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Novel fractional order sinusoidal oscillators using operational trans resistance amplifier

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ABSTRACT

The design of fractional order circuits in very large-scale integration (VLSI) domain is gaining the interest of many researchers. At the same time design of fractional circuits using the current mode devices is attracting the research community. In this paper, several possible fractional order sinusoidal oscillators using operational trans resistance amplifier (OTRA) as a basic building block is presented. The necessary condition for the frequency of oscillation and condition for oscillations is derived. Fractional order operator s^{α} is the most crucial one to be approximated. In this paper, the fractional order element is approximated by the continued fraction expansion (CFE). The approximation is carried out up to fifth order. The circuits are tested with the simulation software named LTspice. The results agree with the theoretical one. The proposed circuits offers a frequency of 15 MHz, 20 MHz, and 25 MHz which is higher in value as compared to the existing circuits. The proposed circuits finds applications in bio medical, communication circuits.

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1. INTRODUCTION

The circuit which is capable of producing oscillations without any external input is called an oscillator [1]. This can be sinusoidal or relaxation type oscillator. The sinusoidal oscillators find wide applications in the areas of control systems, signal processing, communications and other fields. Conventionally operational amplifier is used to be the active element. Many of the filter circuits, oscillators (sinusoidal as well as relaxation) are proposed in the literature with operational amplifier as a basic element.

Fractional-order oscillators possess several uses in engineering and physics, providing more precise models of real-world systems by effectively capturing memory and hysteresis phenomena. Principal applications encompass vibration control and structural health monitoring, sophisticated filtering and signal processing within communication systems, the generation of intricate signals for chaotic systems and security applications such as voice encryption, as well as the modeling of complicated phenomena in bio engineering.

There are several number of active elements present in the literature such as current conveyor, operational transconductance amplifier, current feedback operational amplifier, and operational trans resistance amplifier. Few of them are available commercially also. These devices have their own advantages and disadvantages [2]. In this article, operational trans resistance amplifier (OTRA) is considered as an active device as in [3], [4].

Realization of fractional oscillator is not an old topic dates back to 2000 [5]. Similarly non sinusoidal oscillators are also designed in [6]. Novel topologies of sinusoidal oscillators are proposed in [7] and are simulated using Orcad PSpice. Fractional-order oscillators employ fractional-order capacitors or inductors, enhancing the design flexibility and tunability of oscillators relative to conventional integer-order oscillators [8]. These oscillators are characterized by non-integer-order differential equations, providing control over oscillation frequency and phase.

Two oscillator topologies with two impedances for a universal fractional order oscillator based on a two port network are covered in paper [7], [8]. The two fractional impedances can be combined in four ways for each topology. A thorough analysis and design of fractional-order oscillators using double Op-Amps are presented in the paper in [9]. To verify how the fractional order affects the oscillation parameters, MATLAB simulations are analyzed. The numerical solution in [9] is validated by PSpice simulations and experimental results. Ahmad *et al.* [10], a fractional order Wien bridge oscillator based on state space equations is proposed.

Carlson approximation, mastudas approximation, power series expansion, and continued fraction expansion can all be used to realize fractional order transfer functions. Continued fraction expansion has yielded better results as compared to others [11]. A fractional order sinusoidal oscillator (FSO) with two fractional capacitors, four resistors, and one OTRA is provided by the work in [12]. Nodal analysis was used to determine the frequency, condition, and phase difference between the output voltages of the proposed fractional order oscillator and simulations are carried out using PSpice.

A differential voltage current conveyor (DVCC) based fractional order Butterworth lowpass filter is realized in [13]. A twofold complexity, fractional-order dual coupling duffing system is proposed in the study [14] to detect ship-radiated noise. Jacobi collocation and nested picard iteration (NPI) are used in [15] to solve the fractional order oscillatory chemical reaction model. The outcomes of the NPI and Jacobi collocation approaches are strikingly similar. Kubanek *et al.* [16], the transfer functions of order $(1 + \alpha)$ are proposed. Tsirimokou *et al.* [17] discusses the use of fractional order analog circuits in medicine. In study [18], [19], fractional filters with voltage differencing transconductance amplifier (VDTA) are suggested and modeled.

Saçu and Alçı [20] designs and simulates a low-voltage, low-power, operational transconductance amplifier (OTA)-based fractional order low-pass and high-pass filter of order $(n + \alpha)$ using Cadence-PSpice, where $0 < \alpha < 1$ and $n < 1$. Saçu and Alçı [21] describe a universal filter topology with low-voltage active elements that offer all types of responses in a single circuit. Tsirimokou *et al.* [22] proposed novel fractional-order generalized filter topologies. multiple-feedback topologies and operational transconductance amplifiers were used to achieve the above. The proposed designs are validated by simulations using Cadence integrated circuit (IC) design suite and the Austrian micro systems design kit. New fractional order integrator implementation methods are provided in [23]. After analyzing integer order approximation methods, fractional order integrators with active circuit elements are designed utilizing successfully implemented approximate methods from the literature.

Historical perspective of the fractional order elements is presented by Kartci *et al.* [24], the mathematical expressions for the fractional order circuits using two ladder elements is developed in [25]. Current mode fractional order differentiators and integrators is proposed in [26] which are reconfigurable. The objective of the study in [27] is to use commercially available LT1228 ICs with three inputs and one output (TISO) to develop an electronically tunable voltage-mode (VM) universal filter. Two LT1228s, four resistors, and two grounded capacitors make up the recommended filter. PSpice simulation and hardware implementation support the suggested filter's performance. Arora [28] investigates the potential uses of voltage differencing current conveyors (VDCC) as sinusoidal oscillators and current mode universal filters. Only grounded passive components and a small number of active elements were used in the resultant network. The digitally programmable complementary metal–oxide–semiconductor (CMOS) is used to develop a digital modulation system in [29]. PSpice software is used to simulate and analyze this new communication approach. The study suggests further research on noise resistance in digitally programmable (DP) modulation techniques and exploring digitally programmable CMOS technology-enabled modulation methods like quadrature amplitude modulation (QAM) or orthogonal frequency division multiplexing (OFDM).

A current-controlled current conveyor second generation (CCCII)-based shadow filter and oscillator is presented in the study in [30]. Natural frequency and filter quality factor are determined by CCCII current gains. It is simpler to combine the resistorless filter with grounded capacitors. In a single topology, the filter utilizes input signals to generate all types of transfer functions. To confirm the unique architecture, simulation program with integrated circuit emphasis (SPICE) simulates the suggested circuit using AT&T ALA400-CBIC-R bipolar transistor arrays.

In this paper, the conventional capacitors are replaced with fractional order one. The necessary expression for frequency of oscillation, condition for sustained oscillations are derived. By varying the values of fractional order, the output variation is studied. The simulations are carried out using LTspice. The results agree with the theoretical one.

The paper is structured as follows. Section 2 deals with the rational approximations. Section 3 deals with the derivation for frequency of oscillation and condition for sustained oscillations. Implementation of the circuits and results are presented in section 4. Section 5 deals with the conclusions.

2. PROPOSED MATHEMATICAL METHODS

2.1. Rational approximations

To calculate the integer-order rational fractance approximations, a number of frequency-domain approximation techniques have been documented in the literature [11]. This technique is popular for function evaluation because it expands the complex plane's domain more quickly than power series expansions. Continued fraction expansion is described by considering the continued fraction expansion of $(1+x)^\alpha$ as:

$$(1+x)^\alpha = \cfrac{1}{1-\cfrac{\alpha x}{1+\cfrac{(1+\alpha)x}{2+\cfrac{(1-\alpha)x}{3+\cfrac{(2+\alpha)x}{2+\cfrac{(2-\alpha)x}{5+\ldots\ldots\cfrac{(N+\alpha)x}{2+\cfrac{(N-\alpha)x}{2N+1}}}}}}}} \quad (1)$$

Substituting $x = s-1$, and considering the first ten terms the rational function is given by [11].

$$s^\alpha = \frac{P_0 s^5 + P_1 s^4 + P_2 s^3 + P_3 s^2 + P_4 s + P_5}{Q_0 s^5 + Q_1 s^4 + Q_2 s^3 + Q_3 s^2 + Q_4 s + Q_5} \quad (2)$$

The co-efficients $P_0, P_1, ...P_5, Q_0, Q_1, ...Q_5$ are given by:

$$\begin{aligned}
P_0 = Q_5 &= -\alpha^5 - 15\alpha^4 - 85\alpha^3 - 225\alpha^2 - 274\alpha - 120\\
P_1 = Q_4 &= 5\alpha^5 + 45\alpha^4 + 5\alpha^3 - 1005\alpha^2 - 3250\alpha - 3000\\
P_2 = Q_3 &= -10\alpha^5 - 30\alpha^4 + 410\alpha^3 + 1230\alpha^2 - 4000\alpha - 12000\\
P_3 = Q_2 &= 10\alpha^5 - 30\alpha^4 - 410\alpha^3 + 1230\alpha^2 + 4000\alpha - 12000\\
P_4 = Q_1 &= -5\alpha^5 + 45\alpha^4 - 5\alpha^3 - 1005\alpha^2 + 3250\alpha - 3000\\
P_5 = Q_0 &= \alpha^5 - 15\alpha^4 + 85\alpha^3 - 225\alpha^2 + 274\alpha - 120
\end{aligned} \quad (3)$$

The magnitude, phase and error responses of the ideal and approximated functions for $\alpha = 0.5$ and $\alpha = 0.25$ are as shown in Figure 1. From the Figure 1 it is evident that the proposed response matches the ideal one for larger range of frequencies in both magnitude and Phase. The error is minimum in the range of frequencies from $[10^{-2}]$ to $[10^2]$ Hz.

The values of the 5^{th} order coefficients obtained for various α is tabulated in Table 1. The synthesized resistor–capacitor (RC) network values using partial fraction expansion method are as shown in Table 2. One of the possible synthesized RC network is as shown in Figure 2. In the next section details of the current mode device named operational transresistance amplifier is explained.

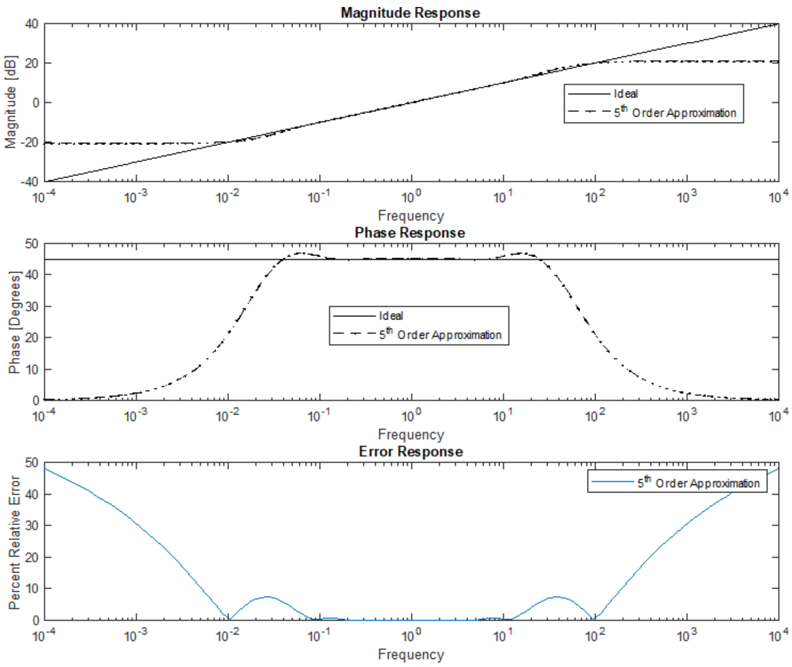

Figure 1. Magnitude, phase, and error plots

Table 1. 5^{th} order approximated coefficents for various values of α

α	P_0	P_1	P_2	P_3	P_4	P_5
0.1	149.7365	3.3350e+03	1.2387e+04	1.1588e+04	2.6851e+03	94.7665
0.2	184.5043	3.6901e+03	1.2748e+04	1.1154e+04	2.3902e+03	73.5437
0.3	224.8689	4.0649e+03	1.3078e+04	1.0701e+04	2.1152e+03	55.8741
0.4	271.4342	4.4593e+03	1.3378e+04	1.0230e+04	1.8600e+03	41.3338
0.5	324.8438	4.8727e+03	1.3643e+04	9.7453e+03	1.6242e+03	29.5313
0.6	385.7818	5.3045e+03	1.3873e+04	9.2489e+03	1.4074e+03	20.1062
0.7	454.9746	5.7541e+03	1.4066e+04	8.7435e+03	1.2092e+03	12.7284
0.8	533.1917	6.2206e+03	1.4218e+04	8.2317e+03	1.0290e+03	7.0963
0.9	621.2470	6.7029e+03	1.4330e+04	7.7164e+03	866.1229	2.9360

Table 2. Resistor and capacitor values for 5^{th} approximation

α	R_a	R_b	C_b	R_c	C_c	R_d	C_d	R_e	C_e	R_f	C_f
0.1	0.6329	0.1849	0.3024	0.1163	2.7561	0.1126	9.3996	0.1535	23.2565	0.3798	61.4173
0.2	0.3986	0.2569	0.2450	0.1970	1.7371	0.2183	5.1342	0.3432	11.1552	1.0947	24.7963
0.3	0.2485	0.2652	0.2652	0.2448	1.4900	0.3100	3.8278	0.5648	7.2878	2.3913	13.4318
0.4	0.1523	0.2394	0.3262	0.2634	1.4742	0.3809	3.3000	0.8080	5.4904	4.7229	8.2238
0.5	0.0909	0.1975	0.4366	0.2569	1.6076	0.4240	3.1414	1.0536	4.5509	8.9771	5.3886
0.6	0.0521	0.1503	0.6302	0.2296	1.9113	0.4325	3.2646	1.2681	4.0999	17.0544	3.6856
0.7	0.0280	0.1043	0.9941	0.1859	2.5063	0.4000	3.7450	1.3956	4.0548	33.6310	2.5950
0.8	0.0133	0.0629	1.7977	0.1302	3.7972	0.3203	4.9649	1.3438	4.6034	73.2658	1.8647
0.9	0.0047	0.0279	4.4048	0.0668	7.8470	0.1883	8.9763	0.9616	7.0677	210.3463	1.3590

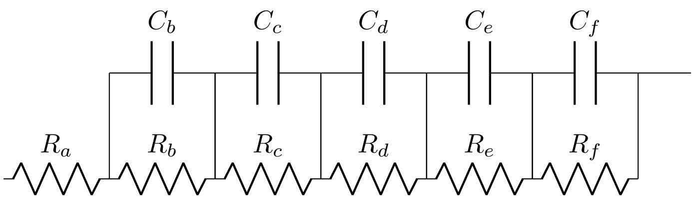

Figure 2. Fifth order approximated fractance

2.2. Operational trans resistance amplifier

Analog IC designers have recently paid a lot of attention to OTRA. OTRA is an active gadget with three terminals. The output voltage of OTRA is dependent on the input current and can be shown as the transfer matrix.

$$\begin{bmatrix} V_p \\ V_n \\ V_0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_0 \end{bmatrix} \tag{4}$$

where R_m is the trans-resistance gain of the OTRA. The output voltage V_0 is given by (5).

$$V_0 = R_m(I_p - I_n) \tag{5}$$

The blockdiagram of OTRA is as shown in Figure 3.

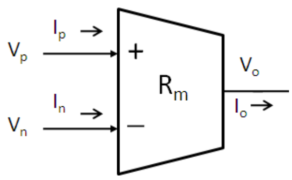

Figure 3. Blockdiagram of OTRA

Inverting and noninverting OTRA are possible. Both scenarios have the same gain. OTRA was proposed in 1992 and is used in analog signal processing. The following subsections explain the existing OTRA circuits named Salama OTRA and CMOS based OTRA as shown in Figures 4(a) and (b).

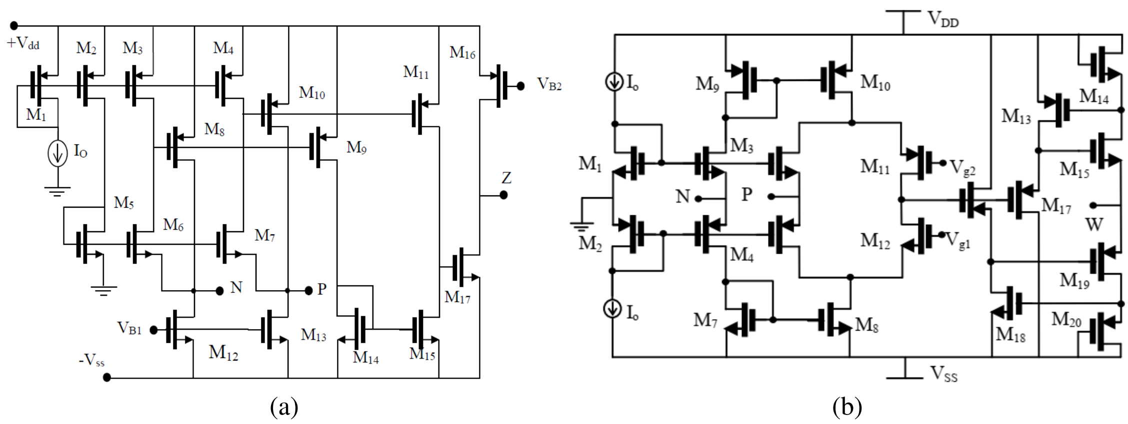

Figure 4. Different types of operational transconductance amplifier: (a) salama OTRA and (b) OTRA using CMOS

2.2.1. Salama OTRA

The modified differential current conveyor (MDCC) and common source amplifier are cascaded to form the CMOS realization of OTRA, as illustrated in Figure 4(a). While the common source amplifier provides high gain, MDCC performs current differencing and effectively grounds the two input terminals. The current mirror is created by $(M_1 - M_4)$. The output voltage in the OTRA design is produced by biasing the output stage transistors with currents M_9 and M_{11}.

2.2.2. CMOS based OTRA

A viable CMOS OTRA internal circuit construction is shown in Figure 4(b) and consists of two primary functional blocks: a voltage buffer circuit and a differential-current-controlled current source. All P-channel metal–oxide–semiconductor (PMOS) and N-channel metal–oxide–semiconductor (NMOS) transistors in this circuit have their substrate terminals connected to positive and negative supply voltages, respectively. As current reflectors, transistors M_1, M_3, and M_5 guarantee that the currents flowing through transistors M_9 and M_{10} are equal. Similarly, equal currents are forced into transistors M_7 and M_8 by the current mirrors composed of M_2, M_4, and M_6. Transistors M_1 and M_2 have grounded sources.

3. METHODOLOGY FOLLOWED

This section provides the proposed fractional order oscillators. Three of the circuits existing in [7] are modified by replacing the capacitors by fractional order one and the conditions for sustained oscillations and frequency of oscillations is derived.

3.1. OTRA based fractional order sinusoidal oscillators

The generalized block diagram of OTRA based fractional order sinusoidal oscillators is as shown in Figure 5. Let V_a be the voltage at the interconnection of Y_1, Y_3, Y_4, Y_6 and Y_7. The currents at the inverting and non-inverting terminals can be written as:

$$V_0 Y_2 + V_a Y_3 = I_p \tag{6}$$

$$V_0 Y_5 + V_a Y_4 = I_n \tag{7}$$

From the ideal behavior od OTRA since the current I_p, I_n to be equal,

$$V_0 = V_a \left(\frac{Y_4 - Y_3}{Y_2 - Y_5} \right) \tag{8}$$

Writing KCL at node a,

$$V_0 \left(Y_1 + Y_6 \right) = V_a \left(Y_1 + Y_3 + Y_4 + Y_6 + Y_7 \right) \tag{9}$$

Substituting the values of V_a and simplifying the characteristic equation for the oscillator is going to be:

$$\begin{aligned} &\mathrm{Y_1Y_2+Y_2Y_3+Y_2Y_4+Y_2Y_6+Y_2Y_7+Y_1Y_3+Y_3Y_6-Y_1Y_5-Y_1Y_4-Y_4Y_6-Y_3Y_5-} \\ &\mathrm{Y_4Y_5-Y_5Y_6-Y_5Y_7} = 0 \end{aligned} \tag{10}$$

Different topologies can be obtained by changing the values of Y's. Some of the possible topologies by replacing Y with fractional order capacitor are as explained in the coming sections.

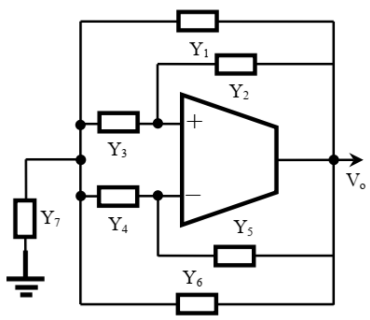

Figure 5. Blockdiagram of OTRA based sinusoidal oscillator

3.2. Case A

$Y_1 = Y_6 = 0, Y_2 = s^{\alpha} C_2, Y_4 = s^{\beta} C_4$, the characteristic equation becomes, $Y_2Y_3 + Y_2Y_4 + Y_2Y_7 - Y_3Y_5 - Y_4Y_5 - Y_5Y_7 = 0$. On substituting the values of Y's and simplifying the equations for the frequency of operation and condition for oscillations will be:

$$\begin{aligned} &\omega^{\alpha+\beta} \cos\left(\tfrac{(\alpha+\beta)\pi}{2}\right) c_2 c_4 + \omega^{\alpha} \cos\left(\tfrac{\alpha\pi}{2}\right) c_2 \left(G_3 + G_7\right) - \omega^{\beta} \cos\left(\tfrac{\beta\pi}{2}\right) G_5 c_4 - \\ &G_5 (G_3 + G_7) = 0 \end{aligned} \tag{11}$$

$$\omega^{\alpha+\beta} \sin\left(\frac{(\alpha+\beta)\pi}{2}\right) c_2 c_4 + \omega^{\alpha} \sin\left(\frac{\alpha\pi}{2}\right) c_2 \left(G_3 + G_7\right) - \omega^{\beta} \sin\left(\frac{\beta\pi}{2}\right) G_5 c_4 = 0 \tag{12}$$

3.3. Case B

$Y_2 = Y_4 = 0$, $Y_5 = s^\alpha C_5, Y_6 = s^\beta C_6$, the characteristic equation becomes, $Y_1Y_3 + Y_3Y_6 - Y_1Y_5 - Y_3Y_5 - Y_6Y_5 - Y_5Y_7 = 0$. On substituting the values of Y's and simplifying the equations for the frequency of operation and condition for oscillations will be:

$$\begin{aligned}&\omega^{\alpha+\beta}\cos\left(\tfrac{(\alpha+\beta)\pi}{2}\right)c_5c_6+\\&\omega^{\alpha}\cos\left(\tfrac{\alpha\pi}{2}\right)c_5\left(G_1+G_3+G_7\right)-\omega^{\beta}\cos\left(\tfrac{\beta\pi}{2}\right)G_3c_6-G_1G_3=0\end{aligned}\tag{13}$$

$$\omega^{\alpha+\beta}\sin\left(\frac{(\alpha+\beta)\pi}{2}\right)c_5c_6+\omega^{\alpha}\sin\left(\frac{\alpha\pi}{2}\right)c_5\left(G_1+G_3+G_7\right)-\omega^{\beta}\sin\left(\frac{\beta\pi}{2}\right)G_3c_6=0\tag{14}$$

3.4. Case C

$Y_1 = Y_5 = 0$, $Y_3 = s^\alpha C_3, Y_6 = s^\beta C_6$, the characteristic equation becomes, $Y_1Y_3 + Y_3Y_6 - Y_1Y_5 - Y_3Y_5 - Y_6Y_5 - Y_5Y_7 = 0$. On substituting the values of Y's and simplifying the equations for the frequency of operation and condition for oscillations will be:

$$\begin{aligned}&\omega^{\alpha+\beta}\cos\left(\tfrac{(\alpha+\beta)\pi}{2}\right)c_3c_6+\\&\omega^{\alpha}\cos\left(\tfrac{\alpha\pi}{2}\right)G_2c_3+\omega^{\beta}\cos\left(\tfrac{\beta\pi}{2}\right)\left(G_2c_6-G_4c_6\right)+G_2\left(G_4+G_7\right)=0\end{aligned}\tag{15}$$

$$\omega^{\alpha+\beta}\sin\left(\frac{(\alpha+\beta)\pi}{2}\right)c_3c_6+\omega^{\alpha}\sin\left(\frac{\alpha\pi}{2}\right)G_2c_3+\omega^{\beta}\sin\left(\frac{\beta\pi}{2}\right)\left(G_2c_6-G_4c_6\right)=0\tag{16}$$

3.5. Special cases

The following analysis illustrates the influence of the fractional order on the oscillation parameters.

– $\alpha = \beta = 1$

$$\begin{aligned}s^{\alpha+\beta} &= e^{j\pi}\omega^2 = -\omega^2\\ s^{\alpha} &= e^{j\frac{\pi}{2}}\omega = j\omega\end{aligned}\tag{17}$$

The frequency of oscillation is found to be:

$$\omega^2k_1 + k_4 = 0 \Rightarrow \omega^2 = -k_4/k_1\tag{18}$$

The condition for the sustained oscillations becomes:

$$k_2 + k_3 = 0\tag{19}$$

– $\alpha = \beta \neq 1$

$\cos(\alpha\pi) \approx \cos\left(\frac{\alpha\pi}{2}\right) = 1, \sin(\alpha\pi) \approx \alpha\pi, \sin\left(\frac{\alpha\pi}{2}\right) \approx \frac{\alpha\pi}{2}$. Substituting the above conditions and simplifying (20).

$$\omega^{2\alpha}k_1 + \frac{1}{2}\left(\omega^\alpha k_2 + \omega^\alpha k_3\right) = 0\tag{20}$$

The (20) reduces to:

$$\omega^\alpha = -\frac{k_2+k_3}{2k_1}\tag{21}$$

Substituting the above condition in the (22).

$$\omega^{2\alpha}k_1 + \omega^\alpha k_2 + \omega^\alpha k_3 + k_4 = 0\tag{22}$$

This (22) reduces to:

$$k_2 + k_3 = 2\sqrt{k_1k_4}\tag{23}$$

The derived expressions for frequency of oscillations and condition for sustained oscillations for both the cases, $\alpha = \beta = 1$ and $\alpha = \beta \neq 1$ are tabulated in Table 3.

Table 3. Conditions of oscillators

	$\alpha=\beta=1$		$\alpha=\beta\neq 1$	
Circuit	ω	Condition	ω^{α}	Condition
Case A	$\sqrt{\frac{G_5(G_3+G_7)}{c_2c_4}}$	$c_2\left(G_3+G_7\right)=G_5c_4$	$\frac{G_5c_4-c_2(G_3+G_7)}{2c_2c_4}$	$c_2\left(G_3+G_7\right)=G_5c_4$
Case B	$\sqrt{\frac{G_1G_3}{c_5c_6}}$	$c_5\left(G_1+G_3+G_7\right)=G_3c_6$	$\frac{G_5c_6-c_5(G_1+G_3+G_7)}{2c_5c_6}$	$c_5\left(G_1+G_3+G_7\right)=G_3c_6$
Case C	$\sqrt{\frac{G_2(G_4+G_7)}{c_3c_6}}$	$c_6G_4=G_2\left(c_3+c_6\right)$	$\frac{G_4c_6-G_2c_6-G_2c_3}{2c_3c_6}$	$G_2c_3+G_2c_6-G_4c_6=2\sqrt{G_2c_3c_6\left(G_4+G_7\right)}$

4. RESULTS AND DISCUSSIONS

The proposed circuits in three cases has been simulated using LTspice. The fractional order of value 0.5 is chosen and the simulations are carried out for all the three topologies. The component values used for the simulation are Case A ($Y_3 = 60\Omega, Y_5 = 1000\Omega, Y_7 = 300\Omega$), Case B ($Y_3 = 150\Omega, Y_7 = 15\Omega$), Case C ($Y_2 = 1000\Omega, Y_4 = 60\Omega, Y_7 = 50\Omega$). The obtained results are as shown in Figure 6. The fast fourier transform (FFT) analysis is depicted in Figure 7 and the corresponding results are tabulated in Table 4.

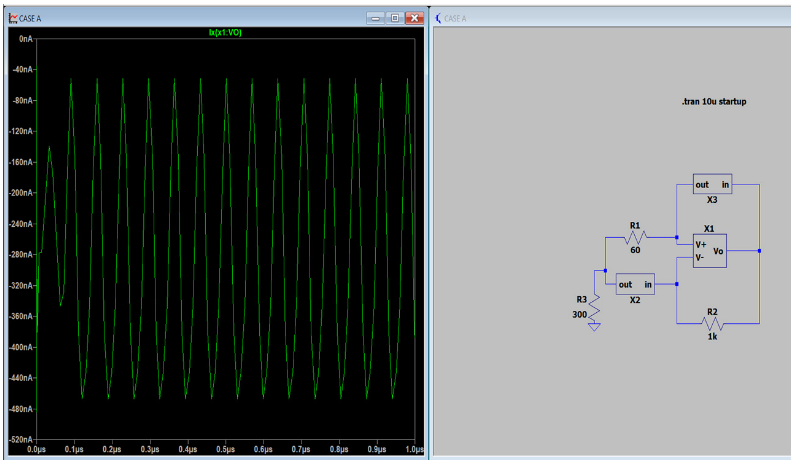

Figure 6. Simulation results for Case A circuit

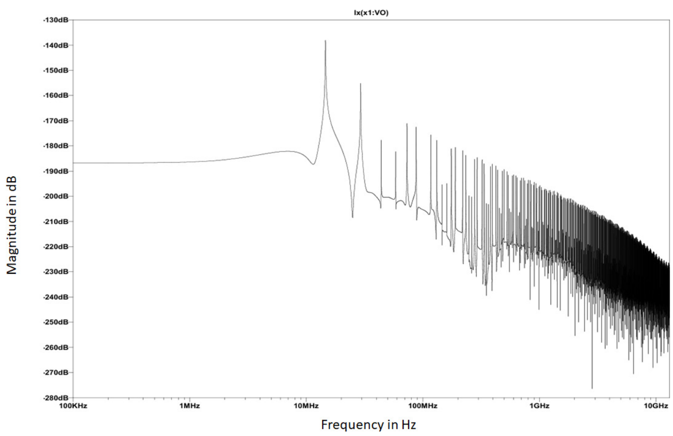

Figure 7. FFT analysis of Case A circuit

Table 4. FFT Analysis of proposed oscillators

S. no	Type of circuit	Frequency	Magnitude(dB)
1	Circuit A	15MHz	-138
2	Circuit B	20 MHz	-148
3	Circuit C	25 MHz	-150

5. CONCLUSION

The main purpose of this paper is to propose a novel fractional order oscillator using operational transconductance amplifier. The derivations pertaining to the fractional order sense are derived. The basic idea of the oscillator is developed by replacing conventional capacitors with fractional-order elements. The fractional order elements are to be approximated by a rational approximations to a finite order. In this paper, the rational approximation of the fractional elements is obtained using a continued-fraction expansion approach. The mathematical equations for the sustained oscillations is derived in terms of fractional order and are tabulated. The special cases of similar fractional order and dissimilar fractional orders is also discussed. For simulation purpose the fractional order $\alpha = 0.5$ is chosen. The values chosen for the simulation are also indicated. The FFT analysis of the results is carried out. It has been observed that at $\alpha = \beta = 1$, the expressions are similar to the expressions for the conventional oscillators. The theoretical values of oscillation frequency is proven to be same as the theoretical one. The circuits proposed are simple and can be used in communications, encryption and decryption applications.

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AUTHOR CONTRIBUTIONS STATEMENT

The corresponding author will be responsible for all conceptualization, methodology, formal analysis, or investigation, as well as at least one aspect of writing.

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C	: **C**onceptualization	I	: **I**nvestigation	Vi	: **Vi**sualization
M	: **M**ethodology	R	: **R**esources	Su	: **Su**pervision
So	: **So**ftware	D	: **D**ata Curation	P	: **P**roject Administration
Va	: **Va**lidation	O	: Writing - **O**riginal Draft	Fu	: **Fu**nding Acquisition
Fo	: **Fo**rmal Analysis	E	: Writing - Review & **E**diting		

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data can be available from the author with request.

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