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, Signal 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 circuits/systems 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. 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.

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:
A Multifunctional Voltage Mode Fractional Order Filters using a Single CFOA

\[
\frac{V_0}{V_{in}} = \frac{y_1 y_2}{y_4 (y_1 + y_2 + y_3)}
\]

(1)

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
\[y_3 = s^\alpha C_1, y_4 = s^\alpha C_4 + \frac{1}{R_4}, y_1 = \frac{1}{R_1} \quad \text{and} \quad y_2 = \frac{1}{R_2}\]

The resultant transfer function becomes
\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^{\alpha} + \frac{1}{\frac{1}{C_1 R_1 R_2 R_3} + \frac{1}{C_4 R_4 R_5 R_6}}} \tag{2}
\]

(ii) FOBP filter: if we select
\[y_1 = s^\alpha C_1, y_4 = s^\alpha C_4 + \frac{1}{R_4}, y_2 = \frac{1}{R_2} \quad \text{and} \quad y_3 = \frac{1}{R_3}\]

The resultant transfer function will become
\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^{\alpha} + s^{\alpha} \left(\frac{1}{C_1 R_1} + \frac{1}{R_1 R_2} + \frac{1}{R_1 R_2 R_3} + \frac{1}{C_4 R_4 R_5 R_6}\right)} \tag{3}
\]

(iii) FOHP filter: if we take
\[y_1 = s^\alpha C_1, y_2 = s^\alpha C_2, y_4 = s^\alpha C_4 + \frac{1}{R_4} \quad \text{and} \quad y_3 = \frac{1}{R_3}\]

The resultant transfer function will be
\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^{\alpha} + s^{\alpha} \left(\frac{1}{C_1 C_2} + \frac{1}{R_2 C_2} + \frac{1}{R_2 R_3 C_2} + \frac{1}{R_2 R_3 R_4 C_2}\right)} \tag{4}
\]

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 \(\alpha = 1\).

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 (\(\alpha = 0.5 \text{ to } 0.9\)) is used in simulation of proposed FOFs.

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 \(\alpha (\alpha = 0.5 \text{ to } 0.9)\) 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.

Fig.1. Configuration of FOFs

[Diagram showing configuration of FOFs]

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

[Diagram showing 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.

The simulation results of proposed FOFs with PSPICE and MATLAB simulations are compared in Table I. These results thus, validate the theoretical findings.
Fig. 3. Frequency responses of FOFs using PSPICE
(a) FOLP (b) FOBP (c) FOHP

Table I. Component values for realization of FOFs in PSPICE

<table>
<thead>
<tr>
<th>Type of filter</th>
<th>Resistor</th>
<th>Fractional Capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOILP</td>
<td>$R_1 = 780\Omega$</td>
<td>$C_3 = 0.0995\mu F/\text{sec}(\alpha-1)$</td>
</tr>
<tr>
<td></td>
<td>$R_2 = 780\Omega$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R_3 = 1560\Omega$</td>
<td>$C_4 = 0.0995\mu F/\text{sec}(\alpha-1)$</td>
</tr>
<tr>
<td>FOIBP</td>
<td>$R_1 = 1665\Omega$</td>
<td>$C_1 = 0.0995\mu F/\text{sec}(\alpha-1)$</td>
</tr>
<tr>
<td></td>
<td>$R_3 = 1665\Omega$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R_4 = 3330\Omega$</td>
<td>$C_4 = 0.0995\mu F/\text{sec}(\alpha-1)$</td>
</tr>
<tr>
<td>FOIHP</td>
<td>$R_1 = 3500\Omega$</td>
<td>$C_2 = 0.0995\mu F/\text{sec}(\alpha-1)$</td>
</tr>
<tr>
<td></td>
<td>$R_4 = 1750\Omega$</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Order ($\alpha$)</th>
<th>FOLP</th>
<th>FOBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>1.005</td>
<td>1.005</td>
</tr>
<tr>
<td>0.9</td>
<td>2.083</td>
<td>2.101</td>
</tr>
<tr>
<td>0.8</td>
<td>5.67</td>
<td>5.384</td>
</tr>
<tr>
<td>0.7</td>
<td>19.21</td>
<td>18.67</td>
</tr>
<tr>
<td>0.6</td>
<td>115.99</td>
<td>101.8</td>
</tr>
<tr>
<td>0.5</td>
<td>1792</td>
<td>1160</td>
</tr>
</tbody>
</table>
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 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 CFOAs has been tested using PSPICE and MATLAB simulation results using macro model of AD844 type CFOA.

IV. CONCLUSION

A Multifunctional Voltage Mode Fractional Order Filters using a Single CFOA


AUTHORS PROFILE

Manoj Kumar Assistant Professor in the Department of Electronics and Communication Engineering, G B Pant Engineering College, Paun-Garhwal (Uttarakhand) India, was born in Patna, India. He received his B.E. (Electronics and Communication) in 1999, M.Tech (Bio-Electronics) from Tezpur Central University, Tezpur, Assam, India in 2008. Currently, he is pursuing Doctoral studies in the Department of Electrical Engineering at Delhi Technological University, Delhi under MHRD (Government of India) scheme of Quality Improvement Program. His teaching and research interests are in the area of Analog Circuits, Filter Design, and Fractional Order Systems.

D. R. Bhaskar, received B.Sc. degree from Agra University, B. Tech. degree from Indian Institute of Technology (IIT) Kanpur, M. Tech. from IIT Delhi and Ph.D. from University of Delhi. Prof. Bhaskar held the positions of Lecturer (1984–1990) and Senior Lecturer (1990–1995) at the Electrical Engineering Department of Delhi College of Engineering (now Delhi Technological University). He joined the Electronics and Communication Engineering (ECE) Department of Jamia Millia Islamia in July 1995, as a Reader and became a Professor in January 2002. He served as the Head of the Department of ECE from 2002 to 2005. Presently, he is working in the Department of Electronics and Communication Engineering, Delhi Technological University, Delhi, India.

REFERENCES


Retrieval Number: C8808019320/2020/BEIESP
DOI: 10.35940/ijitee.C8808.029420

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication
His teaching and research interests are in the areas of Bipolar and CMOS Analog Integrated Circuits and Systems, Current Mode/Voltage Mode Signal Processing, Communication Systems, Fractional Order Filters and Electronic Instrumentation. Prof. Bhaskar has authored or co-authored 93 research papers—all in international journals of repute, 10 international conference papers and 4 book chapters. He has co-authored 3 monographs published by Springer. He has acted/has been acting as a Reviewer for several journals of IEEE, IEE and other international journals of repute.

Pragati Kumar, Professor in Department of Electrical Engineering, Delhi Technological University, New Delhi, India was born in Muzaffarpur, Bihar, India. He received his Ph.D. from the University of Delhi in 2008. His teaching and research interests are in the area of Network Analysis and Synthesis, Microelectronics, CMOS Analog Integrated Circuits and Fractional Order Circuits/Systems. He has co-authored 16 research papers in various international journal/conferences/edited book volumes.