Realization of Inductor Behavior using Generalized Impedance Circuit (GIC)

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Abstract:

This paper investigates the realization of inductor behavior by applyinga Generalized Impedance Circuit (GIC). GIC, as an innovative approach, introduces a generalized impedance element to capture the dynamic characteristics of an inductor. The study involves theoretical modelingof LT Spice implementation and Simulation result validation of the GIC-based inductor. Results indicate that the GIC approach provides an accurate and flexible representation of inductor behavior, offering potential advantages in various electronic applications.

Keywords: Generalized Impedance Circuit (GIC), LT Spice, Inductor, Bode plot, frequency Analysis.

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1 Introduction

Generalized Impedance Converters (GICs) can be used to simulate inductors in filter circuits [1]. GICs are versatile active circuits that can be implemented using CCII and grounded passive elements [2]. They can be used to realize ideal grounded inductance and FDNR simulators [3]. The nonidealities of opamp amps are considered while formulating the frequency characteristics of fractional order inductors using GICs [4]. GICs can be cascaded to create stable DC bias and are applied to bandpass filters[5].GICs can also create constant current outputs, making them suitable for applications such as bias networks and LED drivers. GICs offer attractive features such as high-qualityfactors, independent Q and pole frequency tuning, low voltage, low component count, and low sensitivities.Inductors are fundamental components in electronic circuits, critical for energy storage and signal filtering. However, their conventional implementations often exhibit size, efficiency, and frequency response limitations. The Generalized Impedance Circuit (GIC) presents an alternative method to model and realize the behavior of inductors by incorporating a generalized impedance element. This paper explores the application of GIC in the realization of inductor behavior, aiming to overcome traditional limitations and enhance the performance of electronic systems.Previous research has explored various approaches to model and realize inductor behavior. Traditional inductor models rely on idealized components, leading to inaccuracies in dynamic behavior. The emergence of fractional-order circuits and generalized impedance models has offered new perspectives in capturing the intricacies of inductor dynamics. Notable contributions include works by Sharma and Li, who introduced fractional-order elements in inductor design, laying the groundwork for more advanced circuit modeling.

2 Theoretical Modeling

2.1 Inductor Basics

The theoretical modeling of a Generalized Impedance Circuit (GIC) functioning as an inductor involves understanding the fundamental behavior of an inductor. The relationship between the current i(t), inductance(L) and voltage v(t) is given by Equation 1

$$v(t)=L\frac{di(t)}{dt} \quad (1)$$

2.2 Impedance Representation

An inductor's impedance (ZL) in the frequency domain is expressed as Z_L=jωL, where j is the imaginary unit, ω is the angular frequency, and L is the inductance. The impedance is purely imaginary and directly proportional to both frequency and inductance.

2.3 GIC Integration

In the context of GIC, the inductor's impedance is generalized, considering additional factors that may influence its behavior within the circuit. The GIC may introduce parameters that modify the basic inductor impedance based on the specific circuit configuration. $Z_{GIC\text{-}L}=J\omega L_{eff}$ Here,L_{eff}represents the effective inductance, accounting for the impact of other components or conditions within the GIC.

2.4 Frequency Response Analysis

A Generalized Impedance Converter (GIC) is a circuit that can realize different types of impedances, such as inductors, capacitors, or resistors[6]. The frequency response of a GIC configured as an inductor circuit depends on its design parameters and the components used[7].One common configuration of a GIC as an inductor circuit involves operational amplifiers (op-amps) and passive components like resistors and capacitors[8]. The GIC circuit acts as a "simulated inductor" where the impedance behaves like an inductor over a certain frequency range[9].The frequency response of such a circuit can be analyzed using circuit analysis techniques[10]. However, the specifics of the frequency response would depend on the particular design of the GIC circuit[11]. In general, the frequency response of a GIC configured as an inductor would exhibit characteristics similar to that of an ideal inductor[12]. At low frequencies, the impedance would be minimal, behaving similarly to a short circuit. As the frequency increases, the impedance of the GIC would increase, simulating the behavior of an inductor[13].The GIC inductor's response to varying frequencies is crucial for understanding its behavior within the circuit. Frequency response analysis illuminates how the impedance changes concerning alterations in frequency[14].

2.5 Equivalent Circuit Model

For more intricate GIC designs, the inductor may be part of a larger circuit. Representing the GIC as an equivalent circuit helps visualize its role within the broader system, often employing electrical symbols and interconnected components[15].This theoretical foundation allows for a more accurate representation of inductor behavior under varying conditions[16]. The formula used to determine the exact value of impedance is given by Equation.2

$$Z_{GIC}=\frac{Z_1Z_3Z_5}{Z_2Z_4} \quad (2)$$

The representation of Z_1 is shown by R_1, Z2 by R2, Z3 by R3, Z4 by C1, and Z_5 by R_4. For the realization of GIC acting as an Inductor, the value of Z4 is replaced with the appropriate

2.6 Transient Response Exploration

Examining the transient response of the GIC inductor involves studying how the voltage and current evolve during changes in the input signal or other circuit conditions.The GIC-based inductor is modeled using generalized impedance elements that account for the resistive and reactive components of inductor behavior. Theoretical formulations are derived from the generalization of impedance equations, incorporating parameters to control the order and dynamics of the circuit. This theoretical foundation allows for a more accurate representation of inductor behavior under varying conditions.

3 Implementation using LT Spice

The GIC-based inductor is practically implemented in electronic circuits, considering manufacturing constraints and real-world applications [17]. The design process involves selecting appropriate components, determining optimal parameter values, and ensuring compatibility with existing circuitry [18]. Practical challenges and considerations in implementing GIC-based inductors are discussed, emphasizing the feasibility of integrating this novel approach into electronic systems.

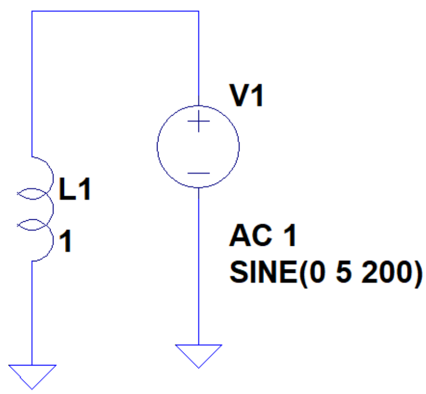

Figure 1 Ac source connected to inductor

The GIC is implemented in Figure 2. The input signal with a voltage magnitude of 5v and a frequency of 200Hz is applied across R_1. The output is taken across R_4. The inductance value of 1mH is connected in GIC. The value of R_1, R_2, and R_4 is 1kΩ. The two opamp Op07 is taken for the implementation of GIC. Port 7 of opamp U1 and U2 is applied with +Vsat(15v), and port four is used with –Vsat(-15v). The inverting terminal (port 2) of opamp U1 and U2 is connected across R_3.The noninverting terminal of U1 is connected to R1, and the noninverting terminal of U_2 is connected to R_4.

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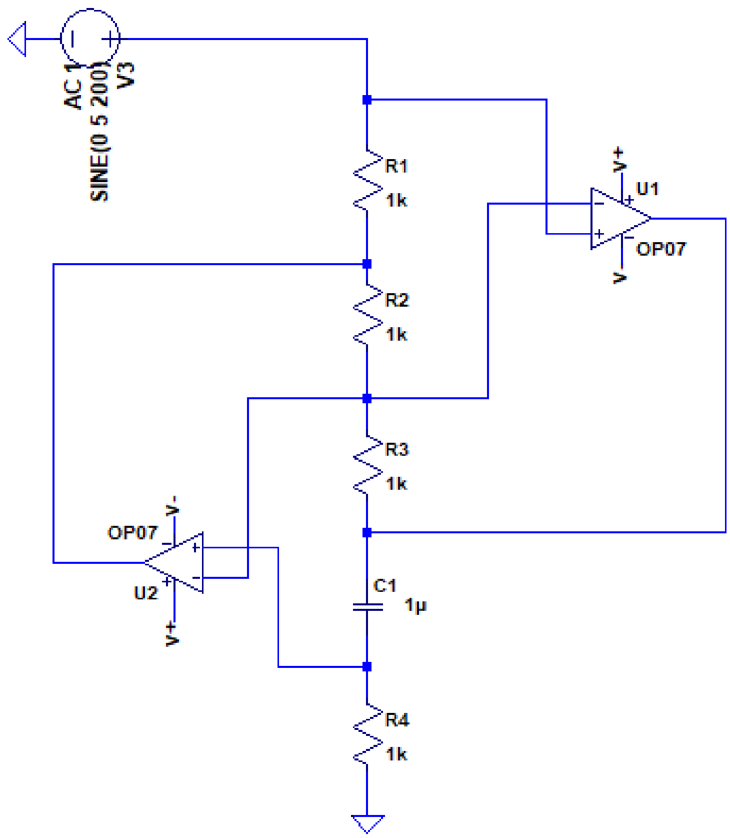

Figure 2GIC circuit implementing inductor behavior

4 Simulation Result Validation

Experimental results validate the effectiveness of the GIC-based inductor in comparison to traditional models. Measurements are conducted under different operating conditions to assess the accuracy and flexibility of the GIC approach. All output voltage measurements, like magnitude and phase, use LT Spice Simulation. The waveform across the inductor for the node (Vn001) and GIC acting as an inductor (Vn006) is shown in Figure andFigure .

4. Even though the magnitude of GIC (Vn006) shown in **Error! Reference source not found.** is almost same as the magnitude of the output voltage of pure inductorr (Vn001), the phase of both the voltage (Vn001) and (Vn006) is the same, and it validates that GIC is showing inductor behavior. The experimental validation demonstrates that GIC provides a more realistic representation of inductor behavior, showcasing its potential to improve the performance of electronic systems

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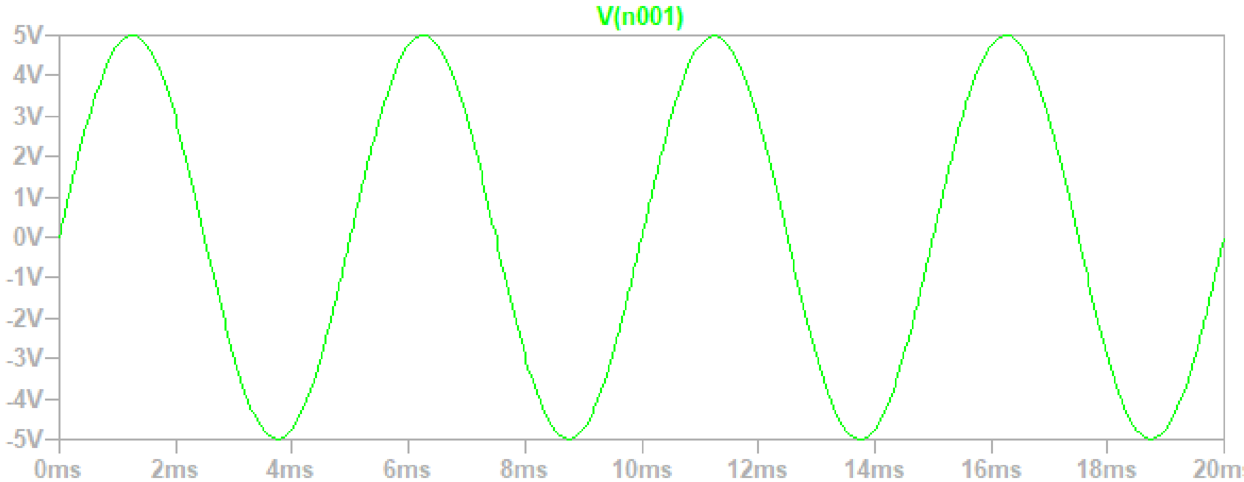

Figure 3 Output waveform across the inductor

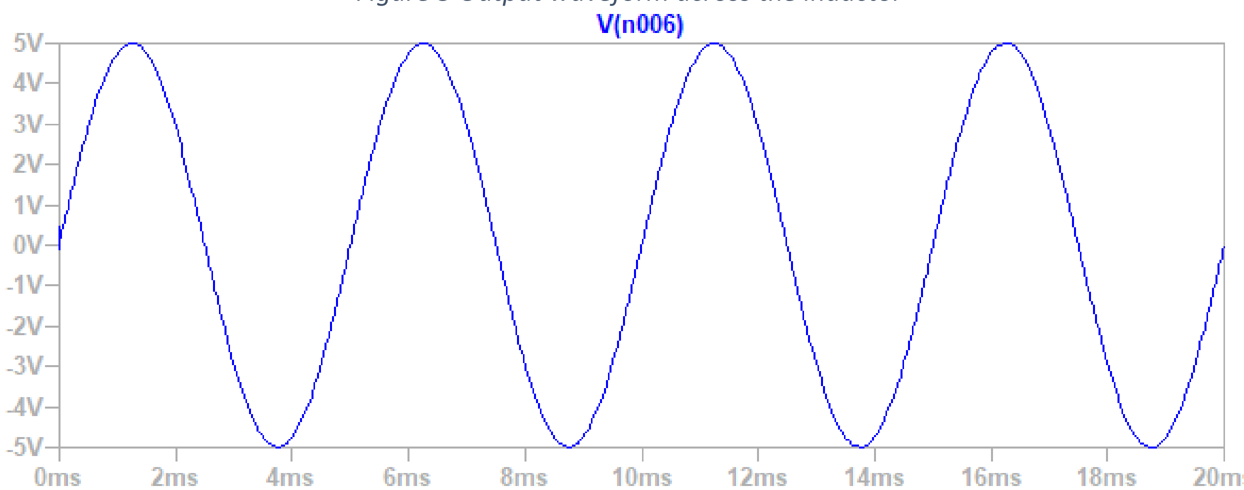

Figure 4 Output waveform across GIC acting as aninductor

Table 1 Magnitude and phase response with respect to frequency

Freq.	V(n001)	V(n006)
1	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-2.21727944964394e+001dB,8.58589467252612e+001°)
10	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-3.97347827520993e+000dB,5.41596979412461e+001°)
100	(0.00000000000000e+000dB,0.00000000000000e+000°)	(5.93162950690040e-001dB,7.88976214789162e+000°)
1000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(6.74925525294227e-001dB,8.67278117849663e-001°)
10000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(6.89357428158091e-001dB,8.16841368858363e-001°)
100000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(1.90096925723598e+000dB,4.43748173431694e+000°)
1000000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-2.87637437529057e+000dB,-1.29945751218462e+002°)
10000000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-4.84883361406682e+001dB,1.01265418421202e+002°)

The magnitude and phase concerning frequency are tabulated in Table 1. The magnitude plot of pure inductor and GIC acting as inductor is shown in Figure 5. The magnitude plot of GIC (Vn006)acting as a inductor is amost same in the range of 100Hz and 100KHz the pure inductor(Vn001) magnitude.

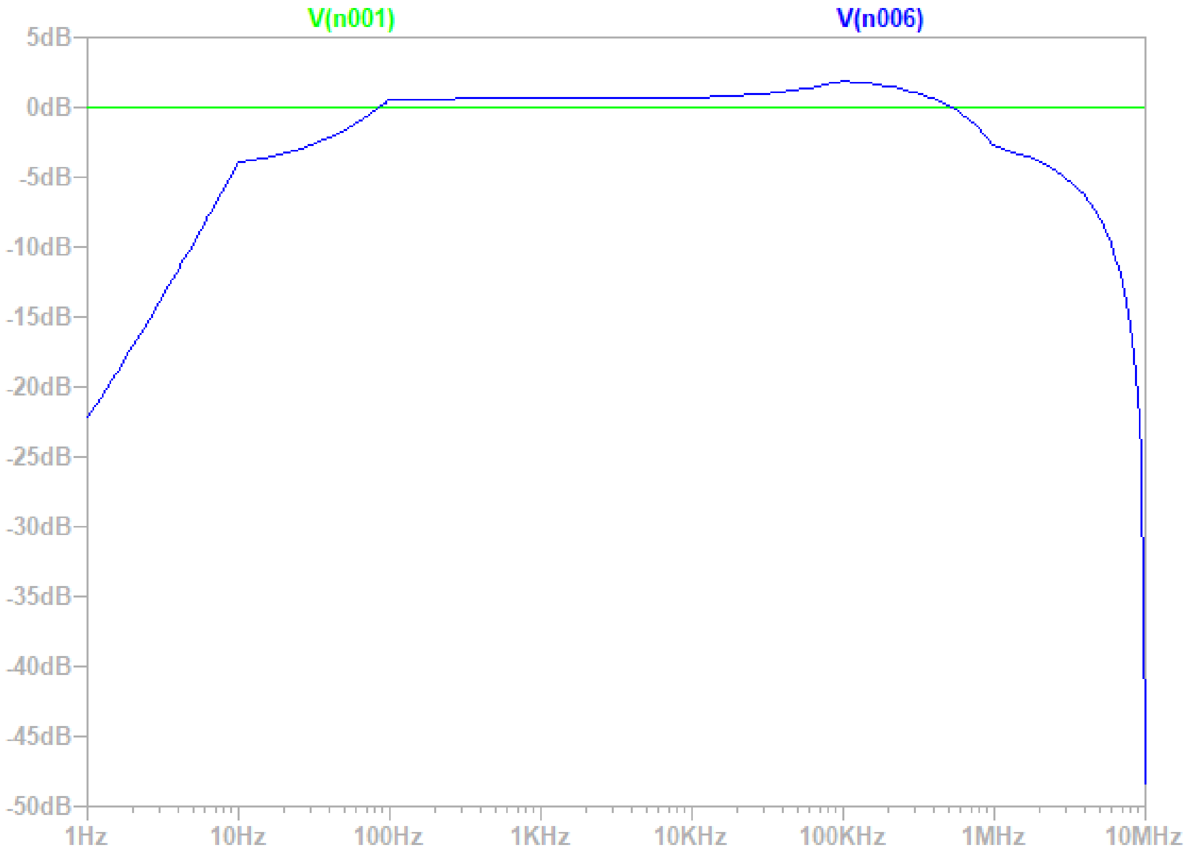

Figure 5 Magnitude plot of pure inductor and GIC

The Phase plot of the inductor and GIC acting as the inductor is shown inFigure 5. From Figure 5,it can be confirmed that GIC is acting as an inductor between the ranges of 100Hz and 100 KHz.

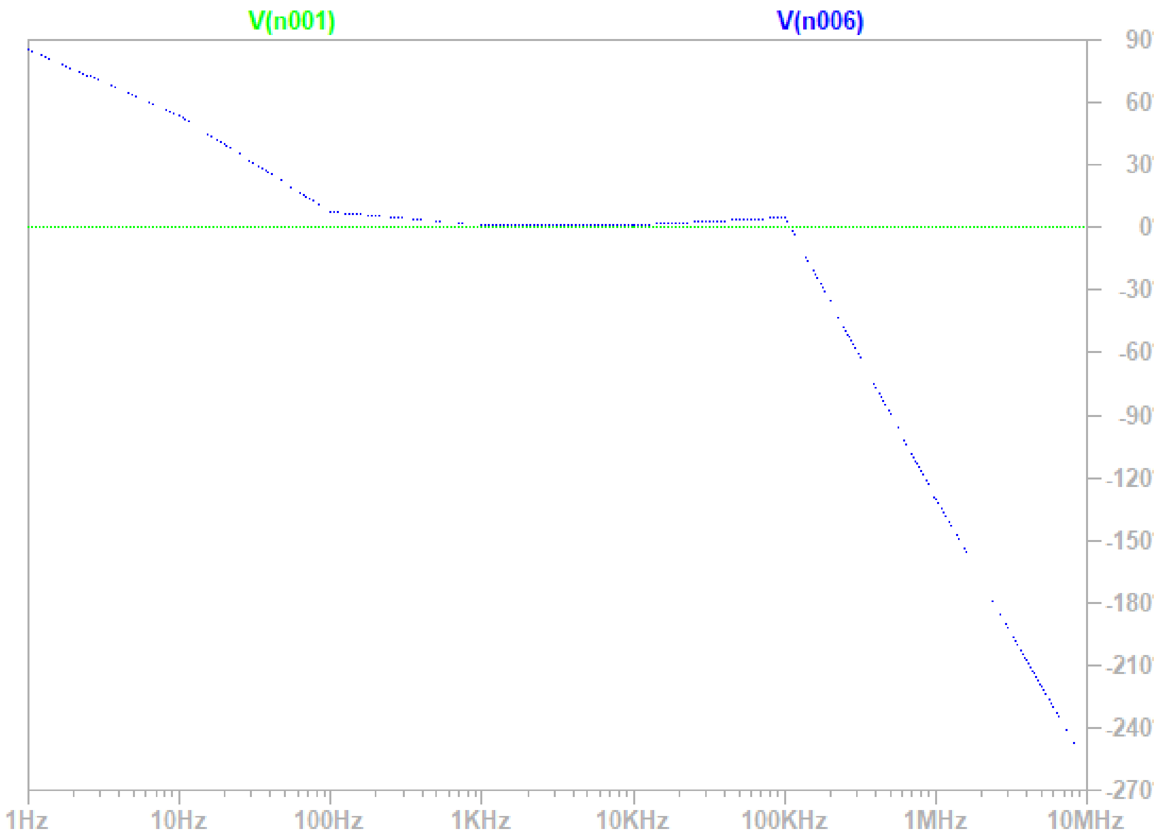

Figure 6 Phase plot of the pure capacitor and GIC

5 Discussion and conclusion

The discussion section analyzes the implications of utilizing GIC-based inductors in practical applications. Comparative studies with traditional inductors highlight the advantages and trade-offs of the GIC approach. Potential applications, including power electronics, signal processing, and communication systems, are explored, shedding light on the broad impact of GIC inductor realization.In conclusion, applying Generalized Impedance Circuit (GIC) in realizing inductor behavior represents a promising advancement in circuit design. The study contributes to the growing research on advanced circuit modeling and provides a foundation for further exploration of GIC-based components. The GIC-based inductor offers a more accurate and flexible representation of inductor behavior, with potential applications in diverse electronic systems. Future research should focus on optimizing GIC-based designs for specific applications and further exploring the practical implications of this innovative approach.

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