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TO STUDY THE PERFORMANCE OF FRACTIONAL ORDER LOW PASS FILTERS USING LT-SPICE

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Abstract: Fractional Order filters were First Proposed in RADWAN in 2008 where design Procedure for all filters with fractional order was introduced. General expressions for the maximum frequencies, quality factor, the right phase, and half power frequencies were derived. In addition, the effect of the transfer function parameters on the filter poles and hence the stability introduced. Here in this paper we studied the LT-SPICE Simulation results to validate the theoretical findings. Different filters responses are obtained from general delayed transfer function. We first have used the CFOAs technique to design the fractional Order low pass filters. Then we have used CHEBYSHEV low pass filters for designing fractional Order low pass filters. We have designed fractional Order low pass filters of order 1.2, 1.5, 1.8 by using both designing techniques and then compared their results.

Index Terms - Fractional Order, LT-SPICE, CFOAs, CHEBYSHEV, Quality Factor

I. INTRODUCTION

The importance of filters in signal processing and other engineering areas is unquestionable. Continuous time filters are widely used as functional blocks, from simple anti-aliasing filters preceding ADCs to high-SPEC channel-select filters in integrated RF transceivers. Four classical classes of filters which are currently used: Butterworth, Chebyshev, Elliptic and Bessel (Zverev, 1969). Even in the integer order case, filter design is challenging, mainly when the system has to meet a wide set of constrains. Most tools for filter design are based on the transfer functions of the above classes, which impose only requirements related to the magnitude or phase responses.

Active RC filters are the class of frequency selective circuits in which resistances, capacitances and OP- AMPs are the only components used. The modern IC fabrication precludes the use of inductors. Even in discrete component circuit, the use of inductors is avoided because they are bulky heavy and non- linear. In addition, they generate stray magnetic field may dissipate considerable amount of power.

The growing research interest for employing the concept of fractional calculus in electronic engineering is mainly originated from the interdisciplinary nature of this research area. For example, the modelling of viscoelasticity as well as of biological cells and tissues has been performed through the utilization of the fractional-order calculus. Biological signals such as electrocardiograms (ECG) and electroencephalographs (EEG) have spectra that do not increase or decrease by multiples of ±6 dB/octave but by multiples of ±6·a dB/octave ($0<a<1$). In addition, the capability for precisely controlling the attenuation gradient in fractional-order filters in comparison with the corresponding integer-order filters is an attractive feature. Fractional Order Elements (FOEs) are the main building blocks for performing signal processing according to the fractional calculus. Unfortunately, these elements are not commercially available and, thus, FOEs are approximated by appropriately configured RC networks.

Following this approach a number of voltage-mode filters where Operational Amplifiers (Op-Amps), second-generation Current Conveyors (CCIIs), and Current Feedback Operational Amplifiers (CFOAs) are employed as active elements have been proposed in the literature.

II. Designing Fractional-order filters using CFOAs

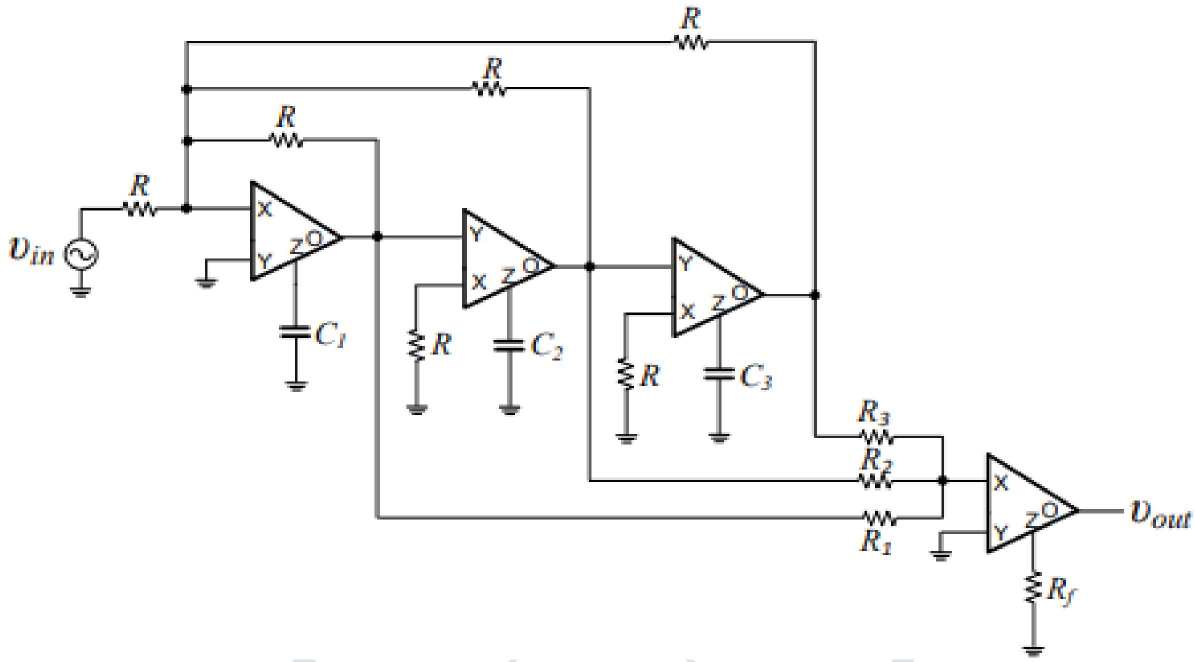

FIG. 1 ARCHITECTURE OF FRACTIONAL-ORDER FILTER USING CFOAS

(a) Low Pass Fractional Order Filter Using CFOAs (Order n = 1.1)

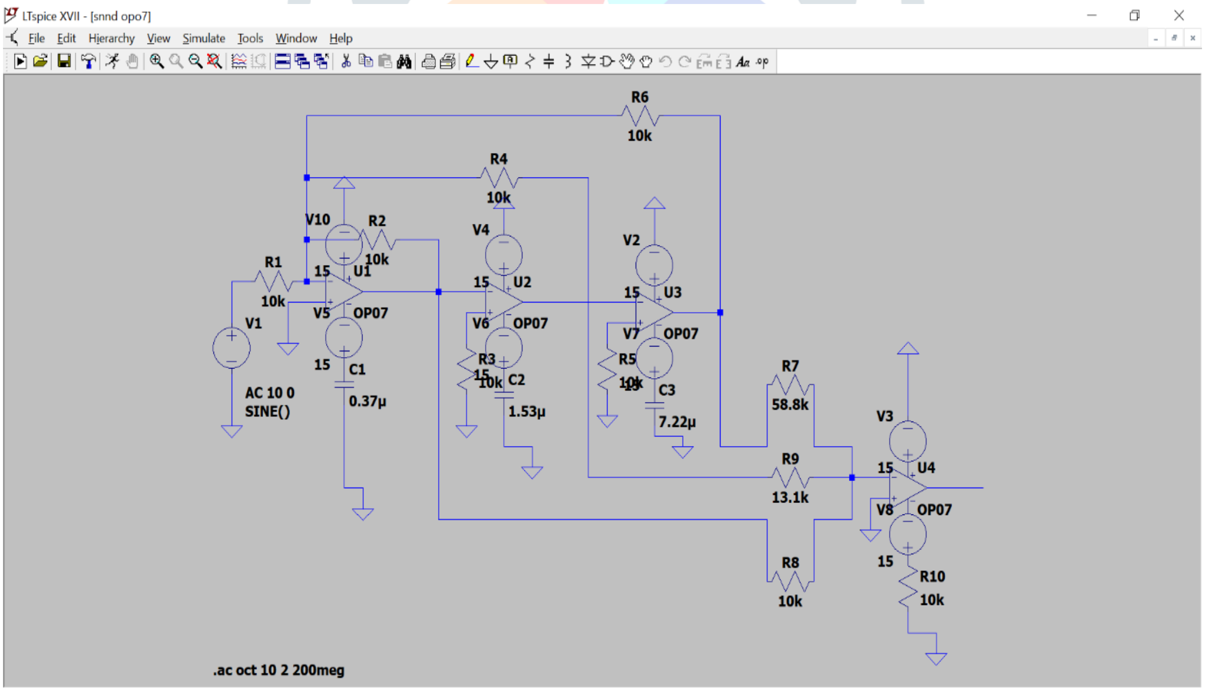

Fig. 2 CIRCUIT OF FRACTIONAL-ORDER FILTER USING CFOAs (Order n = 1.1)

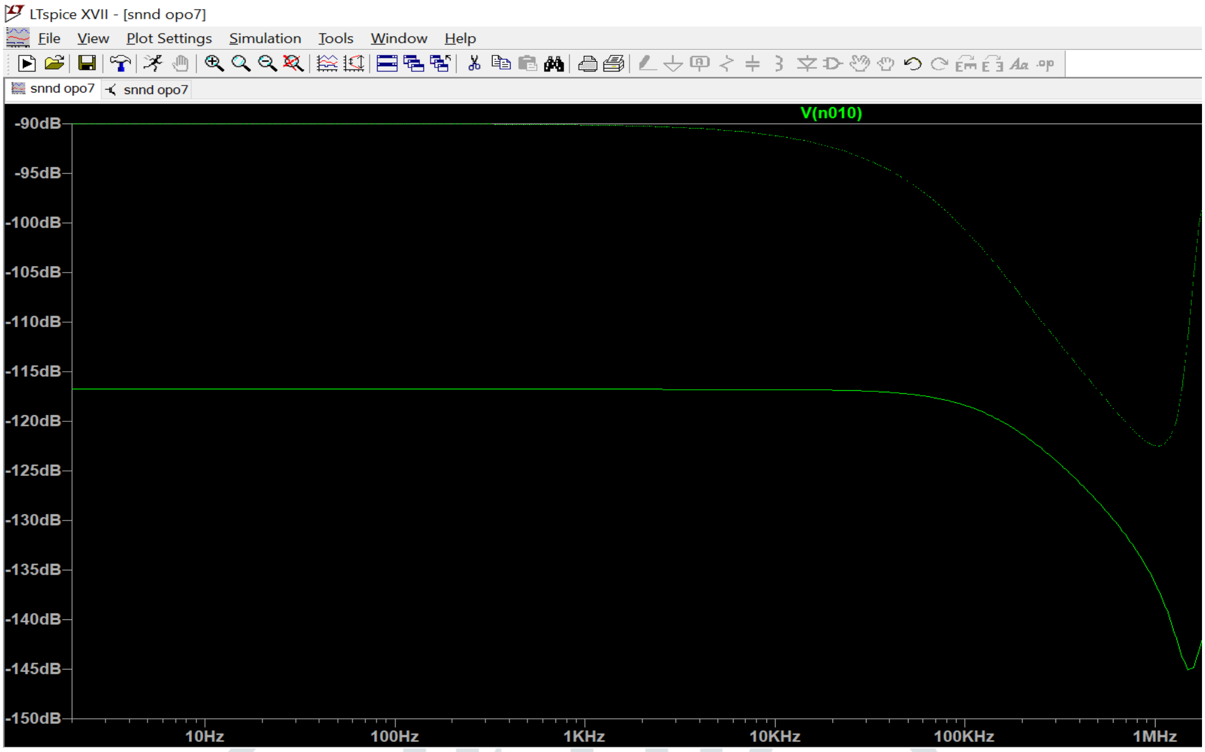

FIG. 3 SPICE SIMULATION OF FRACTIONAL-ORDER FILTER USING CFOAS (ORDER N = 1.1)

The measured frequency response of a 1.1 order filter is demonstrated in Fig.3, where the cut-off frequency is 96 kHz while the slope of the stop band attenuation is equal to -9.5dB/oct. Taking into account that the corresponding theoretically predicted values are 100kHz and -9dB/oct, respectively, the correct operation of the filter in Fig.2 is verified. The observed deviations are mainly caused by the tolerances of the used passive resistors and capacitors. These can be easily compensated through appropriate trimming.

(b) Low Pass Fractional Order Filter Using CFOAs (Order n = 1.5)

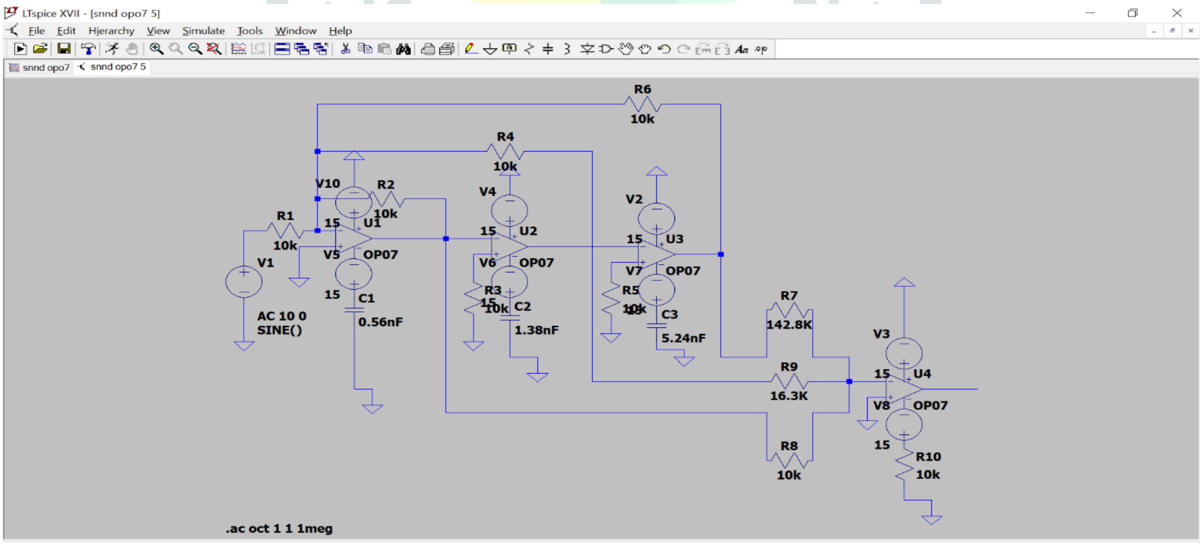

FIG. 4 CIRCUIT OF FRACTIONAL-ORDER FILTER USING CFOAS (ORDER N = 1.5)

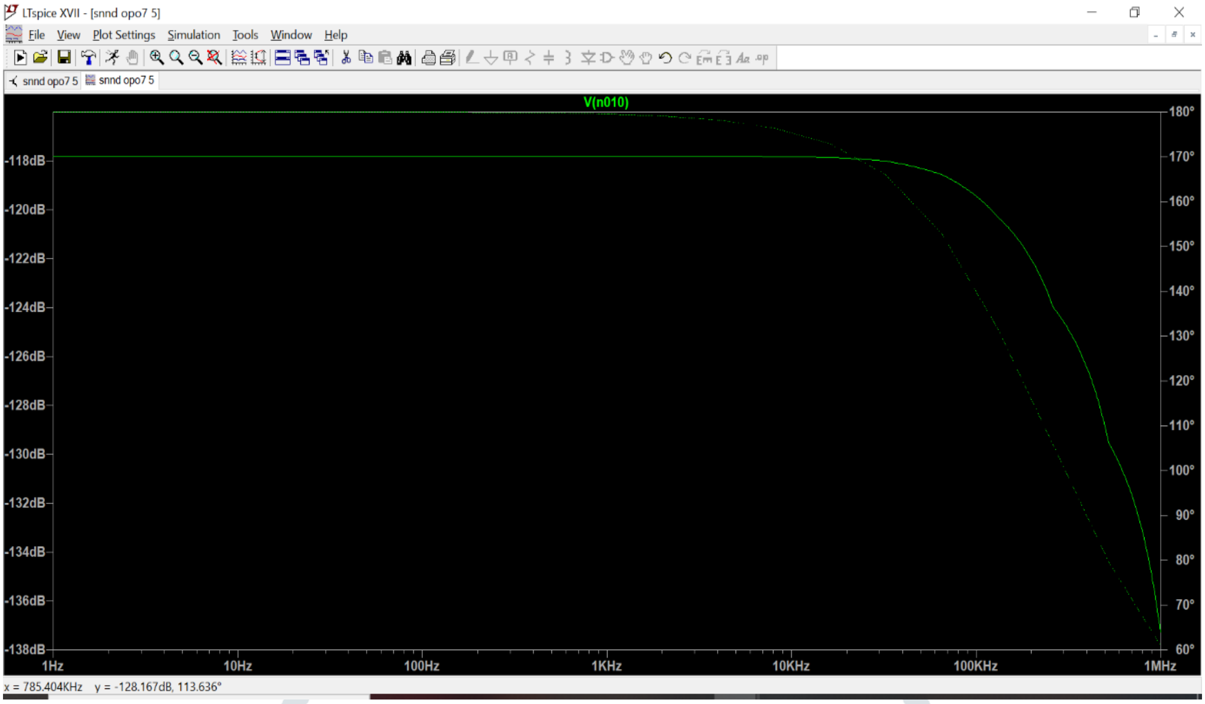

FIG. 5 SPICE SIMULATION OF FRACTIONAL-ORDER FILTER USING CFOAS (ORDER N = 1.5)

The measured frequency response of a 1.5 order filter is demonstrated in Fig.5, where the cut-off frequency is 95 kHz while the slope of the stop band attenuation is equal to -9.6dB/oct. Taking into account that the corresponding theoretically predicted values are 100kHz and -9dB/oct, respectively, the correct operation of the filter in Fig.4 is verified. The observed deviations are mainly caused by the tolerances of the used passive resistors and capacitors. These can be easily compensated through appropriate trimming.

(c) Low Pass Fractional Order Filter Using CFOAs (Order n = 1.8)

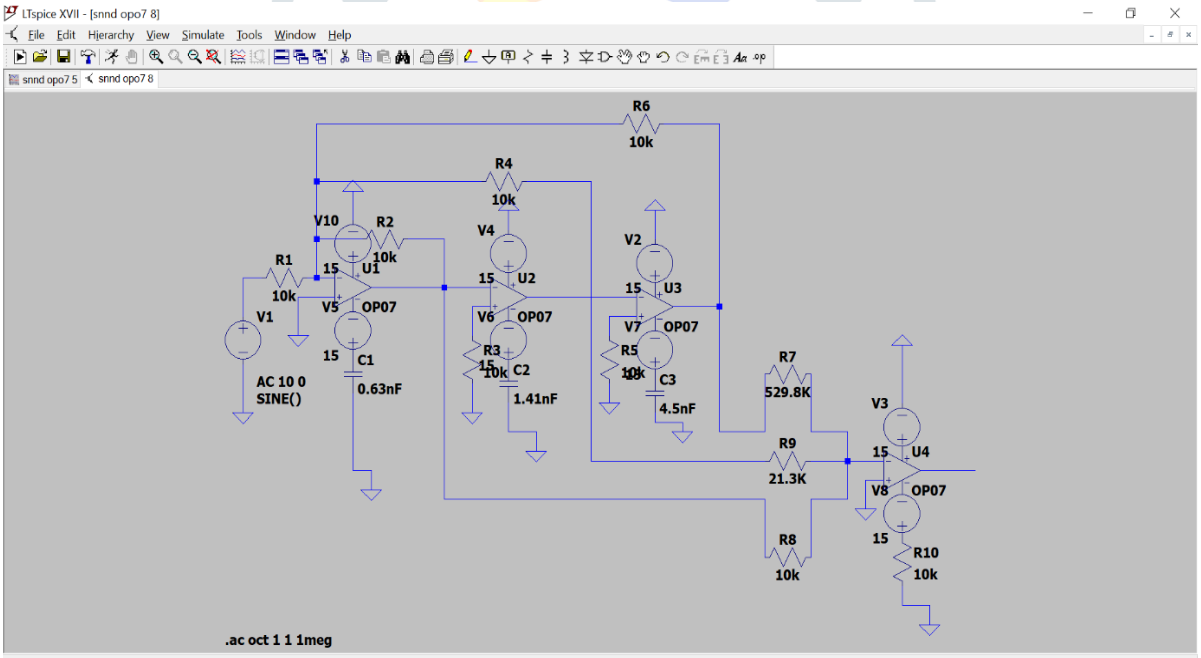

FIG. 6 CIRCUIT OF FRACTIONAL-ORDER FILTER USING CFOAS (ORDER N = 1.8)

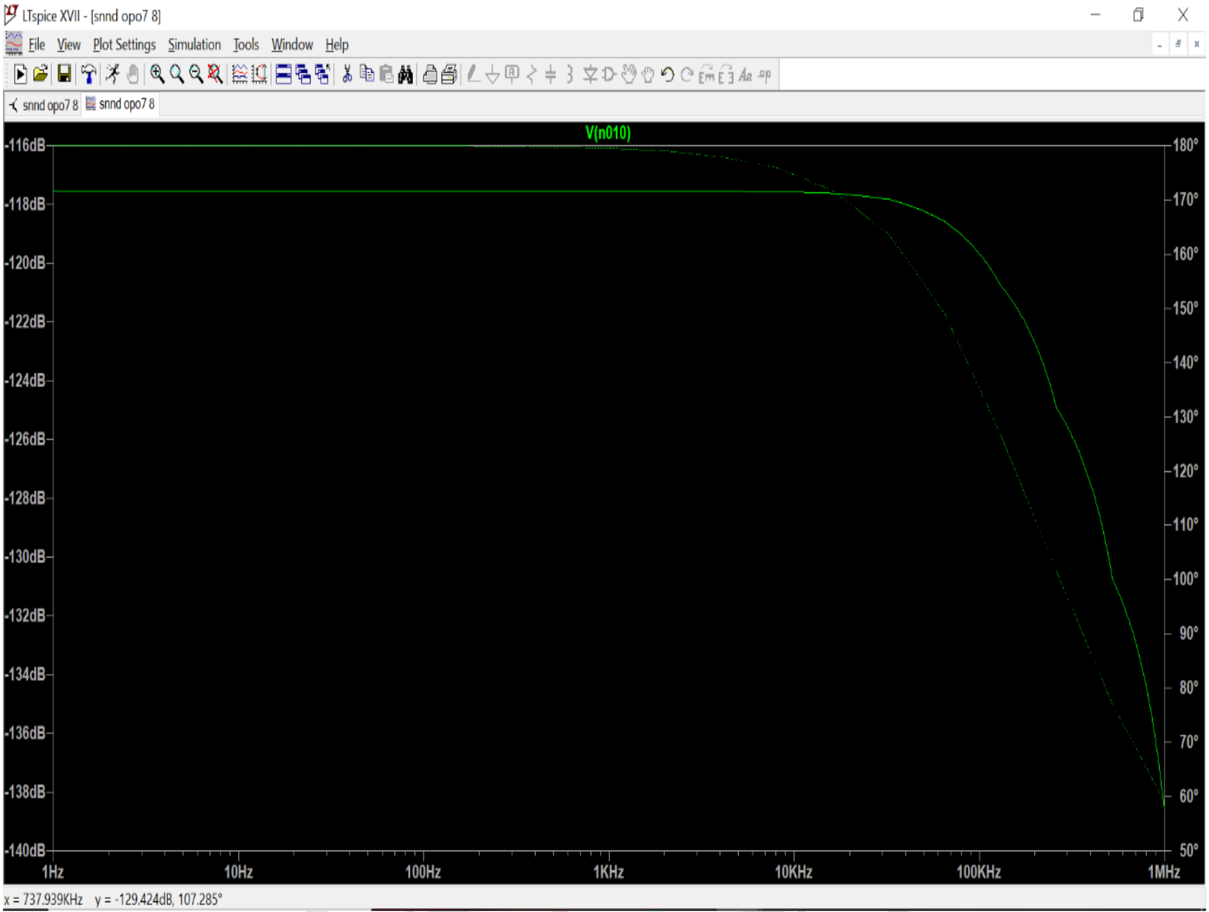

Fig. 7 SPICE SIMULATION OF FRACTIONAL-ORDER FILTER USING CFOAs (Order n = 1.8)

The measured frequency response of a 1.8 order filter is demonstrated in Fig.7, where the cut-off frequency is 95 kHz while the slope of the stop band attenuation is equal to -9.6dB/oct. Taking into account that the corresponding theoretically predicted values are 100kHz and -9dB/oct, respectively, the correct operation of the filter in Fig.6 is verified. The observed deviations are mainly caused by the tolerances of the used passive resistors and capacitors. These can be easily compensated through appropriate trimming.

III. Approximated Fractional Order Chebyshev Low Pass filters

Circuit Realization

Pafnuty Chebyshev suggested the designing of frictional order filters by utilizing the fractional order transfer function that can be realized by the Tow-Thomas Biquad topology, given in Figure 8. This topology was previously employed in to realize fractional order filter circuits with flat pass band characteristics and fractional attenuations in the stop band. The architecture of the fractional order Tow - Thomas Biquad at the non inverting low pass output is given below:

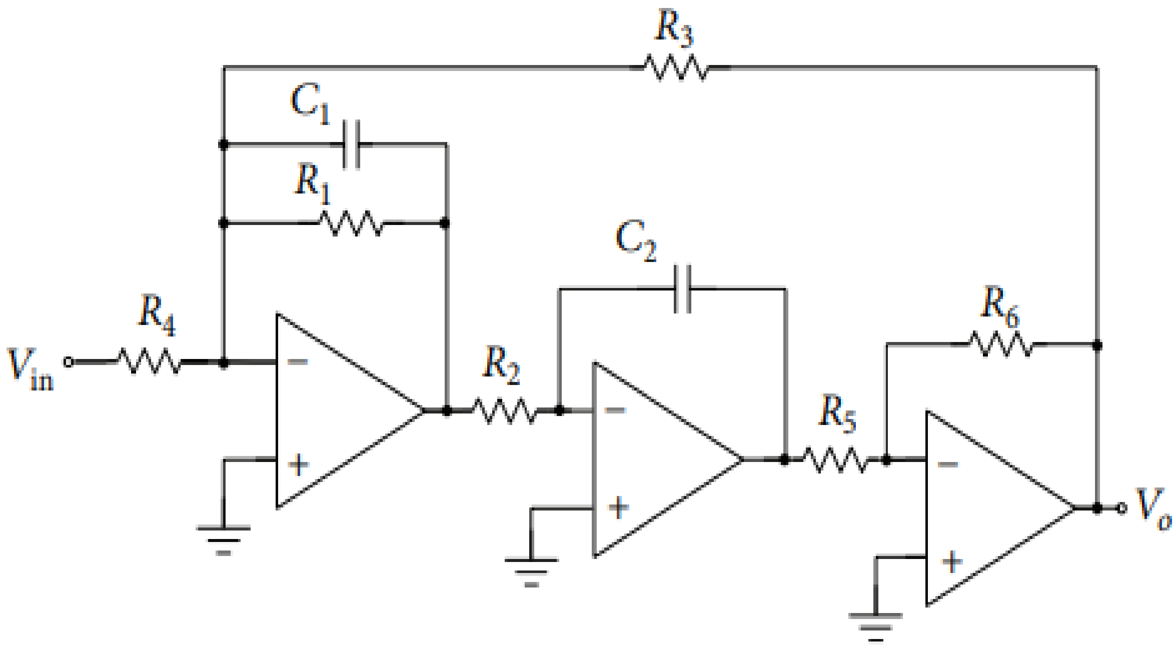

FIG. 8 ARCHITECTURE OF FRACTIONAL-ORDER TOW - THOMAS BIQUAD TOPOLOGY

(a) Approximated Fractional Chebyshev Low pass filter (Order n=1.1)

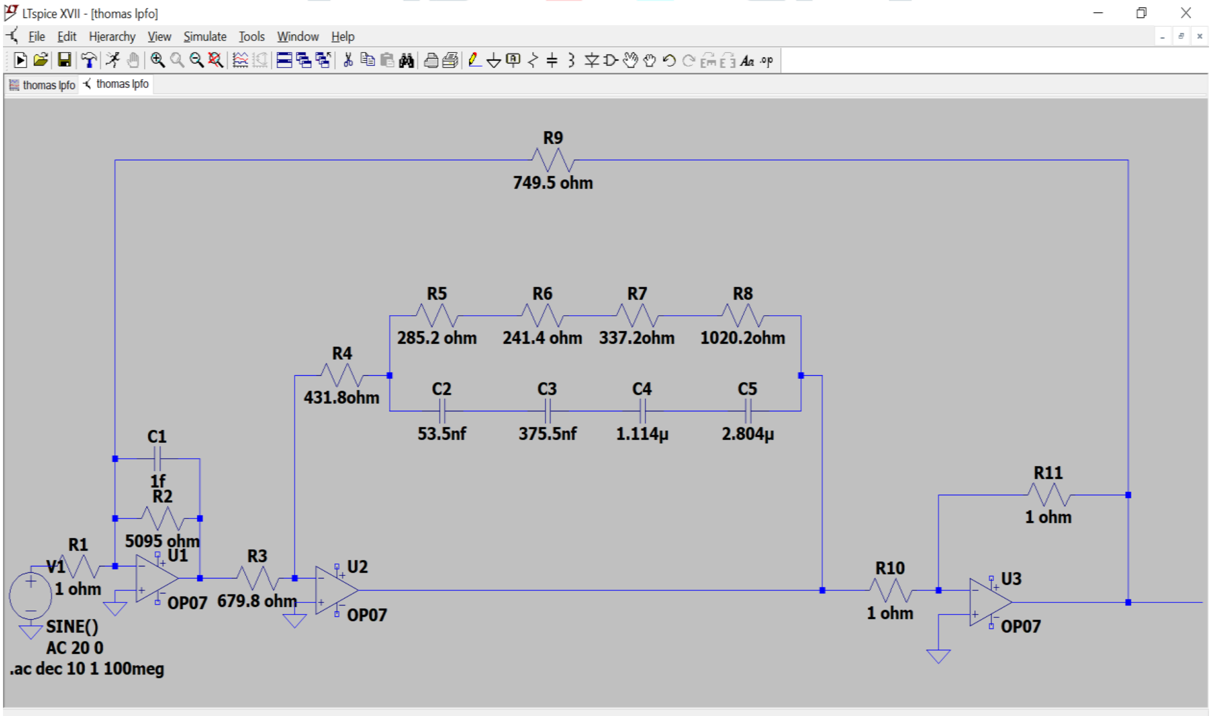

FIG. 9 CIRCUIT OF APPROXIMATED FRACTIONAL CHEBYSHEV LOW PASS FILTER (ORDER N=1.1)

FIG. 10 SPICE SIMULATION OF APPROXIMATED FRACTIONAL CHEBYSHEV LOW PASS FILTER (ORDER N=1.1)

The measured frequency response of a 1.1 order filter is demonstrated in Fig.10, where the cut-off frequency is 9.6 MHz while the slope of the stop band attenuation is equal to -13.6dB/oct. Taking into account that the corresponding theoretically predicted values are 10MHz and -15 dB/oct, respectively, the correct operation of the filter in Fig.9 is verified. The observed deviations are mainly caused by the tolerances of the used passive resistors and capacitors. These can be easily compensated through appropriate trimming.

(b) Approximated Fractional Chebyshev Low pass filter (Order n=1.5)

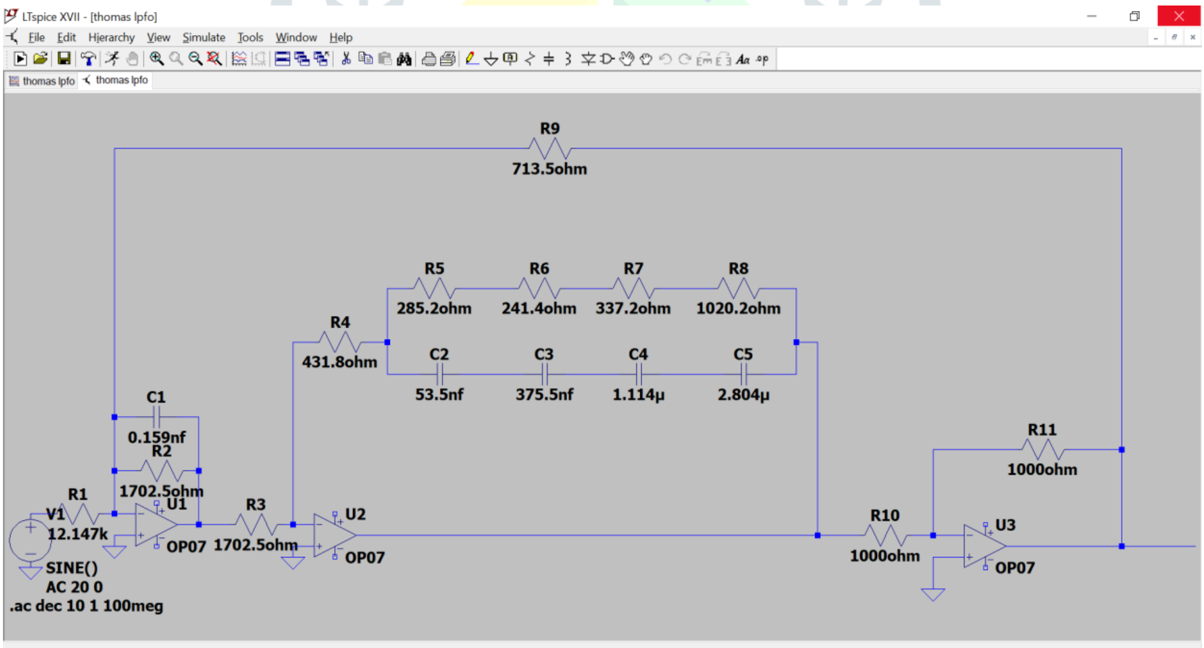

FIG. 11 CIRCUIT OF APPROXIMATED FRACTIONAL CHEBYSHEV LOW PASS FILTER (ORDER N=1.5)

FIG. 12 SPICE SIMULATION OF APPROXIMATED FRACTIONAL CHEBYSHEV LOW PASS FILTER (ORDER N=1.5)

The measured frequency response of a 1.5 order filter is demonstrated in Fig.12, where the cut-off frequency is 9.7 MHz while the slope of the stop band attenuation is equal to -13.4dB/oct. Taking into account that the corresponding theoretically predicted values are 10MHz and -15 dB/oct, respectively, the correct operation of the filter in Fig.11 is verified. The observed deviations are mainly caused by the tolerances of the used passive resistors and capacitors. These can be easily compensated through appropriate trimming.

(c) Approximated Fractional Chebyshev Low pass filter Order (n=1.8)

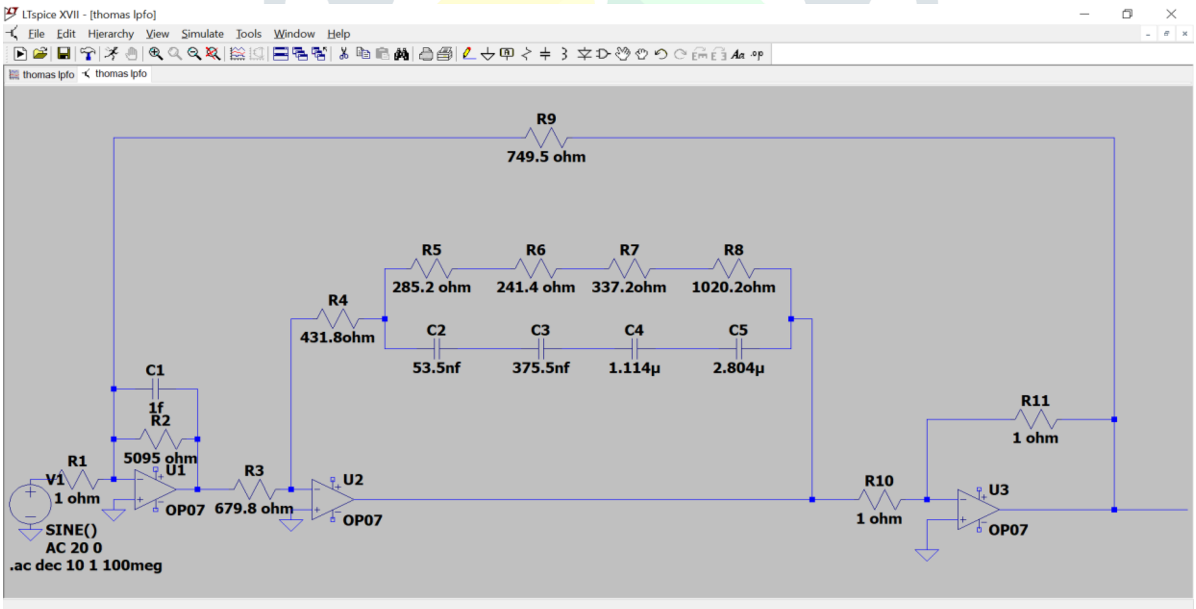

FIG. 13 CIRCUIT OF APPROXIMATED FRACTIONAL CHEBYSHEV LOW PASS FILTER (ORDER N=1.8)

FIG. 14 SPICE SIMULATION OF APPROXIMATED FRACTIONAL CHEBYSHEV LOW PASS FILTER (ORDER N=1.8)

The measured frequency response of a 1.8 order filter is demonstrated in Fig.14, where the cut-off frequency is 9.9 MHz while the slope of the stop band attenuation is equal to -13.8 dB/oct. Taking into account that the corresponding theoretically predicted values are 10MHz and -15 dB/oct, respectively, the correct operation of the filter in Fig.13 is verified. The observed deviations are mainly caused by the tolerances of the used passive resistors and capacitors. These can be easily compensated through appropriate trimming.

IV. Conclusion

When we compared the Low Pass Fractional Order Filter Using CFOAs with Approximated Fractional Order Chebyshev Low Pass filters we can see that a Chebyshev filter of the same order has a faster roll-off in the transition region. Because of this, the attenuation with a Chebyshev filter is always greater than the attenuation of a Fractional Order Filter Using CFOAs of the same order. Also in case of Fractional Order Filter Using CFOAs the transition from pass band to stop band is smooth and no ripple is present in the pass band. It is also evident from the above results that as the order of a filter increase its response also becomes better. In some applications, a flat pass-band response is not important. In this case, a Chebyshev approximation may be preferred because it rolls off faster in the transition region than a other filters. The price paid for this faster roll-off is that ripples appear in the pass band of the frequency response. The LT-SPICE simulations are very important in selecting the order of filter required for a particular type of application.

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