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Lossy/Lossless Grounded Inductance Simulators Using Current Feedback Operational Amplifier (CFOA)

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ABSTRACT

Active elements are critical in 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 simulations performed with the LTSpice program 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 amplifer (CDBA) [13,14], four terminal floating nullor (FTFN) [15], voltage differencing buffer amplifer (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 inherantel advantages over the voltage mode operational amplifers 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 boundries that are basic characteristics of the traditional operational amplifiers.

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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.

The Proposed Inductor Simulators

The equivalent circuit of CFOA is shown in Figure 1. 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 $I_y = 0$, $I_z = I_x$, $V_x = V_y$ and $V_w = V_z$, are going to be stated by the following equation:

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

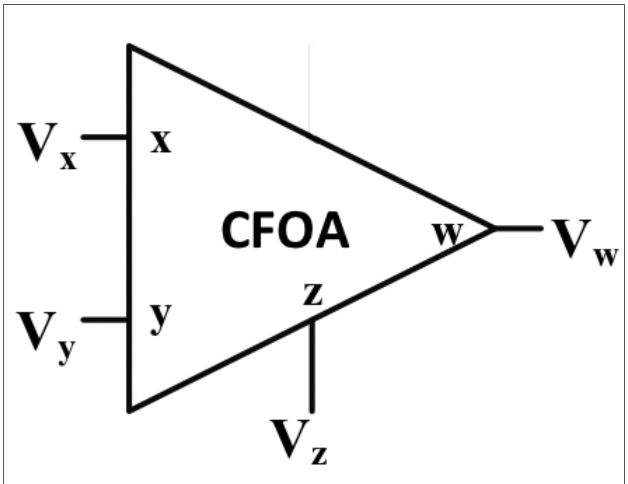

Figure 1. Equivalant circuit of CFOA

Table 1. Equivalent impedances of proposed inductance simulators

Circuit	Non-ideal impedances (Z_{eq})	Ideal impedances (Z_{eq})
Figure 2 (a)	$\frac{R_1}{1+Cs\alpha(\gamma-\beta)R_2}+\frac{R_2}{1+Cs\alpha(\gamma-\beta)R_2}+\frac{Cs\alpha\gamma R_1R_2}{1+Cs\alpha(\gamma-\beta)R_2}$	$R_1+R_2+CsR_1R_2$
Figure 2 (b)	$-\frac{CR_1R_2s}{\beta\gamma+CR_2s(-1+\beta\gamma)}$	$-CR_1R_2s$
Figure 2 (c)	$\frac{C_2R_1R_2s}{C_2R_2s-\alpha\beta\gamma-C_1R_2s\alpha\beta\gamma}$	$\frac{C_2R_1R_2s}{-1-C_1R_2s+C_2R_2s}$
Figure 2 (d)	$\frac{R_1}{1-Cs(-1+\alpha\beta\gamma)R_2}+\frac{CsR_1R_2}{1-Cs(-1+\alpha\beta\gamma)R_2}$	$R_1+CsR_1R_2$

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)	$\frac{1}{R_1+R_2+Cs\alpha\gamma R_1R_2}+\frac{Cs\alpha(-\beta+\gamma)R_2}{R_1+R_2+Cs\alpha\gamma R_1R_2}$	$\frac{1}{R_1+R_2+CsR_1R_2}$
Figure 2 (b)	$-\frac{\beta\gamma}{CR_1R_2s}+\frac{1-\beta\gamma}{R_1}$	$-\frac{1}{R_1R_2Cs}$
Figure 2 (c)	$\frac{1}{R_1}-\frac{C_1\alpha\beta\gamma}{C_2R_1}-\frac{\alpha\beta\gamma}{C_2R_1R_2s}$	$\frac{1}{R_1}-\frac{C_1}{C_2R_1}-\frac{1}{C_2R_1R_2s}$
Figure 2 (d)	$\frac{1}{R_1+CsR_1R_2}+\frac{Cs(1-\alpha\beta\gamma)R_2}{R_1+CsR_1R_2}$	$\frac{1}{R_1+CsR_1R_2}$

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.

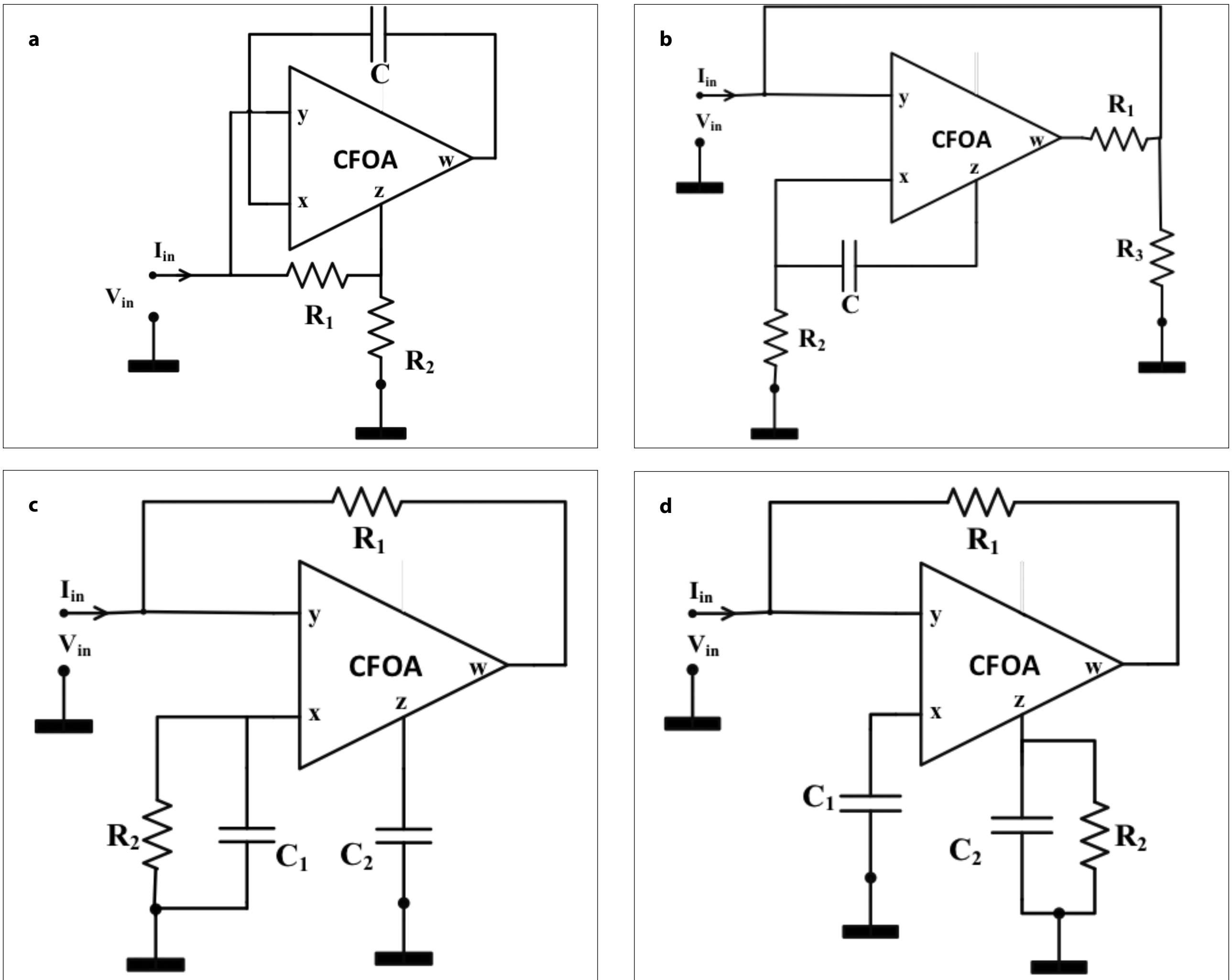

Figure 2. a-d. Proposed inductance simulators made with CFOA

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.

LTSpice program is used to explain the performance of the presented inductance simulator. 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 1 kHz to 50 MHz.

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 induc-

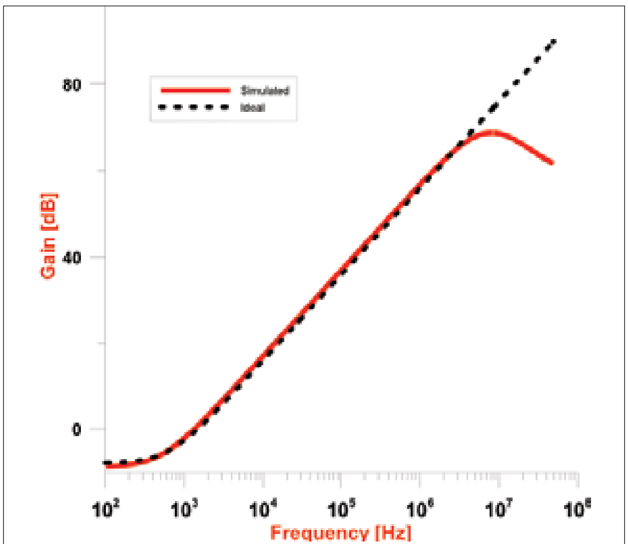

Figure 3. Simulated magnitudes of impedance of presented inductance simulator in comparison with ideal inductance

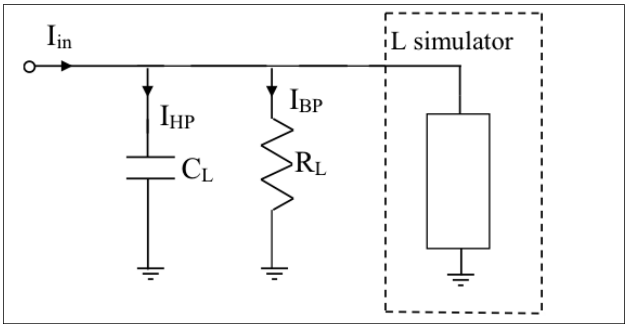

Figure 4. RLC Filter application of the proposed inductance simulator

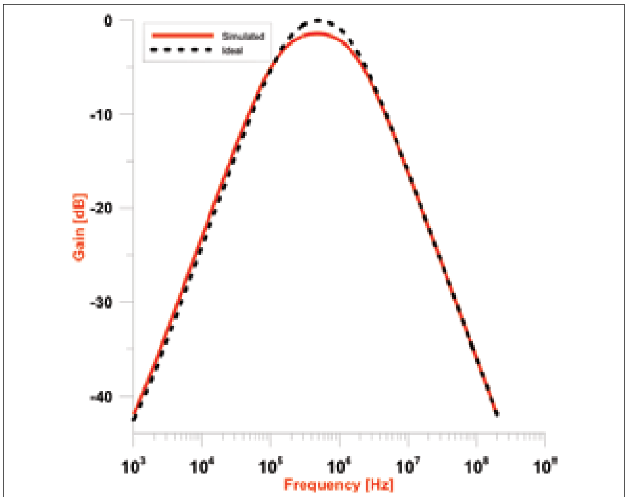

Figure 5. Simulated bandpass response of the filter

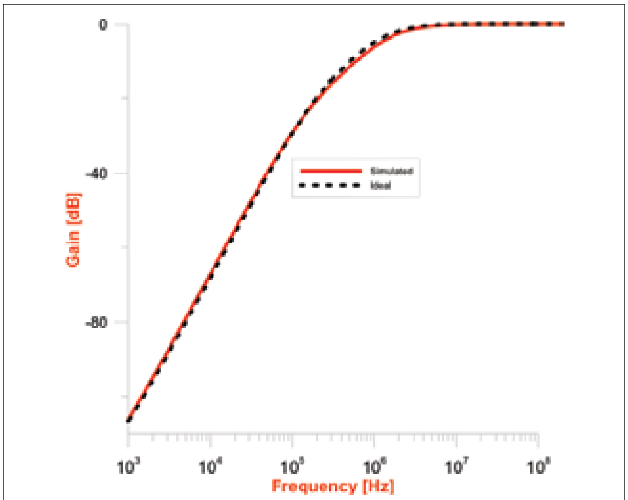

Figure 6. Simulated highpass response of the filter

tance simulator circuit in Figure 2b replaces the parallel inductor. The transfer functions are given by the following equations:

$$\frac{I_{HP}}{I_{in}}=\frac{s^2}{s^2+\frac{G_L}{C_L}s+\frac{1}{L_{eq}C_L}} \tag{2}$$

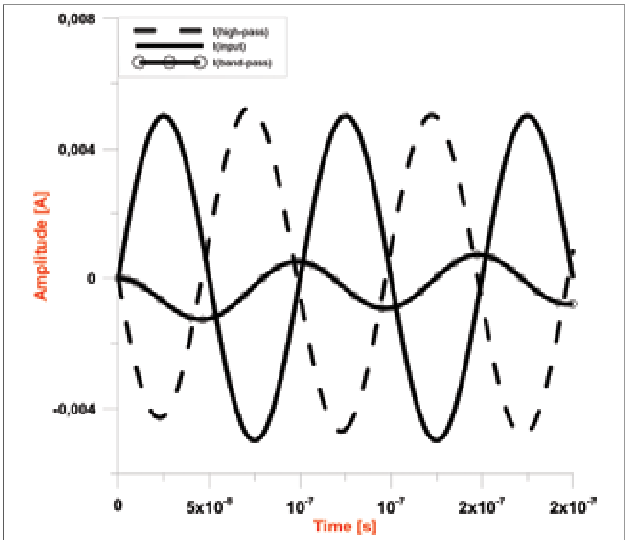

Figure 7. Time domain response of RLC filter high-pass and band-pass filter for 10mA peak-to-peak 10MHz sine wave input

$$\frac{I_{BP}}{I_{in}}=\frac{\frac{G_L}{C_L}s}{s^2+\frac{G_L}{C_L}s+\frac{1}{L_{eq}C_L}} \tag{3}$$

The realized filter is simulated with LTSpice program using AD844. Supply voltages are taken as V_{DD} = 12V and V_{SS} = −12 V. 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=100Ω R_1= R_2=R_3=1kΩ and C=50pF, thus an inductor L_{eq}=100µH is obtained. In order to analysis time responses of RLC filter, peak-to-peak 10 mA and 10 MHz 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.

Conclusions

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. In order to show the effectiveness of the proposed inductance simulators, LTSpice simulation tests were put into practice. This study sets out provide the further possibilities to the designers in the realization of analog integrated circuits such as filters and oscillator applications.

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