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Current Feedback Operation Amplifier Based on Floating Passive and Active Inductors in Filter Applications

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Keywords

Passive and Active Inductance Simulator

CFOA

Band-Stop (BS) Filter

Abstract

This paper proposes using current feedback operation amplifiers (CFOAs) as an active filter in creating floating passive and active inductance simulators is a versatile and efficient solution for circuit design. CFOAs are popular for their high slew rate and wide bandwidth which makes them ideal candidates for applications demanding rapid response time alongside high frequencies. It is possible to customize these simulated inductances for different design specifics by changing certain external resistor values. The circuit comprises a trio of CFOAs, an earthed capacitor and three resistors, thus making it quite simple to put into practice at a cheap price. Experiments and LTSPICE simulations have been conducted to examine the performance of the circuit, and closely confirmed theoretical expectations. In other words, this confirms the trustworthiness and preciseness of the introduced floating active inductance simulator. Voltage-mode band-stop filtering is one real-world scenario where this circuit is used. This indicates that our proposed technique can have more applications than one in circuit design. This is further proof that our idea can be used in other circuits as well. In conclusion, using CFOAs in active filters for building a grounded passive active inductance simulator is a solid and effective answer to circuit designers. This makes it an appealing choice for numerous applications because of its simplicity in designing the network as well as its high performance and customizability. Circuit design and application can be greatly improved if more study is done in this field.

Cite

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1. INTRODUCTION

Filters are circuits that allow signals within a certain frequency range to pass and do not allow signals at other frequencies to pass. Because of these features, filters are also called selective circuits. Active filters include active circuit elements such as transistors and operational amplifiers, as well as passive circuit elements such as resistors and capacitors. Passive circuit elements determine the cut-off frequency, while active circuit elements provide voltage gain. Filters are generally classified according to the state of the output voltage (signal) in response to the change in frequency of the input voltage (signal). Accordingly, there are generally four types of active filters. These are low-pass, high-pass, band-pass and non-band-pass filters (Demirel, 2017).

Operational amplifiers, one of the most important elements used in filters, are very high-gain differential amplifiers that use voltage feedback to provide a specified voltage gain. These amplifiers have a very high open-loop gain, high input impedance and low output impedance design. Operational amplifiers are used in many circuits such as addition, subtraction, multiplication, integration, and derivative operations in analog calculators, phase shifting, signal processing, instrumentation, communication, alarm, measurement, test circuits and filter applications (Demirel, 2017).

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The interest in developing signal processing circuits is increasing day by day. In particular, the focus is on the design and production of circuits such as active filters without the need for real coils. The advantages of this approach include the ability to design and produce circuits with smaller dimensions compared to physical coils by using spiral inductors in integrated circuits. However, this method also has some disadvantages. For example, there may be some limitations in terms of space usage and we may encounter some difficulties in terms of adjustability, cost and efficiency.

Inductance simulators play an important role in overcoming such disadvantages. These simulators allow the simulation of inductance behavior without physically using real coils. Thus, they can provide more flexible and efficient solutions in active and passive filter designs, analog phase shifters, parasitic element cancellation applications and oscillator designs. This allows the industry to develop more compact, more flexible and more efficient signal processing circuits. Subsequently, the emphasis switches to the inductance simulation, which makes use of many high-performing active building components. including operational trans-conductor amplifier (O.T. A). Current conveyors, current feedback op-amps (CCCFO), four-terminal floating nullar (F.T.F.Ns), current differencing buffered amplifiers (CDBAs), etc. Most of the circuits that have been documented require the usage of active components with numerous outputs. Furthermore, some earlier works make use of active components that aren't yet ICs that are sold commercially. Therefore, utilizing off-the-shelf components to create the circuits is not a simple task.

An intriguing active component that is particularly well-suited for a certain kind of analog signal processing is the current feedback amplifier (C.F.A) or current feedback operational amplifier (CFOA) (Demirel & Ahmed, 2023a; Dikicioğlu & Polat, 2024; Mohammed et al., 2024). This device offers versatility and allows for a range of circuit configurations. It can function in both current and voltage modes. Furthermore, it can provide beneficial attributes such fast slew rate, absence of parasitic capacitances, broad bandwidth, and ease of implementation (Feng et al., 2011; Shkir & Abdulazeez, 2017; Ahmed & Demirel, 2023; Demirel & Ahmed, 2023b; Mohammed et al., 2023; Mohammed & Demirel, 2023). Currently, the CFA is available for purchase; one example is Analog Devices Inc.'s AD844.

LTspice (Linear Technology SPICE) is a powerful SPICE simulation software tool created by Analog Devices, originally by Linear Technology. It is used to simulate electronic circuits to predict their behavior. Key features and applications of LTspice include:

- Circuit Simulation: Enables users to simulate the behavior of analog and mixed-signal circuits.
- Schematic Capture: Allows for the creation of circuit diagrams using a graphical interface.
- Waveform Viewer: Visualizes simulation results as voltage, current, and other waveforms.
- Model Library: Offers a comprehensive library of components such as transistors, diodes, capacitors, resistors, and more, with the option to add custom models.
- Transient Analysis: Simulates circuit behavior over time for time-domain analysis.
- AC Analysis: Analyzes frequency response and other AC characteristics of circuits.
- DC Analysis: Evaluates the DC operating points of the circuit.
- Noise Analysis: Simulates the noise performance of circuits.
- Parametric Sweeps: Allows variation of component values to observe their effect on circuit performance.
- Monte Carlo Analysis: Assesses the statistical variation in circuit performance due to component tolerances.

LTspice is widely utilized by electrical engineers and designers for circuit design, testing, and optimization due to its accuracy, speed, and comprehensive features. Additionally, it is freely available, making it accessible for both professional and educational purposes.

This work presents a floating active and passive inductance simulator that uses identical CFOAs as its focus. Using off-the-shelf components makes the suggested circuit straightforward to execute realistically. It is also possible to regulate the inductances by using external resistors. Simulations using LT-Spice and experimentation demonstrate the performances of the suggested circuits, which correlate quite well with the diagrams. To demonstrate the value of the circuit discussed, an application as a voltage-mode (VM) band stop filter is provided (Bhaskar et al., 1999; Jaikla & Lahiri, 2012; Senani et al., 2016).

2. MATERIAL AND METHOD

The method and study format of the study are given below under separate headings. These headings are operational principle of current feedback operational amplifiers, proposed and simulated floating active inductance and non-ideal illustration.

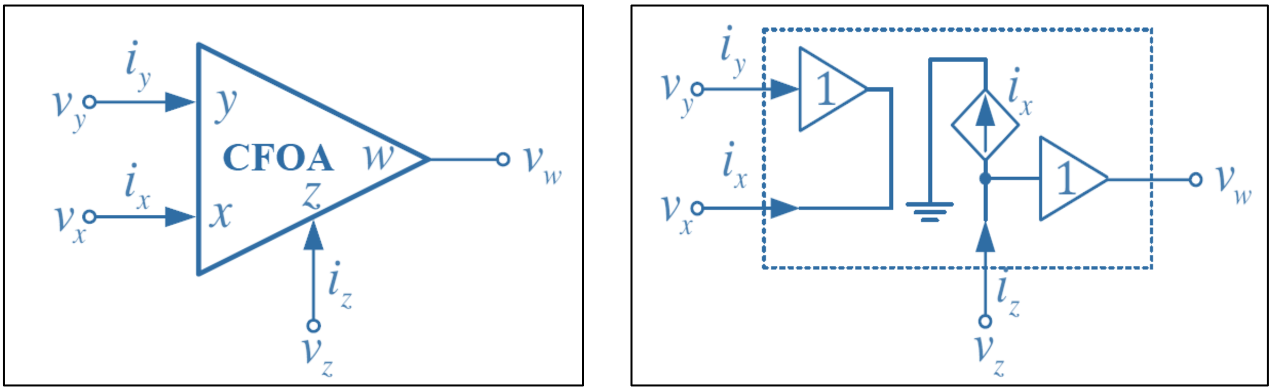
2.1. Operational Principle of Current Feedback Operational Amplifiers (CFOA)

Analog Devices' high-speed current feedback operational amplifiers, operating at speeds greater than 50 MHz, allow for enhanced performance at elevated speeds. These amplifiers typically exhibit broader bandwidths and higher slew rates compared to voltage feedback amplifiers and maintain consistent bandwidth regardless of gain. A current feedback op amp processes an error current at its low-impedance negative input terminal, rather than an error voltage, and generates a corresponding output voltage.

The following equation displays the characteristics of CFOA.

$$\begin{bmatrix} \boldsymbol{Iy.} \\ \boldsymbol{Vx.} \\ \boldsymbol{Iz.} \\ \boldsymbol{Vw.} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \boldsymbol{Ix.} \\ \boldsymbol{Vy.} \\ \boldsymbol{Vz.} \\ \boldsymbol{Vw.} \end{bmatrix} \tag{1}$$

Figure 1a and 1b show the CFOA's symbol and analogous circuit, respectively.



(a) (b)

Figure 1. *CFOA* ***a)*** *the corresponding symbol;* ***b)*** *the comparable circuit*

2.2. Proposed and Simulated Floating Active Inductance

The suggested floating active inductance simulator is seen in Figure 2. Three CFOAs, three resistors, and one capacitor with grounded are all part of the circuit. The circuit in Figure 2 may be readily analyzed to obtain the input impedance using the CFOA characteristics from section 1. (Prommee & Dejhan, 2002; Maheshwari, 2009; Sa-Ngiamvibool & Jantakun, 2014).

$$Z_L(s) = \frac{V_1 - V_2}{I_{in}} = sC.R.R_1 \tag{2}$$

R_2=R_3=R, and I_1=I_2=I_{in}. According to Eq. (2), Figure 2's circuit emulates a floating active inductance with a specified value.

$$Leq = C.R.R_1 \tag{3}$$

Equation (3) demonstrates that altering the resistance and capacitor will change the inductance value (Leq).

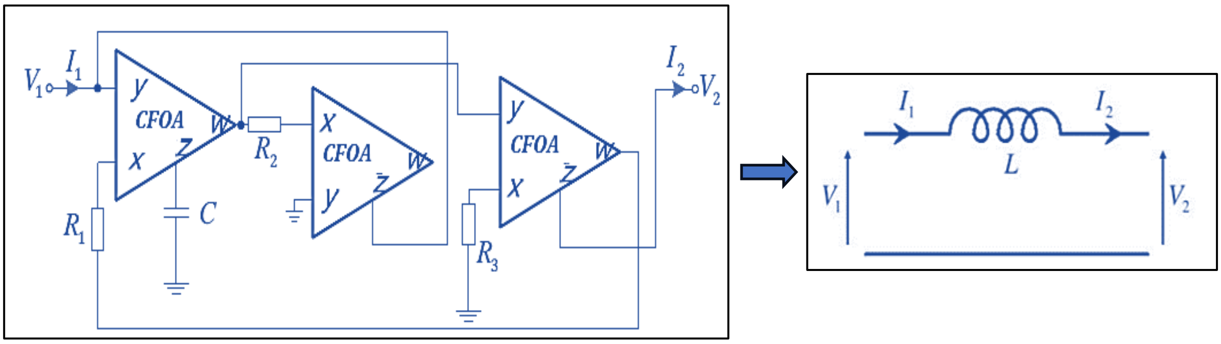


Figure 2. *Proposed Floating Active and passive Inductance*

2.3. Non-ideal Illustration

The following equation illustrates the CFOA qualities for the non-ideal instance (Horng et al., 2010; Horng, 2011).

$$\begin{bmatrix} Iy. \\ Vx. \\ Iz. \\ Vw. \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \beta. & 0 & 0 \\ \alpha. & 0 & 0 & 0 \\ 0 & 0 & \gamma. & 0 \end{bmatrix} \begin{bmatrix} Ix. \\ Vy. \\ Vz. \\ Vw. \end{bmatrix} \tag{4}$$

The transmitted error values, deviating from one, are β, α, and γ. Considering the effects of β, α, and γ on the circuit in Figure 2, I_1 and I_2 may be written as follows:

$$I_1 = (\beta_1 V_1 - \gamma_3 V_2)\frac{\gamma_1 \alpha_1 \alpha_2}{sCR_1 R_2} \tag{5}$$

and

$$I_2 = (\beta_1 V_1 - \gamma_3 V_2)\frac{\gamma_1 \alpha_1 \alpha_2 \beta_3}{sCR_1 R_3} \tag{6}$$

If the conditions $\beta_1 = \gamma_3 = \varepsilon_1$, $\alpha_2 = \alpha_3 * \beta_3 = \varepsilon_2$, the resistance $R_2 = R_3 = R$, and currents $I_1 = I_2 = I_{in}$ the input impedance is approximated, then Eq. (5) and (6) are as follows:

$$Z_L(s) = \frac{V_1 - V_2}{Iin} = \frac{sCRR_1}{\gamma_1 \alpha_1 \varepsilon_1 \varepsilon_3} \tag{7}$$

Based on Eq. (7), the electronic circuit as illustrated in Figure 2 represents a floating active and passive Inductance with a specified value for non-ideal consideration.

$$Leq = \frac{sCRR_1}{\gamma_1 \alpha_1 \varepsilon_1 \varepsilon_2} \tag{8}$$

The magnitude of the inductance value is affected by these errors as determined by Eq. (8). Considering that these errors are temperature dependent, the magnitude of the inductance value will also be slightly temperature dependent. In order to reduce the effects of these results, a suitable CFOA (Current Feedback Operational Amplifier) design should be considered correctly. Correct approaches in CFOA design can minimize the effects of such errors and thus increase the stability of the inductance value. In particular, controlling the effects caused by temperature changes can provide more reliable and consistent operation of the circuits. Therefore, determining the inductance values correctly and reducing the effects of temperature changes can significantly increase the performance of electronic systems.

3. RESULTS AND DISCUSSION

The results of the simulations obtained as a result of the simulations performed in this study are given below. The LT-SPICE simulation program was utilized for the analysis to demonstrate the capabilities of the suggested active and passive inductance simulator. Using the AD.844 macro-model from Analog Devices, the CFOAs were implemented. The supply voltages used in the circuit were biased at ±5V. The circuit in Figure 2. is designed with R1 = R2 = R3 = 2 KΩ and C = 1 pF.

Figure 3. shows the phase and magnitude responses for the impedances in the suggested circuit.

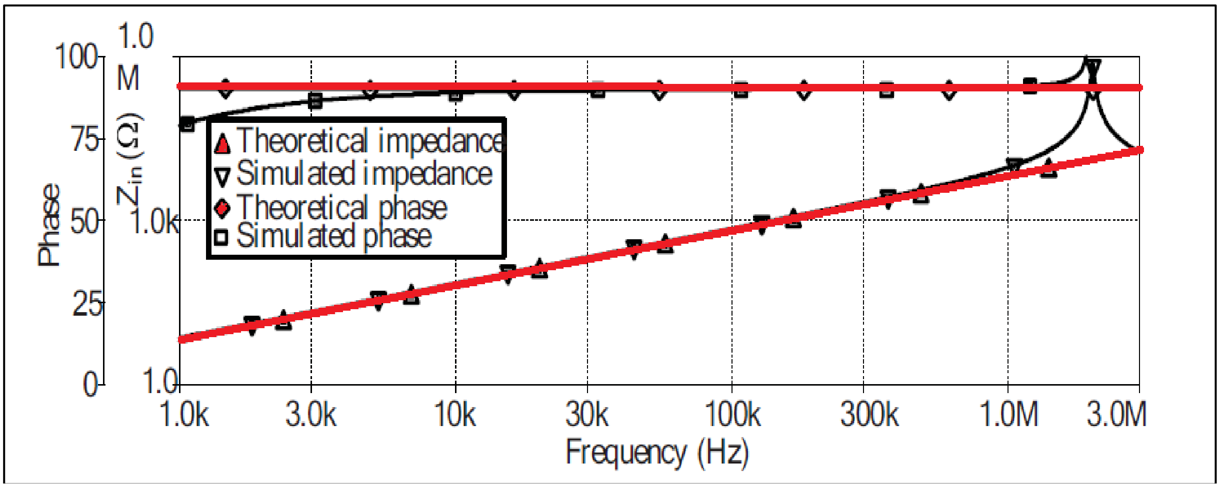


***Figure 3**. Circuit phases and impedances for the floating active and passive inductance*

By changing resistance (R), as seen in Eq. (3), tuning ability is likewise simulated and displayed in Figure 4.

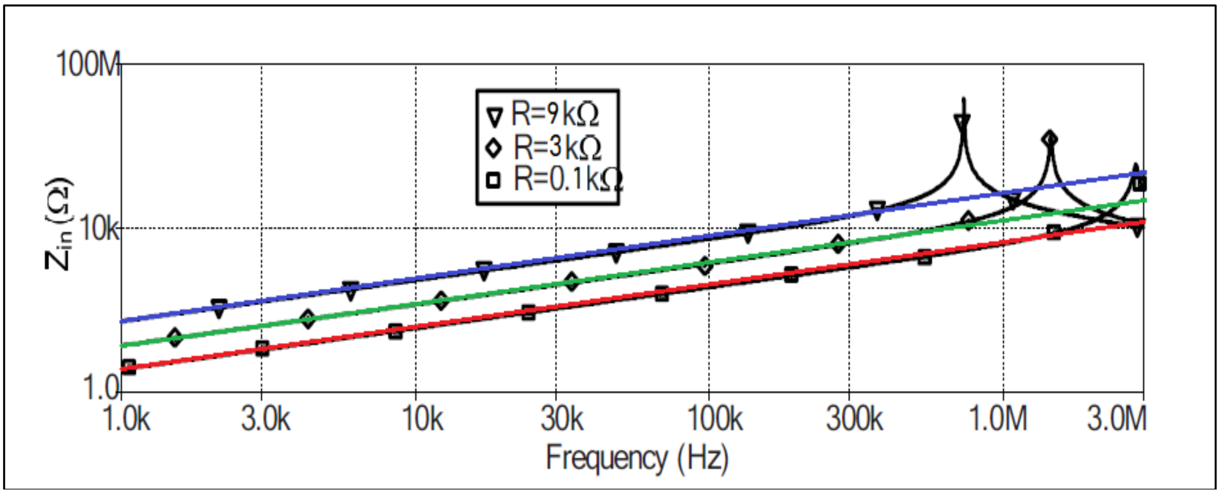


***Figure 4**. Waveforms of the proposed circuits' typical voltage & current*

The voltage & current signal through the suggested floating active inductor when V_2 are grounded are seen in Figure 5.

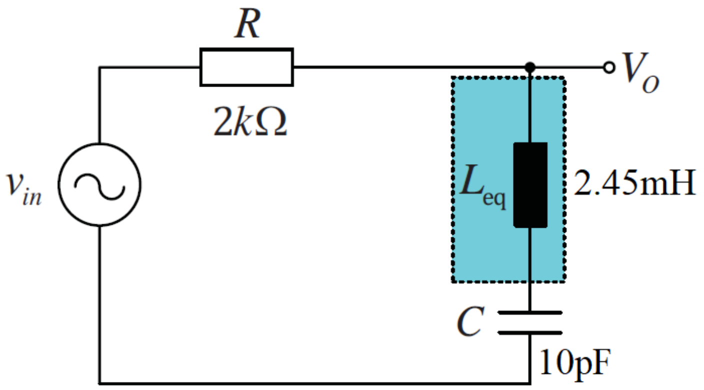


***Figure 5**. A simulator with floating passive inductance is used in a series resonant circuit*

The circuit's simulated magnitude response is shown in Figure 6.

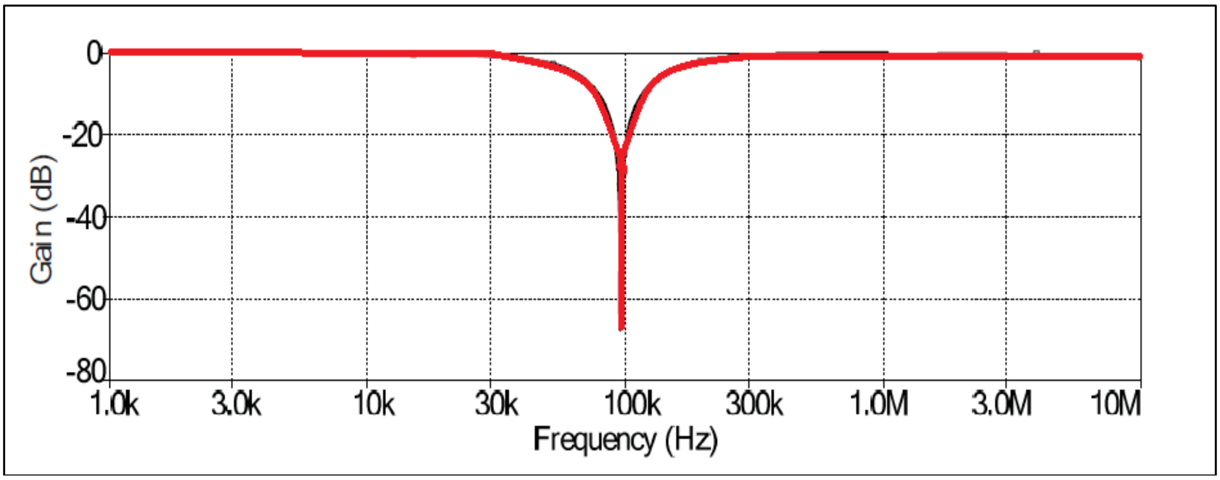


***Figure 6**. The circuit's simulated magnitude response*

Figure 7 shows waveforms of the proposed active floating inductance simulator that are being tested for voltage & current.

Meas 1 Frequency µ': 100.0 Hz
Meas 2 Amplitude µ': 1.934 V
Meas 3 Amplitude µ': 309.8 mV
Meas 4 Phase µ': 280.0 Deg

Ch 1 220 mV/div 10 X 500 MHz
Ch 2 42 mV/div 10 X 500 MHz
AFG Sine 100 Hz 1 Vpp
Horizontal 4 ms/div SR: 5 MS/s RL: 200 kpts
Trigger 299.2 mV

***Figure 7.** Waveforms of the proposed active floating inductance simulator that are being tested for voltage & current.*

The circuit's experimental magnitude response is shown in Figure 8.

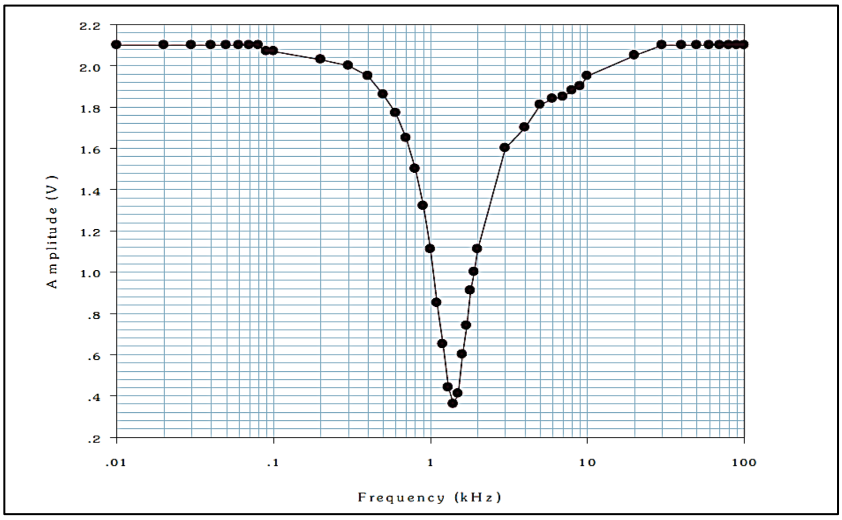


***Figure 8.** The circuit's experimental magnitude response*

4. CONCLUSION

This study introduces both active and passive floating inductance simulators. The proposed circuit can be effectively built using components that are readily available in the market, making it highly accessible and practical. The active building blocks used in the study, especially Current Feedback Operational Amplifiers (CFOA), are shown to be suitable for both voltage and current signal processing modes. A significant advantage of this design is that the capacitors are connected to the Z terminal, which has a high output impedance (Z). This configuration prevents unnecessary additional poles from being created in the circuit.

Both proposed circuits offer a wide frequency response range, making them superior to circuits built with traditional methods. The wide range of frequency responses increases the usability of these circuits in different applications and provides flexibility. For example, these circuits can be used in various analog signal processing applications, such as filtering, signal conversion, and signal conditioning.

Another important contribution of the study is the support of simulation and experimental results. LTspice simulations and laboratory experiments confirm the advantages and effectiveness of the proposed design. Simulations show that the circuit performs as expected theoretically, while experimental results demonstrate its reliability and practicality for real-world applications.

In conclusion, this work provides significant contributions from both theoretical and practical perspectives and proposes an innovative and effective solution for floating inductance simulation. The development of such circuits opens up new opportunities in the fields of electronic circuit design and signal processing, pushing the boundaries of existing technologies.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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