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, CCCII, 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.

\[
\begin{bmatrix}
V_i \\
V_o \\
V_o
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & I_i \\
0 & 0 & 0 & I_i \\
R_m & -R_m & 0 & I_o
\end{bmatrix}
\]

(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

\[Y_1Y_2 + Y_2Y_3 + Y_2Y_4 + Y_2Y_5 + Y_1Y_3 + Y_3Y_4Y_5Y_6 + Y_1Y_2Y_3Y_4Y_5Y_6Y_7 = 0\]

(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

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

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

$$R_m \rightarrow \infty, \quad R_m(s) \approx \frac{1}{sC_p}$$  (4)

Where $R_0$ is DC open loop transresistance gain, $\omega_0$ 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 $V_{SS} = \pm 2 \text{ V}$. For generating the oscillations of the first proposed oscillator circuit in Fig. 4(a) the passive component values were chosen to be $R_3 = 60 \ \Omega$, $R_5 = 1 \text{ k}\Omega$, $R_7 = 300 \ \Omega$, $C_2 = 10 \text{ nF}$ and $C_4 = 100 \text{ nF}$. 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%.

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

<table>
<thead>
<tr>
<th>Proposed designs</th>
<th>Condition of oscillation</th>
<th>Frequency of oscillation ($\omega_0^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>$(C_2 - C_P)(G_3 + G_7) = C_4 G_5$</td>
<td>$\frac{G_5(G_3 + G_7)}{C_4(C_2 + C_P)}$</td>
</tr>
<tr>
<td>(b)</td>
<td>$G_5(C_1 + C_4 + G_7) = (C_P - C_4)G_3$</td>
<td>$\frac{G_5 G_1}{C_1(C_4 + C_P) + C_P(C_4 + G_7)}$</td>
</tr>
<tr>
<td>(c)</td>
<td>$C_6 G_1 = (C_5 + C_P)(G_1 + G_3 + G_7)$</td>
<td>$\frac{G_1 G_5}{(C_5 + C_P)C_6}$</td>
</tr>
<tr>
<td>(d)</td>
<td>$G_2(C_4 + C_P) + G_7(C_6 - C_P) - C_P G_7 = G_2(C_6 + C_4)$</td>
<td>$\frac{(G_3 + G_7)(G_5 - G_2)}{C_4 C_6 + C_P(C_4 + C_6)}$</td>
</tr>
<tr>
<td>(e)</td>
<td>$G_2(C_3 + C_P) = G_2(C_6 + C_P) + C_P G_7$</td>
<td>$\frac{G_2(G_4 + G_7)}{C_3 C_6 - C_P(C_3 + C_6)}$</td>
</tr>
</tbody>
</table>

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

\[ V_{01} = V_{T_1} = V_{2-} = V_{2+} = 0 \quad (7) \]

\[ I_{T_1} = I_{1-} = I_+ \quad (8) \]

\[ I_{T_2} = I_{2-} = I_- - I_{T_1} = I_- - I_+ \quad (9) \]

\[ V_0 = V_{T_2} = -R_m \times I_{T_2} = R_m(I_+ - I_-) \quad (10) \]

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 $T_x$ node of the second AD844AN is open circuited then the transresistance gain $R_m$ is infinite ($R_m = \infty$).
### Table 3. Comparative performance analysis of candidate designs

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

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(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.
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 $R_3 = 60 \, \Omega$, $R_5 = 1 \, k\Omega$, $R_7 = 300 \, \Omega$, $C_2 = 10 \, nF$ and $C_4 = 100 \, nF$. The measured frequency of 22.2 kHz, as shown in Fig. 7(a), which is close to the theoretical result of 22.45 kHz. 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 $C_1 = 100 \, nF$, $C_4 = 100 \, nF$, $C_7 = 100 \, nF$, $R_3 = 150 \, \Omega$, $R_5 = 500 \, \Omega$. 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, $R_3 = 1 \, k\Omega$, $R_5 = 150 \, \Omega$, $R_7 = 15 \, \Omega$, $C_3 = 1 \, nF$ 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 $R_3 = 500 \, \Omega$, $R_3 = 12 \, k\Omega$, $R_5 = 400 \, \Omega$, $R_7 = 2 \, k\Omega$, $C_4 = 10 \, nF$ 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 $R_2 = 1 \, k\Omega$, $R_4 = 60 \, \Omega$, $R_5 = 50 \, \Omega$, $C_6 = 10 \, nF$ and $C_7 = 100 \, nF$ 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 $R_3 =100 \, \Omega$, $R_5 =500 \, \Omega$, $C_2 =100 \, nF$ and $C_4 =100 \, nF$. 
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.

References:


