

High Pass Filter and Bandpass Filter Using Current Feedback Operational Amplifier (CFOA)

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Abstract: The filter proposed in this paper has an advantage of higher the frequency response and better selectivity against the classical band pass filter. A active circuit current feedback operational amplifier (CFOA) has been designed and it uses the application of the implementing active filters, oscillators, rectifiers, and signal processing circuits. We observe that several active circuits have been proposed in the literature. In this study, we have proposed four inductance simulators that employ only one active circuit current feedback operational amplifier and three or four passive components. The first and fourth topologies are designed for series lossy inductance, whereas the second and third topologies are designed for lossless negative inductance simulators. A passive RLC filter is used to demonstrate the effectiveness of the proposed inductance simulators. The circuit design is synthesized using 130nm CMOS technology with $\pm 3.3V$ power supply in cadence virtuoso and the simulation is done using Spectre and the results agree with the theoretical analysis.

Keywords: CFOA, filter, CMOS

INTRODUCTION

Inductance is the source of many problems in electronic circuits and systems. It stands to reason that inductance radiates magnetic energy, it places a larger footprint in the integrated circuit, and it contains more parasitic noises than other components. Bulky and expensive passive inductors motivated the researchers to design the alternative circuits can be worked as inductors. Inductance simulators are widely used, especially for high frequencies, instead of inductors. Therefore, for designing filters or oscillator, for eliminating electromagnetic interferences the inductance simulators are used.

Recently, a considerable literature has grown up the theme of active inductance realization. Several active inductance simulators have been proposed such as operational transconductance amplifier (OTA) [1-3], operational transresistance amplifier (OTRA) [4,5], current-feedback operational amplifier (CFOA) [6-12] current differencing buffer amplifier (CDBA) [13,14], four terminal floating nullor (FTFN) [15], voltage differencing buffer amplifier (VDBA) [16-18], differential voltage current conveyor

(DVCC) [19], second generation current conveyor (CCII) [20,21], dual-X current conveyor (DXCCII) [22-24]. Most of the reported circuits are commercially unavailable such as OTRA, CDBA, DVCC, DXCCII. Some of them such as FTFN [15] can be realized using two active devices such as AD844 CFOA can be commercially available. CFOA is a low-cost, general purpose device that has good AC and DC performance. CFOA is current mode circuit so it has some inherently advantages over the voltage mode operational amplifiers such as wider bandwidth, wider dynamic range and greater linearity. It also allows high slew rate capability and it is free from the slew rate boundaries that are basic characteristics of the traditional operational amplifiers.

Four different inductance simulators employing a single CFOA and three or four passive components were presented in [6]. Three different generic structures were also presented in [11] which employing a single CFOA and three or four passive components. The circuits [25-27] are not operated commercially available devices such as AD844, LM741. The circuits [4, 28-31] can be constructed with more than one AD844.

The overall structure of the study takes the form of four sections. The first section is an introduction, the second section gives the proposed four grounded inductance simulator topologies and parallel resonant circuit is constructed with the proposed inductance simulator, the third section gives the simulation results and the last section is the conclusion. It is expected that the proposed circuit will provide different opportunities to the designers accomplishing of analog integrated circuit applications.

II THE PROPOSED INDUCTOR SIMULATORS

The equivalent circuit of CFOA is shown in Figure 1.a-b. In the ideal case, current gain and voltage gains are $\alpha = 1$ and $\beta_1 = \beta_2 = 1$ respectively. So, CFOA whose electrical symbol ideally specified as $I_y = 0$, $I_x = I_z$, $V_x = V_y$, and $V_w = V_z$, are going to be stated by the following equation:

$$\begin{bmatrix} I_y \\ I_z \\ V_x \\ V_w \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \alpha & 0 & 0 \\ 0 & \beta_1 & 0 \\ 0 & 0 & \beta_2 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \end{bmatrix} \quad (1)$$

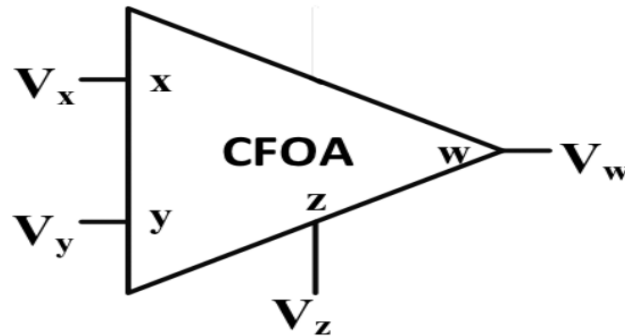


Figure 1.a. Equivalent circuit of CFOA

The simplified schematic of the Proposed Inductor Simulators discussed in this paper is shown in Fig. 1.b. It is made up of two voltage buffers, one at the input (transistors M1-M20) and the other at the output (transistors M1b-M20b). These buffers are realized from a well-known class AB differential stage [32] that is used here in unity gain. Transistors M16-M17 implement two level shifters allowing the analog ground to be set to 0V. The current at the inverting input terminal is mirrored to the high-impedance node at the intermediate stage (M21- M24) which provides the high transresistance gain. Voltage at node A is then buffered to the output by the second buffer. Dominant-pole frequency compensation is obtained through capacitor C_c whereas resistor R_c introduces, as usual, a negative zero.

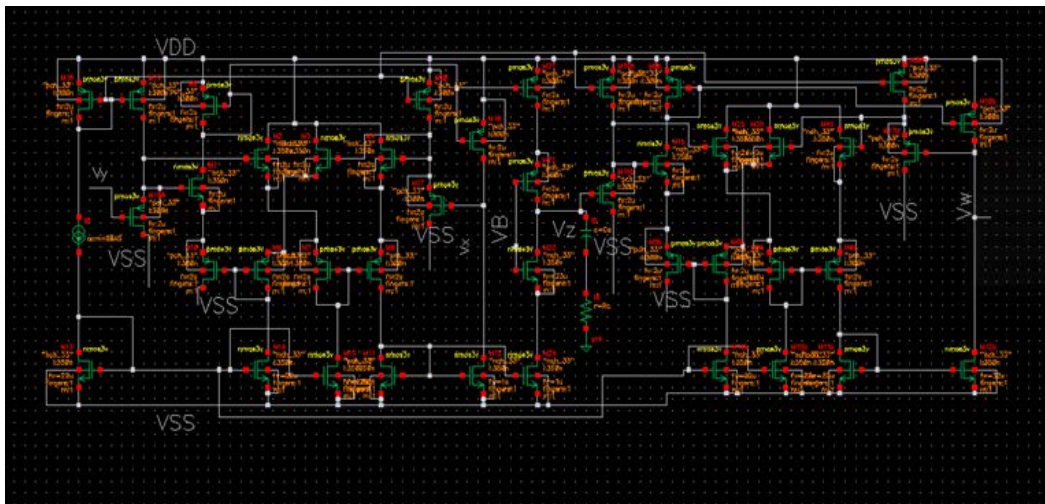


Fig. 1.b. Simplified schematic of the proposed current feedback operational amplifier.

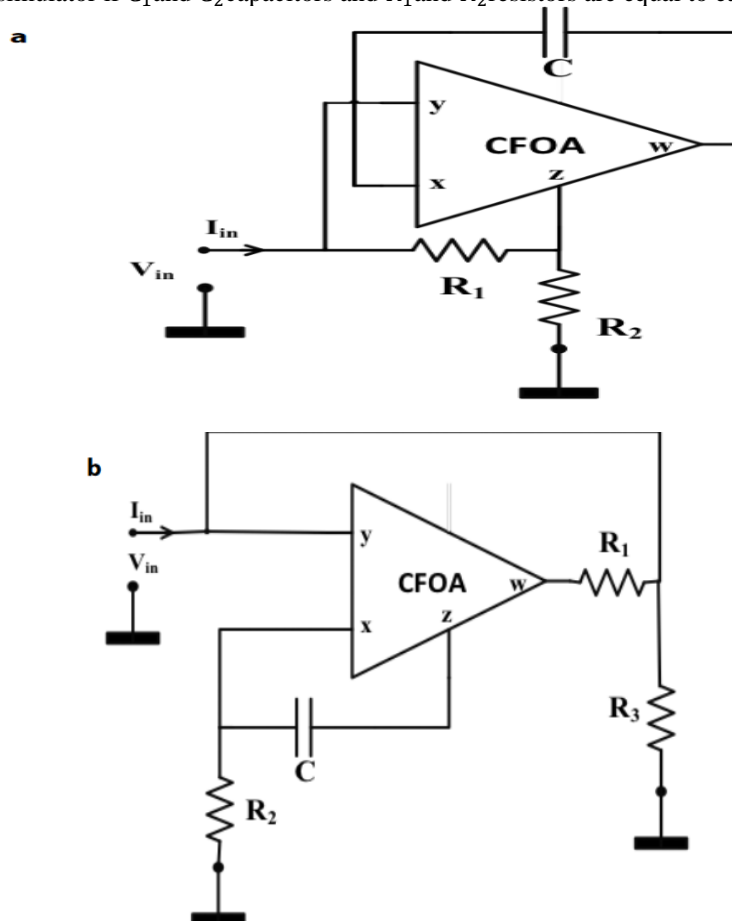
Table 1. Equivalent impedances of proposed inductance simulators

Circuit	Non-ideal impedances (Z_{eq})	Ideal impedances (Z_{eq})
Figure 2 (a)	$\frac{R_1}{1 + Cs\alpha(\gamma - \beta)R_2} + \frac{R_2}{1 + Cs\alpha(\gamma - \beta)R_2} + \frac{R_1R_2Cs\alpha\gamma}{1 + Cs\alpha(\gamma - \beta)R_2}$	$R_1R_2Cs + R_1 + R_2$
Figure 2 (b)	$-\frac{R_1R_2Cs}{\beta\gamma + CR_2\alpha(-1 + \beta\gamma)R_1}$	$-CR_1R_2s$
Figure 2 (c)	$\frac{R_1R_2C_2s}{R_2C_2s + (-\beta\gamma\alpha - \beta\gamma C_1R_2s\alpha)}$	$\frac{R_1R_2C_2s}{R_2C_2s + (-1 - C_1R_2s)}$
Figure 2 (d)	$\frac{R_1}{1 - Cs(-1 + \beta\alpha\gamma)R_2} + \frac{R_1R_2Cs}{1 - Cs(-1 + \beta\alpha\gamma)R_2}$	$R_1R_2Cs + R_1$

Table 2. Equivalent admittances of proposed inductance simulators ideal and non-ideal cases

Circuit	Non-ideal admittances (Y_{eq})	Ideal admittances (Y_{eq})
Figure 2 (a)	$\frac{1}{R_2 + R_1 + Cs\alpha\gamma R_1 R_2} + \frac{Cs\alpha(\gamma - \beta)R_2}{R_2 + R_1 + Cs\alpha\gamma R_1 R_2}$	$\frac{1}{R_1 R_2 Cs + R_1 + R_2}$
Figure 2 (b)	$-\frac{\beta\gamma}{R_1 R_2 Cs} + \frac{1 - \beta\gamma}{R_1}$	$\frac{1}{-CR_1 R_2 s}$
Figure 2 (c)	$\frac{1}{R_1} + \frac{C_1\alpha\gamma\beta}{R_1 C_2} - \frac{\alpha\gamma\beta}{R_1 R_2 s C_2}$	$\frac{1}{R_1} + \frac{C_1}{R_1 C_2} - \frac{1}{R_1 R_2 s C_2}$
Figure 2 (d)	$\frac{1}{R_1 + CsR_1 R_2} + \frac{Cs\alpha(1 - \beta\alpha\gamma)R_2}{R_1 + CsR_1 R_2}$	$\frac{1}{R_1 R_2 Cs + R_1}$

The proposed CFOA based inductor simulators are shown in Figure 2 a-d. The first inductance simulator consists of one CFOA and three passive components while the others consist of one CFOA and four passive components. Transfer functions of the proposed circuits are given in Table 1, 2. According to the equivalent impedance of the first and fourth simulators are intended for lossy series inductors. The second simulator is intended to negative lossless inductance simulator. The third one is also intended to negative lossless inductance simulator if C_1 and C_2 capacitors and R_1 and R_2 resistors are equal to each other.



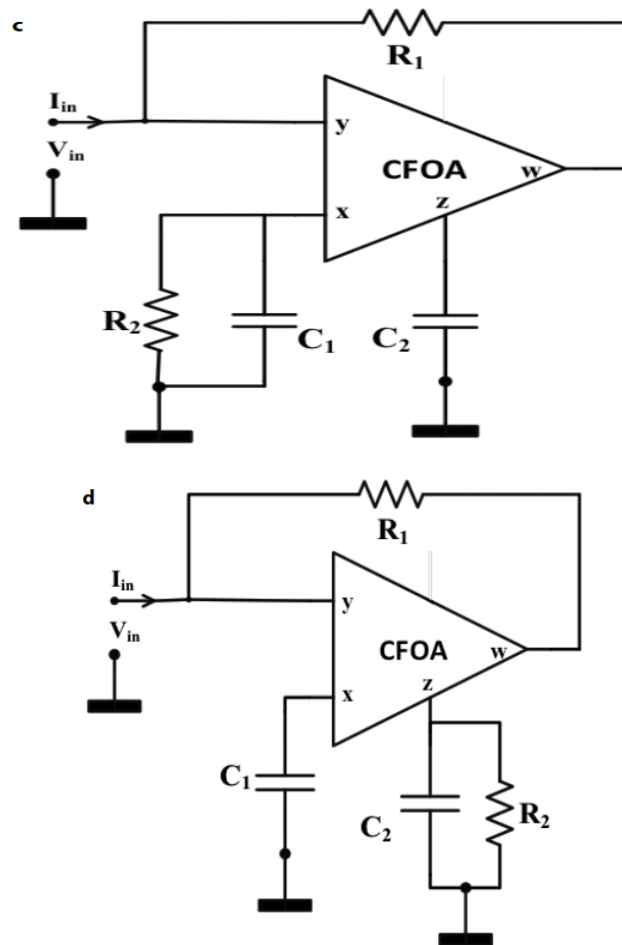


Figure 2. a-d. Proposed inductance simulators made with CFOA

III SIMULATION RESULTS

As long as higher value inductances occupy a bigger area in chips, Inductor will be a central ingredient in deciding the total chip area because higher inductance values imply larger area consumption. In order to solve this problem, it is more convenient to use active implementations of an inductor which offer less area consumption.

TSMC13RF 0.13- μm CMOS technology is used to explain the performance of the presented inductance simulator. The AC response analysis is obtained to find the variation of magnitude Vs frequencies. The simulated frequency response of input impedance for the inductor simulator is given in Figure 2b. The magnitude of impedance of the presented inductance simulator is given in Figure 3. The inductive characteristic extends from 17.29Hz to 73.16MHz.

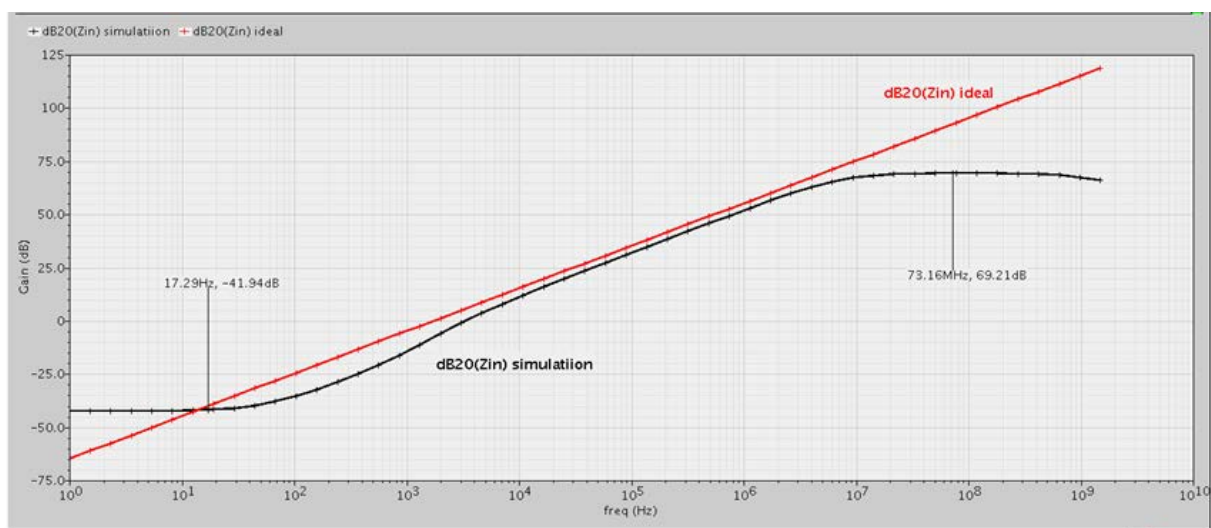


Figure 3. Simulated magnitudes of impedance of presented inductance simulator in comparison with ideal inductance

RLC filter is presented as an application example to demonstrate the performance of the presented inductance simulator. Inductance simulator with a parallel capacitor and resistor formed as a resonant circuit shown in Figure 4. In this Figure actively simulated inductance simulator circuit in Figure 2b replaces the parallel inductor.

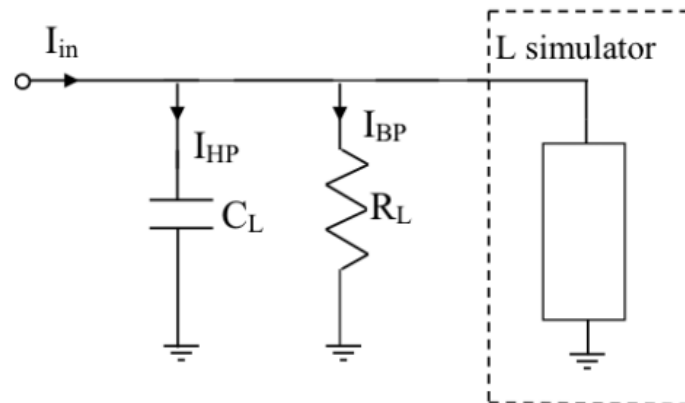
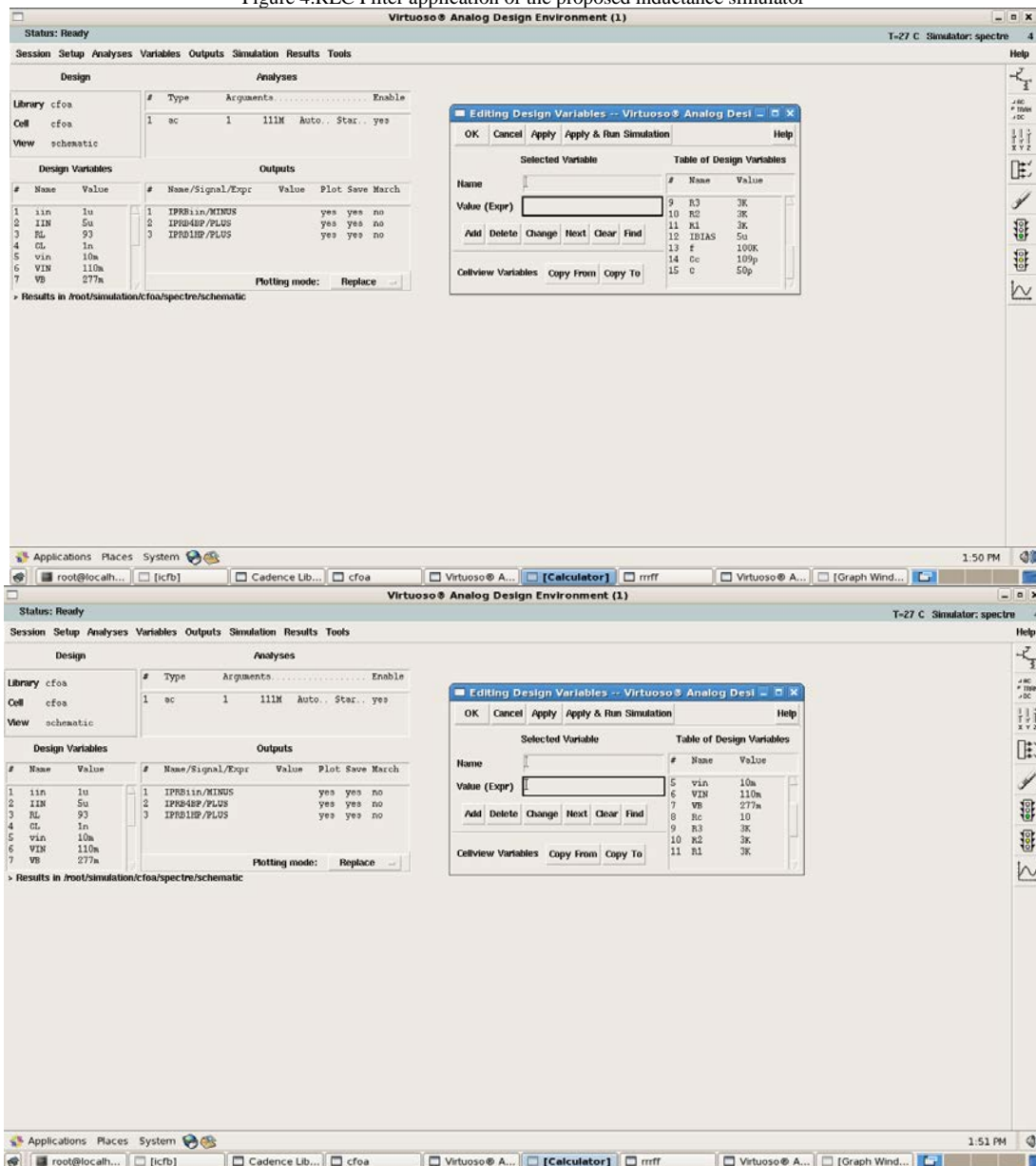


Figure 4. RLC Filter application of the proposed inductance simulator



The CFOA is used to instrument a new Band pass filter and high pass filter. The design makes use of a second-order filter built on a single CFOA [32]. By straight calculations the transfer functions are given by the following equations:

$$\frac{I_{HP}(s)}{I_{in}(s)} = \frac{s^2}{s^2 + s\left(\frac{1}{R_L C_L}\right) + \frac{1}{L_{eq} C_L}} \quad (2)$$

$$\frac{I_{BP}(s)}{I_{in}(s)} = \frac{\left(\frac{1}{R_L C_L}\right)s}{s^2 + s\left(\frac{1}{R_L C_L}\right) + \frac{1}{L_{eq} C_L}} \quad (3)$$

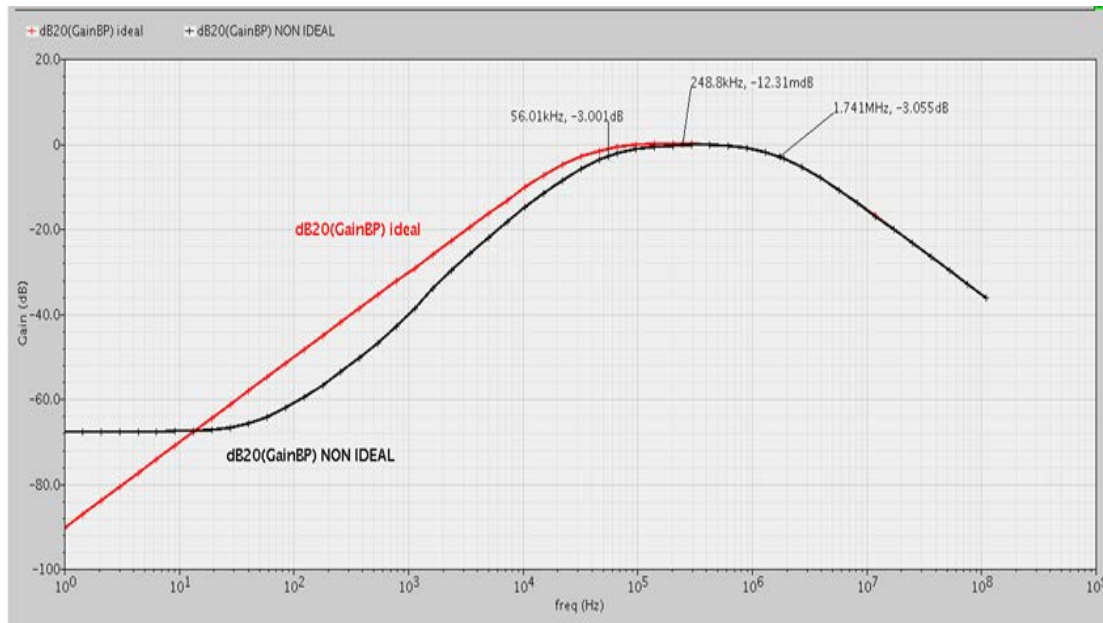


Figure 5. Simulated band pass response of the filter

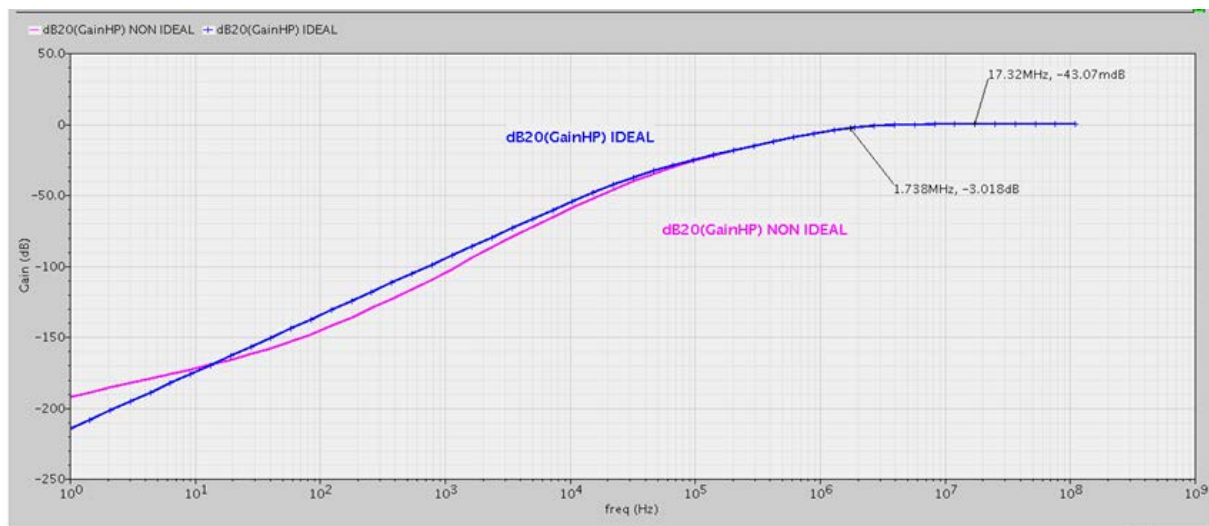


Figure 6. Simulated high pass response of the filter

The realized filter is simulated with CADENCE software in 0.13 um process using Simplified schematic of the proposed current feedback operational amplifier.

Supply voltages are taken as $V_{DD}=3.3V$ and $V_{SS}= -3.3V$. Simulation result of the filter responses, very good agreement with the predicted theory, is given in Figure 5 and Figure 6 respectively. The component values of the accomplished filter are chosen as follows: $C_L=1nF$, $R_L=93\Omega$

$R_1=R_2=R_3=3k\Omega$ and $C=50pF$, thus an inductor $L_{eq}=0.238\mu H$ is obtained. In order to analysis time responses of RLC filter, peak-to-peak 2uA and 100KHz sinusoidal inputs are applied.

The time domain analysis result is given in Figure 7 for bandpass and highpass filter configuration for the circuit in Figure 4.

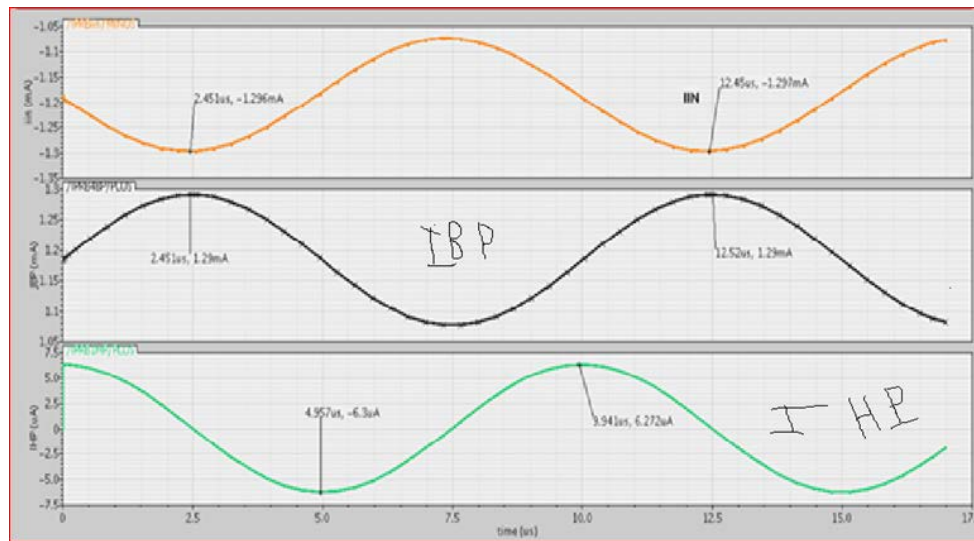


Figure 7. Time domain response of RLC filter high-pass and band-pass filter for 2uA peak-to-peak 100KHz sine wave input

IV CONCLUSIONS

This study has been presented an alternative configuration for the realization of a analysis responses of RLC filter. In this study, A CFOA based inductor simulators are proposed. The proposed circuit consisted only one single of CFOA, and three or four passive components. The aim of the present research was to propose the inductance simulators which consists three or four passive components in addition to single active device named CFOA. A CMOS CFOA has been designed, simulated and analysed using Cadence Tools. CFOA circuit has been applied in a complex pass filter with centre frequency f_0 . It is revealed that the gain can be programmed without altering the Q value of that filter. This circuit find more appropriate for varied range, low voltage and low power applications. The CFOA circuit is considered by the capacity to attain high Gain with low loss of bandwidth.

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