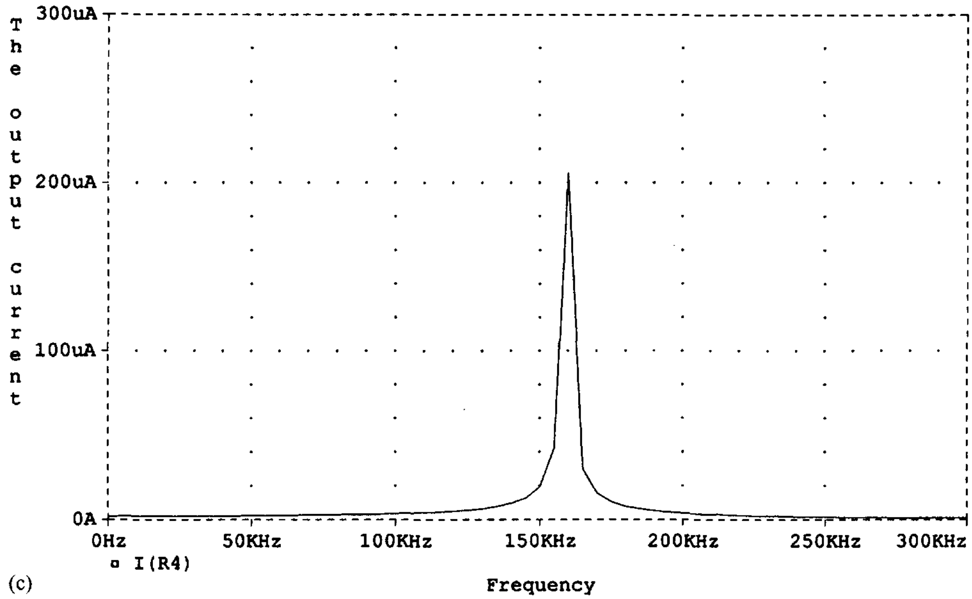


(a)



(b)

Fig. 8. (a) A novel $2C + 3R$ oscillator using two-output CCII and a single output CCII. (b) The output current waveform of the oscillator Fig. 8a, and with $C_1 = C_2 = 0.1$ nF and $R_1 = R_2 = 10$ kΩ. (c) The frequency spectrum of the oscillator of Fig. 8a.



(c)

Fig. 8. (*continued*).

The two transistors M1 and M2 are matched MOS transistors operating in the ohmic region [15]. The magnitude of the resistance R is given by

$$R = \frac{1}{KV_C}, \tag{10}$$

where

$$K = \mu_n C_{ox} \frac{W}{L}, \tag{11}$$

μ_n is the electron mobility, C_{ox} is the gate-oxide capacitance per unit area and W/L is the transistor aspect ratio.

Figure 9b and c represent the PSpice simulated output current waveform and the frequency spectrum, based on using the CCII MOS grounded resistor of Fig. 9a with the NMOS transistors having $W/L = 3.6\ \mu\text{m}/3\ \mu\text{m}$, $\mu_n C_{ox} = 83.84\ \mu\text{A/V}^2$ and $V_C = 1$ V, resulting in a resistor of magnitude $= 9.94\ \text{k}\Omega$. From the simulations it is seen that f_o is very close to its theoretical value of 160.12 kHz.

6. Conclusion

The two-integrator loop oscillator circuit using two opposite polarity CCIIs, is reviewed. Two alternative realizations of the CCII−, using two CCII+ have been described. It is found that one of these realizations can be modified by adding two more resistors to the circuit resulting in a novel three CCII+ oscillator. Two additional grounded C, grounded R oscillators generated from the two-integrator loop oscillator are reported. Minimal passive component oscillators with independent control on condition and on frequency of oscillation and using $2C + 3R$ are generated from two of the proposed oscillators based on using a two-output CCII. The proposed oscillators have the advantages of independent oscillation control by varying a single grounded resistor as well as independent frequency control through another grounded resistor. PSpice simulations demonstrating the performance of the proposed oscillators are included.

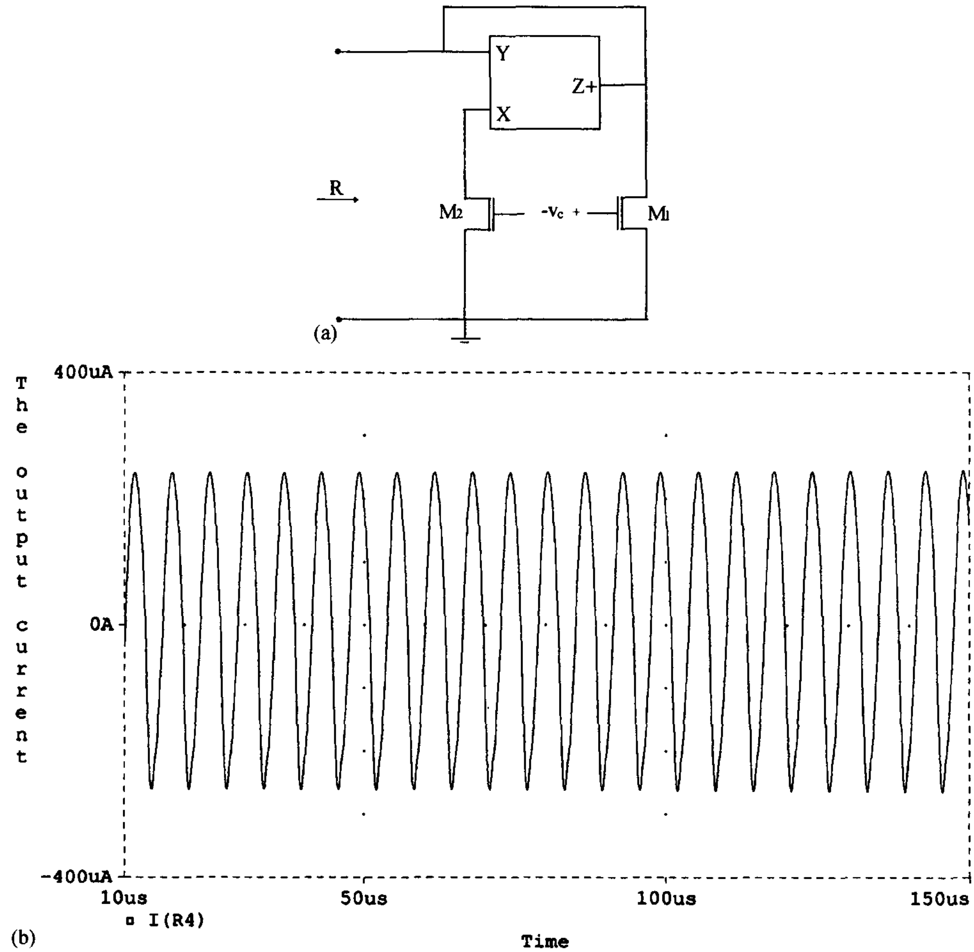
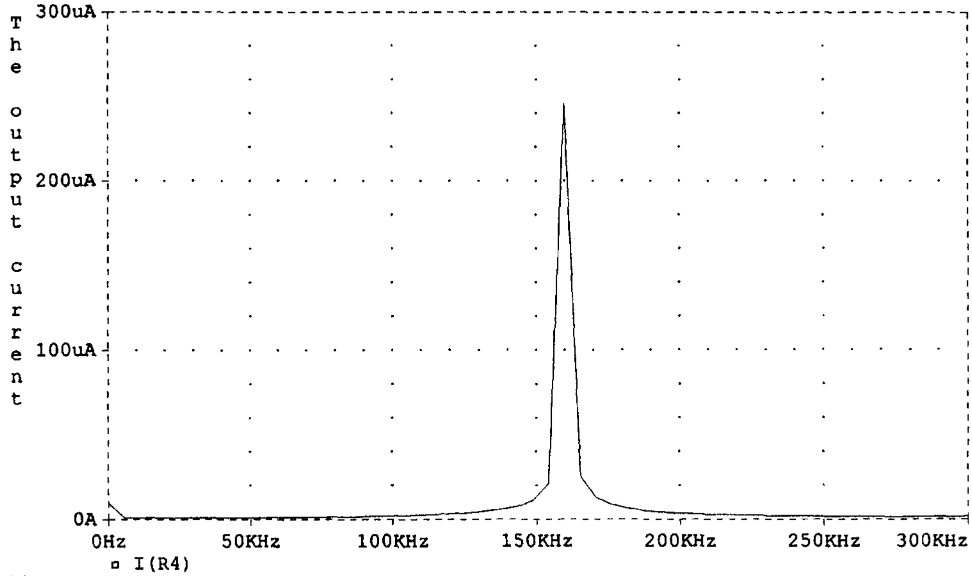


Fig. 9. (a) A CCII MOS grounded resistor (15). (b) The output current waveform of the oscillator Fig. 8a, and with $C_1 = C_2 = 0.1$ nF and $R_1 = R_2 = 9.94$ kΩ. (c) The frequency spectrum of the oscillator of Fig. 8a.



(c)

Fig. 9. (*continued*).

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