Grounded resistance/capacitance-controlled sinusoidal oscillators using operational transresistance amplifier

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Abstract: - This paper represents, five sinusoidal oscillators based on the Operational Transresistance Amplifier (OTRA). The proposed circuits require single OTRA and a few passive components to generate oscillations. The condition of oscillation and frequency of oscillation of the first proposed circuit is controlled by a single grounded resistor. And the remaining circuits depend on independent control of condition of oscillation and frequency of oscillation. In all these proposed circuits the grounded resistor can be replaced by a grounded capacitor, which is important so far on integration point of view. The performance of the proposed circuits is examined using SPICE models. The proposed circuits were built using commercially available current feedback operational amplifier (AD844 AN) on a laboratory bread board and passive components used externally and tested for waveform generation. Theoretical analyses of the proposed circuits are verified by the experimental results carried out with the prototype circuits.

Key-Words: - Oscillators, Operational Transresistance Amplifier, Analog integrated circuit design, Current-mode oscillators, Sinusoidal oscillators.

1 Introduction

The Sinusoidal oscillators have a wide range of applications in many electronic circuits such as communication, control-systems; signal processing, instrumentation and measurement. A variety of sinusoidal oscillators have been proposed using op-amp as an active element in the literature [1]. But the limitations in op-amp are due to slew rate and fixed gain bandwidth product that affect the condition of oscillation, frequency of oscillation and also that it does not operate at high frequencies [1-3]. To overcome these drawbacks, several oscillators based on current conveyor (CCII) and current-feedback operational amplifier (CFOA) as an active element have been proposed in the literature [4-12]. These oscillators draw considerable attention due to their large frequency range, large dynamic range and wider bandwidth. In addition to these active devices, several other building blocks such as OTAs, CCCIIs, FTFNs, DDCC, DO-OTAs and CDBA [13-21] have also shot into prominence due to their advantages over voltage-mode op-amp based oscillators. However, most of the oscillators designed with the above active elements require more than one active element amongst them to control the frequency of oscillation with a grounded resistor or a capacitor [8-15]. More than one active element consumes more power and requires more chip area to fabricate IC.

In the recent past, an active device called operational transresistance amplifier (OTRA) has invited considerable attention with the introduction of several high performance CMOS OTRA realizations [22-24] and it has also been used as one of the basic building blocks in the field of analog integrated circuits and systems. Several circuits for different applications have been proposed in the literature [25-30] based on OTRA as an active element. However, very few oscillator designs are reported in the literature [26-31] using single OTRA with a grounded resistor or capacitor. Based on the above considerations, in this paper an OTRA based oscillators have been presented. The proposed circuits use single OTRA and few passive components.

2 Circuit Description

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 circuit symbol of the OTRA is shown in Fig. 1.

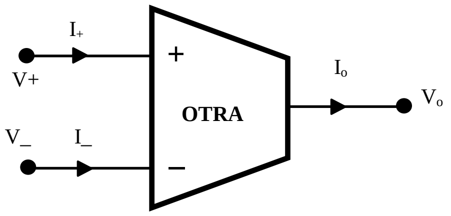


Fig. 1. OTRA circuit symbol

The input and output terminal relations of an OTRA can be characterized by the below matrix.

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

For ideal operation, the transresistance gain R_m approaches infinity forcing the input currents to be equal. The generalized configuration of the proposed single OTRA based sinusoidal oscillator is shown in Fig. 2. Several oscillator circuits can be generated by exploiting the generalized configuration in Fig. 2. Based on the generalized configuration, some-of the oscillator circuits are given in Fig. 4.

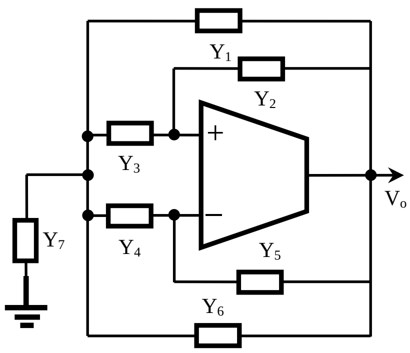


Fig. 2. Generalized configuration of the Single OTRA based sinusoidal oscillator

The characteristic equation of the circuit in Fig. 2 can be written by

$$Y_1Y_2+ Y_2Y_3+ Y_2Y_4+ Y_2Y_6+ Y_2Y_7+ Y_1Y_3+ Y_3Y_6-Y_1Y_5-Y_1Y_4-Y_4Y_6-Y_3Y_5-Y_4Y_5-Y_5Y_6-Y_5Y_7 = 0 \quad (2)$$

where Y_i*'s* are the admittance of the passive components. The condition of oscillation and the frequency of oscillation of the proposed circuits are given in Table 1. All the proposed circuits in Fig. 4 can be controlled by a single grounded resistor. The proposed circuits can also work, if the grounded resistor is replaced with a grounded capacitor. In the second proposed oscillator circuit in Fig. 4(b), the grounded resistor R_7 is replaced by a capacitor C_7. This circuit was reported in [27] with a grounded resistor. Few oscillator circuits that were already available in the literature can also be implemented with the generalized configuration [27, 28].

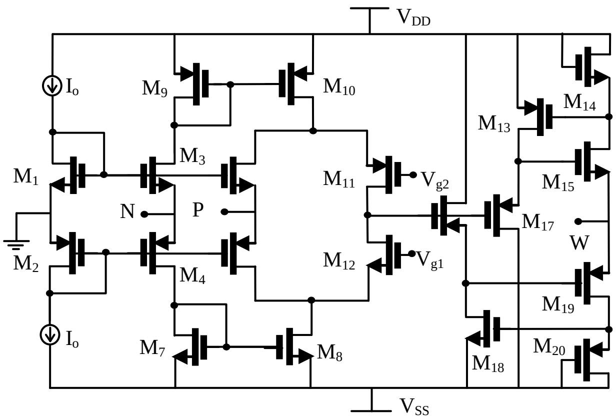
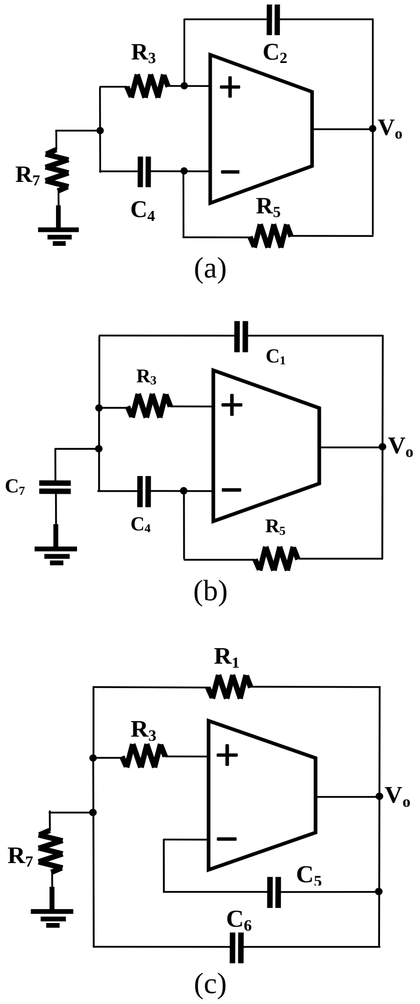


Fig. 3. CMOS implementation of OTRA [24].



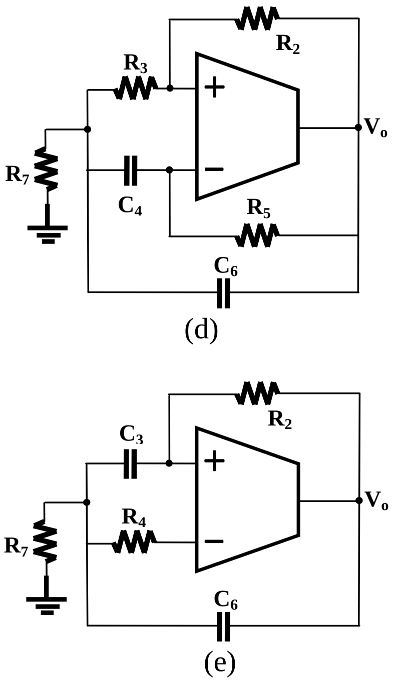


Fig. 4. Proposed oscillator circuits.

3 Non-ideal Analysis

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

$$R_m(s) = \frac{R_m}{1+\frac{s}{\omega_0}} = \frac{R_0\omega_0}{s+\omega_0} = \frac{1}{\frac{s}{R_0\omega_0}+\frac{1}{R_0}} \quad (3)$$

For high frequencies, the transresistance gain $R_m(s)$ reduced to

$$R_o \to \infty, \qquad R_m(s) \cong \frac{1}{sC_p} \quad (4)$$

Where R_0 is DC open loop transresistance gain, ω_0 is the transresistance cut-off frequency and C_p is the parasitic capacitance. For the proposed circuits, the non-ideal analysis gives the following equations in Table. 2

From the equations in Table 2, the effect of parasitic capacitance C_P, disturb the performance of the proposed circuits. The effect of C_P can be eliminated by slightly adjusting value of capacitors connected to the circuits to achieve self compensation.

4 Simulation and Experimental result

The proposed oscillator circuits were simulated using SPICE simulation models. The CMOS realization of the current differencing buffered amplifier is shown in Fig. 3. This CMOS realization can also be used as an alternative implementation of OTRA. For Fig. 3 supply voltages are taken as V_{DD} and V_{SS} = ± 2 V. For generating the oscillations of the first proposed oscillator circuit in Fig. 4(a) the passive component values were chosen to be R_3 = 60 Ω, R_5 = 1 kΩ, R_7 = 300 Ω, C_2 = 10 nF and C_4 = 100 nF. Figure. 5 represents the output waveform of the first proposed oscillator circuit with a frequency of 21.8 kHz. The percentage of error between the simulated and theoretical oscillation frequency is 2.8 %.

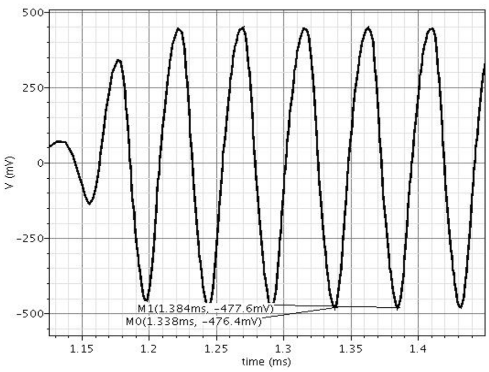


Fig. 5. Simulated output waveform of the first proposed circuit in Fig. 4(a).

To verify the theoretical study, AD844AN is adopted to construct the proposed circuits. The commercial IC AD844AN with current feedback architecture (configuration) is used to implement the OTRA as shown in Fig. 6 [31, 32].

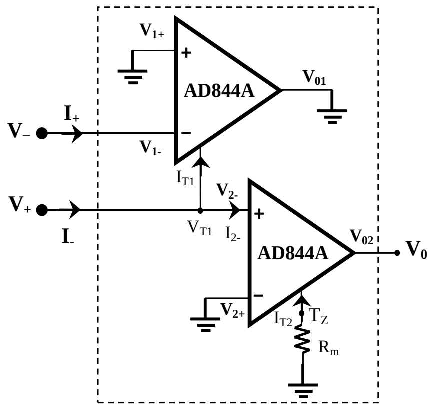


Fig. 6. OTRA implementation with two AD844As.

$$V_+ = V_{1-} = V_{1+} = 0 \quad (5)$$

$$V_- = V_{2-} = V_{2+} = 0 \quad (6)$$

Proposed designs	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Condition of oscillation	Frequency of oscillation (ω_o^2)
(a)	0	sC_2	G_3	sC_4	G_5	0	G_7	$C_2(G_3+G_7) = C_4G_5$	$\frac{G_5(G_3+G_7)}{C_2C_4}$
(b)	sC_1	0	G_3	sC_4	G_5	0	sC_7	$G_5(C_1+C_4+C_7) = C_1G_3$	$\frac{G_5G_3}{C_1C_4}$
(c)	G_1	0	G_3	0	sC_5	sC_6	G_7	$C_6G_3 = C_5(G_1+G_3+G_7)$	$\frac{G_1G_3}{C_5C_6}$
(d)	0	G_2	G_3	sC_4	G_5	sC_6	G_7	$G_2(C_4+C_6)+C_6G_3=G_5(C_6+C_4)$	$\frac{(G_3+G_7)(G_5-G_2)}{C_4C_6}$
(e)	0	G_2	sC_3	G_4	0	sC_6	G_7	$G_2(C_3+C_6) = C_6G_4$	$\frac{G_2(G_4+G_7)}{C_3C_6}$

Table.1**.** Condition of oscillation and frequency of oscillation of the proposed circuits.

Proposed designs	Condition of oscillation	Frequency of oscillation (ω_o^2)
(a)	$(C_2-C_P)(G_3+G_7) = C_4G_5$	$\frac{G_5(G_3+G_7)}{C_4(C_2+C_P)}$
(b)	$G_5(C_1+C_4+C_7) = (C_P-C_1)G_3$	$\frac{G_5G_3}{C_1(C_4+C_P)+C_P(C_4+C_7)}$
(c)	$C_6G_3 = (C_5+C_P)(G_1+G_3+G_7)$	$\frac{G_1G_3}{(C_5+C_P)C_6}$
(d)	$G_2(C_4+C_6)+G_3(C_6-C_P)-C_PG_7 = G_5(C_6+C_4)$	$\frac{(G_3+G_7)(G_5-G_2)}{C_4C_6+C_P(C_4+C_6)}$
(e)	$G_2(C_3+C_6) = G_4(C_6+C_P)+C_PG_7$	$\frac{G_2(G_4+G_7)}{C_3C_6-C_P(C_3+C_6)}$

Table 2**.** Condition of oscillation and frequency of oscillation of the proposed circuits by using non-ideal analysis.

$$V_{01} = V_{T1} = V_{2-} = V_{2+} = 0 \tag{7}$$

$$I_{T1} = I_{1-} = I_+ \tag{8}$$

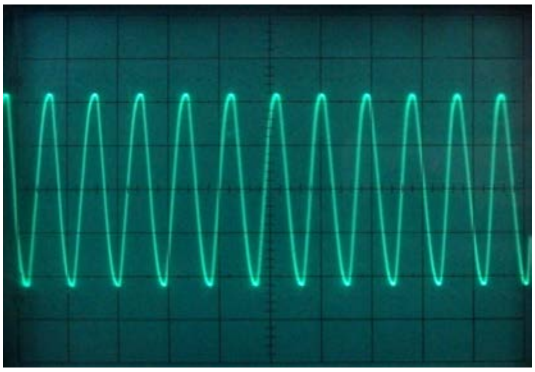
$$I_{T2} = I_{2-} = I_- - I_{T1} = I_- - I_+ \tag{9}$$

$$V_0 = V_{T2} = -R_m \times I_{T2} = R_m(I_+ - I_-) \tag{10}$$

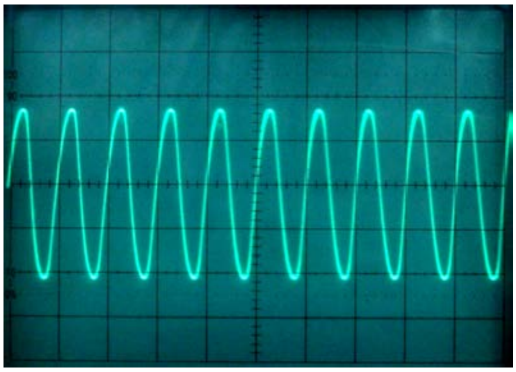
The non-inverting terminals of the AD844ANs have been grounded to simulate the virtual ground for the terminals of the OTRA. The above equations can be obtained from Fig. 6. Therefore, the behavior of the OTRA is obtained with the schematic in Fig. 6. In this figure, if the T_Z node of the second AD844AN is open circuited then the transresistance gain R_m is infinite ($R_m = \infty$).

Oscillator designs [Ref]	No. of Active elements	Total number of passive components	No. of R	No. of C	No. of components grounded	Hardware result implemented with commercial ICs
[10]	3 CFOA	5	3	2	All	Yes
[4]	3 CCII	5	3	2	All	No
[18]	2 DDCC	5	3	2	All	No
[12]	3 OTA	2	--	2	2	Yes
[13]	2 OTA	6	4	2	3	No
[20]	1 CDBA	5	3	2	1 or 2 (Resistors)	Yes
[26] Fig. 5(b)	2 OTRA	6	4	2	None	No
[26] Fig. 3(a)	1 OTRA	4	2	2	None	No
[26] Fig. 3(b) & (c)	1 OTRA	6	4	2	1(Resistor or Capacitor)	No
[27]	1 OTRA	5	3	2	1 Resistor	No
[28]	1 OTRA	5	3	2	1(Resistor or Capacitor)	Yes
[30]	2 OTRA	6	3	3	None	No
Proposed design in Fig. 4 (a)	1 OTRA	5	3	2	1(Resistor or capacitor)	Yes

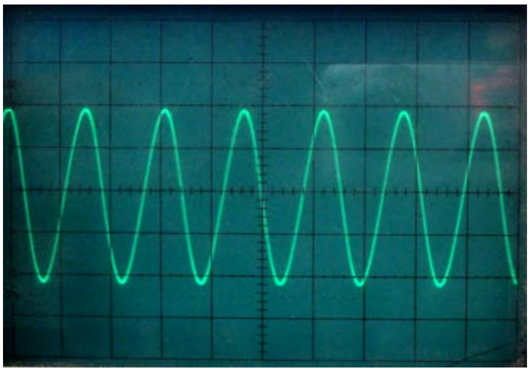
Table. 3. Comparative performance analysis of candidate designs



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

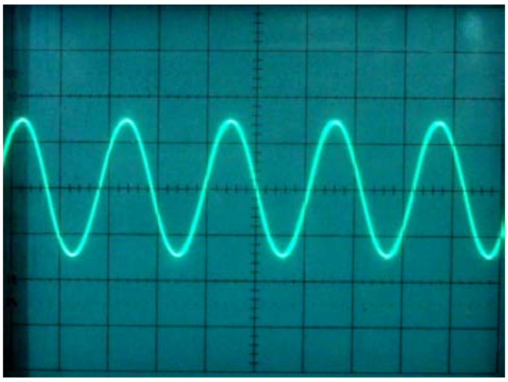


(b)
Scale: X-axis 0.2 ms/div and Y-axis 1 V/div.



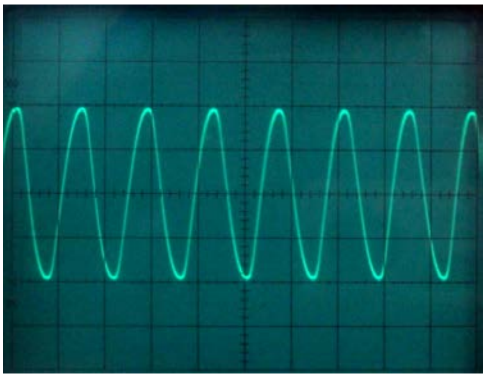
(c)

Scale: X-axis 5 µs/div and Y-axis 1 V/div.



(d)

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



(e)

Scale: X-axis 20 µs/div and Y-axis 1 V/div.

Fig. 7. Output waveforms of the proposed circuits in Fig. 4.

A typical waveform from the oscilloscope screen for the proposed circuit in Fig. 4(a) is presented in Fig. 7 (a), which has been obtained for a supply voltage of ± 5 V and for R_3 = 60 Ω, R_5 = 1 kΩ, R_7 = 300 Ω, C_2 = 10 nF and C_4 = 100 nF. The measured frequency of 22.2 $kH_{z,}$ as shown in Fig. 7(a), which is close to the theoretical result of 22.45 kH_z

The percentage of error between the theoretical and practical oscillation frequency is 1.02%.

The frequency spectrum of the first proposed circuit is given in Fig 8. The second proposed oscillator circuit in Fig. 4(b), was designed with passive components C_1 = 100 nF, C_4 = 100 nF, C_7 = 100 nF, R_3 = 150 Ω, R_5 = 500 Ω. Figure 7(b) represents the output waveform of the second proposed circuit. From Fig. 7(b), the oscillation frequency of the second proposed oscillator circuit stands at 5 kHz, which is close to the theoretical value of 5.78 kHz.

The passive components, R_1 = 1 kΩ, R_3 = 150 Ω, R_7 = 15 Ω, C_5 = 1 nF and C_6 = 10 nF were used to design the third proposed oscillator circuit in Fig. 4(c). The corresponding output waveform for the third proposed oscillator circuit is given in Fig. 7(c). The experimental oscillation frequency of the oscillator circuit in Fig. 4(c) is 125 kHz, which is close to the theoretical value of 129.3 kHz.

The fourth proposed circuit in Fig. 4(d) was constructed with passive components R_2 = 500 Ω, R_3 = 12 kΩ, R_5 = 400 Ω, R_7 = 2 kΩ, C_4 = 10 nF and C_6 = 1 nF. Fig. 7(d) describes the output waveform of the oscillator circuit in Fig. 4(d) with a frequency of 23.8 kHz, whereas the theoretical oscillation frequency is 22.6 kHz

For producing the oscillations in fifth proposed oscillator circuit as in Fig. 4(e), the passive components R_2 = 1 kΩ, R_4 = 60 Ω, R_7 = 50 Ω, C_6 = 10 nF and C_3 = 100 nF were used. The experimental output waveform of the fifth proposed circuit is given in Fig. 7(e) with a frequency of 35.7 kHz, whereas the theoretical oscillation frequency was calculated as 30.2 kHz.

Figure. 9 describes the oscillation frequency variation of the oscillator circuit in Fig. 4(a) against the resistor R_7. For the tunability of resistor $R_{7,}$ the selected passive component values were R_3 =100 Ω, R_5 =500 Ω, C_2=100 nF and C_4=100 nF.

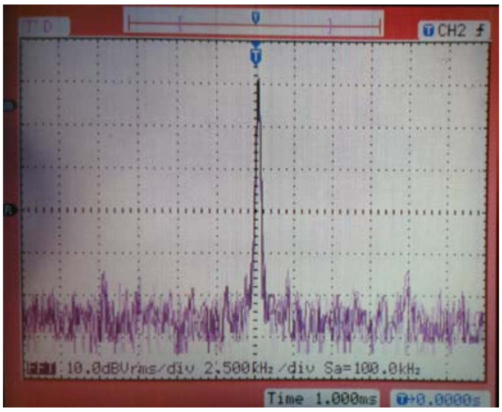


Fig. 8. Frequency spectrum of the proposed circuit in Fig. 4(a).

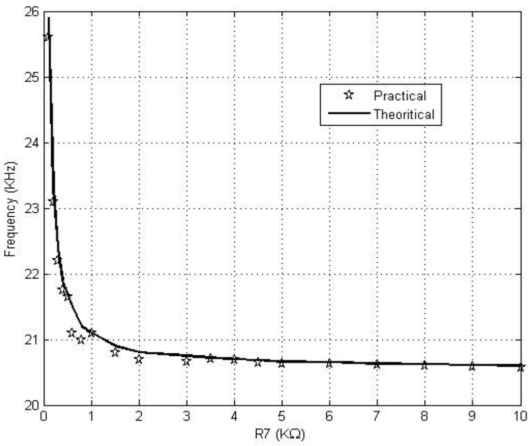


Fig. 9. Variation of Oscillation frequency against resistor R_7.

4 Conclusion

In this paper, five waveform generators based on the generalized configuration are proposed. These circuits use only one OTRA and a few passive components, the proposed circuits are simpler than the voltage-mode (op-amp based) waveform generators. The attractive feature of these topologies is that they are realized using commercially available ICs AD 844 AN at ± 5V supply voltages. Both the simulated and experimental output waveforms are given in Fig. 5 and Fig. 7. The results exhibited by the proposed topologies congruent with the theoretical values. The main advantages of the proposed circuits are less number of passive components, grounded resistor which is useful for integrated realization and the later can be replaced with a grounded capacitor. Comparison of the proposed circuits with other circuits in the literature is given in Table 3. The percentage of Total Harmonic Distortion (THD) for all the proposed circuits is within the acceptable limit. Taking these advantages into consideration, the proposed circuits can have wider applications in many fields of electronics, signal processing and for instrumentation applications.

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