Realization of sinusoidal oscillators using operational Transresistance Amplifier (OTRA)

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Abstract: - In this paper, four new sinusoidal waveform generators based on the operational transresistance amplifier (OTRA) are presented. The first proposed circuit is a minimum component RC sinusoidal oscillator circuit with one OTRA and a few passive components. The second and third proposed circuits consist of one OTRA and a few passive components, among them two passive components are connected to ground. These circuits are able to control the condition of oscillation and frequency of oscillation independently. The fourth proposed quadrature oscillator circuit uses two OTRAs as main active building blocks and a few external passive components to generate the oscillations. The commercially available IC AD 844 AN has been adopted to implement the proposed circuits on a laboratory breadboard with external passive components. Both the SPICE simulation and experimental results are given to verify the theoretical analysis of the proposed circuits.

Key-Words: - Oscillators; Operational transresistance amplifier; Analog integrated circuit design; Current mode oscillators; Sinusoidal oscillators.

1 Introduction

Sinusoidal oscillators have gained much attention due to its applications in the fields of electronic circuits such as signal processing, instrumentation and measurement, control systems and communication. Similarly, a quadrature sinusoidal oscillator typically provides two sinusoids with a 90o phase difference, which is useful in telecommunications for quadrature mixer, in single-sideband generators, in direct-conversion receivers, and also for measurement purposes in vector generators and selective voltmeters [1-4]. A variety of sinusoidal oscillator circuits have been proposed using op-amp as an active element in the literature [1]. Although these oscillator circuits suffer from the limitations incurred by the limited slew rate and fine gain bandwidth product [1-5]. It is a known fact that several oscillator circuits have been proposed in the literature based on current mode devices to overcome the disadvantages posed by classical voltage-mode oscillators [6-28]. Current mode devices have gained considerable attention due to large dynamic range, large frequency range and wider bandwidth compared to voltage mode devices.

In the literature several sinusoidal oscillators are available using current-mode devices like Current Feed-back Operational Amplifier (CFOA), Second Generation Current Conveyor (CCII), Operational Trans-conductance Amplifier (OTA), Differential Difference Current Conveyor (DDCC), Current Differencing Buffer Amplifier (CDBA) and Four Terminal Floating Nuller (FTFN) [6-28]. These oscillators have shot in to prominence due to the advantages gained over voltage mode oscillators. In the current mode oscillators, the oscillation frequency can be adjusted more accurately and the large slew rate compel the oscillation frequency less sensitive to the bandwidth variation of the active device. However, most of the circuits proposed in [6-28] have more number of passive components possess more than one active component. In the last decade, a new current mode device called operational transresistance amplifier has gained considerable attention of the analog IC designers. The operational transresistance amplifier is a high gain current input and voltage output analog building block. Current differencing amplifier and Norton amplifier are the commercially available names of OTRA. These commercial realizations allow input current only in one direction and do not bear internal ground at the input terminal. These disadvantages are eliminated by the introduction of several high performance CMOS OTRA realizations [29, 30]. The OTRA has been used as an important building block in analog circuit design. Several circuit realizations have made their appearance in the literature [31-44] based on OTRA as main active building block like square-wave generator, multivibrators, filters, inductance simulators and many more. Based on the above considerations, in this paper, an OTRA based quadrature oscillator circuits have been presented.

2 Proposed circuits

The circuit symbol of the OTRA and its CMOS implementation is shown in Fig. 1 and Fig. 2 respectively. The OTRA is a three terminal current mode analog device with two low-impedance input terminals and one low-impedance output terminal. The input terminals of the OTRA are virtually grounded. The input and output terminal relations of an OTRA can be characterized by the matrix shown in equation (1). For ideal operation, the transresistance gain R_m approaches infinity forcing the input currents to be equal.

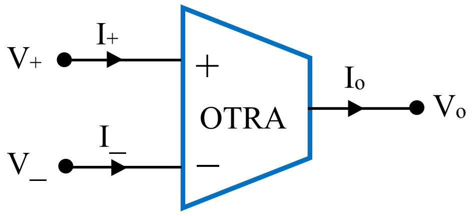


Fig. 1 OTRA circuit symbol

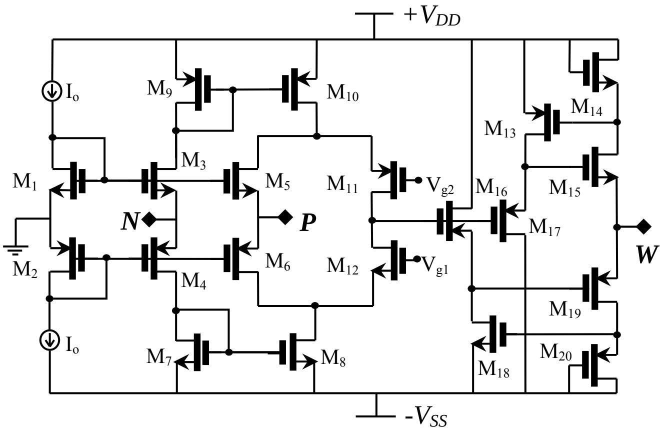


Fig. 2 CMOS implementation of OTRA [32]

$$\begin{bmatrix} V_+ \\ V_- \\ V_0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_+ \\ I_- \\ I_0 \end{bmatrix} \quad (1)$$

2.1 Proposed minimum component oscillator circuit

The minimum component oscillator circuit is shown in Fig. 3. The proposed circuit consists of one OTRA and four passive components

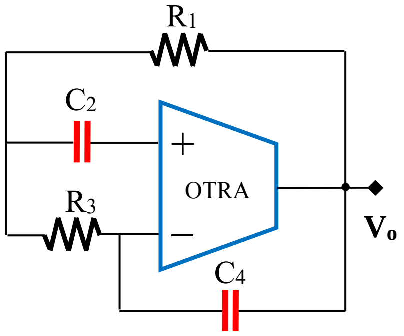


Fig. 3 Proposed minimum component sinusoidal oscillator circuit

The characteristic equation for the above circuit can be written as

$$s^2 C_2 C_4 + s(C_4 G_1 + C_4 G_3 - C_2 G_1) + G_1 G_3 = 0 \quad (4)$$

The condition of oscillation and frequency of oscillation for the first proposed circuit can be derived from the characteristic equation as

$$\text{C.O:} \quad C_4(G_1 + G_3) = C_2 G_1 \quad (5)$$

$$\text{F.O:} \quad f = \frac{1}{2\pi}\sqrt{\frac{G_1 G_3}{C_2 C_4}} \quad (6)$$

The condition of oscillation and frequency of oscillation are not independently controlled by the first proposed circuit.

2.2 Proposed grounded resistance and capacitance sinusoidal oscillator circuits

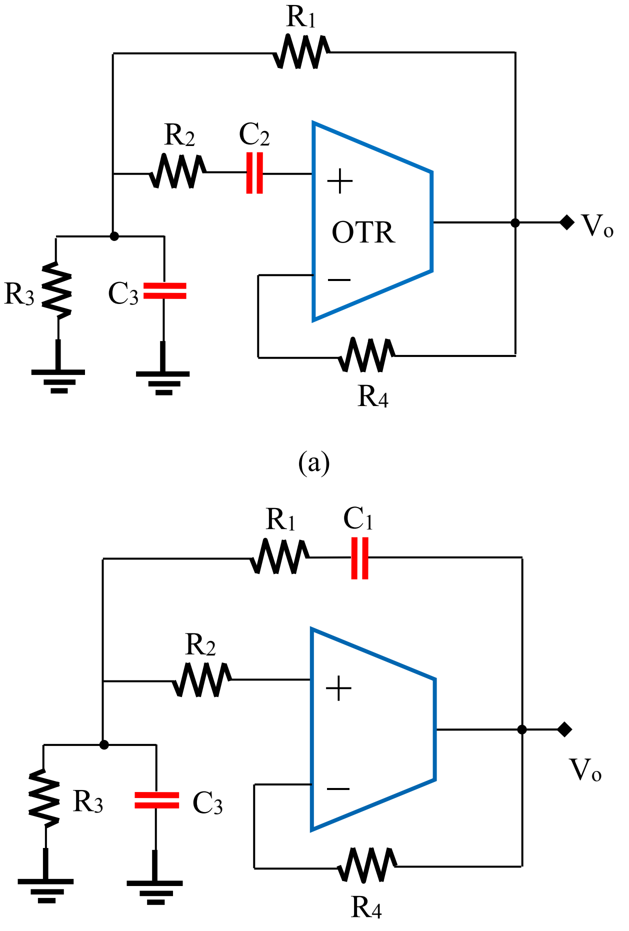
The proposed grounded resistance and capacitance sinusoidal oscillator circuits are shown in Fig. 4. The proposed circuits require two capacitors, four resistors and one OTRA to generate the oscillations. From the input terminal relations and from ideal behaviour of the OTRA, it is easy to derive the characteristic equation of the proposed circuit shown in Fig.4 (a)

$$s^2 C_2 C_3 G_4 + s\big(G_4\big(C_2\big(G_1 + G_2 + G_3\big) + C_3 G_2\big) - C_2 G_2 G_1\big) + G_2 G_4\big(G_1 + G_3\big) = 0 \quad (7)$$

From the above equation (7), the condition of oscillation and frequency of oscillation can be written as

$$G_4\left(C_2\left(G_1+G_3\right)+G_2\left(C_2+C_3\right)\right)=C_2G_2G_1 \qquad (8)$$

$$f=\frac{1}{2\pi}\sqrt{\frac{G_2\left(G_1+G_3\right)}{C_2C_3}} \qquad (9)$$



(a)

(b)

Fig.4 Proposed grounded resistance and capacitance sinusoidal oscillator circuits

Similarly, for the proposed circuit shown in Fig. 4(b), the condition of oscillation and frequency of oscillation can be written as

$$G_4\left(C_1\left(G_2+G_3\right)+G_1\left(C_1+C_3\right)\right)=C_1G_2G_1 \qquad (10)$$

$$f=\frac{1}{2\pi}\sqrt{\frac{G_1\left(G_2+G_3\right)}{C_1C_3}} \qquad (11)$$

It has transpired from the equations (8), (9), (10) and (11) that the condition of oscillation and frequency of oscillation of the proposed circuits in Fig. 4 can be controlled independently by the resistor R4.

2.3 Proposed quadrature sinusoidal oscillator circuit

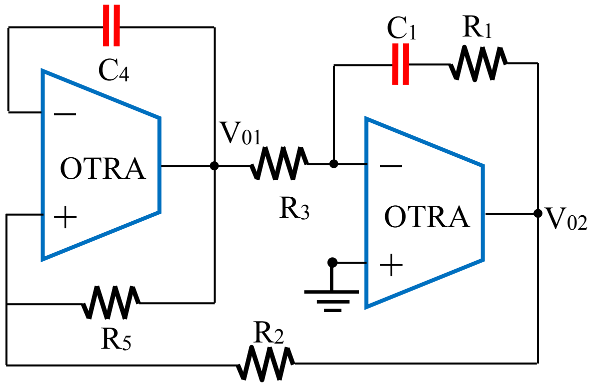


Fig. 5 Proposed quadrature oscillator circuit

The proposed quadrature oscillator circuit is shown in Fig. 5. The proposed circuit requires two OTRAs, two capacitors and four resistors to generate the oscillations. From the ideal behaviour of the OTRA, the characteristic equation of the circuit can be expressed as

$$s^2C_1C_4G_1+sC_1(G_3G_2-G_1G_5)+G_1G_2G_3=0 \qquad (12)$$

The frequency of oscillation and the condition of oscillation can be obtained from the above equation as

$$\text{F.O:}\quad f=\frac{1}{2\pi}\sqrt{\frac{G_2G_3}{C_1C_4}} \qquad (13)$$

$$\text{C.O:}\quad G_3G_2=G_1G_5 \qquad (14)$$

From the equations (13) and (14), it is clear that the frequency of oscillation and the condition of oscillation can be controlled independently by the capacitors C_1, C_2 or by the resistors R_1, R_5.

3 Non-ideal analysis

For ideal operation, the transresistance gain approaches infinity and forces the two input currents to be equal. However, practically the transresistance gain R_m is finite and its effects therefore to be considered. Considering the single pole model, the transresistance gain R_m can be expressed as

$$R_m(s)=\frac{R_m}{1+\frac{s}{\omega_0}}=\frac{R_0\omega_0}{s+\omega_0}=\frac{1}{\frac{s}{R_o\omega_0}+\frac{1}{R_0}} \tag{15}$$

For middle and high frequency frequencies, the transresistance gain $R_m(s)$ is reduced to

$$R_o\rightarrow\infty,\qquad R_m(s)\cong\frac{1}{sC_p} \tag{16}$$

Where R_0 is the DC open loop transresistance gain, ω_0 is the transresistance cut-off frequency and C_P is the parasitic capacitance. For the proposed minimum component oscillator circuit in Fig. 3, the non-ideal analysis gives the following equations for the condition of oscillation and frequency of oscillation.

$$(C_4+C_p)(G_1+G_3)=C_2G_1 \tag{17}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{G_1G_3}{C_2(C_4+C_p)}} \tag{18}$$

The effect of C_P can be minimized by slightly adjusting the value of a feedback capacitor C_4 to achieve self compensation. For the grounded resistance and capacitance sinusoidal oscillator circuit shown in Fig. 4 (a), the non-ideal analysis gives the following equations

$$G_4\left(C_2(G_1+G_3)+G_2\left(C_2+C_3+C_pG_1+C_pG_2\right)\right)=C_2G_2G_1 \tag{19}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{G_2G_4(G_1+G_3)}{C_2\left(C_3G_4+C_p(G_1+G_2+G_3)\right)+C_pC_3G_2}} \tag{20}$$

Similarly, for the proposed circuit shown in Fig. 4(b), the non-ideal condition of oscillation and frequency of oscillation equations are given in eq. (21) and (23)

$$G_4\left(C_1(G_1+G_3)+G_1\left(C_1+C_3+C_pG_1+C_pG_2\right)\right)=C_1G_2G_1 \tag{21}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{G_1G_4(G_2+G_3)}{C_2\left(C_3G_4+C_p(G_1+G_2+G_3)\right)+C_pC_3G_2}} \tag{21}$$

The non-ideal analysis of the quadrature sinusoidal oscillator circuit shown in Fig. 5 is given in the equations (23) and (24) given below.

$$f=\frac{1}{2\pi}\sqrt{\frac{G_1G_2G_3}{G_1C_4(C_1+C_{p1})+C_1C_{p2}+C_{p1}C_{p2}}} \tag{23}$$

$$G_3G_2=G_1G_5 \tag{24}$$

The capacitor C_1 is tuned to achieve the self compensation in the proposed circuit as shown in Fig. 5.

3 Simulation and experimental results

The proposed oscillator circuits were simulated using SPICE simulation models. The CMOS realization of the OTRA was shown in Fig. 2. Fig. 2 is designed by using CMOS gpdk 180 nm technology with a supply voltage of ± 1.8 V. For generating the oscillations in the first proposed minimum component oscillator circuit in Fig. 3, the passive component values were chosen to be R_1 = 10 kΩ, R_3 = 1 kΩ, C_2 = 100 pF and C_4 = 1 nF. Fig. 6 represents the simulated output waveform of the first proposed minimum component oscillator circuit with a frequency of 161.5 kHz. The percentage of error between the simulated and theoretical oscillation frequency is 1.5 %. The frequency spectrum for the minimum component oscillator circuit is shown in Fig. 7.

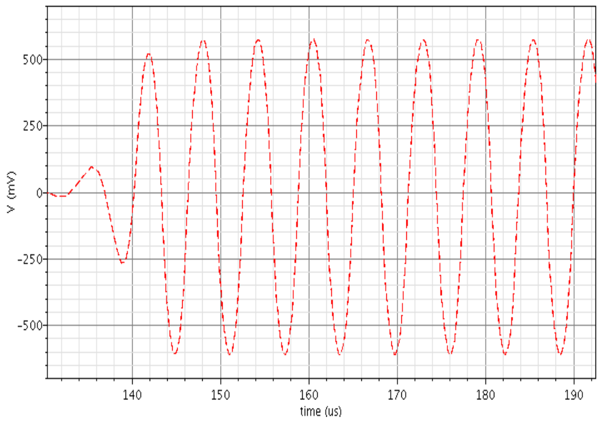


Fig. 6 Simulated output waveform of the proposed circuit in Fig. 3

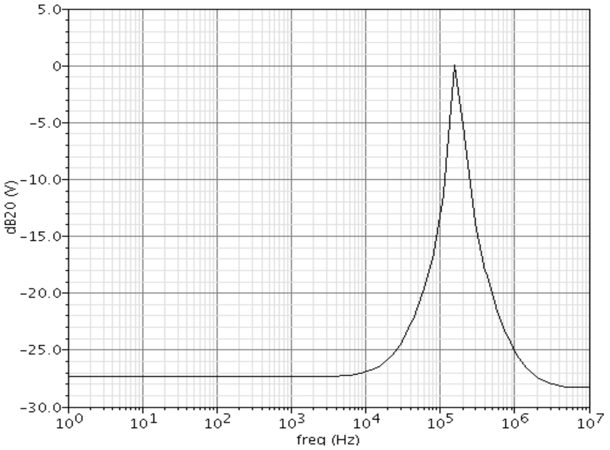


Fig. 7 Frequency spectrum of the proposed circuit in Fig. 3

The following passive component values were chosen to simulate the second proposed circuit in Fig. 4 (a), R_1 = 100 Ω, R_2 = 1.2 kΩ, R_3 = 600 Ω, R_4 = 5.5 kΩ, C_2 = 150 pF and C_3 = 150 pF. Fig. 8 represents the simulated output waveform of the proposed circuit in Fig. 4(a) with a frequency of 3.18 MHz. The simulated frequency in Fig. 8 is very close to the theoretical frequency of 3.24 MHz. The frequency spectrum of the proposed circuit in Fig. 4(a) is shown in Fig. 9.

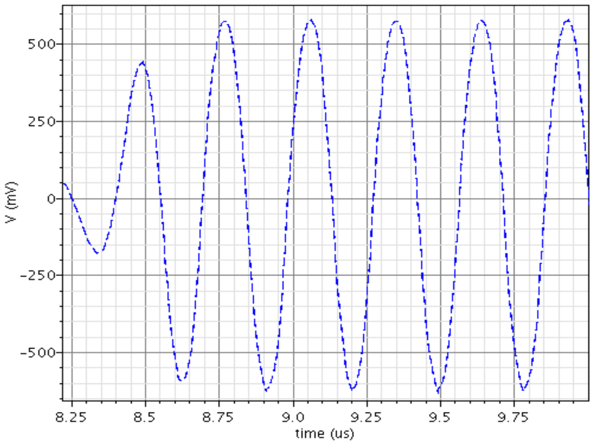


Fig. 8 Simulated output waveform of the proposed circuit in Fig. 4 (a)

Similarly, the passive components R_1 = 100 Ω, R_2 = 1.2 kΩ, R_3 = 600 Ω, R_4 = 5.5 kΩ, C_1 = 200 pF and C_3 = 200 pF were chosen to produce the oscillations in the proposed circuit shown in Fig. 4(b). Fig. 10 represents the simulated output waveform of the proposed circuit in Fig. 4 (b) with a frequency of 2.9 MHz. The simulated frequency in Fig. 10 is very close to the theoretical frequency of 3.79 MHz. The frequency spectrum for the proposed circuit in Fig. 4 (b) is shown in Fig. 11.

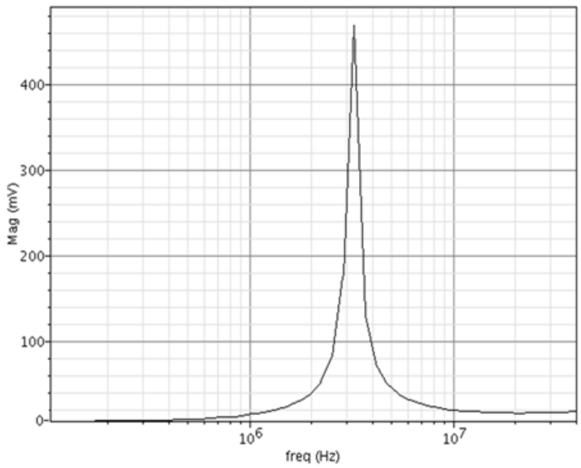


Fig. 9 Frequency spectrum of the proposed circuit in Fig. 4 (a)

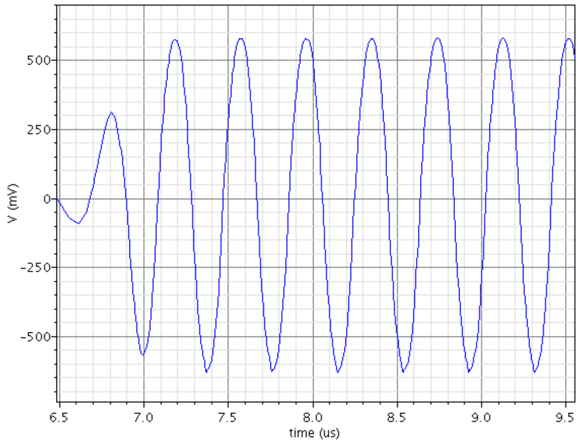


Fig. 10 Simulated output waveform of the proposed circuit in Fig. 4 (b)

The proposed circuit in Fig. 5 was connected with the passive component values, R_1 = 9 kΩ , R_2 = 500 Ω, R_3 = 1 kΩ, R_5 = 100 Ω, C_1 = 100 pF and C_4= 100 pF. The simulated output waveform with a frequency of 2.4 MHz is shown in Fig. 12. The frequency spectrum for the proposed circuit in Fig. 5 is shown in Fig. 13. In order to verify the theoretical study on a laboratory breadboard, AD844AN is adopted to construct the proposed circuits. The commercial IC AD844AN with current feedback architecture is used to implement the OTRA as shown in Fig. 14 [44-45].

$$V_0 = V_{T2} = -R_m \times I_{T2} = R_m(I_+ - I_-) \qquad (25)$$

The non-inverting terminals of the AD844ANs have been grounded, to simulate the virtual ground, for the terminals of the OTRA. The above equation can be verified from Fig. 14.

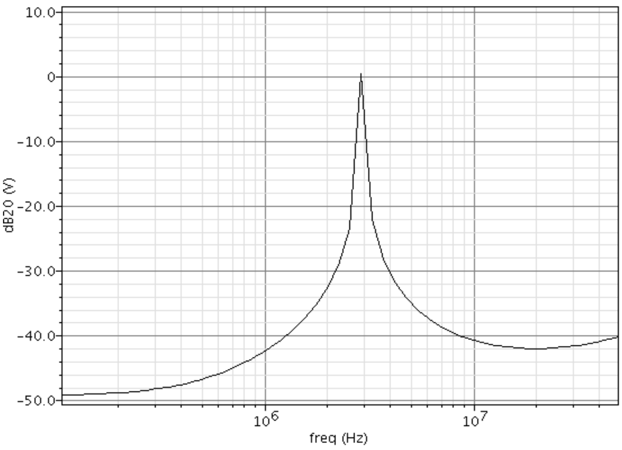


Fig. 11 Frequency spectrum of the proposed circuit in Fig. 4 (b)

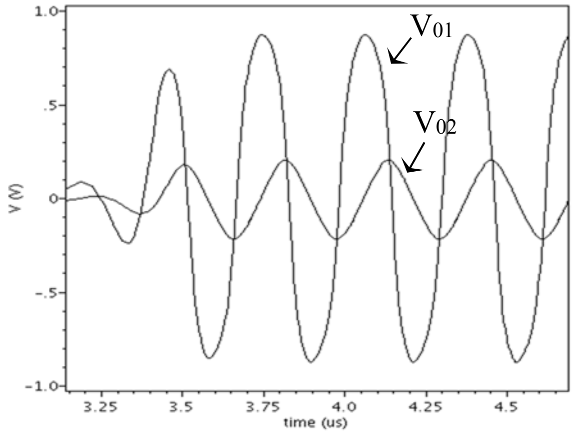


Fig. 12 Simulated output waveform of the proposed circuit in Fig. 5

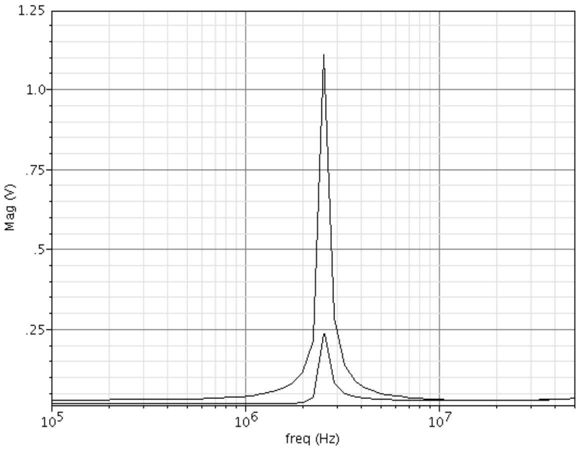


Fig. 13 Frequency spectrum of the proposed circuit in Fig. 5

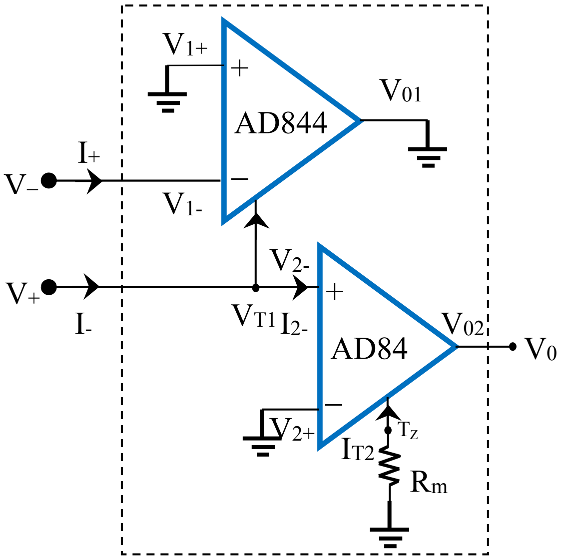
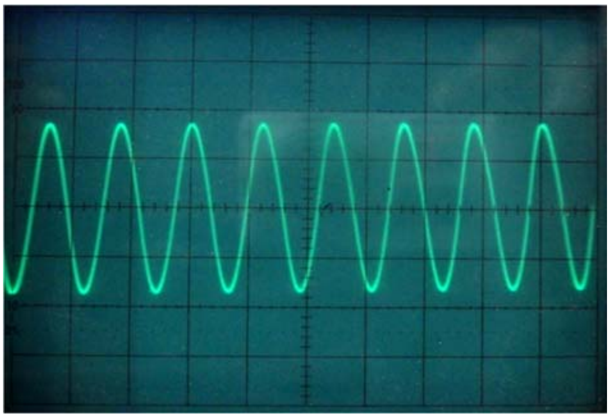


Fig. 14 OTRA constructed with two AD 844 ANs.

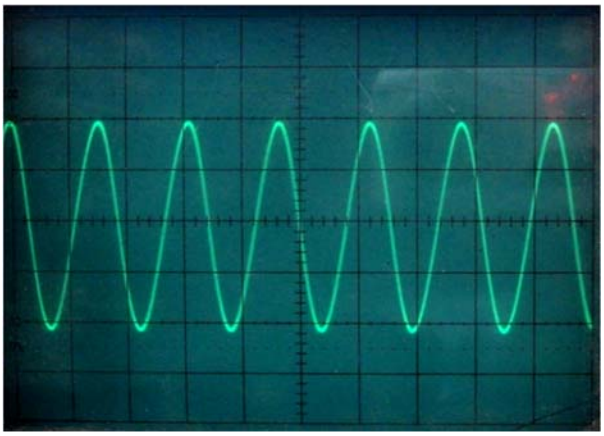
Therefore, the behaviour of the OTRA is obtained with the schematic shown in Fig. 14. In this figure, if the T_Z node of the second AD844AN is an open circuited then the transresistance gain R_m is infinite ($R_m = \infty$).



Scale: X-axis 50 µs/div and Y-axis 1 V/div.

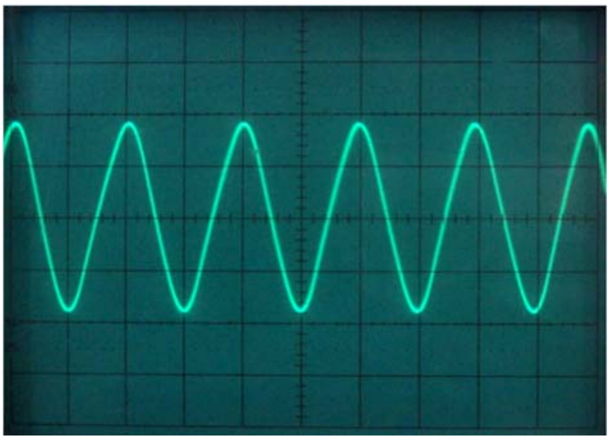
Fig. 15 Experimental output waveform of the proposed circuit in Fig. 3.

The passive components, $R_1 = 10\ \Omega$, $R_3 = 1\ k\Omega$, $C_2 = 10$ nF and $C_4 = 1$ nF were used to design the first proposed minimum component oscillator circuit in Fig. 3. The corresponding output waveform for the proposed oscillator circuit is shown in Fig. 15. The experimental oscillation frequency of the oscillator circuit in Fig. 3 is 15.3 kHz, which is close to the theoretical value of 15.9 kHz.



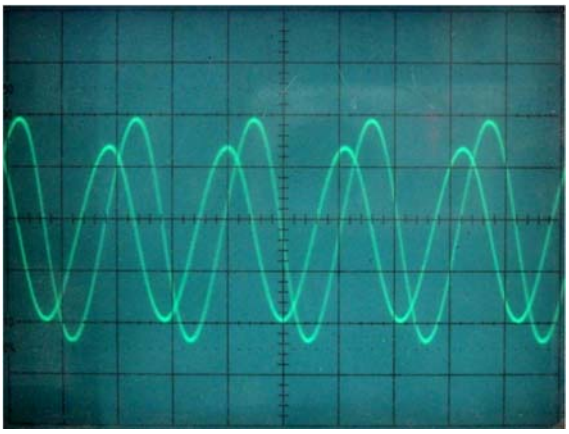
Scale: X-axis 50 µs/div and Y-axis 1 V/div.
Fig. 16 Experimental output waveform of the proposed circuit in Fig. 4 (a).

The following passive component values were chosen for the second proposed circuit in Fig. 4 (a), R_1 = 100 Ω, R_2 = 1.2 kΩ, R_3 = 600 Ω, R_4 = 5.5 kΩ, C_2 = 10 nF and C_3 = 100 nF. Fig. 16 represents the experimental output waveform of the proposed circuit in Fig. 4 (a) with a frequency of 13.8 kHz, which is close to the theoretical value of 14.2 kHz.



Scale: X-axis 20 µs/div and Y-axis 1 V/div.
Fig. 17 Experimental output waveform of the proposed circuit in Fig. 4 (b).

Similarly, the proposed circuit shown in Fig. 4 (b) was connected on a laboratory bread board with the following external passive components R_1 = 100 Ω, R_2 = 1.2 kΩ, R_3 = 600 Ω, R_4 = 5.5 kΩ, C_1 = 10 nF and C_3 = 100 nF. The experimental output waveform is depicted in Fig.17 with a frequency of 25.2 kHz, which is close to the theoretical frequency of 24.8 kHz. For generating oscillations in the proposed quadrature oscillator circuit shown in Fig. 5, the passive components R_1 = 9 kΩ , R_2 = 500 Ω, R_3 = 1 kΩ, R_5 = 100 Ω, C_1 = 10 nF and C_4= 10 nF were used. Fig. 18 represents the experimental output waveform of the proposed circuit in Fig. 5 with a frequency of 21.41 kHz, which is close to the theoretical value of 22.71kHz. The output voltages V_{01} verses V_{02} of the proposed circuit in Fig. 5 is given in Fig. 19.



Scale: X-axis 20 µs/div and Y-axis 1 V/div.
Fig. 18 Experimental output waveform of the proposed circuit in Fig. 5.

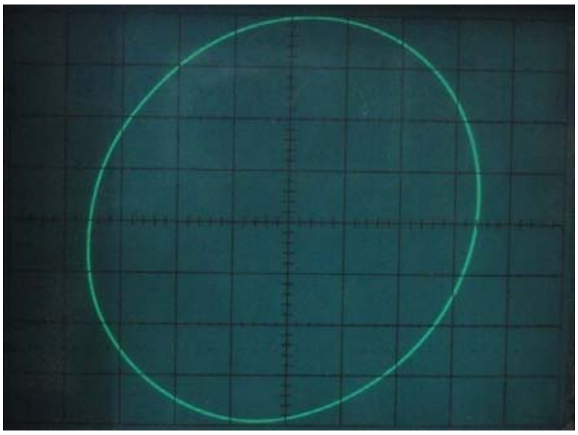


Fig. 19 The voltage V_{01} versus V_{02} of the proposed quadrature oscillator on oscilloscope

4 Conclusion

In this paper four new sinusoidal oscillator circuits using OTRA are presented. The first proposed circuit produces single sinusoidal output with two capacitors and two resistors. This circuit can also be called as minimum passive component RC sinusoidal oscillator circuit. The advantage of this circuit is that it possess minimum number of passive components. The second and third proposed circuits are grounded resistance and capacitance sinusoidal oscillator circuits.

Table 1 Comparative analysis of the proposed circuits

Ref. no	No. of active elements	No. of resisters	No. of capacitors	No. of grounded component	S.O or M.O	Supply voltage	Power consumption
[9]	2 CCII	3	4	all	S.O	± 15 V	≈ 600 mW
[12] Fig. 4	2 CCII	4	3	6	M.O	± 9V	308 mW
[13] Fig. 1(a)	3 CFOA	4	2	all	S.O	±12 V	648 mW
[15]	1 CFOA	4	3	5	S.O	±12 V	280 mW
[17]	3 OTA	0	2	2	M.O	± 15 V	≈800 mW
[18]	2 OTA	2	2	2	S.O	± 15 V	580 mW
[26] Fig. 1(a)	6 OTA	0	2	2	S.O	--	--
[34] Fig. 4	2 OTRA	4	2	0	M.O	± 5V	250.8 mW
[34] Fig. 5 (a) & 5 (b)	2 OTRA	4	2	0	M.O	± 5V	250.2 mW
[35]	1 OTRA	3	2	1	S.O	± 5V	106.2 mW
[36] Fig. 4(a)	1 OTRA	2	2	0	S.O	± 5V	88.3 mW
[36] Fig. 4(b)	1 OTRA	3	2	1	S.O	± 5V	106.3 mW
[38]	2 OTRA	3	3	0	S.O	± 5V	230.2 mW
[40] Fig. 2	3 OTRA	5	3	0	M.O	± 5V	480.3 mW
[40] Fig. 3	3 OTRA	5	3	0	M.O	± 5V	480.6 mW
[42]	1 OTRA	4	2	1	S.O	± 5V	125.3 mW
[43]	2 OTRA	4	2	0	M.O	± 5V	248.5 mW
Proposed circuit in Fig. 3	1 OTRA	2	2	0	S.O	± 5V	87.2 mW
Proposed circuit in Fig. 4 (a) and (b)	1 OTRA	4	2	2	S.O	± 5V	120.2 mW
Proposed circuit in Fig. 5	2 OTRA	4	2	0	M.O	± 5V	248.8 mW

S.O: Single output
MO: Multiple outputs

These circuits require two capacitors, four resistors and one OTRA, to produce the oscillations. The main advantage of these circuits is the presence of grounded resistor and capacitor, which is useful for integrated realization. The fourth proposed circuit produces two sinusoidal waveforms at the output terminals V_{01} and V_{02} with a 90^0 phase shift. This circuit uses two OTRAs, two capacitors and four resistors, to generate the oscillations. In the second, third and fourth proposed circuits the condition of oscillation and frequency of oscillation is tuned independently. The comparative analysis of the proposed circuit is given in table 1. The proposed circuits are simulated using spectre simulation model parameters and realized on a laboratory breadboard using commercially available ICs AD 844 AN at ± 5V supply voltages. The simulated and experimental results have confirmed in agreement with theoretical analysis.

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