Experimental observation of frequency of oscillation, amplitude and temporal symmetry of a Clapp oscillator incorporating a physical memristor

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The Clapp oscillator consists of one voltage amplifier, one inductor, three capacitors, and three resistors. The proposed work analyses the Clapp oscillator when two resistors are replaced by a commercially available physical memristor, *e.g.* the Knowm memristor, and a third case when the polarity of the memristor is inverted. In this manner, three cases are analyzed and compared with the responses of the Clapp oscillator without a memristive element. The responses of the experiments show how the position and polarity of the Knowm memristor influence the steady-state behavior of the LC resonant oscillator. The results show that the three cases, using the Knowm memristor, produce measurable changes in frequency of oscillation, amplitude, and temporal symmetry of the output waveform, whereas reversing the memristor polarity, reverses both frequency and temporal asymmetry trends. As a conclusion, the observed behaviors indicate that the memristor acts as a dynamic and history-dependent element, *i.e.* it modifies the oscillation conditions of the Clapp oscillator beyond the effects of a static resistive component. These findings establish that the Clapp oscillator topology is a suitable experimental platform for studying memristive effects in LC resonant systems. The results provide insights into the role of memristive devices position and polarity in shaping oscillatory dynamics.

Keywords: Knowm memristor; Clapp oscillator; frequency; amplitude; symmetry.

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1. Introduction

Oscillators based on LC resonant networks, as the Colpitts, Hartley and Clapp, remain fundamental building blocks in analog and radio-frequency systems, where frequency stability, spectral purity, and robustness against parameter variations are essential. In such oscillatory systems, the balance between reactive elements and system losses determines whether sustained oscillations exist, how they are sustained, and their quality [1].

The Colpitts oscillator was modified by James Kilton Clapp in 1948 through the introduction of an additional capacitor in series with the inductor. This modification improved frequency stability by making the frequency of oscillation primarily dependent on the series capacitor and the inductor, thereby reducing the influence of parasitic capacitances and active device variations, The modified circuit was named Clapp oscillator. For instance, the resonant tank of the Clapp oscillator consists of three capacitors and one inductor, forming a capacitive divider that provides the necessary feedback to satisfy the Barkhausen criteria. By selecting the series capacitor to dominate the equivalent capacitance, the circuit achieves greater frequency precision while maintaining stable sinusoidal oscillations, which makes it suitable for high-frequency and variable frequency applications [2].

The proposed work reaffirms that the inclusion of nonlinear or time-varying elements in an oscillator topology can significantly affect not only the oscillation frequency but also the signal's stability and waveform integrity. In this context, memristors have attracted increasing attention as circuit elements that introduce nonlinearity and history-dependent impedance into electrical systems.

Since the theoretical formulation as the fourth fundamental circuit element [3], the memristor has been characterized by a constitutive relationship between voltage and current that depends on the past excitation history. This memory effect enables behaviors that conventional passive components cannot replicate and has motivated its application in analog and nonlinear systems, and emerging electronic architectures. For instance, early works on memristor-based oscillators have been focused predominantly on non-resonant, or RC-based topologies. Among them, the Wien bridge oscillator is the most extensively studied topology.

The authors in Refs. [4, 5] introduced a theoretical framework based on time-domain oscillatory poles to analyze the stability of memristor-based Wien oscillators, primarily relying on mathematical models and numerical simulations. In parallel, memristive nonlinearity has been exploited to generate complex dynamics, including chaotic oscillations, often through fractional-order memristor emulators [6]. More recently, memristor-based relaxation oscillators and reconfigurable signal generators have been explored in configurations lacking resonant networks, revealing a strong dependence of the oscillatory dynamics on control signals and memristor state evolution [7, 8]. Recent experimental studies have shown the influence of real physical memristors on RC-based oscillators, including both relaxation and Wien-bridge configurations, demonstrating that non-ideal memristive dynamics can induce significant frequency shifts and waveform modifications compared to conventional implementations [9].

Despite the widespread practical relevance of LC resonant oscillators, experimental studies integrating memristors into highly stable LC topologies remain scarce. Recent review articles on memristor-based sinusoidal oscillators explicitly highlight this gap and emphasize the lack of experimental validation using real physical memristors in such configurations [10]. Although related oscillatory structures have been reported, they have been investigated predominantly through simulation-based approaches [11].

The availability of commercial physical memristors has recently enabled experimental studies beyond idealized models and active emulators. In particular, Self-Directed Channel (SDC) devices manufactured by Knowm Technologies provide a platform for evaluating memristive behavior under realistic laboratory conditions. Unlike idealized models, physical memristors exhibit non-ideal dynamics that depend on excitation frequency, polarity, and prior stimulus history, which may critically influence the operation of resonant oscillators [12]. In this manner, the proposed work uses the Clapp oscillator –a topology that provides enhanced frequency stability and reduced sensitivity to parasitic capacitances–, to be employed as a test platform to experimentally assess the impact of a nonlinear, history-dependent resistive element on an LC resonant system.

Section 2 shows the experimental waveform responses of the Clapp oscillator considering three characteristics, namely: frequency of oscillation, amplitude, and temporal symmetry. The measurement setup is implemented using the Analog Discovery Studio kit from Digilent, and three cases are established by replacing two passive resistors by the physical Knowm memristor, and a third case by changing the polarity of the memristor. Section 3 shows the experimental observation of the changes in the output waveform for each of the three cases, and shows the procedures to observe the frequency of oscillation, amplitude, and temporal symmetry when using the Knowm memristor and changing its polarity. Section 4 discusses the experimental observations of the output waveforms for the three cases. Finally, Sec. 5 summarizes the main conclusions.

2. Experimental methodology

A Clapp oscillator can be understood as a slight modification of the famous Colpitts topology [13]. The design of the experiment begins by the implementation of the topology of the Clapp oscillator shown in Fig. 1, whose experimental results are taken as the baseline for all subsequent comparisons. This topology is used herein as a stable, well-characterized resonant system, with its nominal behavior assumed known.

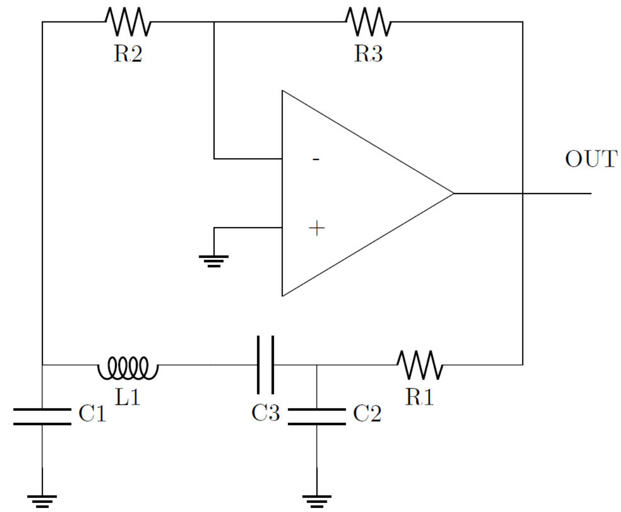

FIGURE 1. Clapp oscillator circuit topology consisting of one voltage amplifier, one inductor, three capacitors and three resistors.

The oscillator topology shown in Fig. 1 is implemented to operate in a steady-state sinusoidal regime, where the oscillation frequency is primarily determined by the LC resonant tank, which has low sensitivity to parasitic capacitances. Throughout the analysis, all reactive and active components of the circuit are kept constant to ensure that any observed variation in oscillatory behavior can be attributed exclusively to modifications in the resistive elements, which are changed by the Knowm memristor one at a time, rather than to changes in the resonant network or the amplification stage.

In the proposed work, no adaptive tuning mechanisms, automatic gain control, or compensation strategies are implemented during the oscillator circuit operation. This omission is deliberate, as the main goal is not to restore or enforce ideal oscillation conditions, but rather to observe how the intrinsic dynamics of a nonlinear, history-dependent element, as the Knowm memristor, perturb an oscillator topology that is inherently designed for spectral stability. Under these assumptions, the topology shown in Fig. 1 is taken as a reference configuration that defines the experimental framework to perform a comparison between the stable and previously characterized LC oscillator against the impact of incorporating a physical memristive device by interchanging the memristor with one of the resistors given in the classical Clapp oscillator topology. This experimental approach allows isolating the effects induced by the memristor without conflating them with a circuit reconfiguration or parameter readjustment.

The experimental evaluation of the Clapp oscillator shown in Fig. 1, is based on a set of directly observable criteria selected to reflect relevant changes resulting from incor-

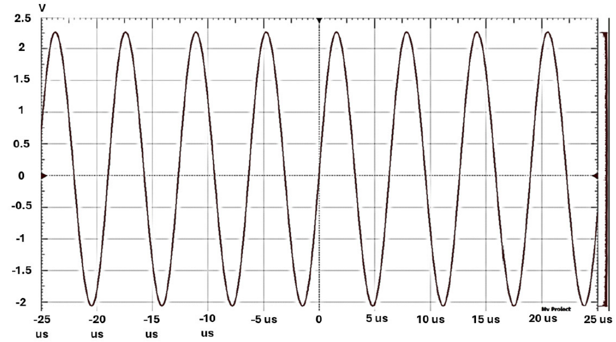

FIGURE 2. Experimental output waveform of the Clapp oscillator shown in Fig. 1.

porating a nonlinear, history-dependent resistive element. These criteria are defined before the memristor is included to avoid post hoc interpretations and ensure consistent comparisons across the three cases when each resistor is replaced by the Knowm memristor.

The first evaluation parameter is the frequency of oscillation of the Clapp topology, defined as the dominant component in the output voltage spectrum under steady-state conditions. The second parameter that is considered in the experimental observations is the amplitude of the output signal, which is analyzed and quantified by the maximum, minimum, and peak-to-peak values of the oscillatory voltage waveform. The amplitude parameter enables assessment of the memristive element's impact on the system gain balance and identification of potential saturation or attenuation effects associated with nonlinear resistive dynamics. The third parameter being measured concerns the temporal symmetry of the output waveform, which is examined through the time distribution of the positive and negative half-cycles. Alterations in this symmetry may indicate that the circuit behavior depends on the instantaneous signal polarity, which is particularly relevant for physical memristive devices, as the Knowm memristor, which exhibits asymmetric dynamics.

Figure 2, shows the output waveform of the classical Clapp oscillator using the circuit element values given in Table I. To ensure the reliability of the baseline circuit, a theoretical estimation of the expected oscillation frequency was carried out based on the resonant tank of the Clapp topology.

TABLE I. Circuit element values to implement the Clapp topology shown in Fig. 1.

Element	Identifier	Value
Resistor	R1	100 Ω
Resistor	R2	1 kΩ
Resistor	R3	47 kΩ
Capacitor	C1, C2, C3	100 nF
Inductor	L1	30.5 μH
Supply	V^+	12 V
Supply	V^-	−12 V

In this configuration, the effective capacitance C_{eq} is determined by the series combination of C_1, C_2, and C_3, as given in Eq. (1),

$$C_{eq} = \frac{C_1C_2C_3}{C_1C_2 + C_1C_3 + C_2C_3} = \frac{(100\text{ nF})^3}{3(100\text{ nF})^2} = 33.3\ \text{ nF}. \tag{1}$$

The frequency of oscillation depends on the LC values, so that it is evaluated by Eq. (2),

$$f = \frac{1}{2\pi\sqrt{(L_1)(C_{eq})}} = \frac{1}{2\pi\sqrt{(30.5\times10^{-6})(33.3\times10^{-9})}} \approx 1.5814 \times 10^5\,\text{Hz}. \tag{2}$$

This theoretical value is used as a reference for the subsequent analysis of both the classical and memristor-based configurations, enabling a consistent comparison among theoretical predictions, simulation results, and experimental measurements.

The experimental measurement setup is implemented using the Analog Discovery Studio kit from Digilent. Table II summarizes the experimental characteristics of the Clapp oscillator. All measurements are performed with the supply conditions, load, and connection topology held constant, so that any differences observed between the Clapp oscillator configurations without and with memristor, can be attributed to the memristive element rather than to external variations in the experimental environment.

Prior to perform the measurements, each oscillator configuration was allowed to operate continuously until transient effects associated with the memristive dynamics had settled. All circuits maintained stable operation for over one hour, with no appreciable variations in the frequency of oscillation, waveform shape, or amplitude beyond normal measurement uncertainty. This confirms that, under the considered conditions, the system reaches a steady-state regime without long-term drift or transitions to alternative dynamical behaviors, and the reported results therefore correspond to steady-state operation.

It is worth noting that the experimentally measured frequency of oscillation (158.14 kHz) shows strong agreement with the theoretical estimation (158 kHz). The minimal deviation observed falls within expected tolerances and can be attributed to non-ideal effects such as component tolerances, parasitic elements, and the finite bandwidth of the active

TABLE II. Standard Clapp oscillator: voltage, frequency, and duty cycle measurements.

V Max	2.2133 V
V Min	-2.0592 V
Vpp	4.2725 V
Frequency	158.14 kHz
Duty cycle (+ / –)	48.33 % / 51.66 %

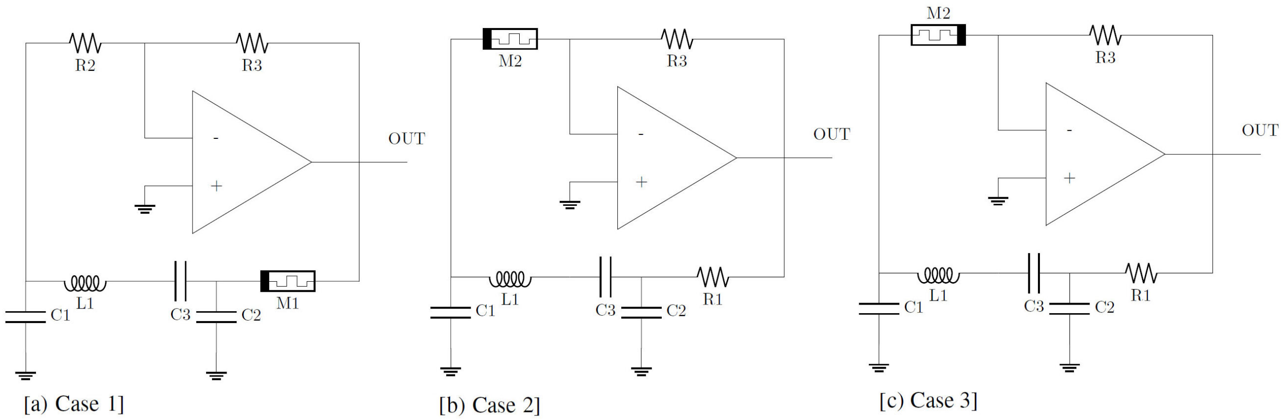

FIGURE 3. Three representative cases by replacing the resistors shown in Fig. 1 by the Knowm memristor: a) memristor M1 replaces resistor R1, b) memristor M2 replaces resistor R2, and c) memristor M2 replaces resistor R2 but in an opposite polarity compared to b).

device. This close correspondence validates the theoretical model used as a reference for subsequent analysis.

Taken as reference the topology of the classical Clapp oscillator shown in Fig. 1, three experimental scenarios are defined herein in which the physical Knowm memristive device is integrated into specific resistive positions within the electrical circuit. In the proposed work, the experimental analysis is deliberately restricted to three representative cases denoted as: Case 1, where the memristor M1 replaces resistor R1 as shown in Fig. 3a); Case 2, where the memristor M2 replaces resistor R2 as shown in Fig. 3b); and Case 3, where the memristor M2 replaces resistor R2 as shown in Fig. 3c), but in an opposite polarity compared to Fig. 3b). As one can infer, specifically these three cases show that the memristor is used as a replacement for R1 and R2, in which Case 3 considers the effect of inverted polarity of the memristor. These three cases exhibit clearly distinguishable behaviors in terms of oscillation frequency, signal amplitude, and temporal symmetry, as shown in the following section.

3. Experimental results

The comparison between the reference Clapp oscillator and Cases 1, 2 and 3 shown in Fig. 3, is performed in this section by using the circuit element values given in Table I. Figure 4 shows the experimental steady-state output waveforms corresponding to Cases 1, 2, and 3 of the Clapp oscillators incorporating the physical memristive device. It can be appreciated that in the three configurations using the Knowm memristor, sustained oscillatory operation appears, confirming that the inclusion of the memristor does not suppress the fundamental oscillation condition. However, noticeable differences in waveform shape, amplitude, and temporal characteristics are evident among the three cases, indicating a strong dependence on both the position and orientation of the memristive element within the circuit.

Observing the experimental output waveform shown in Fig. 4a), which is associated to the topology for Case 1 shown in Fig. 3a), the signal has the largest amplitude among the three configurations and deviates from the sinusoidal behavior of the classical Clapp oscillator shown in Fig. 2. Figure 4a) shows the experimental output waveform with slightly sharper transitions and mild asymmetry between the positive and negative half-cycles, suggesting that the memristor directly influences the steady-state oscillatory regime when placed in a configuration that strongly interacts with the resonant loop.

Figure 4b) shows an experimental output waveform associated to Case 2, which behavior is closer to a sinusoidal signal, with less distortion than in Case 1, but also a little bit different to the experimental sinusoidal response shown in Fig. 2. In this Case 2, which is associated to the topology shown in Fig. 3b), although the memristor is located outside the LC tank network, its presence still affects the oscillatory behavior, resulting in observable but less pronounced deviations from the reference configuration of the Clapp oscillator shown in Fig. 1. This indicates that the memristive dynamics influence the oscillator indirectly by modifying the loop conditions rather than directly participating in the resonance mechanism.

A different behavior is observed in Case 3 in Fig. 4c). Here, the memristor M2 replaces R2 as done in Fig. 3c) but now with an inverted polarity. The experimental output waveform of Case 3 causes a distinct reduction in waveform amplitude and increases the number of oscillation cycles in a similar time window, indicating a higher frequency of oscillation. Notably, the distortion of the waveform is particularly pronounced during the negative half-cycle. This demonstrates that the memristor effect on the oscillating circuit is polarity-dependent, driven by the asymmetric internal dynamics of its structure.

The general experimental results show that incorporating the memristor in Cases 1 and 2 leads to a significant increase in the output signal amplitude relative to the reference configuration of the classical Clapp oscillator, whose characteristics are given in Table II. This effect is accompanied by a notable reduction in the frequency of oscillation. In contrast, Case 3 exhibits a distinctly different behavior: although the

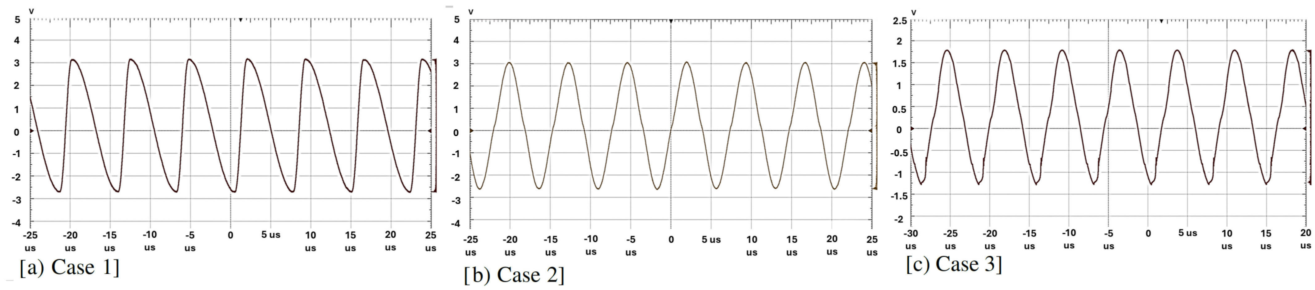

FIGURE 4. Experimental output waveforms of the three representative cases shown in Fig. 3.

oscillation frequency approaches the value of the reference oscillator, the signal amplitude is considerably reduced.

Across the experimental results of the output waveform for all three cases, slight temporal asymmetries are evident in the relative durations of the positive and negative half-cycles. These features suggest that the observed behavior is influenced not only by instantaneous signal conditions but also by specific memristive effects, such as the device's sensitivity to signal polarity and the evolution of its internal state over time.

3.1. Variation of the frequency of oscillation

The frequency of oscillation constitutes a primary indicator of how the inclusion of a memristive element alters the dynamics of the Clapp oscillator. Table III summarizes the experimentally measured frequencies for the reference configuration of the classical Clapp oscillator and for Cases 1, 2 and 3.

As one can appreciate, the experimental oscillation shown in Fig. 2 for the reference Clapp oscillator, indicates that it operates at 158.14 kHz. This measured frequency is consistent with the expected behavior of a stable LC resonant circuit. However, when the physical Knowm memristor is introduced to replace resistors, as shown in Fig. 3, the experimental measured frequencies diminishes. For instance, the experimental waveform shown in Fig. 4a) associated to Case 1, shows that the frequency of oscillation decreases significantly, dropping to 137.41 kHz. This change represents about 13% deviation from the reference configuration of the classical Clapp circuit.

A similar reduction is observed in the experimental output waveform shown in Fig. 4b), associated to Case 2, where the frequency of oscillation decreases to 135.89 kHz, but in general the frequency shift remains comparable to that of Case 1. This confirms that the memristive device's influence on the frequency of oscillation is not limited to direct interaction with the resonant tank but can also arise from indirect modifications to the loop dynamics.

TABLE III. Frequencies of oscillation for the classical Clapp oscillator shown in Fig. 1 and the three cases shown in Fig. 3.

Clapp	Case 1	Case 2	Case 3
158.14 kHz	137.41 kHz	135.89 kHz	155.37 kHz

In contrast, the experimental output waveform shown in Fig. 4c), associated to Case 3 shows a markedly different behavior. When the memristor is placed in the same circuit position as in Case 2 but with reversed polarity, the frequency of oscillation is also lower than that of the reference one shown in Fig. 2, but compared to the experimental output waveform shown in Fig. 4b), reversing the polarity of the memristor makes an increase to 155.37 kHz, approaching the value of the classical Clapp oscillator. This change in frequency trend underscores the strong dependence of oscillatory behavior on the orientation of the physical memristor's polarity.

Overall, the results demonstrate that integrating a physical memristive device can either reduce or increase the oscillation frequency of a Clapp oscillator, depending on its position and polarity within the circuit. These findings support the idea that the memristor acts as a dynamic element that alters the effective oscillation conditions of an LC resonant system, rather than merely introducing a static resistive perturbation.

3.2. Amplitude behavior

The effect of the physical Knowm memristor on the amplitude of the oscillation waveform is evaluated herein by the maximum, minimum, and peak-to-peak voltages of the output signal. These parameters provide direct insight into how the memristive dynamics influence the balance between loop gain and effective losses in the Clapp oscillator. For clarity, the measured amplitude values for the Classical Clapp configuration and for Cases 1, 2 and 3, are summarized in Table IV.

The reference Clapp oscillator exhibits a peak-to-peak voltage of 4.2725 V, corresponding to a stable oscillatory regime with moderate amplitude. When the memristor is in-

TABLE IV. Maximum, minimum, and peak-to-peak voltages comparison for the classical Clapp oscillator and Cases 1, 2 and 3.

Case	V_{Max}	V_{Min}	V_{pp}	Amplitude
Clapp	2.2133 V	-2.0592 V	4.2725 V	2.1363 V
Case 1	3.2022 V	-2.5892 V	5.7921 V	2.8961 V
Case 2	3.1627 V	-2.6002 V	5.7630 V	2.8815 V
Case 3	1.8350 V	-1.2386 V	3.0692 V	1.5346 V

troduced in Case 1, a substantial increase in signal amplitude is observed, with the peak-to-peak voltage rising to 5.7921 V. This increase is consistent with the waveform shown in Fig. 4a), where the signal exhibits larger excursions together with mild distortion.

A similar amplitude enhancement is observed in Case 2, where the peak-to-peak voltage reaches 5.763 V. This behavior indicates that the memristive element can significantly affect the oscillation amplitude by indirectly modifying the loop conditions.

In contrast, Case 3 displays a markedly different amplitude response. When the memristor is placed with inverted polarity, the peak-to-peak voltage decreases to 3.0692 V, representing a substantial reduction relative to both the reference configuration and the other memristor-based cases. This reduction is clearly reflected in the waveform shown in Fig. 4c), where the signal exhibits smaller voltage excursions and increased distortion.

Overall, the amplitude results demonstrate that the physical memristor can either enhance or suppress the oscillation amplitude depending on its placement and polarity within the circuit.

4. Discussion

The experimental observations of the frequency of oscillation, amplitude and symmetry of the temporal responses performed in the proposed work, indicate that the behavior of an LC resonant oscillator can be significantly reshaped by adding a memristive element, even when the overall circuit topology remains unchanged. The dependence of the oscillatory regime on the device's position and polarity highlights that the memristor introduces additional dynamic degrees of freedom into the system.

From a physical perspective, the observed frequency shifts suggest that the memristor alters the dynamic balance between energy storage and dissipation within the oscillation loop. Rather than contributing a constant resistive term, the memristor serves as a state-dependent resistive and memory element. Its instantaneous influence on the oscillation cycle arises from its internal state changing in response to the voltage and current history, directly affecting circuit dynamics. This state dependence provides a clear explanation for the different frequency trends observed across the tested configurations.

The polarity-dependent changes in amplitude and temporal symmetry further support this interpretation. The inversion of waveform asymmetry observed when the memristor orientation is reversed indicates that the device's internal dynamics are not symmetric with respect to voltage polarity. Such asymmetry implies that the memristor interacts differently with the oscillatory loop during positive and negative signal excursions, leading to unequal energy exchange between the two halves of each cycle.

Importantly, these effects persist even when the memristor is not embedded in the LC tank. This indicates that the memristor's role is not limited to simply modifying the resonant network. Rather, the memristor modulates the oscillator by altering the global loop conditions, thus influencing gain, losses, and phase throughout the system. This demonstrates that memristive effects in resonant oscillators arise from the memristor's system-wide interactions, rather than being confined to a single circuit element or described by purely static models.

Overall, this highlights that the memristor acts as an active element in oscillation dynamics: its state evolution and polarity sensitivity directly shape the system's steady-state behavior. Recognizing these roles is essential for understanding and predicting how resonant circuits incorporating memristive devices will behave.

5. Conclusions

The proposed work experimentally demonstrates that a physical memristive device can be integrated into a Clapp oscillator without suppressing sustained oscillation. The presence of the memristor leads to reproducible changes in oscillation frequency, output amplitude, and temporal symmetry, which depend on both the device's position and polarity within the circuit.

The experimental analysis shows that the frequency of oscillation is strongly influenced by both the placement and orientation of the memristor. Circuit configurations corresponding to Cases 1 and 2 exhibit a clear reduction in frequency relative to the reference oscillator, whereas reversing the polarity of the device in Case 3 produces an increase in frequency approaching the reference value. These observations confirm that the memristor introduces a dynamic contribution to the oscillation conditions that cannot be described as a fixed resistive effect.

Amplitude measurements further reveal that the memristor can either enhance or suppress the output signal depending on the configuration. While Cases 1 and 2 lead to a significant increase in peak-to-peak voltage, Case 3 results in a pronounced reduction in amplitude. This contrasting behavior, observed under otherwise identical circuit conditions, highlights the oscillation loop's sensitivity to the device's internal state and polarity-dependent dynamics.

In addition to frequency and amplitude variations, all memristor-based configurations exhibit measurable temporal asymmetries between positive and negative half-cycles. These temporal features reinforce the interpretation of the memristor as a history-dependent element that modifies the steady-state oscillatory regime beyond conventional linear expectations.

The results confirm that the memristor cannot be treated as a static resistive element in an LC resonant oscillator, as its dynamic and polarity-dependent behavior directly influences the steady-state oscillatory regime. The Clapp topology has been shown to provide a stable, well-defined platform for observing these effects under controlled experimental conditions.

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