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Novel oscillators using the operational transresistance amplifier

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Abstract

This paper introduces several novel active RC oscillator circuits using the operational transresistance amplifier (OTRA) as the basic active building block. A general configuration using a single OTRA is introduced, from which a minimum component oscillator is generated. Four new oscillator circuits based on using two OTRAs are reported. HSpice simulations to confirm the analysis are given.

Keywords: Oscillators; Operational transresistance amplifier

1. Introduction

A variety of sinusoidal oscillators using the operational amplifier (op amp) as the active element are available in the literature [1]. It is well known that the finite gain bandwidth product of the op amp affects both the condition and frequency of oscillation [1,2]. To overcome this problem, several oscillators have been introduced in the literature using the current conveyor as the active element [3–6] or the current feedback operational amplifier [7,8].

In this paper, new oscillator circuits using the operational transresistance amplifier (OTRA) are reported. HSpice simulation results confirming the practicality of these oscillators are given.

The operational transresistance amplifier (OTRA) is a three terminal analog building block shown symbolically in Fig. 1 with a describing matrix in the form:

$$\begin{bmatrix} V_1 \\ V_2 \\ V_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_o \end{bmatrix}. \quad (1)$$

Both the input and output terminals are characterized by low impedance, therefore eliminating response limitations incurred by capacitive time constants [9]. The input terminals are virtually grounded leading to circuits that are insensitive to the stray capacitances. Ideally, the transresistance gain, R_m, approaches infinity, and external negative feedback must be used which forces the input currents, I_1 and I_2, to be equal.

Although the OTRA is commercially available from several manufacturers under the name Norton amplifier [10] it has not gained attention until recently [11]. These commercial realizations [12] do not provide virtual ground at the input terminals and they allow the input current to flow in one direction only. Few recent realizations have been suggested to implement the OTRA [13,14].

2. The single OTRA oscillators

Fig. 2 represents the generalized configuration of the single OTRA oscillator. Assuming an ideal OTRA the characteristic equation, is given by:

$$Z_2 + Z_5\left(1 + \frac{Z_2}{Z_3}\right) = Z_1 + Z_6\left(1 + \frac{Z_1}{Z_4}\right). \quad (2)$$

Several oscillator circuits can be generated based on the generalized configuration of Fig. 2. Three special cases are given in Fig. 3 and are described in this section.

2.1. The minimum R, C oscillator

Minimum passive component oscillators are receiving considerable attention in the literature [15,16]. Fig. 3(a) represents the $2R + 2C$ oscillator using the OTRA. The condition of oscillation and the radian frequency of oscillation

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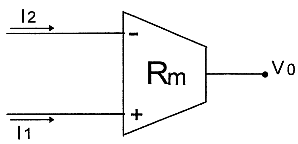


Fig. 1. Symbolic representation of the OTRA.

are given by:

$$\frac{R_1}{R_2} + \frac{C_2}{C_1} = 1, \tag{3}$$

$$\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}. \tag{4}$$

As is the case with all minimum component oscillators, the condition of oscillation and the frequency of oscillation cannot be independently controlled. It is seen that the ω_0 sensitivity to R_i or C_i ($i = 1, 2$) equal to $-1/2$.

In order to achieve independent control on the condition of oscillation without affecting the frequency of oscillation, the circuit shown in Fig. 3(b) is derived from the general configuration of Fig. 2. For this circuit, the condition of oscillation is given by:

$$\frac{R_1}{R_2} + \frac{C_2}{C_1} = 1 + \frac{R_3}{R_2} + \frac{R_3}{R_4}. \tag{5}$$

It is seen that the grounded resistor R_4 controls the condition of oscillation without affecting ω_0 which is given by:

$$\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_1 R_2 \left(1 - \frac{R_3}{R_1}\right)}}. \tag{6}$$

It should be noted that it is also possible to achieve independent control on the frequency of oscillation using a single OTRA. Fig. 3(c) represents a noncanonic single OTRA oscillator. The radian frequency of oscillation is

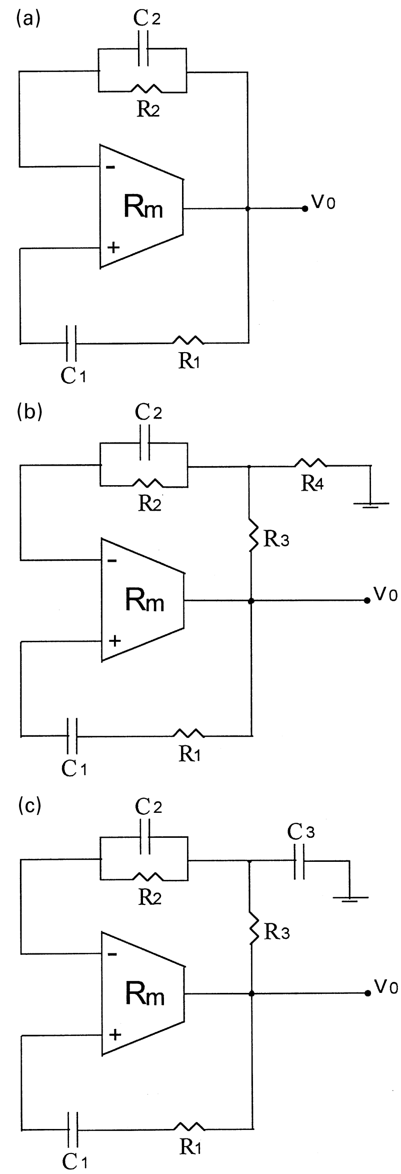


Fig. 3. Three single OTRA oscillator circuits.

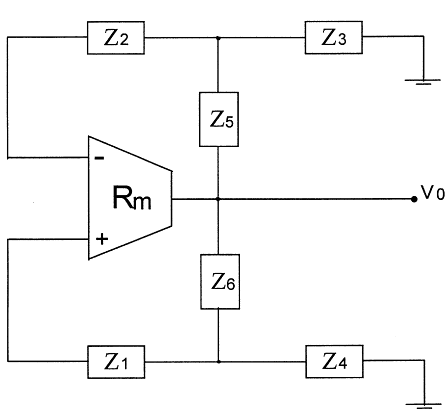


Fig. 2. The single OTRA generalized oscillator.

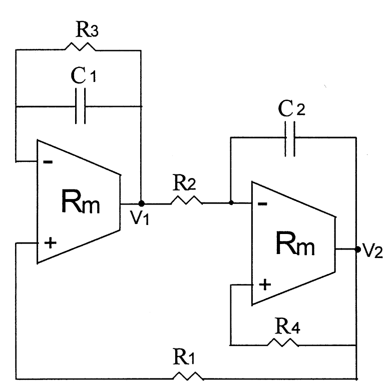


Fig. 4. Two OTRA oscillator circuit with independent control on the frequency of oscillation.

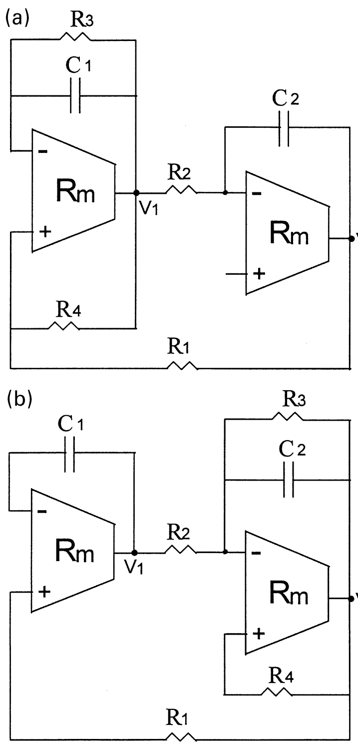


Fig. 5. Two equivalent quadrature oscillators.

given by:

$$\omega_0 = \frac{1}{\sqrt{C_1C_2R_1R_2\left[1 - \frac{R_3}{R_1}\left(1 + \frac{C_3}{C_2}\right)\right]}}. \tag{7}$$

It is seen that ω_0 can be independently controlled by varying C_3 without affecting the condition of oscillation which is given by:

$$\frac{R_1}{R_2} + \frac{C_2}{C_1} = 1 + \frac{R_3}{R_2}. \tag{8}$$

3. The two OTRA oscillators

In this section four novel oscillators using two OTRAs are proposed. Each oscillator employs the minimum number of capacitors, namely two plus four or five resistors.

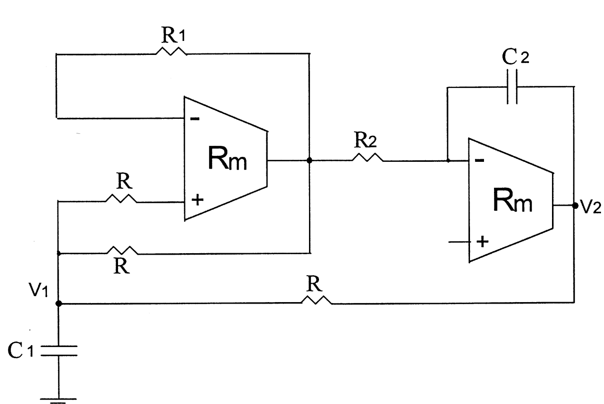


Fig. 6. An oscillator based on a novel grounded inductor using two OTRAs.

The state matrix equation for the oscillator shown in Fig. 4 is given by:

$$\begin{bmatrix} \frac{dv_1}{dt} \\ \frac{dv_2}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{C_1R_3} & \frac{1}{C_1R_1} \\ -\frac{1}{C_2R_2} & \frac{1}{C_2R_4} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \tag{9}$$

The condition of oscillation is given by:

$$C_1R_3 = C_2R_4. \tag{10}$$

The radian frequency of oscillation is given by:

$$\omega_0 = \sqrt{\frac{1}{C_1C_2R_1R_2}\left(1 - \frac{R_1R_2}{R_3R_4}\right)}. \tag{11}$$

The frequency of oscillation can be controlled by varying R_1 or R_2 without affecting the condition of oscillation. This oscillator can be used to generate very low frequencies without using large valued capacitors by taking R_1R_2 slightly less than R_3R_4 [17].

This oscillator circuit however cannot provide independent control on the condition of oscillation. Changing the position of R_4 to be in the positive feedback path of the first OTRA instead of the second OTRA, the oscillator of Fig. 5(a) is obtained. The state matrix equation in this case is given by:

$$\begin{bmatrix} \frac{dv_1}{dt} \\ \frac{dv_2}{dt} \end{bmatrix} = \begin{bmatrix} \frac{1}{C_1}\left(\frac{1}{R_4} - \frac{1}{R_3}\right) & \frac{1}{C_1R_1} \\ -\frac{1}{C_2R_2} & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}. \tag{12}$$

In this case the condition of oscillation and the frequency of oscillation are given by:

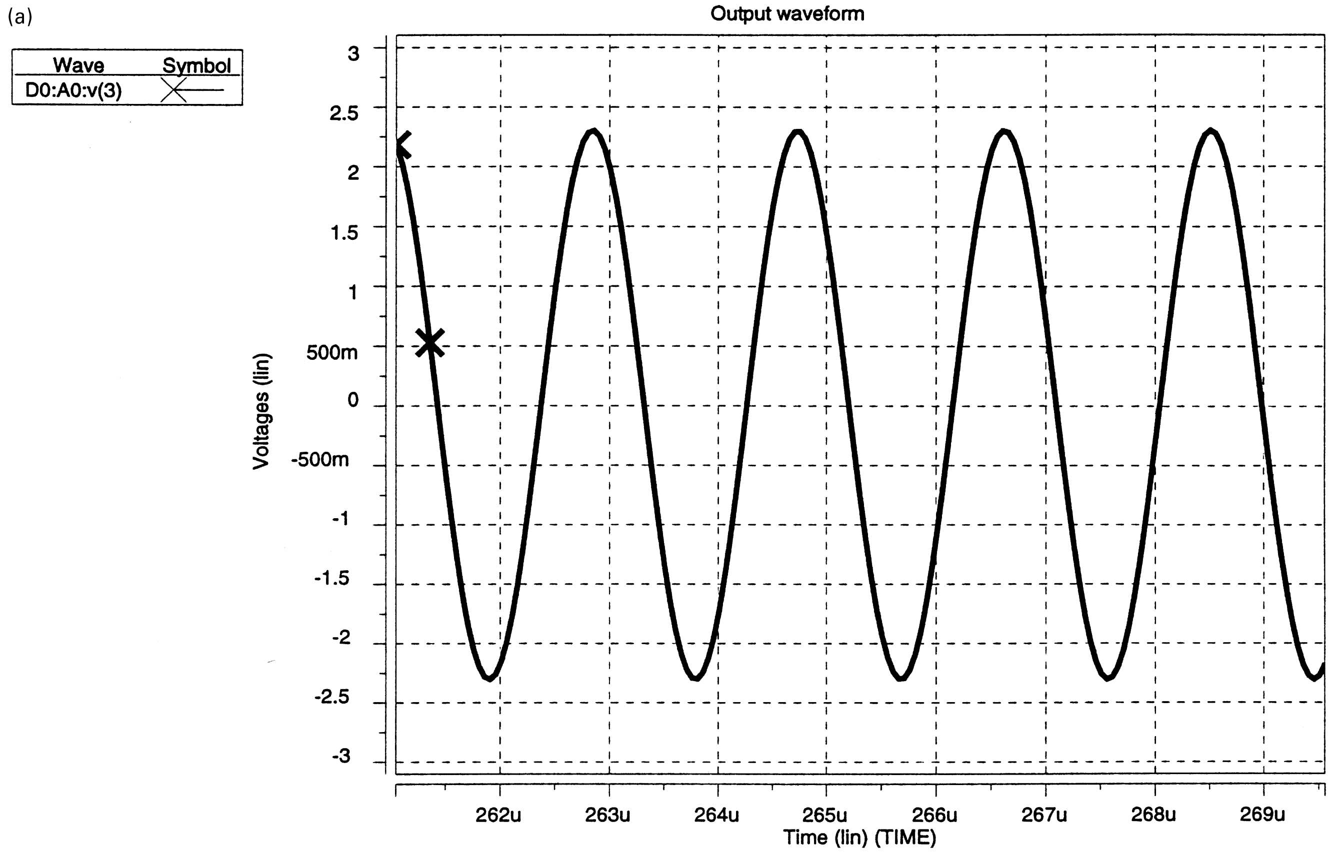
$$R_3 = R_4, \tag{13}$$

$$\omega_0 = \frac{1}{\sqrt{C_1C_2R_1R_2}}. \tag{14}$$

It is seen that either R_3 or R_4 can be adjusted to control the condition of oscillation without affecting ω_0. Also ω_0 can be adjusted by varying R_1 or R_2 without disturbing the condition of oscillation. This circuit is considered to be a two-phase oscillator or quadrature oscillator. Another modification to the circuit of Fig. 4 is to change the position of R_3 and this results in the quadrature oscillator shown in Fig. 5(b). The state matrix equation in this case is given by:

$$\begin{bmatrix} \frac{dv_1}{dt} \\ \frac{dv_2}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{C_1R_1} \\ -\frac{1}{C_2R_2} & \frac{1}{C_2}\left(\frac{1}{R_4} - \frac{1}{R_3}\right) \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}. \tag{15}$$

The condition of oscillation and the radian frequency of oscillation are the same as given by Eqs. (13) and (14).



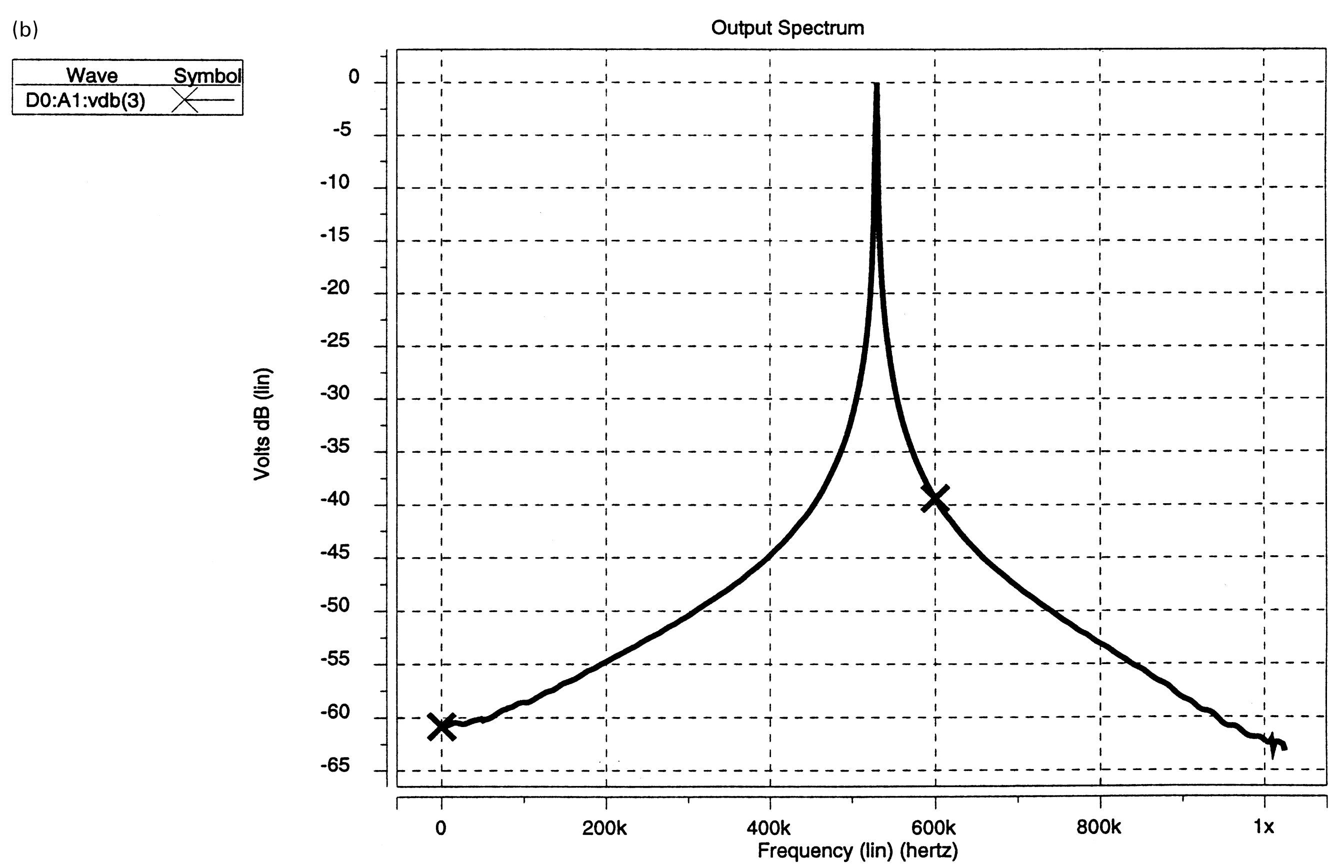
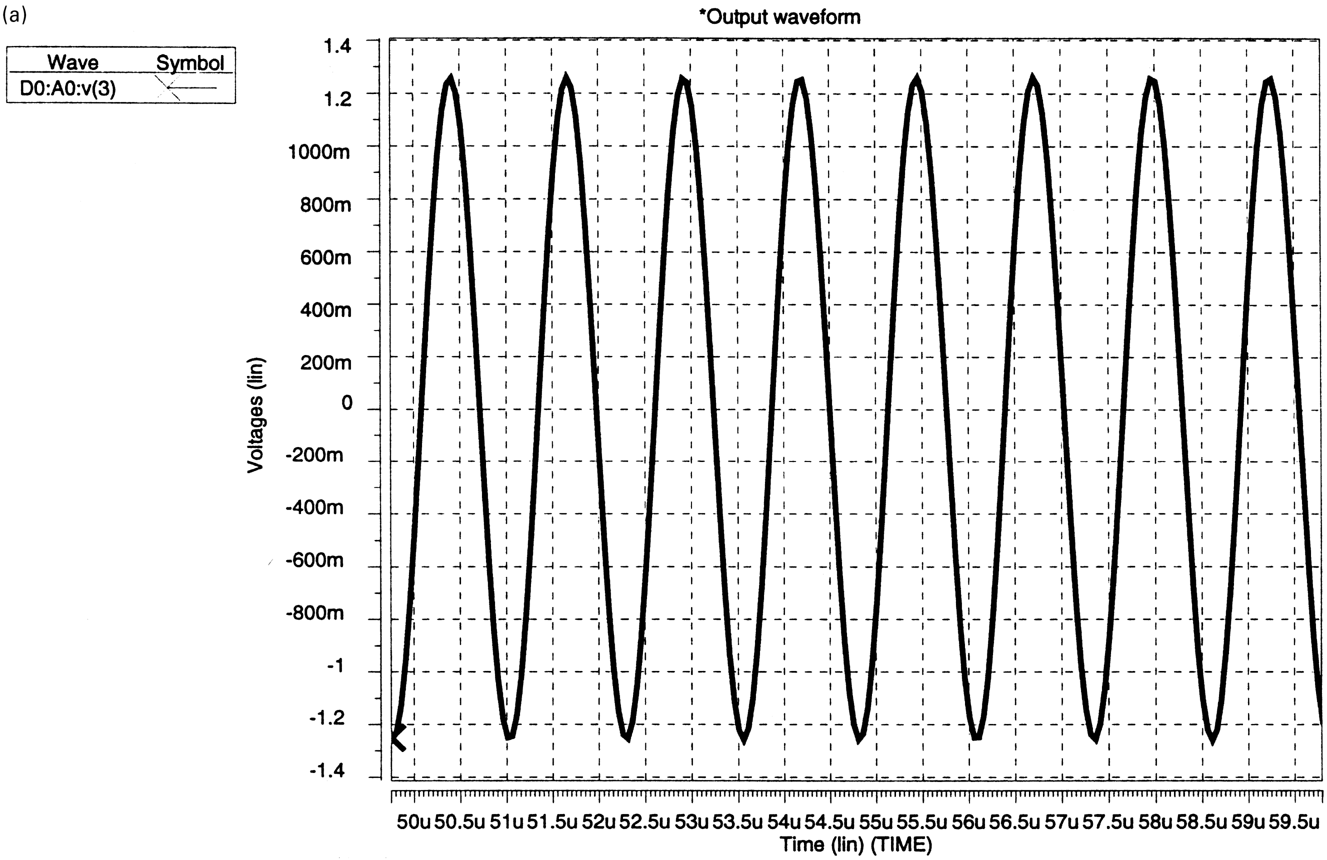


Fig. 7. (a) The output waveform of the oscillator of Fig. 3(a). (b) The frequency spectrum of the oscillator of Fig. 3(a).

(a)



(b)

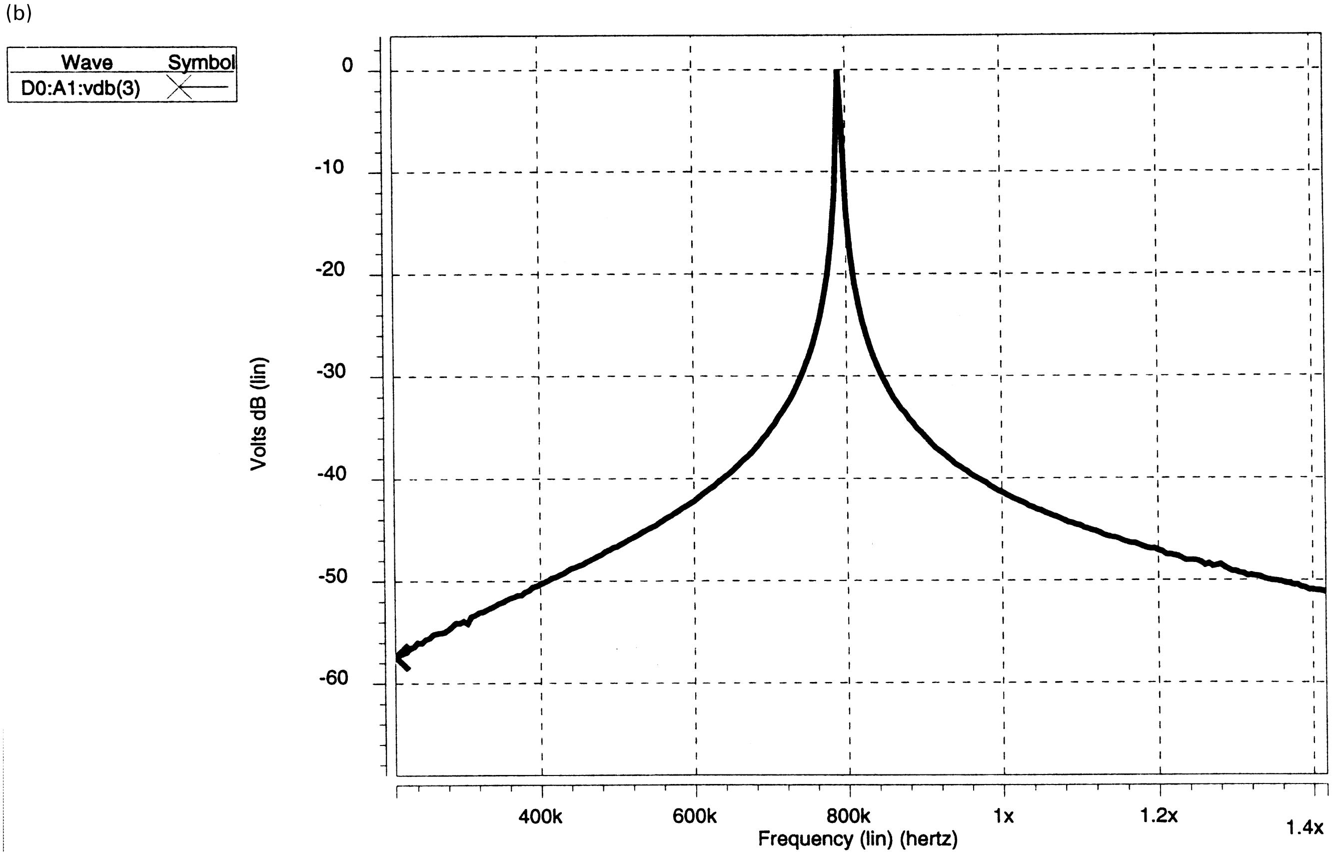
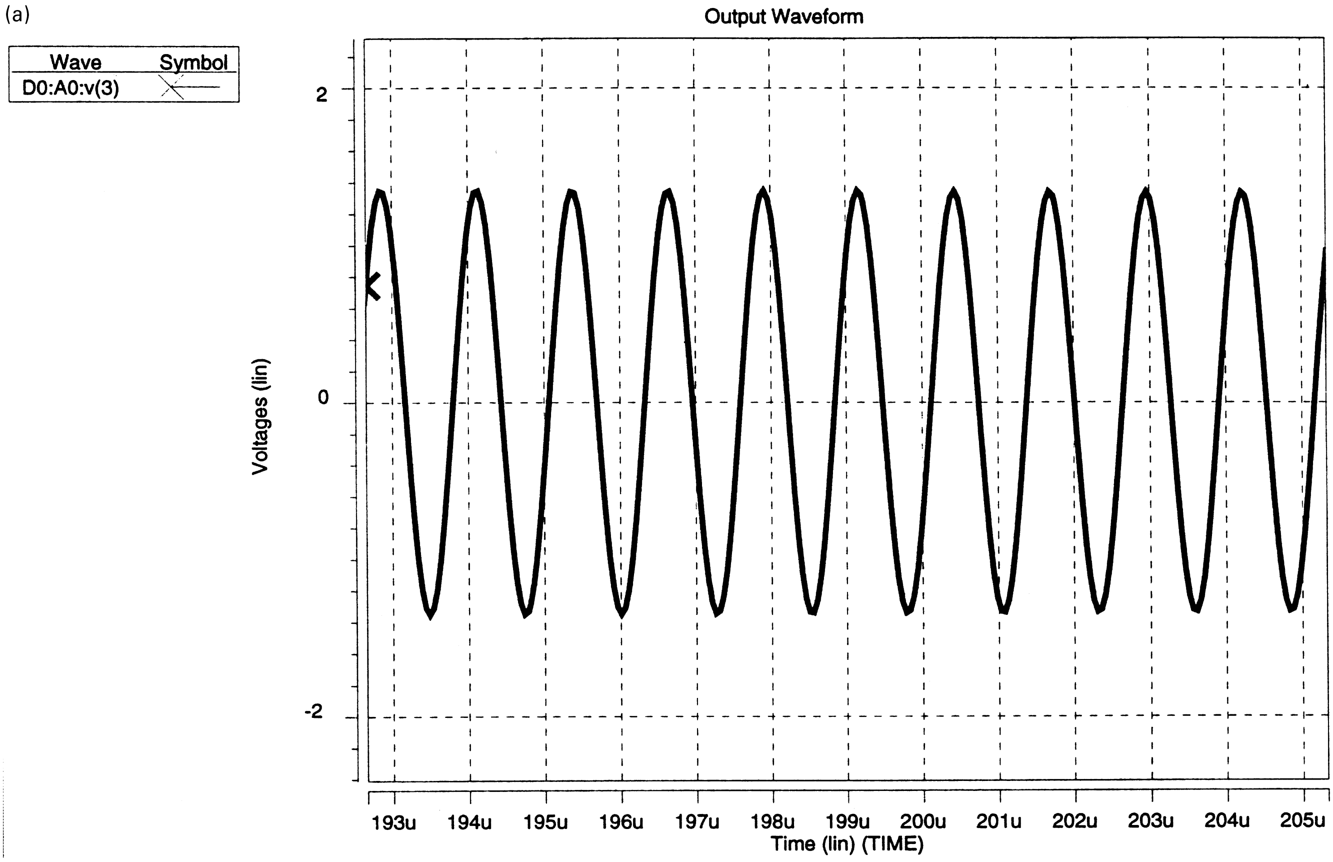


Fig. 8. (a) The output waveform of the oscillator of Fig. 3(b). (b) The frequency spectrum of the oscillator of Fig. 3(b).



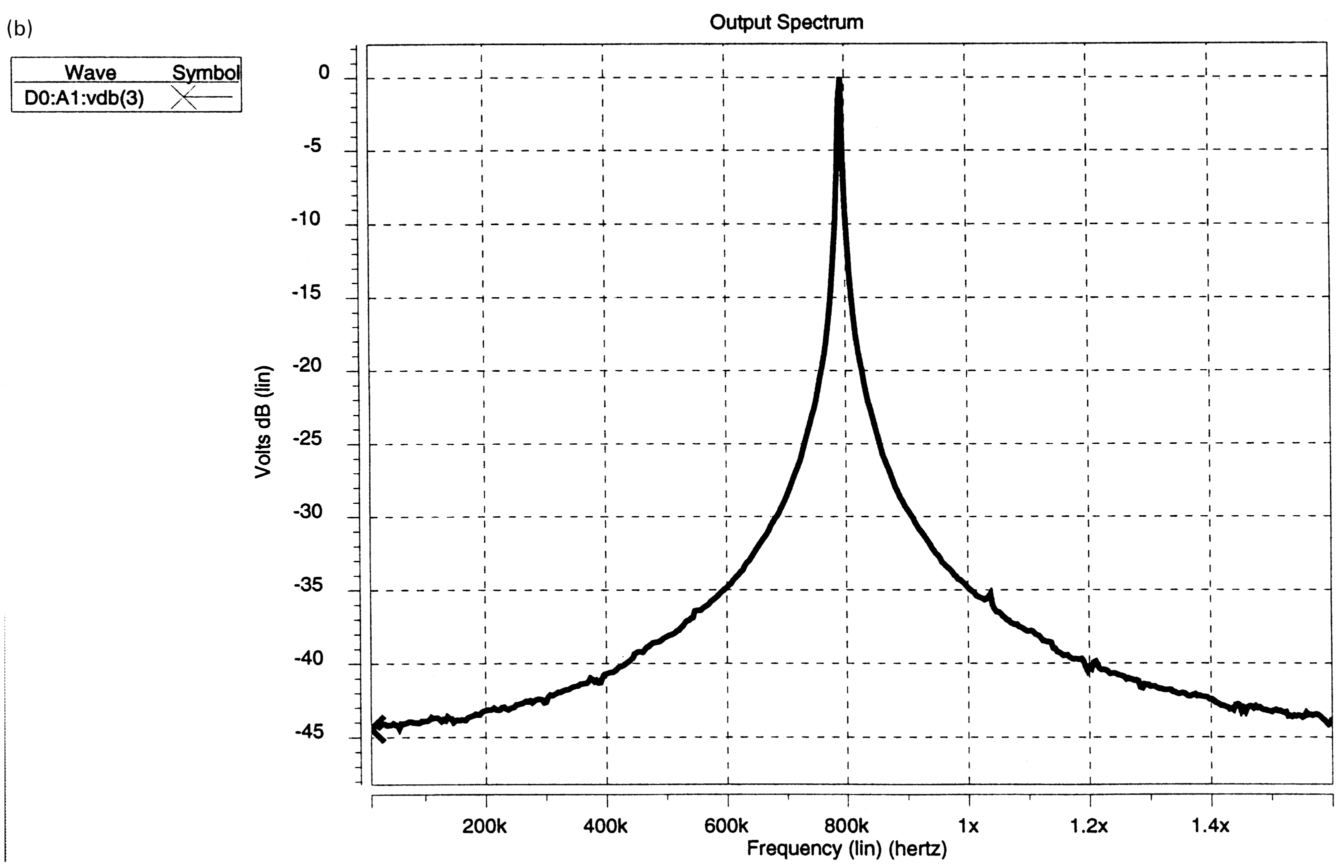
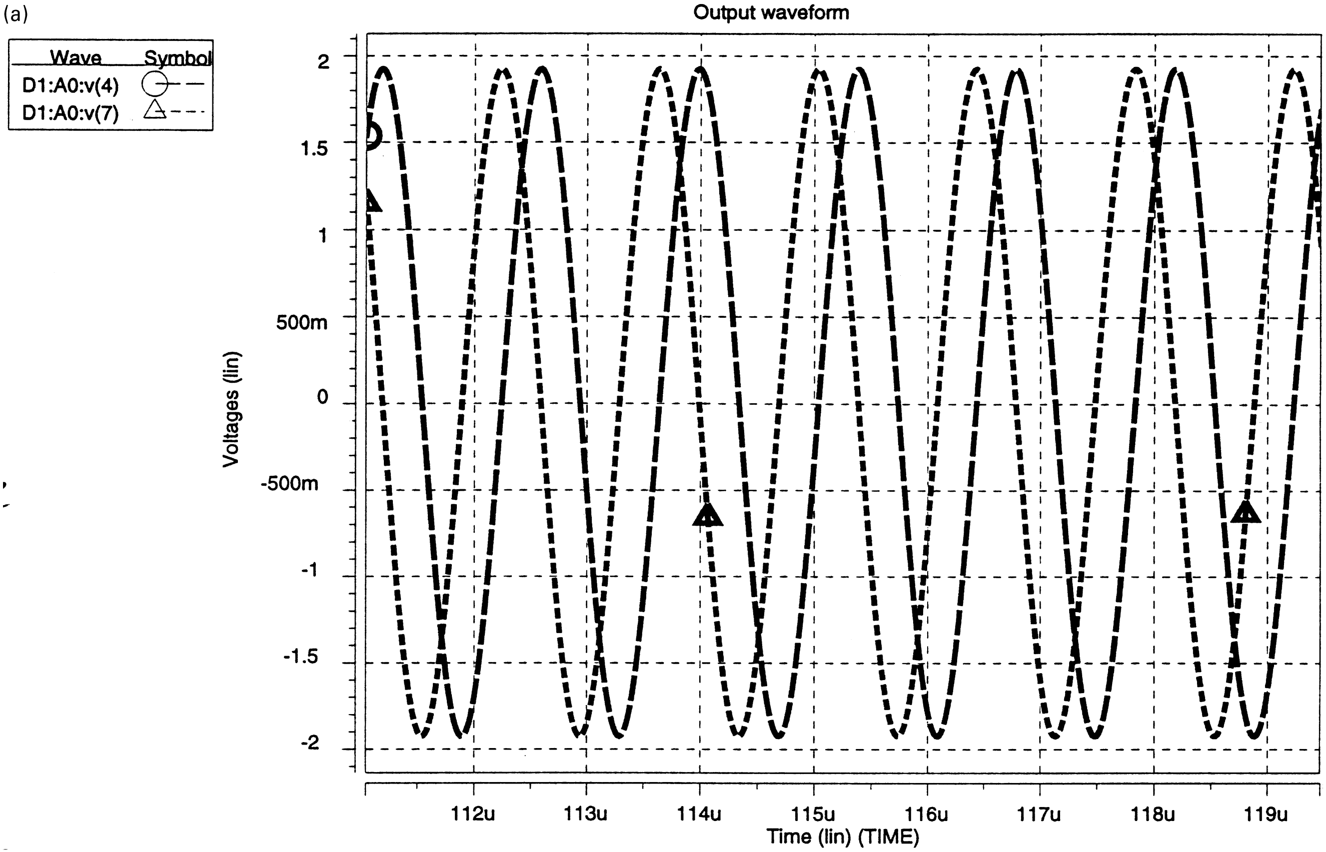


Fig. 9. (a) The output waveform of the oscillator of Fig. 3(c). (b) The frequency spectrum of the oscillator of Fig. 3(c).

(a)



(b)

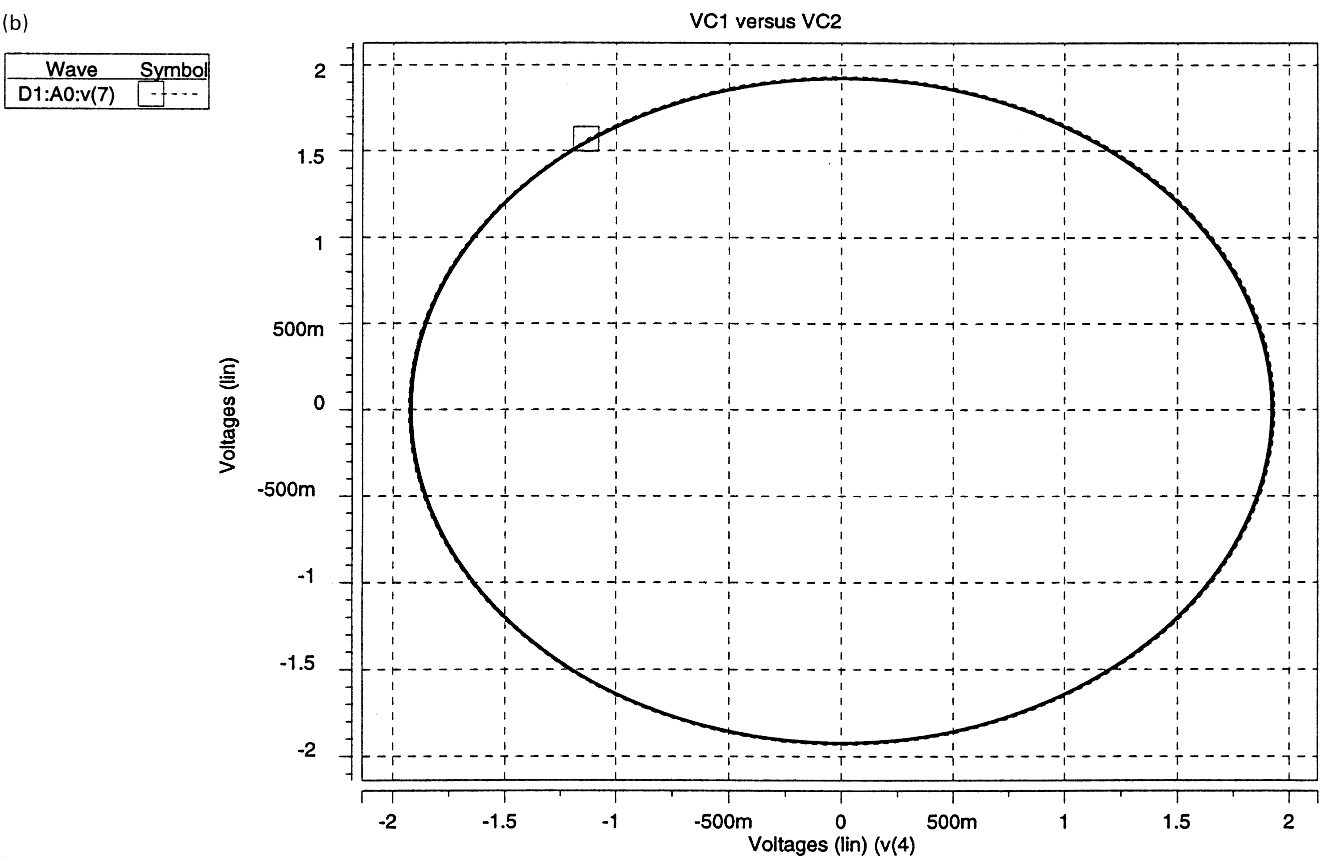


Fig. 10. (a) The output waveform of the oscillator of Fig. 5(b). (b) The voltage V_1 versus V_2 of the oscillator of Fig. 5(b).

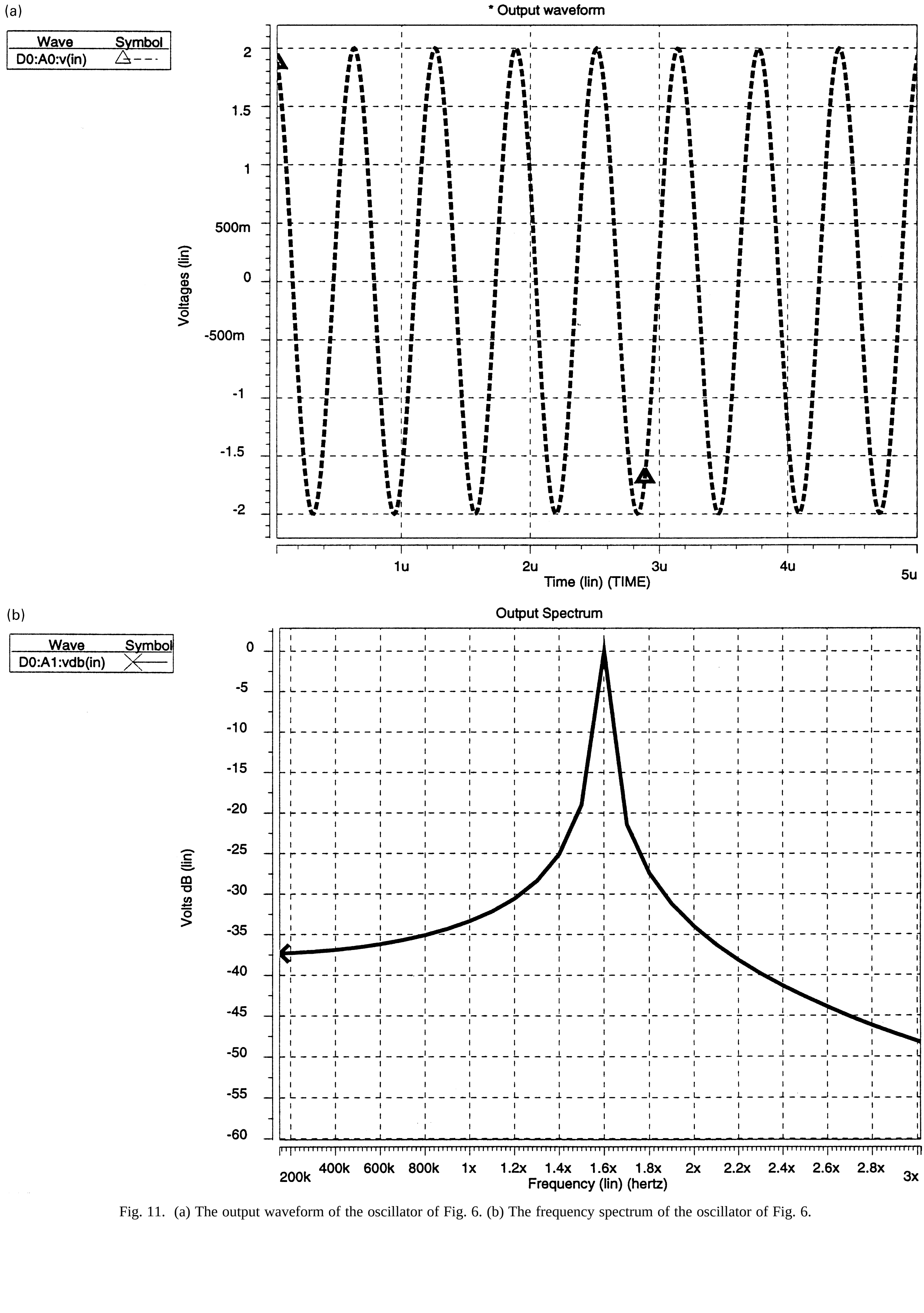


Fig. 11. (a) The output waveform of the oscillator of Fig. 6. (b) The frequency spectrum of the oscillator of Fig. 6.

The fourth circuit described in this section is shown in Fig. 6. This oscillator is based on a novel grounded inductor realized by two OTRAs, five resistors and a single capacitor C_2. The state matrix equation is given by:

$$\begin{bmatrix} \frac{dv_1}{dt} \\ \frac{dv_2}{dt} \end{bmatrix} = \begin{bmatrix} \frac{1}{C_1 R}\left(\frac{R_1}{R} - 3\right) & \frac{1}{C_1 R} \\ -\frac{R_1}{C_2 R_2 R} & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}. \quad (16)$$

Therefore, the condition of oscillation and the radian frequency of oscillation are given by:

$$R_1 = 3R, \quad (17)$$

$$\omega_0 = \sqrt{\frac{3}{C_1 C_2 R R_2}}. \quad (18)$$

The resistor R_1 controls the condition of oscillation without affecting ω_0, and the resistor R_2 controls ω_0 without disturbing the oscillation condition.

4. HSpice simulation results

The HSpice simulations given in this paper were performed using an OTRA based on the cascaded connection of the modified differential current conveyor (MDCC) reported in Ref. [18] and a common source amplifier. The MDCC provides the current differencing operation, whereas the common source amplifier provides the high gain [14]. The OTRA circuit was biased with $\pm$ 2.5 V. This OTRA realization is much simple than the previously reported OTRA realization using three current feedback operational amplifiers [19].

The oscillator circuit of Fig. 3(a) was designed with $R_1 = 10$ kΩ, $R_2 = 20$ kΩ, $C_1 = 30$ pF and $C_2 = 15$ pF. Fig. 7(a) represents the output waveform and Fig. 7(b) represents the frequency spectrum.

The oscillator of Fig. 3(b) was designed with $R_1 = R_2 = 20$ kΩ, $R_3 = 15$ kΩ, $R_4 = 60$ kΩ and $C_1 = C_2 = 20$ pF. Fig. 8(a) represents the output waveform and Fig. 8(b) represents the frequency spectrum.

The oscillator of Fig. 3(c) was designed with $R_1 = R_2 = 20$ kΩ, $R_3 = 5$ kΩ, $C_1 = 40$ pF, $C_2 = 10$ pF and $C_3 = 20$ pF. Fig. 9(a) represents the output waveform and Fig. 9(b) represents the frequency spectrum.

The circuit of Fig. 5(b) was designed with $R_1 = R_2 = 5$ kΩ, $R_3 = R_4 = 10$ kΩ and $C_1 = C_2 = 45$ pF. Fig. 10(a) represents the output waveform and Fig. 10(b) represents V_1 versus V_2 showing a simple limit cycle of period one, indicating a single harmonic frequency. From the simulations $f_0 =$ 695 kHz, thus $\Delta f_0/f_0 = -1.79\%$ and the THD is equal to 2.4%.

The circuit of Fig. 6 was designed with $R = 3$ kΩ, $R_1 = 9$ kΩ, $R_2 = 10$ kΩ, $C_1 = 10$ pF and $C_2 = 100$ pF. Fig. 11(a) represents the output waveform and Fig.11(b) represents the frequency spectrum.

5. Conclusion

Several novel active RC oscillator circuits using the operational transresistance amplifier (OTRA) as the basic active building block. A general configuration using a single OTRA is introduced, from which a minimum component oscillator is generated. Four oscillator circuits based on using two OTRAs are reported. To the best of authors' knowledge, these are the first active RC oscillators reported in the literature using the OTRA as the active building block. HSpice simulations to confirm the analysis are given.

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