A Multifunctional Voltage Mode Fractional Order Filters using a Single CFOA

Manoj Kumar, D. R. Bhaskar, Pragati Kumar

Abstract: ***A multifunction voltage mode fractional order filter structure is described using a single current feedback operational amplifier (CFOA). This configuration realizes three fractional order filters (FOFs) namely fractional order low pass (FOLP), fractional order band pass (FOBP) and fractional order high pass (FOHP) filters. The performance of the proposed structure has been verified through PSPICE and MATLAB simulation results using macro model of AD844 type CFOA.***

Keywords **: CFOA, S*ignal processing, analog filters, Filters in fractional domain.***

I. INTRODUCTION

Fractional calculus [1] is the branch of mathematics, which describes integration and differentiation of non-integer order. Utilizing the concept of fractional calculus [2], the fractional order circuits or systems are designed and these fractional order systems/circuits are more precise and accurate as compared to their integer order counterparts.

Recently researchers have shown great interest in the area of designing fractional order analog circuits [2-17]. Consequently, it has become a very promising research area due to its inter-disciplinary applications in the field of science and engineering [2], biomedical [3], control systems and analog circuits [4-17]. The advantages of fractional order filters [FOFs] over classical filters are (i) the design flexibility and (ii) additional degree of freedom for the controllability of fractional order filters provided by fractional parameter (α) [13]. First time FOF of first order [4] and second order [5] were introduced in 2008 and 2009 respectively. After this, a lot of work on FOFs has been reported in the open literature during the last one decade.

A brief summary of work done performed on FOFs in the last one decay is as follows:

In [4], authors have proposed first order filters in fractional domain.

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In [5] , authors have implemented second order filters in fractional domain to realize FOLP,FOHP,FOBP, fractional order notch [FON] and fractional order all pass [FOAL] filters. The experimental result of FOF of KHN biquad configuration using two fractional order capacitor (FC) of order (α = 0.5) have also been reported therein.

FOFs have been proposed in [6] with approximated fractional order transfer function of order (n+α), where n is an integer and α lies between 0-1, using field programmable analogue array (FPAA) hardware to realize FOLP and FOHP filters. The experimental results of FOLP and FOHP filters of order (1+ α) and (4+ α) using FPAA kit are shown along with MATLAB simulations results. Tripathy, Biswas and Sen in [7] have implemented the KHN biquad filter using FCs of different order. Comparative results obtained from MATLAB and PSPICE are provided to verify the performance of proposed FOFs. The stability and sensitivity of FOFs are also described in this paper. In [8], authors have proposed a op-amps (MC-1459) based high order (n+α) FOLP and FOHP filters, where n = 5 and (0 < α < 1). Comparison of (5+α) order FOLP with 5^{th} and 6^{th} order Butterworth low pass filter are also shown. In [9] authors have presented FOFs (FOLP, FIHP and FOBP) employing two FCs of different order. A fractional order capacitor approach was introduced in [10] to implement FOBP filters having high quality factor and asymmetric slopes. Authors have also shown the experimental and SPICE results to verify the theoretical findings. In [11], authors have shown the use of FCs in Tow-Thomas biquad filter structure for the realization of FOLP and FOBP filters of order $(0 < (\alpha_1+\alpha_2) < 2)$. The workability of FOLP and FOBP filters using MC-1458 op-amps was verified with MATLAB and PSPICE simulations. While, second generation current conveyors (CCIIs) based FOFs are proposed in [12]. Single input multiple output (SIMO) type FOFs for inverting and non-inverting mode employing three CFOAs have been presented in [13]. The proposed structures simultaneously provide FOLP, FOHP and FOBP responses of filters. The PSPICE simulation results of these FOFs have also been provided to verify the performance of these filters.

Thus, in this paper we have proposed a new multifunctional FOF structure using a single CFOA to realize FOLP, FOHP and FOBP filters by the suitable selection of the branch admittance(s). The workability of this multifunction topology is validated with PSPICE and MATLAB simulation results.

II. THE PROPOSED FOF CIRCUIT

The generalized configuration of the proposed FOFs as shown in Fig.1 is analyzed assuming an ideal CFOA

($i_y = 0, v_x = v_y, i_z = i_x$ and $v_w = v_z$) and we have a following transfer function:

$$\frac{V_0}{V_{in}} = -\frac{y_1 y_2}{y_4(y_1 + y_2 + y_3)} \qquad (1)$$

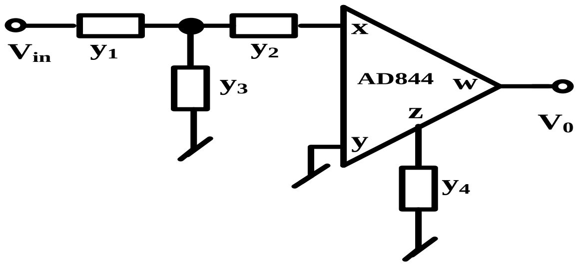


Fig.1. Configuration of FOFs

where $y_i, i = 1-4$ are the branch admittances.

With proper selection of admittances, the various FOFs can now be realized using equation (1) and are as follows:

(i)FOLP filter : if we choose

$y_3 = s^{\alpha}C_3, y_4 = s^{\alpha}C_4 + \frac{1}{R_4}, y_1 = \frac{1}{R_1}$ and $y_2 = \frac{1}{R_2}$

The resultant transfer function becomes

$$\frac{V_0(s)}{V_{in}(s)} = -\frac{(\frac{1}{C_3C_4R_1R_2})}{s^{2\alpha} + s^{\alpha}\{\frac{1}{C_3}(\frac{1}{R_1} + \frac{1}{R_2}) + \frac{1}{R_4C_4}\} + \frac{1}{C_3C_4R_4}(\frac{1}{R_1} + \frac{1}{R_2})} \qquad (2)$$

(ii) FOBP filter: if we select

$y_1 = s^{\alpha}C_1, y_4 = s^{\alpha}C_4 + \frac{1}{R_4}, y_2 = \frac{1}{R_2}$ and $y_3 = \frac{1}{R_3}$

The resultant transfer function will become

$$\frac{V_0(s)}{V_{in}(s)} = -\frac{(\frac{1}{C_4R_2})s^{\alpha}}{s^{2\alpha} + s^{\alpha}\{\frac{1}{C_1}(\frac{1}{R_2} + \frac{1}{R_3}) + \frac{1}{R_4C_4}\} + \frac{1}{C_1C_4R_4}(\frac{1}{R_2} + \frac{1}{R_3})} \qquad (3)$$

(iii) FOHP filter: if we take

$y_1 = s^{\alpha}C_1,\ y_2 = s^{\alpha}C_2,\ y_4 = s^{\alpha}C_4 + \frac{1}{R_4}$ and $y_3 = \frac{1}{R_3}$

The resultant transfer function will be

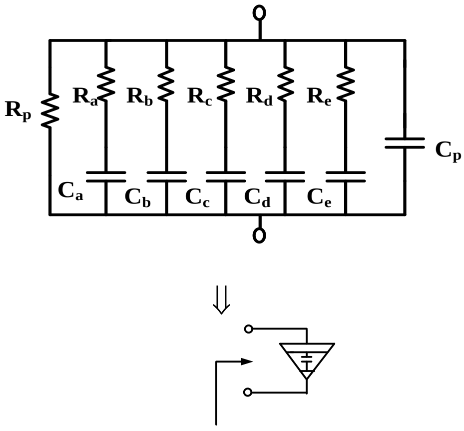
$$\frac{V_0(s)}{V_{in}(s)} = -\frac{(\frac{C_1C_2}{C_4(C_1 + C_2)})s^{2\alpha}}{s^{2\alpha} + s^{\alpha}\{\frac{1}{R_3(C_1 + C_2)} + \frac{1}{R_4C_4}\} + \frac{1}{R_3R_4C_4(C_1 + C_2)}} \qquad (4)$$

III. SIMULATION RESULTS OF FOFS.

The workability of the FOFs presented in this paper was confirmed by PSPICE and MATLAB simulation results.

PSPICE simulations: The FOFs of Fig.1 are simulated using an AD844 type CFOA in PSPICE for cut-off frequency/peak frequency of 1 kHz for α = 1.

Using VALSA method [14], fractional order capacitor is designed as R-C ladder structure [14-15] and it's equivalent circuit shown in Fig. 2. Same structure of FC for different order (α = 0.5 to 0.9) is used in simulation of proposed FOFs.

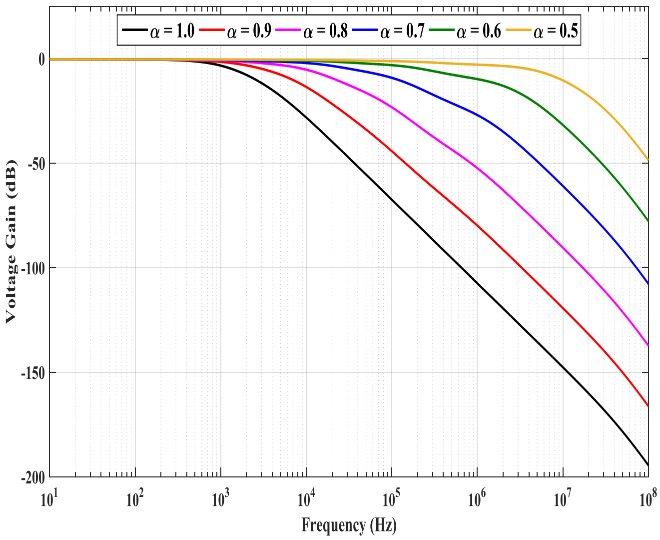


$$Z_{in} = \frac{1}{s^{\alpha}C_f}$$

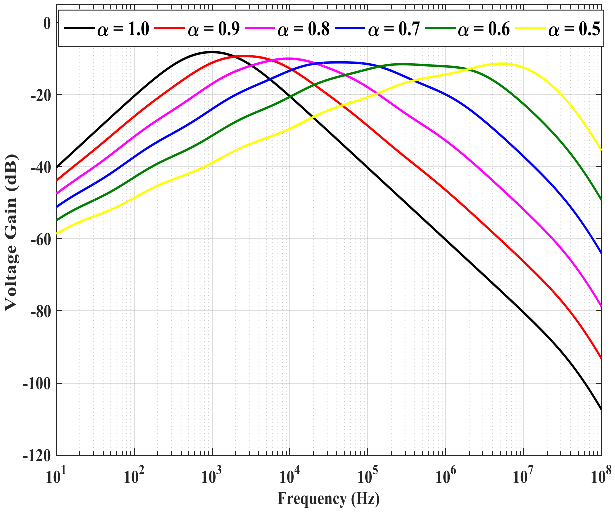
Fig. 2. Equivalent R-C Ladder circuit of FCs

The simulation results of proposed FOFs for the structure of Fig.1 are shown in Fig. 3. The used component values in simulation of proposed FOFs are given in Table I

MATLAB simulations: The fractional order transfer functions obtained from equation (1) by appropriate selection of branch admittances for FOLP, FOHP and FOBP are also simulated in MATLAB. We have taken the same values for resistors and FCs in MATLAB simulations as in PSPICE simulations. The simulation results using MATLAB of the proposed FOFs for various values of α (α = 0.5 to 0.9) are shown in Fig.4. A brief summary of simulation results of proposed FOFs with PSPICE and MATLAB are tabulated in Table II and Table III respectively. These results thus, validate the theoretical findings.



(a)



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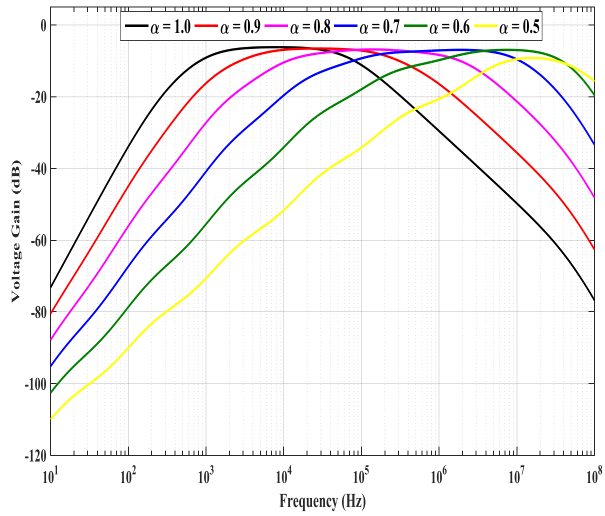
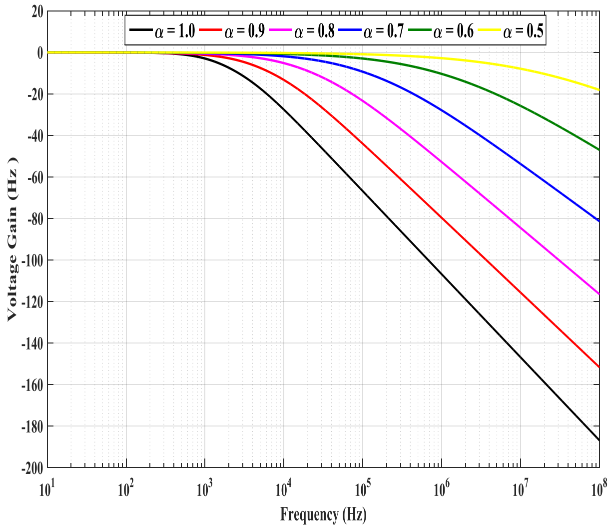
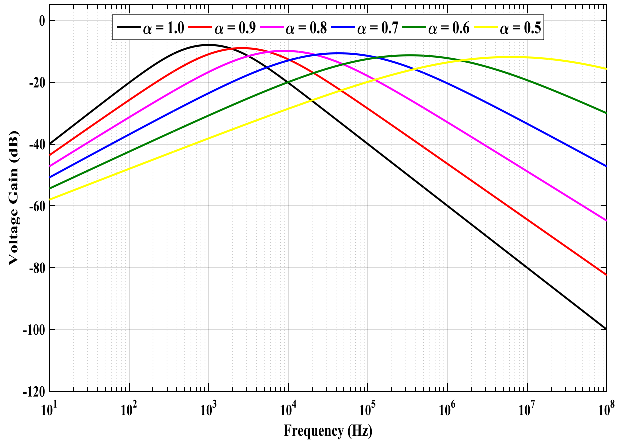


(c)

Fig. 3. Frequency responses of FOFs using PSPICE (a) FOLP (b) FOBP (c) FOHP



(a)



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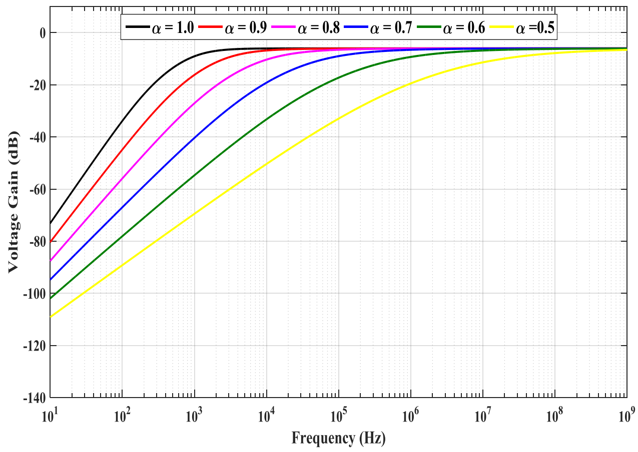

(c)

Fig. 4. Frequency responses of FOFs using MATLAB
(a) FOLP (b) FOBP (c) FOHP

Table I. Component values for realization of FOFs in PSPICE

Type of filter	Resistor	Fractional Capacitor
FOILP	$R_1 = 780\Omega$ $R_2 = 780\Omega$	$C_3 = 0.0995\mu F/sec^{(\alpha-1)}$
	$R_4 = 1560\Omega$	$C_4 = 0.0995\mu F/sec^{(\alpha-1)}$
FOIBP	$R_2 = 1665\Omega$	$C_1 = 0.0995\mu F/sec^{(\alpha-1)}$
	$R_3 = 1665\Omega$ $R_4 = 3330\Omega$	$C_4 = 0.0995\mu F/sec^{(\alpha-1)}$
FOIHP	$R_1 = 3500\Omega$	$C_2 = 0.0995\mu F/sec^{(\alpha-1)}$
	$R_4 = 1750\Omega$	$C_1 = 0.0995\mu F/sec^{(\alpha-1)}$ $C_4 = 0.0995\mu F/sec^{(\alpha-1)}$

TABLE II. Simulation results for cut off frequency (in KHz)

Order (α)	**FOLP**	
	PSPICE	**MATLAB**
1.0	1.005	1.005
0.9	2.083	2.101
0.8	5.67	5.384
0.7	19.21	18.67
0.6	115.99	101.8
0.5	1792	1160
Order (α)	**FOBP**	

	PSPICE	MATLAB
1.0	1.00	0.980
0.9	2.60	2.654
0.8	9.49	8.974
0.7	41.62	40.76
0.6	277.44	310.4
0.5	5131	5950
Order (α)	**FOHP**	
	PSPICE	**MATLAB**
1.0	0.982	0.998
0.9	3.07	3.335
0.8	11.80	14.70
0.7	79.64	97.00
0.6	940	1138
0.5	4375.17	24060

TABLE III. Stop band attenuation of proposed FOFs (in dB/decade)

Order (α)	**FOLP**	
	PSPICE	**MATLAB**
1.0	39.96	39.70
0.9	36.96	35.24
0.8	32.42	31.79
0.7	27.46	26.43
0.6	21.93	19.45
0.5	14.32	10.49
Order (α)	**FOBP**	
	PSPICE	**MATLAB**
1.0	19.75	19.88
0.9	17.80	18.05
0.8	15.87	15.91
0.7	13.93	13.57
0.6	11.95	11.82
0.5	9.95	9.97
Order (α)	**FOHP**	
	PSPICE	**MATLAB**
1.0	38.46	39.29
0.9	35.26	35.51
0.8	31.67	31.66
0.7	27.87	27.82
0.6	23.94	23.85
0.5	19.95	19.92

IV. CONCLUSION

A new CFOA-based multifunction fractional *order filter structure* is proposed which can realize FOLP, FOHP and FOBP filters using a single CFOA (with appropriate choice (s) of branch admittances). The simulation results of the proposed FOFs with their integer order counterparts have also been provided in Tables II and III respectively. The cutoff frequency as well as slope of stop band attenuation of proposed FOFs can be controlled by fractional parameter (α). The workability of the FOFs has been tested using PSPICE and MATLAB simulation results using macro model of AD844 type CFOA.

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