A comparative study on the Implementation of Fractional Order Butterworth Lowpass Filter using Differential Voltage Current Conveyor

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Abstract- In this paper, two fractance devices and an active implementation of a differential voltage current conveyor (DVCC) based on a Butterworth lowpass filter in fractional order are presented (FDs). The transfer function for a fractional order system is initially established. The conventional fractional order Butterworth equation is then used to compare the transfer function of the created system. This can be equated to obtain the generalised condition under which the created system functions as a Butterworth filter of fractional order. Additionally, using Monte Carlo analysis, the impact of current and voltage faults on DVCC response is investigated. Finally, to validate the theoretical results, a fractional order Butterworth filter is simulated in the PSpice environment using 0.5 μm CMOS technology using a suggested R-C network-based fractional order capacitor.

Keywords- Current Conveyor, Differential Voltage, Fractional order, Synthesis, Differentiator, Integrator, RC Network, Simulation.

I. Introduction

In the field of signal processing, active filters are among the most common types of filters used . When data is transmitted over a physical medium, it must first undergo a conversion into electromagnetic signals. Data itself can take the form of either an analogue or digital signal. This conversion must take place before the data can be transmitted. The nature of digital signals is discrete, and they are represented by a succession of voltage pulses. An analogue signal has the form of a continuous waveform and is represented by electromagnetic waves that are also unbroken. Numerous applications make use of various types of filters. A circuit that can be designed to modify, reshape, or reject all frequencies of an electrical signal that are not desired while allowing only the desired frequencies to pass through it is called an electrical filter. There are two different kinds of filters, namely active filters and passive filters. Components such as capacitors, resistors, and inductors are examples of passive elements that are used in the design of passive filters. When we design active filters, such as op amps and the like, we make use of an active element. Active filters offer high gain without the loading effect of passive filters. There are four distinct varieties of filters, which are referred to as lowpass filters, highpass filters, bandpass filters, and bandreject filters respectively. One more kind is called an all pass filter. It lets through all of the frequencies, but the phase response changes are blocked out. The ripple in the passband, the attenuation in the stopband, and the roll off in the passband are the specifications of a filter. The ripple in the passband is kept to a minimum while the roll off is increased to its maximum. If the order is increased, roll off will also increase, as will the intensity of passband ripples. As a result, it is difficult to exercise control over the exchange between passband ripple and roll off rate. Therefore, the name "fractional order filters" refers to the application of the fractional order system to those filters. In this application, fractance filters and devices are utilised. Capacitors and inductors are used in their place instead of reluctance devices. The passband ripple, roll off rate, and stop band attenuation can all be controlled more precisely thanks to the additional degree of freedom provided by these filters. It is possible to achieve increased design flexibility and improved performance by utilising fractional order filters.

Integration and differentiation with values that are not integers are the focus of the mathematical discipline known as the "fractional component"[1-4]. Different types of differentiation and integration at fractional order have been developed by mathematicians. When dealing with fractional order differentiation and integration systems, the Riemann-Liouville definition is among the most useful ones. Fractional differentiation is displayed in [5] below.

$$\frac{d^\alpha}{dx^\alpha} f(x) = \frac{1}{\Gamma(n-\alpha)} \frac{d^n}{dx^n} \int_0^x (x-t)^{n-1-\alpha} f(t)dt \quad (1)$$

where, $n-1 < \alpha < n$ and $\Gamma(.)$ is a Gamma Function.

Fractance device exhibits fractional order impedance matching properties. The angular frequency of capacitance -1, resistance 0, and inductance 1 as follows[8].

$$Z(s) = s^{\alpha} \tag{2}$$

Different mathematical models, such as continued fraction expansion, regular newton process, and Taylor series expansion with higher order using R-L, R-C networks all make use of fractionance devices. The applications of continuous time signal processing include things like filters, oscillators, integrators, and differentiators, amongst other things. The fractional order system has the disadvantage of being more complicated in general and being difficult to envision being used in any practical context. This is the system's primary limitation. in order to minimise the dimensions of the fractance device.

To begin, lowpass, highpass, bandpass, and band reject filters of the first order were fractionally implemented, and then the system was further extended to the second order. Utilizing differential voltage current conveyor allows for the presentation of a Butterworth lowpass filter with a fractional order. It is possible to enhance the performance of the system while simultaneously lowering the amount of power that it requires thanks to the utilisation of current mode active devices. DVCC is one of the building blocks that can be used for a variety of applications of analogue circuits. It possesses the benefits of both first- and second-generation current conveyors, including larger dimensions, increased linearity, and an extensive dynamic range. In addition to this, DVCC demonstrates high input impedance in addition to high arithmetic operations. DVCC-based fractional order Butterworth lowpass filters are used for a variety of applications, including high-quality radio receivers, portable biomedical devices, robotics, and so on. These filters are designed to improve system performance.

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In today's world, the application of fractance, also known as fractional order elements, is a topic that is fascinating to research. Both a theoretical and a practical application of the fractance device are viable options. It finds application across a wide range of engineering and research domains. The qualities of a resistor, an inductor, and a capacitor can all be demonstrated with a single element. As a direct consequence of this, there is a significant amount of interest in locating a device of this kind.

Within the body of published work, one can find many different mathematical realisations. Several examples of these types of approximations include Mastuda's approximation, Chareff's approximation, the Continued fraction expansion approach, and others. The rational approximation can be computed using these approaches. After that, a suggestion is made for an equivalent circuit by using the process of network synthesis.

The design of fractional order filters is becoming an increasingly common area of research these days. The realisation of the filters is something that a lot of VLSI engineers are interested in. In this article, a novel fractional order lowpass filter that uses a smaller number of components is proposed.

The following is the structure of this paper: The DVCC is covered in detail in Section 2. Literature review is discussed in Section3. The fourth section presents an in-depth analysis of the fractional order lowpass filter as well as the Carlson approximation. In section 5, the designing of a fractional order Butterworth filter that is based on DVCC is presented. The simulation of the circuit and the results are in section 6. The conclusions are presented in the seventh section.

II. Differential Voltage Current Conveyor(DVCC)

Since the beginning of the twenty-first century, all electronic applications have been constructed using current mode because of the many advantages it offers, including high performance and versatility. The justifications for switching from voltage mode to current mode are indisputable and include having a high slew rate, having a higher dynamic range, having a better bandwidth, having an easier time fabricating circuits, and saving power. In addition to the benefits that can be gained from the grounded capacitor feature, the waveform generator that makes use of the operational transconductance amplifier (OTA) that has been proposed needs more active elements and has more passive components, both of which contribute to an increase in the amount of power that is consumed as well as the amount of space that is required. The circuit consisted of only a few active components, but it had seven passive components and lacked a grounded capacitor. Additionally, there was no grounded capacitor. The given circuit suffers from the same flaw that arises from using a greater number of passive and active components than is strictly required, which restricts the circuit's applicability in integrated circuit manufacturing.

Differential voltage current conveyors each have four terminals on their analogue blocks, and the voltages and currents that they carry are described in accordance with a matrix.

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ I_X \\ V_Z \end{bmatrix} \tag{3}$$

The block diagram representation of the DVCC is as shown in Fig.1. The CMOS implementation of the DVCC is as shown in Fig.2. The aspect ratios of the transistors is tabulated in Table.1.

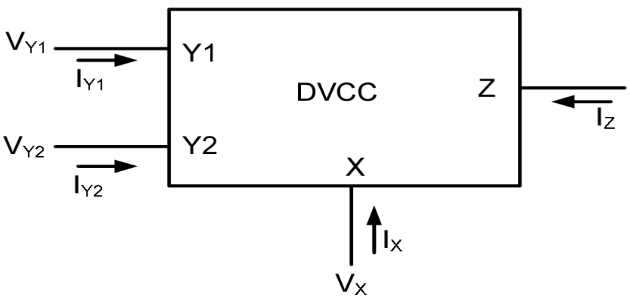

Fig. 1: DVCC Block Diagram.

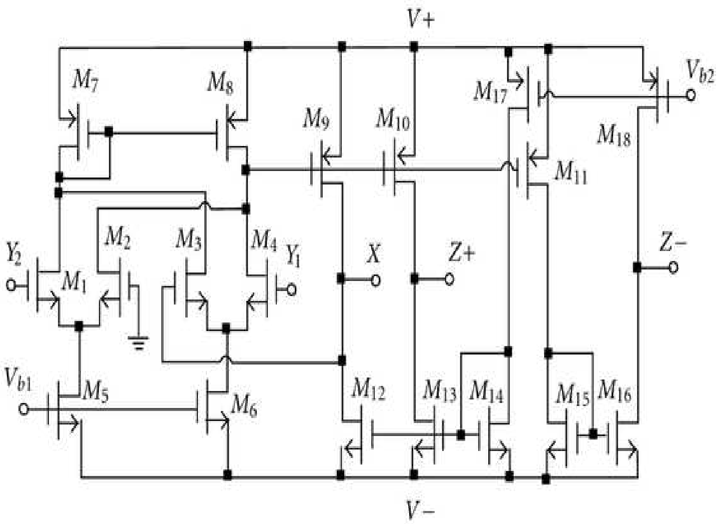

Fig. 2: DVCC using CMOS.

Table 1: Aspect Ratios of the Transistors

M1, M2, M3, M4	$\frac{2.5}{1}$
M5, M6	$\frac{8}{1}$
M7, M8	$\frac{10}{1}$
M9, M10, M11, M17, M18	$\frac{40}{2}$
M12, M13, M14, M15, M16	$\frac{20}{2.5}$

III. Literature Review

- Shalabh Kumar Mishra, Manisha Gupta, Dharmendra Kumar Upadhyay "Active realization of fractional order Butterworth lowpass filter using DVCC" Journal of King Saud University This paper covers the design of a fractional order system Butterworth lowpass filter. One of the most well-known and frequently utilised tools in the field of signal processing is the electronic filter. Passband roll-off, stopband attenuation, and passband ripple are the three main characteristics of filters. Filters should have maximal roll-off and little passband ripple for the best design. The roll-off increases and the passband ripples get stronger as the order rises. It is crucial to have a justifiable trade-off between roll-off and pass-band ripple. Controlling two of them at once is challenging, though. As a result, fractional calculus is used to create filters; these filters are referred to as fractional-order filters. Fractance devices (FDs) are used in place of traditional capacitors and inductors in fractional-order filters. These filters offer an additional level of design flexibility and offer fine-grained control over pass band ripple, roll-off, and stop band attenuation.

Additionally, it should be noted that the responses of fractional-order filters can be changed solely by changing the order of FDs, negating the requirement to alter the filters' capacitance and inductance values numerically. Mathematicians who study the fractional calculus study the integration and differentiation of non-integer order. Although fractance devices are not commercially available, they can be approximated using a number of mathematical methods, including Taylor series expansion, continuous fraction expansion, and regular Newton process.

Various fractional order circuits and systems, including filters, oscillators, integrators, differentiators, etc., are realised using these FDs in continuous time signal processing applications. The fractional-order system is therefore larger and more difficult to implement in practise. This is the fractional-order system's main flaw. But there have been numerous attempts to make fractance devices smaller, and it is also thought that fractance devices may soon be accessible.

First, the fractional domain low pass, high pass, band pass, and band reject filters were proposed. Later, the notion of the fractional filter was expanded to second-order systems. Then Ali et al. introduced the KHN and Sallen key filter in a fractional sense as well as the active and passive realisations of the fractional order Butterworth filter. Additionally, a number of already-existing filters (including Chebyshev and Tow-Thomas) have also been realised in a fractional sense. Active building blocks (ABBs) for current mode systems are widely employed today to boost system performance. The system's overall power consumption can be decreased with the aid of these ABBs.

The DVCC is one of the most widely used and technologically advanced building blocks for various analogy circuits because it combines the benefits of the differential difference amplifier and the second-generation current conveyor (large signal bandwidth, excellent linearity, and wide dynamic range) (high input impedance, high arithmetic operation capability). Although the Butterworth filter has been effectively approximated in a fractional sense, it is noteworthy that literature on their realisation utilising current mode active building blocks is scarce. As a result, it is necessary to design the fractional order Butterworth filter with current mode ABBs in order to take use of its benefits and enhance system performance. This work introduces a fractional order Butterworth lowpass filter based on DVCC that can be used for various applications.

- Elwan, H.O., Soliman., A.M., 1997. Novel CMOS differential voltage current conveyor and its applications, IEEE Proc. Circuits Dev. Syst. 144 The differential voltage current conveyor is an extension of the second-generation current conveyor (CCII) introduced by Sidra and smith. Recently CCII has been realized using MOS transistors, with the intension to integrate the different CCII circuit applications on one chip. The CCII proves to be a versatile building block that can be used to implement a variety of high-performance circuits which are simple to construct. The CCII has a disadvantage that only one of the input terminals has ahigh input impedance. This disadvantage becomes evident when the CCII is required to handle differential signals as in the case of an instrumentation amplifier. The design of such an amplifier requires two or more CCIIs. Realization of instrumentation amplifier results in an amplifier structure that has the advantage of a high CMRR without the need for an accurately matched resistor network. The circuit uses two floating resistors to provide floating input handling capability. Moreover, the floating resistor is connected between the X terminals of the two CCIIs. As each X terminal has an output resistance Rx, the effective resistance between the two X terminal is R+2Rx, that is the error caused by the nonzero X terminal resistance is doubled.In this paper the DVCC building block is proposed. The DVCC is a novel building block specially defined to handle differential signals.

- Upadhyay, D.K., Mishra, S.K., 2015. Fractional Order Microwave Lowpass- Bandpass Filter. In: 2015 Annual IEEE India Conference (INDICON). New Delhi, India, Doi 10.1109/INDICON.2015.7443282 Microwaves are electromagnetic spectrums with frequencies between GHz. These signals are highly directive in nature due to the very tiny wavelength of their spectra, which is in the millimetre. Microwave spectrums are utilised in a variety of Line of Sight (LOS) communications, including radar, satellite, DTH-TV, mobile, and weather forecasting systems for aeroplanes. One of the most important components in every communication system is the filter, which gives the desired frequency signal selectivity. The selectivity of the filter serves as a gauge of its effectiveness. The realisation of filters in a fractional sense is one of the most common and successful filter realisation techniques, and there have been some notable developments in this area in recent years. The fractional calculus, which deals with integral and derivative functions with fractional order, is the foundation of this technique. Researchers in the fields of engineering and technology, such as control design, electrical circuits, stability analysis, mechanics, electromagnetics, and bioengineering, have found fractional calculus to be one of the most useful mathematical tools.

  Higher order passive RC or RLC trees, along with a few active circuits, can be used to simulate a capacitance device. It has been noted that the practical implementation of fractance devices for microwave signals is constrained by the fact that the existing approximation circuit for fractional devices may contain numerous lumped elements for a single fractional element.

- Natisha Shrivastava, Pragya Varshney "Implementation of Carlson based fractional differentiation in control of fractional plants" I.J. Intelligent Systems and Applications,2018, 9, 66-74 In this study, fractional differentiators' reduced integer order models are presented. There is a two-step process used. Approximated second iteration models of fractional differentiators are created using the Carlson method of approximation. This technique produces transfer functions with large orders, which make the system more complex and make their realisation challenging. As a result, reduced order models are created using the Balanced Truncation method, the Matched DC gain method, and the Pade Approximation approach. These models enable the implementation of fractional Proportional-Derivative and fractional Proportional-Integral-Derivative controllers on a fractional order plant and the acquisition of closed loop responses. The authors have made an effort to illustrate how the Carlson method, in conjunction with reduction strategies, can be utilised to create effective lower-order fractional differentiator models. The frequency responses of the models produced by the various reduction methods are compared to both the original model and to one another.

IV. Fractional order Lowpass Filter

The transfer function of the fractional order filter is obtained as:

$$T(s) = \frac{k_3}{s^{\alpha+\beta} + k_1 s^{\alpha} + k_2} \tag{4}$$

where $k_1 = \frac{R}{L}$ and $k_2 = k_3 = \frac{1}{LC}$.Fractional order Butterworth lowpass filter of frequency response is given by, $f_c = \frac{1}{2\pi} k_1^{\frac{1}{\alpha+\beta}}$.

Carlson and Halijak proposed the approximation for approximating fractance [35], $\left(\frac{1}{s}\right)$, using regular Newton process. The general expression of the approximation is given by

$$G_{k+1}(s) = G_k(s)\frac{(n-1)G_k^n(s) + (n+1)H(s)}{(n+1)G_k^n(s) + (n-1)H(s)}, \quad (5)$$

where n is order of approximation and k is iteration number. The interval of frequencies where the approximation is valid is always centered at unity. We assume $G_0(s) = 1$ in the rational approximation for

$$s^{-0.5} = \frac{s^4 + 36s^3 + 126s^2 + 84s + 9}{9s^4 + 84s^3 + 126s^2 + 36s + 1}. \quad (6)$$

When using this method, approximations for the fractance device of even integer order are the only ones that can be obtained. The requirements of the user determine the order in which the approximation is performed. Nevertheless, in the event that the order quantity increases, the realisation will become more challenging and will call for additional hardware. Figures 3 and 4 respectively show a comparison between the ideal approximation and the Carlson approximation.

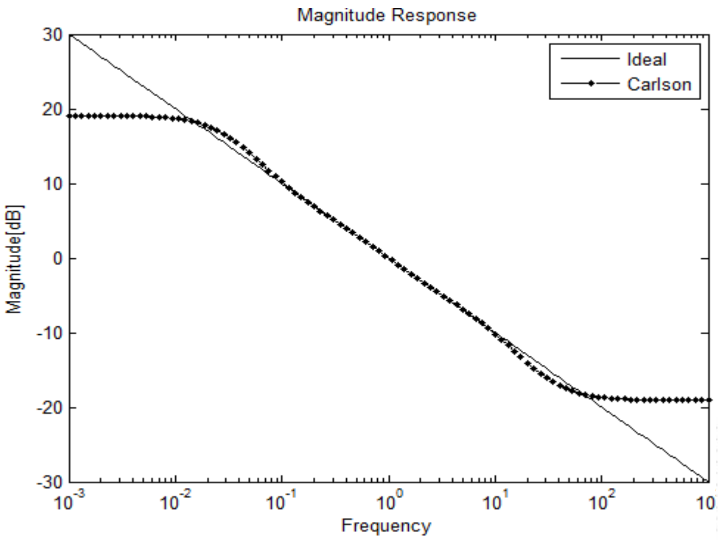

Fig. 3: Magnitude Response Comparison.

V. DVCC based Fractional order Butterworth filter design

The DVCC based fractional order Lowpass filter using two fractional order elements is as shown in Fig.5. Here Inductor and Capacitor are of fractional order in nature. In this paper, the values of chosen fractional order are $\alpha = 0.5$ and $\beta = 1$. For $\alpha = 0.5$, the transfer function given in Eqn.6 has been realized using network synthesis procedure in the form of a Ladder network. The PSPICE diagram used for the realization of the lowpass filter is in Fig.7. The proposed RC circuit is shown

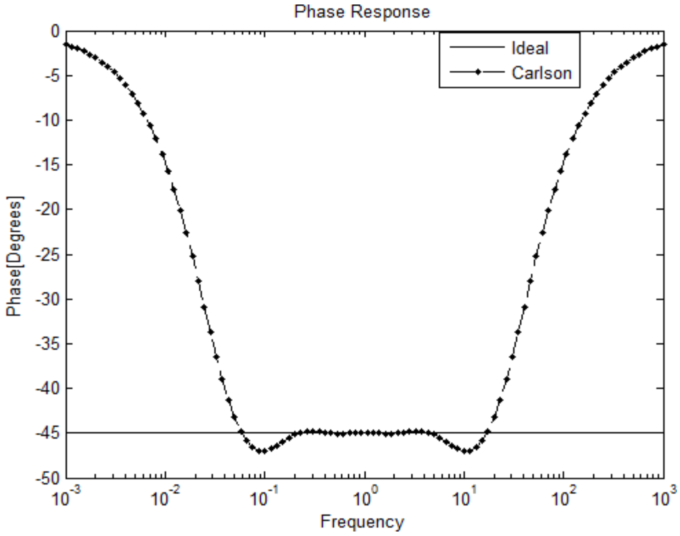

Fig. 4: Phase Response Comparison.

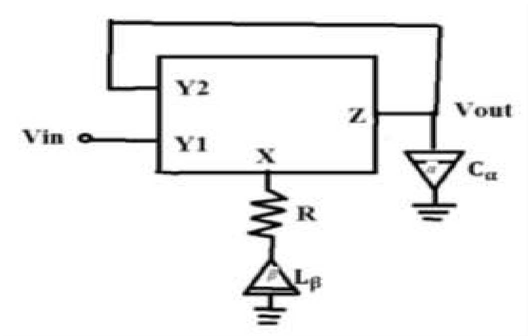

Fig. 5: Fractional order Lowpass Filter diagram.

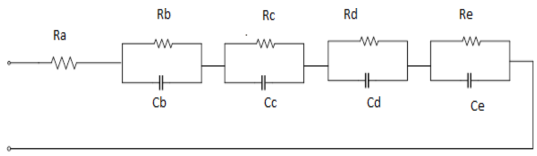

Fig. 6: RC Ladder Network.

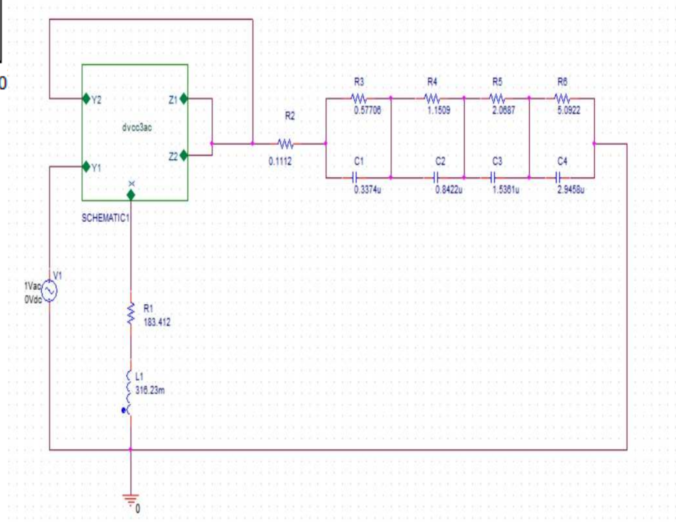

Fig. 7: Carlson Based realization using PSPICE.

above figure. The circuit can be realised by five resistors and four capacitors are placed in place of fractional capacitor of fractional order Butterworth lowpass filter design.

VI. Results and Discussion

The fractional order Butterworth lowpass filter is simulated in PSpice software. In this Butterworth condition is satisfied by $k_2 = 31622.77$ and $k_1 = 580$ and the circuit parameters as $R = 183.412\Omega$, $L = 316.23mH$, $C = 100\mu F$. CMOS schematic of DVCC is simulated by 0.5µm CMOS model. Width to length ratio of DVCC are listed in table, and supply voltages are $V_{DD} = -V_{SS} = 1.5V$ and biasing voltages are -0.52v and 0.33v respectively.

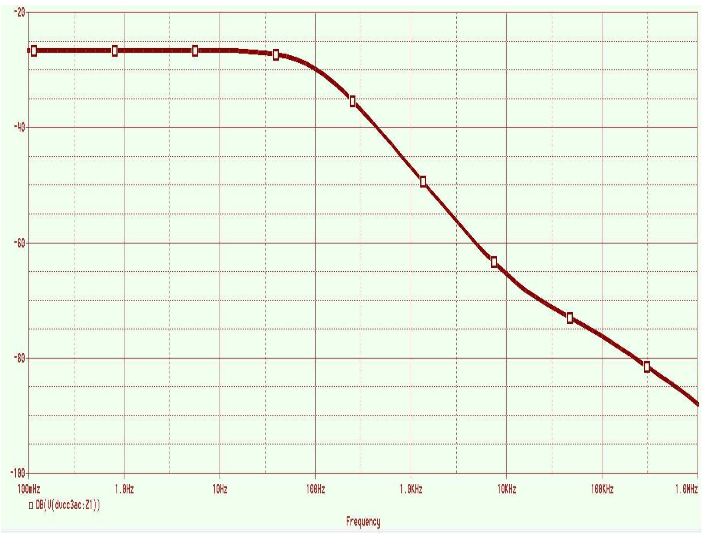

Fig. 8: Magnitude response of Proposed realization using PSPICE.

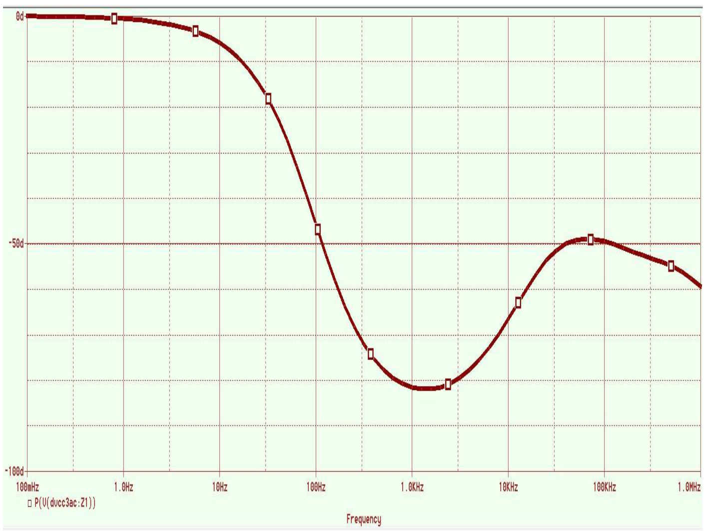

Fig. 9: Phase response of Proposed realization using PSPICE.

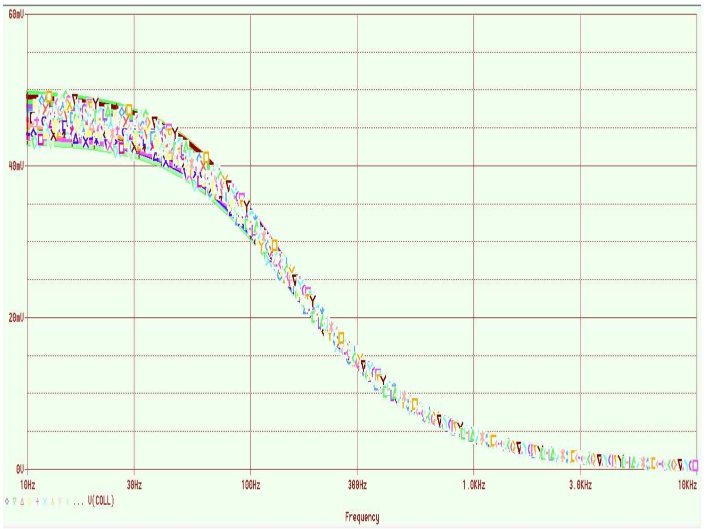

Fig. 10: Monte Carlo Simulations.

VII. Conclusions

The fractional order lowpass filter using carlson based approximation technique is realized in this paper. Initially carlson approximation technique is studied. The fourth order approximation is considered keeping in view of the hardware complexity. A block for DVCC is created in PSPICE. The circuit is simulated in PSPICE environment. It has been observed that butterworth filter can be realized with lesser hardware as compared to previous procedures.

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