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Realization of Capacitor Behaviour using Generalized Impedance Circuit (GIC)

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Abstract: This paper explores the realization of capacitor behavior by applying a generalized impedance circuit (GIC). GIC, an innovative approach, introduces a generalized impedance element to capture the dynamic characteristics of a capacitor. The study involves theoretical modeling, LT Spice implementation, and Simulation result validation of the GIC-based capacitor. Phase plots indicate that the GIC approach provides an accurate and flexible representation of capacitor behavior, offering potential advantages in various electronic applications.

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

1 Introduction

Capacitors are crucial in electronic circuits as energy storage elements and signal filters [1]. Traditional capacitor models, however, may exhibit limitations in dynamic behavior. The Generalized Impedance Circuit (GIC) offers an alternative method to model and realize capacitor behavior by incorporating a generalized impedance element[2]. This paper investigates the application of GIC in the realization of capacitor behavior, aiming to enhance the performance of electronic systems. The Generalized Impedance Circuit (GIC) serves as a dynamic and adaptive solution in electrical engineering, finding its application in various circuit configurations[3]. One particularly noteworthy application is its role as a capacitor circuit, where the GIC's unique characteristics prove instrumental in manipulating and managing electrical signals[4]. GIC showcases its ability to enhance energy storage, signal filtering, and overall circuit performance in capacitor circuits. As a capacitor circuit, GIC plays a pivotal role in influencing the flow of electrical currents, demonstrating an inherent capability to store and release energy efficiently. Its ability to function as a versatile energy storage device makes GIC essential in diverse electronic systems, ranging from power supplies to electronic filters[5]. The circuit's adaptability and reliability make it a preferred choice for engineers seeking optimal solutions in designing and implementing electronic devices[6]. The present article delves into the intricacies of GIC operating as a capacitor circuit in this exploration. From understanding its impedance characteristics to its impact on signal filtering and energy transfer, this paper uncovers the nuanced role GIC plays in shaping the behavior of electrical systems. The present article discusses the fundamental principles and practical applications of GIC within capacitor circuits, highlighting its significance in advancing electrical engineering. Previous research has explored various approaches to model and realize capacitor behavior. Traditional capacitor models often rely on idealized components, leading to inaccuracies in dynamic response. The emergence of fractional-order circuits and generalized impedance models has provided new insights into capturing the intricate dynamics of capacitors[7]. Notable contributions include works by researchers who introduced fractional-order elements in capacitor design, laying the foundation for more advanced circuit modeling [8]–[10].memory is also designed based on fractional-order circuits[11]. GIC is also used in implementing first-order filters [12]

2 Theoretical Modeling

The theoretical modeling of a Generalized Impedance Circuit (GIC) operating as a capacitor involves understanding its electrical behavior and characteristics. A capacitor in a GIC context typically consists of complex impedance, which is influenced by frequency, capacitance, and other circuit parameters. Let's explore the theoretical modeling of GIC as a capacitor:

2.1 Basic Capacitor Equations

The fundamental relationship governing a capacitor is given by

$$i(t)=c\frac{dv(t)}{dt} \tag{1}$$

i (t) is the current flowing through the capacitor, C is the capacitance, and v(t) is the voltage across the capacitor terminals.

2.2 Impedance Modeling

C is the capacitance. This impedance is purely imaginary and inversely proportional to both frequency and capacitance.

$$Z_c=\frac{1}{j\omega c} \tag{2}$$

2.3 GIC Incorporation

In the context of GIC, the capacitor's impedance is generalized to accommodate additional complexities. The GIC may introduce parameters that modify the essential capacitor impedance based on the specific circuit configuration.

$$Z_{GIC\text{-}C}=\frac{1}{j\omega c_{eff}} \tag{3}$$

It represents effective capacitance, considering the influence of other components or conditions within the GIC.

2.4 Frequency Response

The GIC capacitor's behavior across different frequencies can be analyzed by examining the frequency response. This involves studying how the impedance changes concerning variations in frequency.

2.5 Equivalent Circuit Modeling

In more intricate GIC designs, the capacitor may be part of a larger circuit. The GIC can be represented as an equivalent circuit, often using electrical symbols and interconnected components to illustrate its behavior within a broader system.

Transient Analysis

Understanding the transient response of the GIC capacitor involves examining how the voltage and current evolve during changes in the input signal or other circuit conditions.

The GIC-based capacitor is modeled using generalized impedance elements that account for capacitor behavior's resistive and reactive components [13]. Theoretical formulations are derived from the generalization of impedance equations, incorporating parameters to control the order and dynamics of the circuit[14]. This theoretical foundation allows for a more accurate representation of capacitor behavior under varying conditions. The formula used to determine the exact value of impedance is given by Equation.4

$$Z_{GIC} = \frac{Z_1 Z_3 Z_5}{Z_2 Z_4} \tag{4}$$

The representation of Z_1 is shown by R_1, Z2 by R2, Z3 by R3, Z4 by L1, and Z_5 by R_4. For the realization of GIC acting as a capacitor, the value of Z4 is replaced with the appropriate inductance.

3 Implementation

The GIC-based capacitor is practically implemented in electronic circuits, considering manufacturing constraints and real-world applications[15]. The design process involves selecting appropriate components, determining optimal parameter values, and ensuring compatibility with existing circuitry [16]. Practical challenges and considerations in implementing GIC-based capacitors are discussed, emphasizing the feasibility of integrating this novel approach into electronic systems [17]. Figure 1 represents a pure capacitor connected to the AC supply.

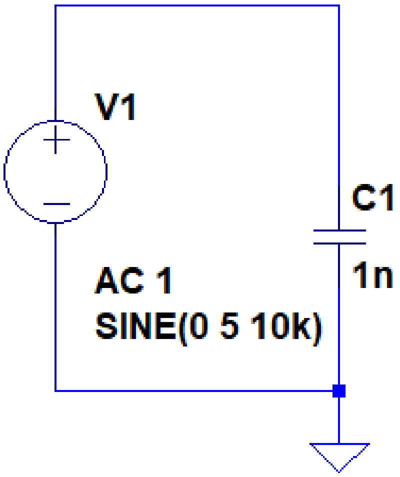

Figure 1 AC source connected to a capacitor

The GIC is implemented in Figure 2. The input signal with a voltage magnitude of 5v and a frequency of 10KHz 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.

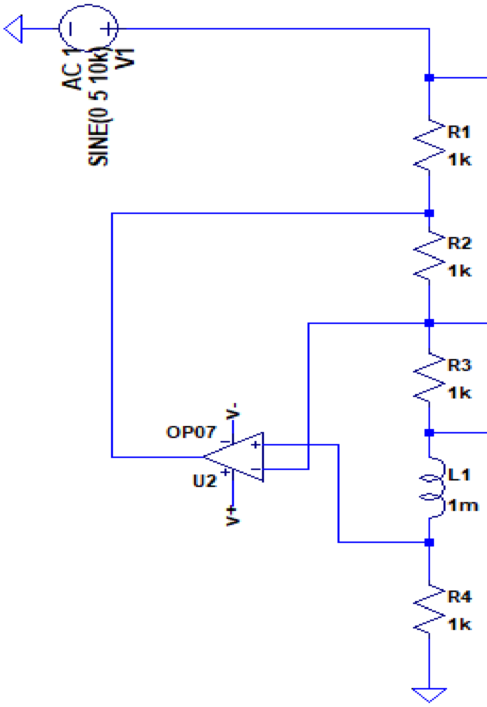

Figure 2 GIC circuit implementing capacitor behavior

4 Simulation Result Validation

Experimental results validate the effectiveness of the GIC-based capacitor 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 capacitor for the node (Vn005) and GIC acting as a capacitor (Vn006) is shown in Figure 3. Even though the magnitude of GIC (Vn006) shown in Figure 3 is lesser than the magnitude of the output voltage of pure capacitor (Vn005), the phase of both the voltage (Vn005) and (Vn006) is the same, and it validates that GIC is showing capacitance behavior. The experimental validation demonstrates that GIC provides a more realistic representation of capacitor behavior, showcasing its potential to improve the performance of electronic systems [15].

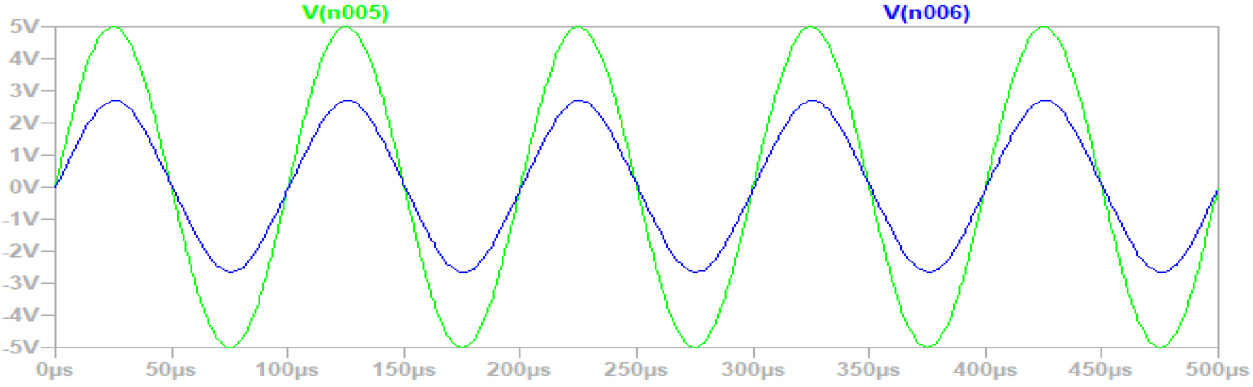

Figure 3 Output waveform across the capacitor and GIC acting as a capacitor

The magnitude and phase concerning frequency are tabulated in Table 1. The magnitude plot of pure capacitor and GIC acting as capacitor is shown in Figure 4. The magnitude plot of GIC (Vn006)acting as a capacitor is 6 dB lesser than the pure capacitance(Vn005) magnitude

Table 1 Magnitude and phase response concerning frequency

Freq.	V(n005)	V(n006)
1	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-6.13959570255126e+000dB,-1.87394504756124e-004°)
10	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-6.13959570616066e+000dB,-1.87395294560583e-003°)
100	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-6.13959608325023e+000dB,-1.87398238103232e-002°)
1000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-6.13964688108133e+000dB,-1.87424984376754e-001°)
10000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-6.14485207038422e+000dB,-1.87309782475187e+000°)
100000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-6.60054334444792e+000dB,-1.78833451218749e+001°)
1000000	(0.00000000000000e+000dB,0.00000000000000e+000°)	(-1.72841891702091e+001dB,-7.36765816046155e+001°)

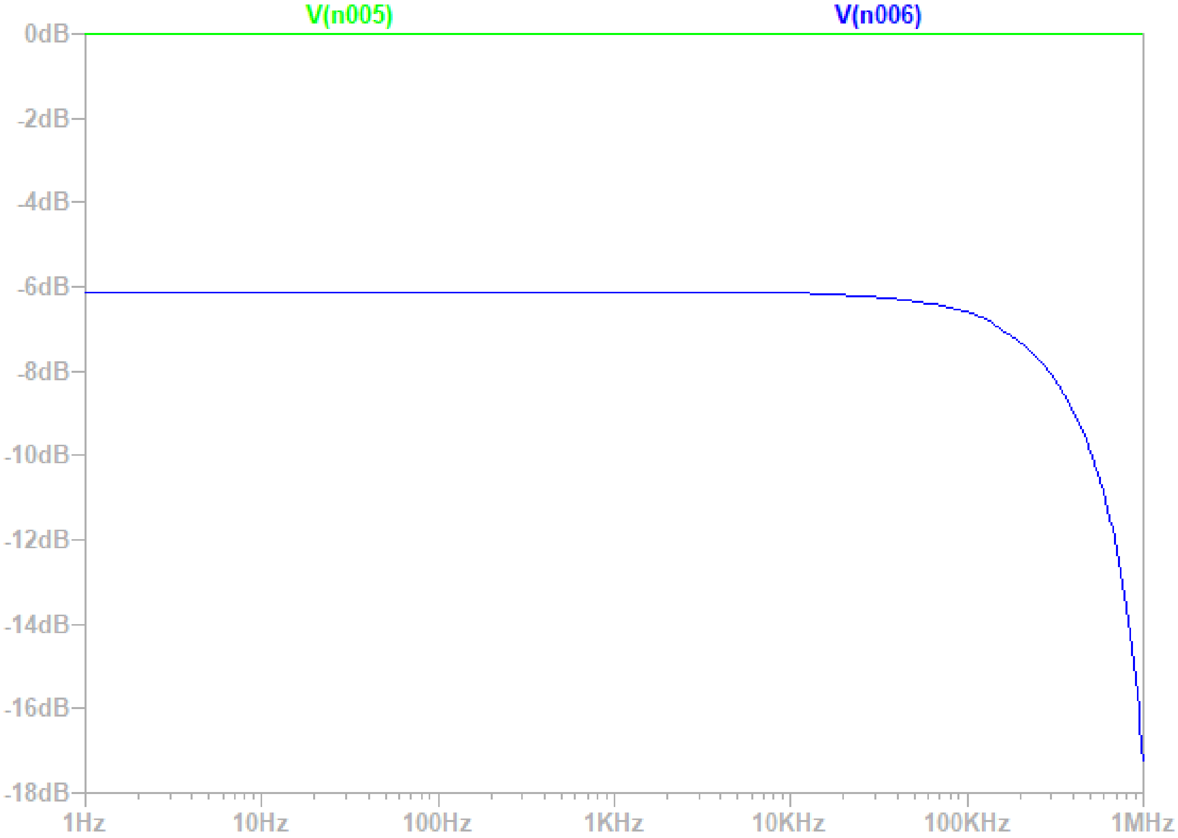

Figure 4 Magnitude plot of pure capacitor and GIC

The Phase plot of the capacitor and GIC acting as the capacitor is shown in Figure 5. From Figure 5, it can be confirmed that GIC is acting as a capacitance between the ranges of 1Hz and 1 KHz. For a frequency range of 1 KHz, the GIC acts as capacitance.

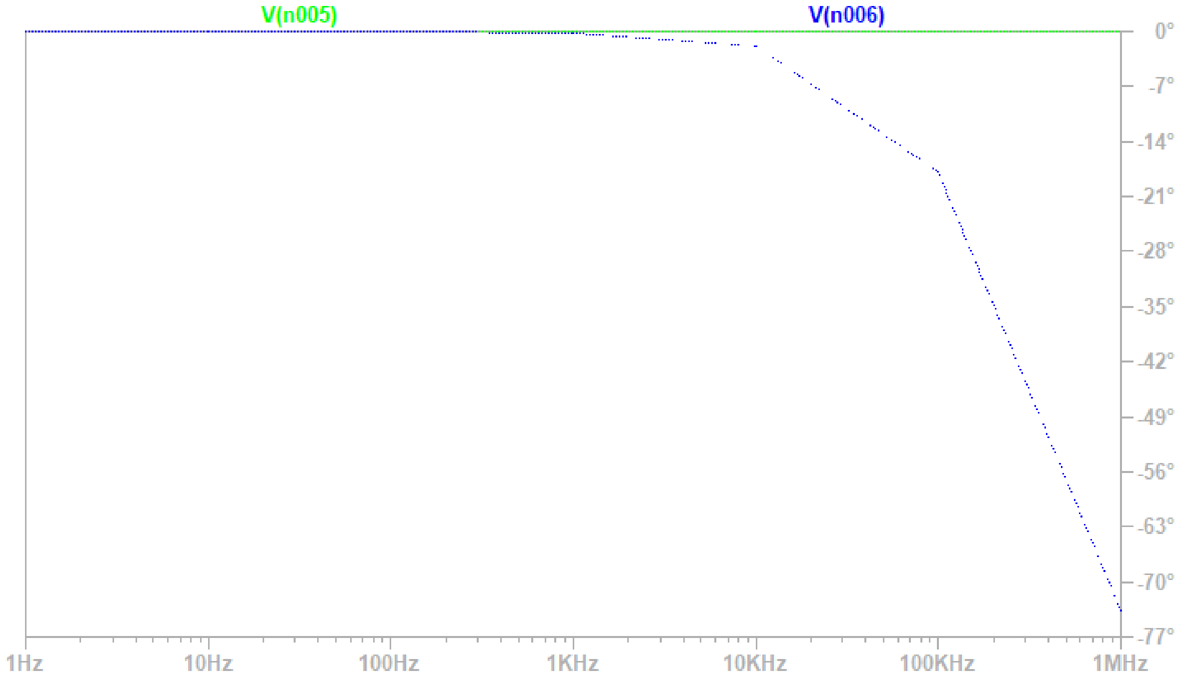

Figure 5 Phase plot of the pure capacitor and GIC

5 Discussion and conclusion

The discussion section analyzes the implications of utilizing GIC-based capacitors in practical applications. A comparison between traditional capacitors highlights the advantages and trade-offs of the GIC approach. The trade-offs between the conventional capacitor and GIC approach are in magnitude. The magnitude of a based capacitor is less than 6 dB. Potential applications, including power electronics, signal processing, and communication systems, are explored, shedding light on the broad impact of GIC in capacitor realization. In conclusion, applying Generalized Impedance Circuit (GIC) to realize capacitor 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 capacitor offers a more accurate and flexible representation of capacitor 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.

References

[1] H. Lill, A. Allik, E. Jogi, M. Hovi, H. Hoimoja, and A. Annuk, “Capacitor and Battery Energy Storage System Sizing Ratio for Wind Microgenerators,” *2018 IEEE Int. Conf. Eng. Technol. Innov. ICE/ITMC 2018 - Proc.*, 2018.

[2] D. Ramirez-Munoz, J. Sanchez, S. Casans, C. Reig, and A. E. Navarro, “Series Sensor Current Loop from a Generalized Impedance Converter Circuit with Reference Current Input,” no. May 2014, pp. 2265–2270, 2007.

[3] J. Koton, D. Kubanek, J. Dvorak, and N. Herencsar, “On systematic design of fractional-order element series,” *Sensors (Switzerland)*, vol. 21, no. 4, pp. 1–23, 2021.

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[4] T. Inoue and F. Ueno, “Analysis and Synthesis of Switched-Capacitor Circuits Using Switched-Capacitor Immittance Converters,” *IEEE Trans. Circuits Syst.*, vol. 29, no. 7, pp. 458–466, 1982.

[5] Y. F. Ma and W. Zong, “A Method of Acquiring and Processing GIC Signal in High-Speed Rail Track Circuit,” *Adv. Mater. Res.*, vol. 1070–1072, pp. 755–758, 2014.

[6] T. R. Qureshi, C. R. Chatwin, N. Huber, A. Zarafshani, B. Tunstall, and W. Wang, “Comparison of Howland and General Impedance Converter (GIC) circuit based current sources for bio-impedance measurements,” *J. Phys. Conf. Ser.*, vol. 224, no. 1, 2010.

[7] Y. Jiang, B. Zhang, X. Shu, and Z. Wei, “Fractional-order autonomous circuits with order larger than one,” *J. Adv. Res.*, vol. 25, pp. 217–225, 2020.

[8] T. Jin, S. Gao, H. Xia, and H. Ding, “Reliability analysis for the fractional-order circuit system subject to the uncertain random fractional-order model with Caputo type,” *J. Adv. Res.*, vol. 32, pp. 15–26, 2021.

[9] T. P. Stefanski and J. Gulgowski, “Fractional Order Circuit Elements Derived from Electromagnetism,” *Proc. 26th Int. Conf. "Mixed Des. Integr. Circuits Syst. Mix. 2019*, no. 3, pp. 310–315, 2019.

[10] A. S. Elwakil, “Circuits and Systems : An Emerging Interdisciplinary,” *Ieee Circuits Syst. Mag.*, 2010.

[11] M. Du, Z. Wang, and H. Hu, “Measuring memory with the order of fractional derivative,” *Sci. Rep.*, vol. 3, no. 1, pp. 1–3, 2013.

[12] A. G. Radwan, A. M. Soliman, and A. S. Elwakil, “The Fractional Domain,” vol. 17, no. 1, pp. 55–66, 2008.

[13] G. K. Bharti and S. Dey, “Anti-symmetric quadruple ring resonator based optical filter,” *Optik (Stuttg).*, vol. 126, no. 24, pp. 5865–5869, 2015.

[14] A. G. Radwan, A. S. Elwakil, and A. M. Soliman, “Fractional-order sinusoidal oscillators: Design procedure and practical examples,” *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 55, no. 7, pp. 2051–2063, 2008.

[15] A. Adhikary, S. Sen, and K. Biswas, “Practical Realization of Tunable Fractional Order Parallel Resonator and Fractional Order Filters,” *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 63, no. 8, pp. 1142–1151, 2016.

[16] A. Adhikary, P. Sen, S. Sen, and K. Biswas, “Design and Performance Study of Dynamic Factors in Any of the Four Quadrants,” *Circuits, Syst. Signal Process.*, vol. 35, no. 6, pp. 1909–1932, 2016.

[17] A. Adhikary, S. Choudhary, and S. Sen, “Optimal Design for Realizing a Grounded Fractional Order Inductor Using GIC,” *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 65, no. 8, pp. 2411–2421, 2018.