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Effects of Memristor on Oscillator and Regulator Circuits

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ABSTRACT

Many recent nanoscale studies have paved the way for obtaining suitable models for describing the nonlinear dynamics of memristive elements. Memristor, which is one of these elements and expresses the relationship between magnetic flux and electric charge, has had a wide application area since it has been modeled. In this study, oscillator and regulator circuits are designed as memristive, and these circuits are investigated with important parameters such as power consumption, operating speed, and regulation. Considering the Wien bridge oscillator and voltage regulator circuits as the working environment, the performance comparison is made by using the memristor circuit model instead of the standard resistor. The results obtained are interesting because they show the advantages of using memristor in both oscillator and regulator circuits in terms of power consumption, speed, and regulation properties.

***Index Terms*—**Memristive systems, memristor, oscillator circuit, regulator circuit

I. INTRODUCTION

Memristive elements offer promising alternatives compared to the conventional memory devices. Having nanoscale structures and permanent memory properties gives them a great advantage over other memory elements [1, 2]. In addition to basic memristive elements such as memristor, memcapacitor, and meminductor, more complex elements such as memdiode, memtransistor, and memristive op-amp have become one of the frequently studied topics in the electronics world under the title of memristive systems [3-6]. Although the memristor, which is the most basic memristive element, is a common application for new memory researches, it can also be used as functional blocks in many basic application circuits such as analog circuits, neuromorphic systems, and logic circuits [7-11]. Memristors whose resistance depends on an internal state variable are two-terminal devices that can be modulated by the external excitation history [12]. Memristor is the fourth basic passive element after resistor, capacitor, and inductor, which is defined in the relationship between electric charge and magnetic flux, which are fundamental quantities of electricity [13, 14].

Studies on the memristor element defined by Chua [13] continued theoretically for many years, and as a result, few studies have been reported. Nearly four decades later, since its physical fabrication by Strukov et al. [15] in 2008, there has been an enormous growing interest in the memristor and its mathematical models [16-19]. It has been reported that many mathematical models proposed for the memristor element give very useful results in the simulation of memristor circuits [20-22]. These memristor designs based on mathematical model are mostly on continuous-time memristor and analog circuit studies. In addition, discrete-time memristor mathematical models, which offer new and important possibilities for memristor modeling and analysis, have also started to take place among the fields of study [23, 24]. Until a completely stable version of the memristor production is realized, it is preferred by many researchers to use emulator circuits instead of memristor element [25, 26]. For example, an emulator circuit designed by using the bridge circuit with a parallel RC filter and a memristor emulator using the op-amp and analog multipliers (AMs) are some of the emulators in the literature [27, 28]. These emulator circuits, which are realized with a small number of elements, allow the experimental establishment of various memristor circuit applications. This situation has led to studies on the performance comparison of these emulator circuits among themselves and also on the determination of performance improvements when the memristor is replaced with a standard resistor [29-33]. These studies are important because they consider a wide range of operating perspectives, such as power

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consumption, operation speed, operating range, signal amplification, and transmission, depending on the circuit's characteristics.

In this study, the oscillator and regulator circuits, which are two important electronic application circuits, are handled as both memristive and resistive, and a performance comparison is presented. Comparison is done in order to obtain a better circuit quality in terms of important circuit parameters such as power consumption, operation speed, and voltage regulation. First of all, a Wien bridge oscillator is taken into account to produce a more undistorted sinusoidal signal, to consume less power, and to have a minimum time delay while generating the oscillator signal. For this purpose, the effects of using a memristor instead of a standard resistor in the oscillator circuit are examined. Then, a voltage regulator circuit is considered, and it is examined that the regulated signal in this circuit has less variation and less oscillation. For this, the effects of the memristor, which is used instead of the standard resistor in the regulator circuit, on the regulation performance and power consumption are examined.

The paper is divided into several sections. General information about the memristor, the memristor emulator circuit to be used in the study, and the working principle of this emulator are reviewed in Section II. Section III explains how to obtain memristive oscillator and regulator circuits by applying the memristor emulator circuit to a Wien bridge oscillator and a voltage regulator circuit. This section also analyzes the simulation results and compares the proposed memristive circuits to the current resistive circuit, with regard to key circuit parameters selected. Section IV concludes the work and sets out its future scope.

II. MEMRISTOR AND EMULATOR CIRCUITS

A. Memristor

Memristor is a two-terminal electronic device whose conductance can be precisely modulated by charge or flux through it [34]. The voltage–current relationship of a memristor is called memristance and is expressed as:

$$M\left(q(t)\right)=\frac{d\varphi(t)}{dq(t)}=\frac{\frac{d\varphi}{dt}}{\frac{dq}{dt}}=v(t)/i(t) \tag{1}$$

Here, the derivative of the magnetic flux and the derivative of the electric charge refer to the voltage and current, respectively. Therefore, the unit of the memristance is ohm, just like the standard resistor element. The voltage–current characteristic of the memristor is shown in Fig. 1. According to this characteristic, the simultaneous passing of the current and voltage from the zero point indicates that the memristor does not store any energy. In addition, the leaves in the characteristic become narrower with increasing source frequency values. Thus, the power is always positive, and this means that the memristor is passive because it consumes power [13].

Memristor element has a structure whose resistance can be increased or decreased according to the current applied to it [35]. When the current is cut off and given again, it continues from the resistance it left off. This situation can be explained more clearly with the analogy of water flowing through an elastic pipe. The diameter

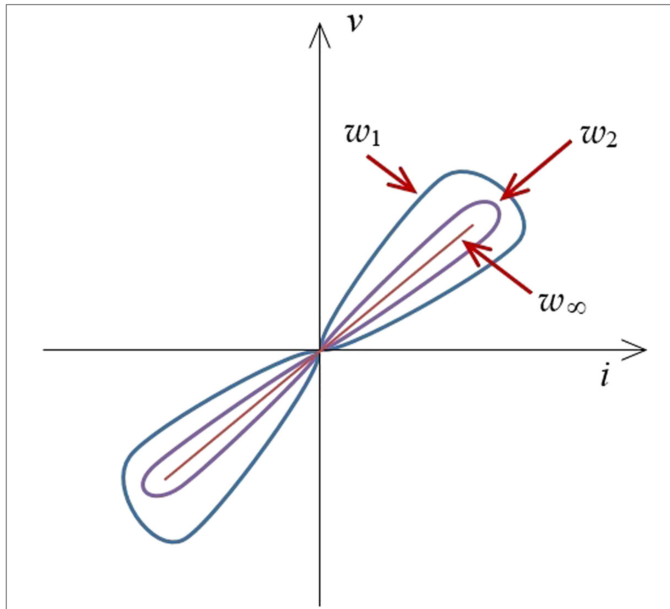

Fig. 1. Voltage–current characteristics of a memristor.

of the pipe expands according to the applied water in one direction and narrows in the opposite direction. When the water is cut off and given again, the diameter of the pipe continues from its last value. This analogy describes the memory state of the memristor [36]. The important point here is that the amount of water flowing from the pipe changes as well as its direction. Therefore, the time-dependent property of the memristance formula in (1) is also physically understood.

B. Memristor Emulator Circuit

Many different mathematical models and circuit emulators have been reported to use the memristor, which is still a new element, in different circuit applications [37]. The most important advantage of a circuit emulator over a mathematical model is that the use of memristors can be applied not only in simulation studies but also experimentally. The circuit emulator used in this study is given in Fig. 2 and includes four positive second-generation current conveyors (CCII+), one AM, one capacitor, and three resistors [25]. The elements used in the circuit are given as $R_1=47$ kΩ, $R_2=10$ kΩ, $R=200$ kΩ, and $C=100$ nF. For the CCII+ and the AM, AD844 and AD633 integrated circuits are used, respectively. Here, v_2 represents the inverting input voltage, v_3 the noninverting input voltage, i_2 the inverting input current, i_3 the noninverting input current, and i_5 the output terminal current for the AD844, while v_{X1}, v_{Y1} are the input voltages, i_{X1}, i_{Y1} are the input currents, and v_W is the output voltage for AD633. For the mathematical analysis of the circuit, first of all, the basic definitions $v_2=v_3$, $i_3=0$, and $i_2=i_5$ for ideal CCII+ and $i_{X1}=i_{Y1}=0$ and $v_W=kv_{X1Y1}$ for ideal AM should be taken into account (k is a constant). Accordingly, if v_C is defined as the capacitance voltage and v_R is the resistor voltage, the general mathematical analysis of the emulator circuit is given as:

$$v_C(t)=\frac{q_c(t)}{C} \tag{2}$$

$$v_R(t)=-\frac{R}{R_1}v(t) \tag{3}$$

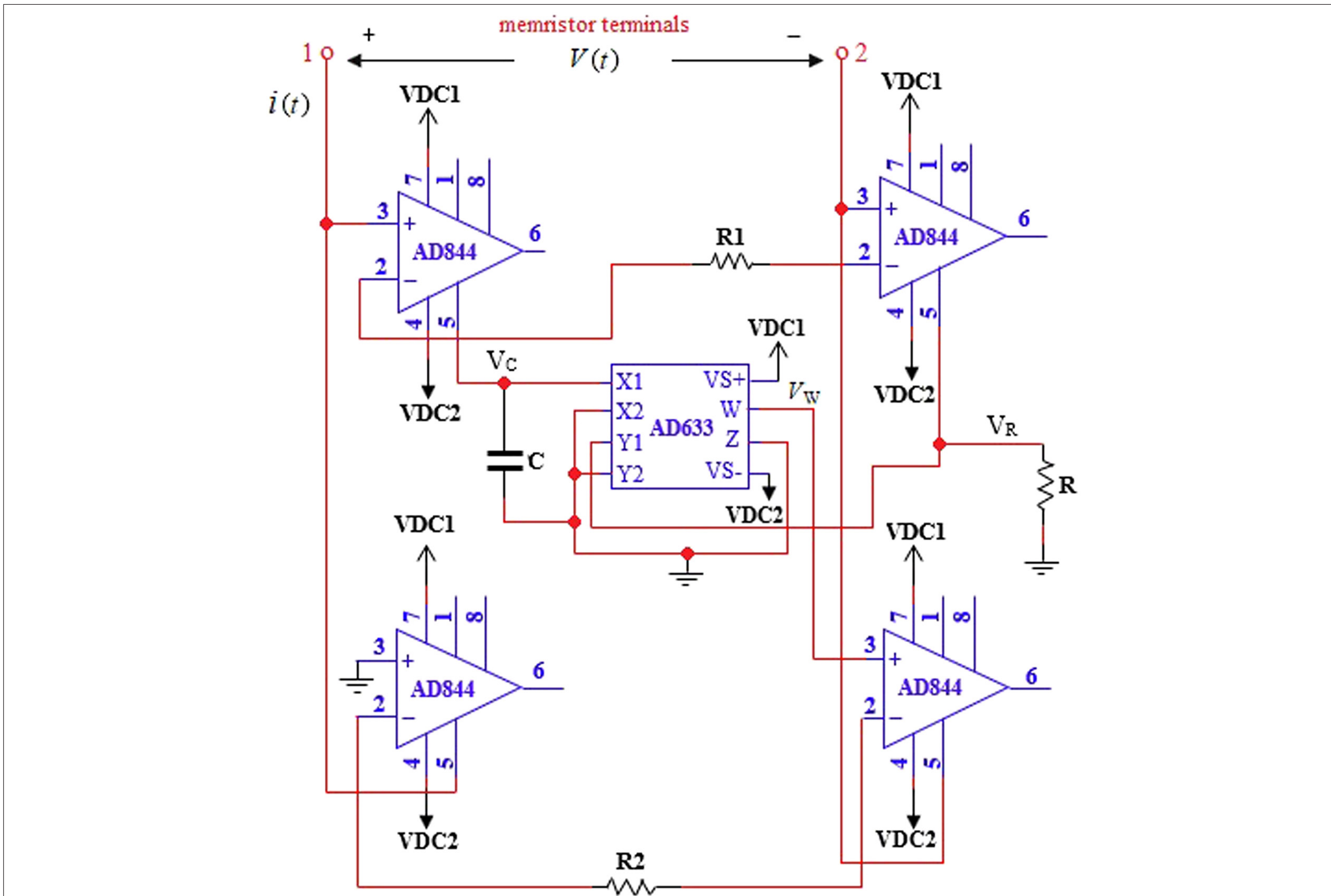

Fig. 2. Emulator circuit model of the memristor [25].

$$v_W(t)=v_C(t)v_R(t)=-\frac{kRq_c}{R_1C}v(t)=\pm R_2 i(t) \quad (4)$$

$$v(t)=M(t)i(t) \quad (5)$$

$$M(t)=\pm\frac{R_1R_2C}{kRq_c(t)} \quad (6)$$

Here, $M(t)$ is the memristance of the memristor. It can be seen from (6) that the memristance is inversely proportional to the charge. The minimum and maximum values of $M(t)$ depend on the passive element values in the circuit. Figure 3 shows the voltage–current characteristics of the emulator circuit obtained with the Multisim simulation program. It is observed from the figure that the emulator provides the memristor characteristic as expected, and the leaves in the characteristic become narrower with increasing frequency values.

III. APPLICATION OF THE MEMRISTOR EMULATOR

The memristor has been the subject of many analog and digital circuit applications due to its memory structure. For detailed information, refer to [1]. In this section, the comparisons are made in terms of some important circuit parameters by using the memristor instead of the a standard resistor in the Wien bridge oscillator and voltage regulator circuits.

A. Implementation of the Memristor Based Wien Bridge Oscillator Using Emulator Circuit

Wien bridge oscillator circuit which is frequently used in electronic applications is shown in Fig. 4. This oscillator circuit is an RC phase shift oscillator that uses both positive and negative feedback. As can be seen in the figure, the R_xC_x part shows a low-pass filter feature, while the R_yC_y part provides a high-pass filter feature. This study aimed to use a memristor instead of the R_y resistor in the oscillator circuit in the figure and to consider the emulator circuit given in Section II as a memristor. Thus, the working principle of the memristive oscillator circuit has been examined. For this application, the elements in the circuit are selected as $R_x=10$ kΩ, $C_x=10$ nF, $R_y=10.6$ kΩ, $C_y=10$ nF, $R_3=10.5$ kΩ, $R_4=22$ kΩ, and U_1 op-amp is UA741. Simulation studies on Multisim show that both the resistive and the memristive oscillators provide the required oscillation as expected. Here, the parameters such as power consumption and operating speed, which are important for an electronic oscillator, are examined. According to the current and voltage values given in Fig. 5, the power consumed by the resistor circuit is 2.552 mW, while the power consumed by the memristive circuit is 1.766 mW. These values show that the memristive oscillator circuit is more advantageous than the resistive one in terms of power consumption. Besides, when the time

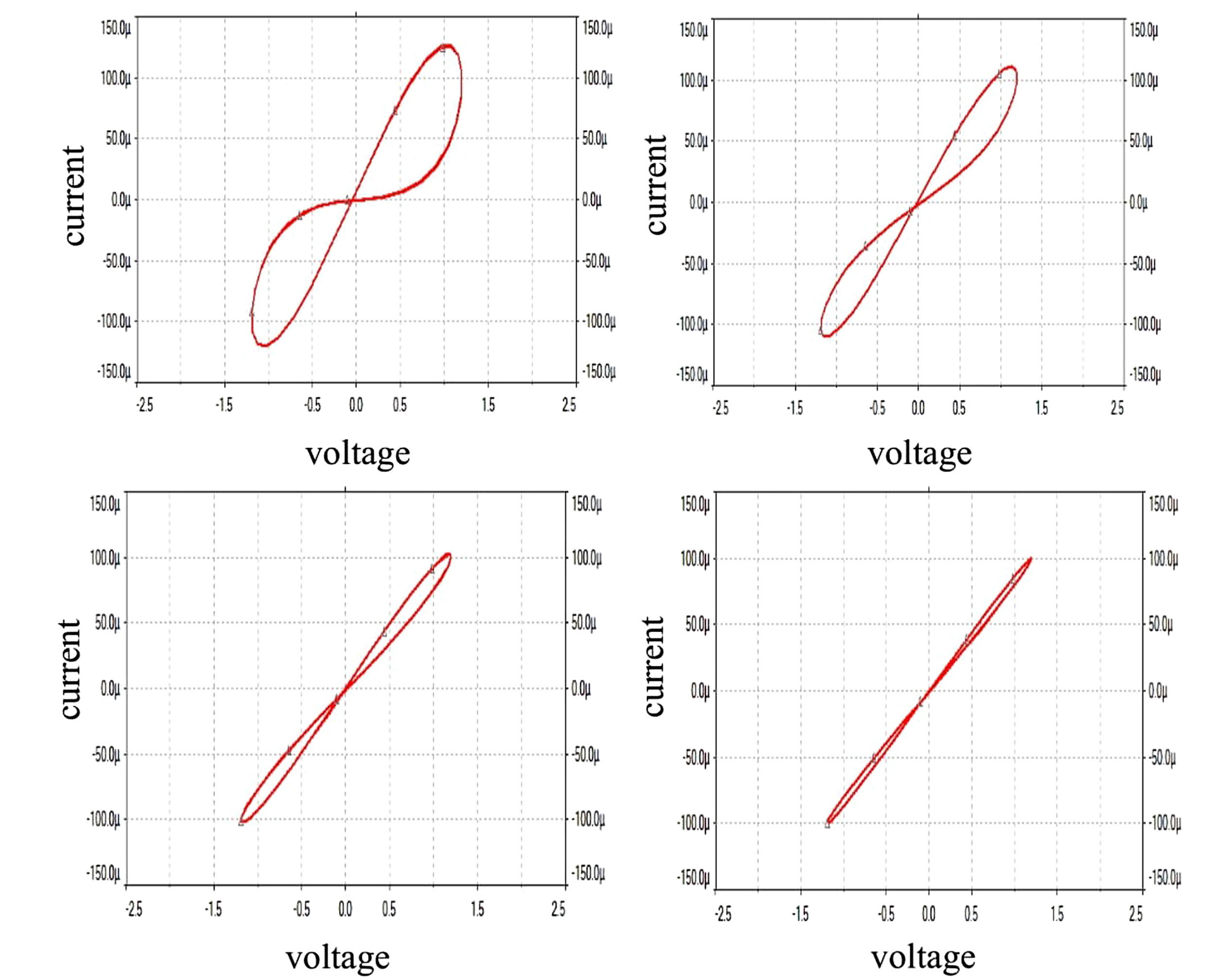

Fig. 3. Current–voltage characteristics of the memristor at different frequencies (20, 40, 100, and 250 Hz).

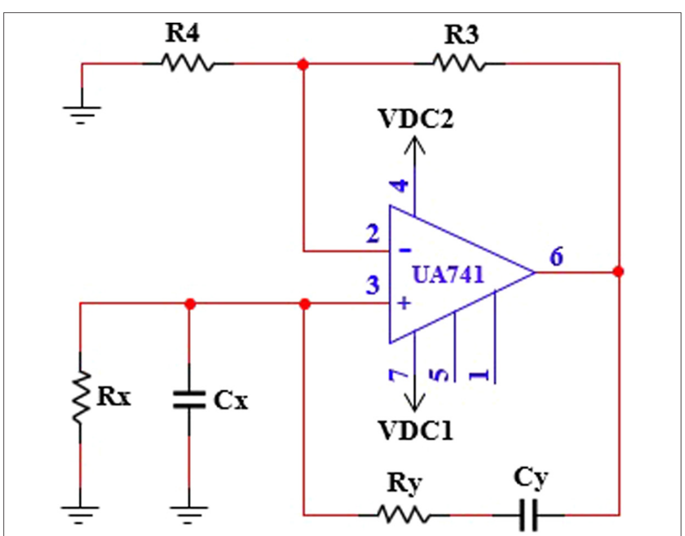

Fig. 4. Wien bridge oscillator circuit.

delay parameter in the oscillators is taken into account, it is seen that the resistive oscillator circuit in Fig. 6 reaches its settling time after 230 ms and the memristive circuit reaches its settling time after 15 ms. These results again reveal that the memristive circuit is more advantageous than the resistive circuit.

B. Implementation of the Memristor-Based Voltage Regulator Circuit Using Emulator Circuit

The DC supply voltage required for electronic circuits must be constant at a certain value and must remain within an acceptable voltage range [38]. Voltage regulator circuits are needed to keep this supply voltage constant. There are various regulator circuits with zener diodes, transistors, op-amps, or integrated circuits to produce a constant output voltage. The most important parameters that determine the operating performance of the voltage regulator circuits are the quality of the voltage regulation and the amount of power consumed by the regulator circuit. In this study, a voltage regulator circuit shown in Fig. 7 is considered. The elements used in here are as follows: $V_1 = 1$ V/100 Hz, $V_2 = 8$ V, $R_1 = 1$ kΩ, $R_2 = 100$ Ω, $R_3 = 8$ kΩ, $R = 10.6$ kΩ, U_1 op-amp is UA741, Q_1 transistor is 2N2222,

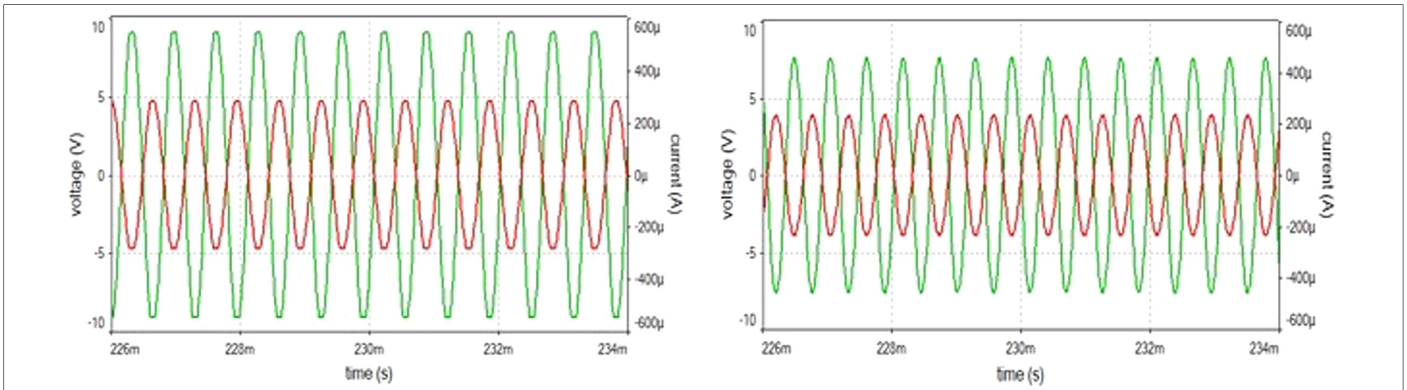

Fig. 5. Resistive (left) and memristive (right) Wien bridge oscillator current (red)–voltage (green) graphs.

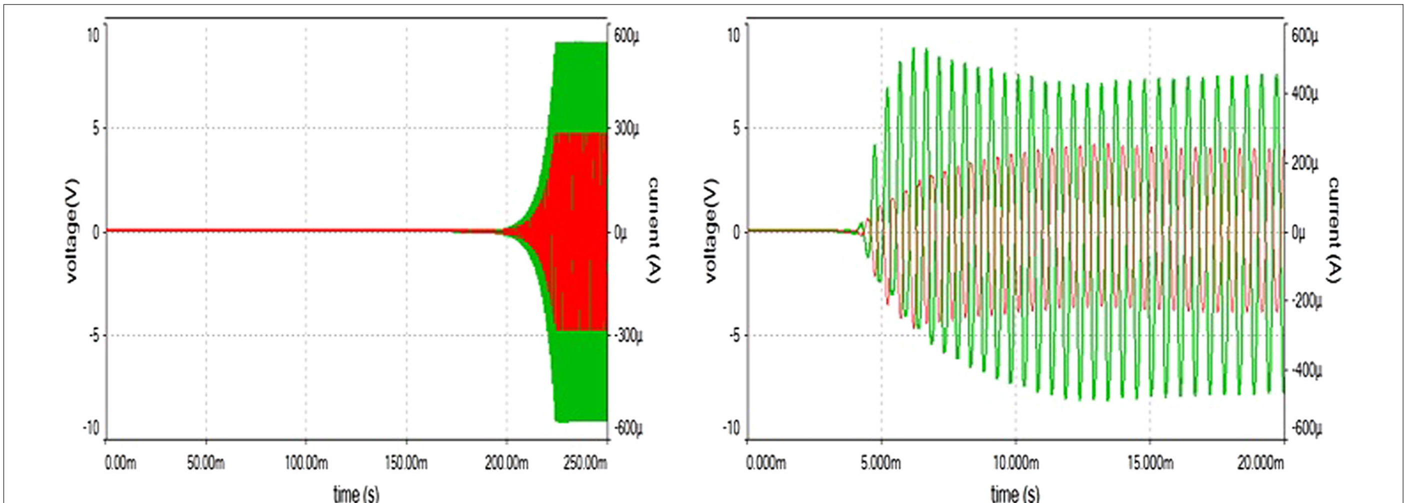

Fig. 6. Settling times of the resistive (left) and memristive (right) Wien bridge oscillator circuits.

and D_1 zener diode is 1N750. The resistive circuit in the figure can be converted into a memristive voltage regulator circuit by using a memristor instead of the resistor *R*. Figures 8 and 9 show the input and output voltage waveforms for resistive and memristive regulators, respectively. The signals shown in red in the figures represent the input voltages in the form of DC voltage added to the AC voltage, and the signals shown in green represent the regulated output voltages. In the lower right part of the figures, these voltages are further emphasized by zooming in. While the peak-to-peak amplitude of the regulated output voltage wave in the resistive voltage regulator circuit was 32.25 mV, this value was measured as 25.14 mV in the memristive regulator circuit. This result means that a memristive voltage regulator provides a better voltage regulation than a resistive voltage regulator. In addition, the power consumed in the resistor circuit is 14.11 mW, and the power consumed in the memristive circuit is 10.65 mW. The memristive regulator circuit consumes less power than the resistive regulator circuit.

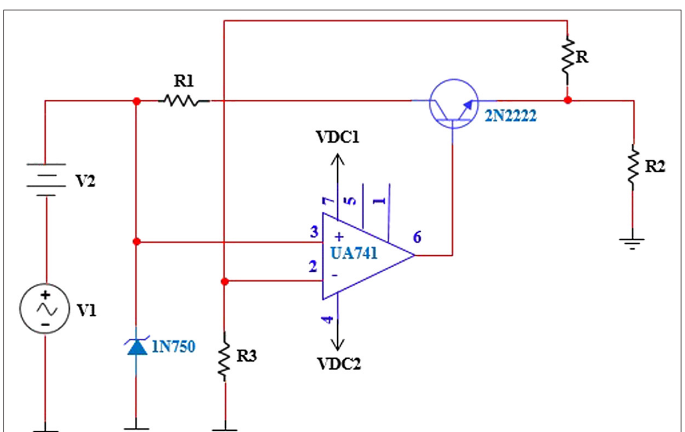

Fig. 7. Voltage regulator circuit.

IV. CONCLUSION AND FUTURE SCOPE

Electronic circuits are designed by considering important parameters that directly affect the quality of the circuit. In this study, the Wien bridge oscillator circuit and the voltage regulator circuit were taken into account, and a performance comparison was made between the resistive and memristive cases of these two circuits by considering some parameters. In the Wien bridge oscillator, the power consumption and the time to reach steady state of the oscillating signal are chosen as the test parameters. Accordingly, it was concluded that the memristive Wien bridge oscillator consumes

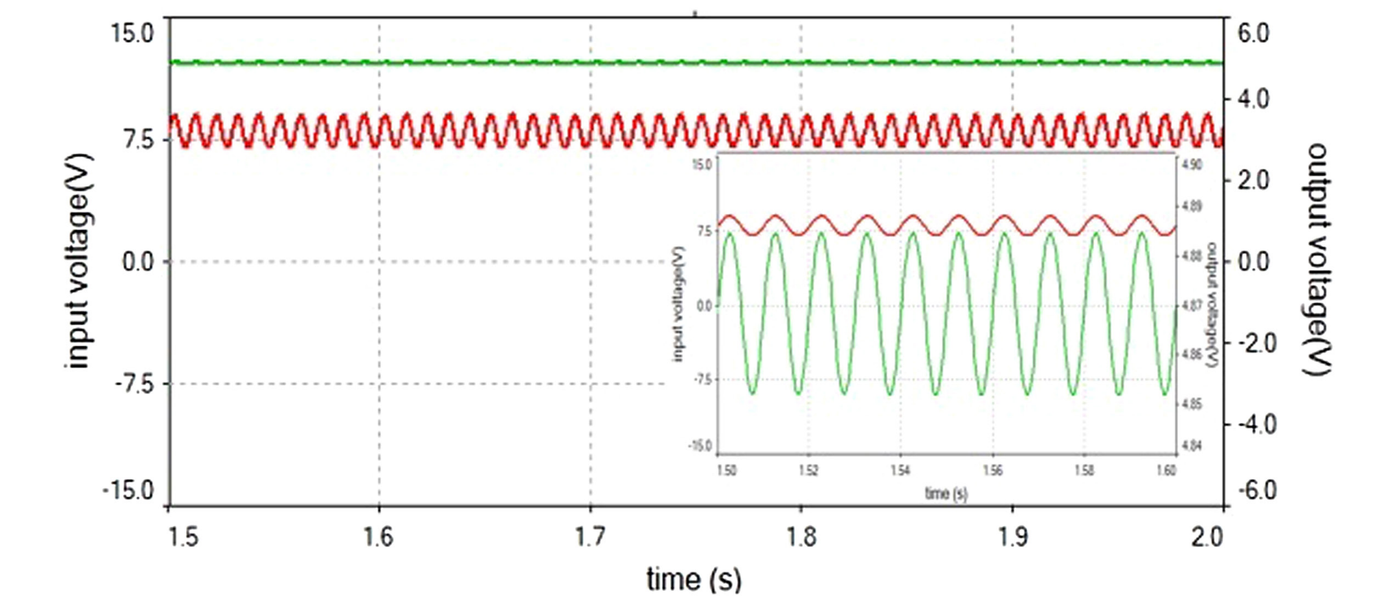

Fig. 8. Input (red) and output (green) voltages of the resistive voltage regulator and their zoomed views.

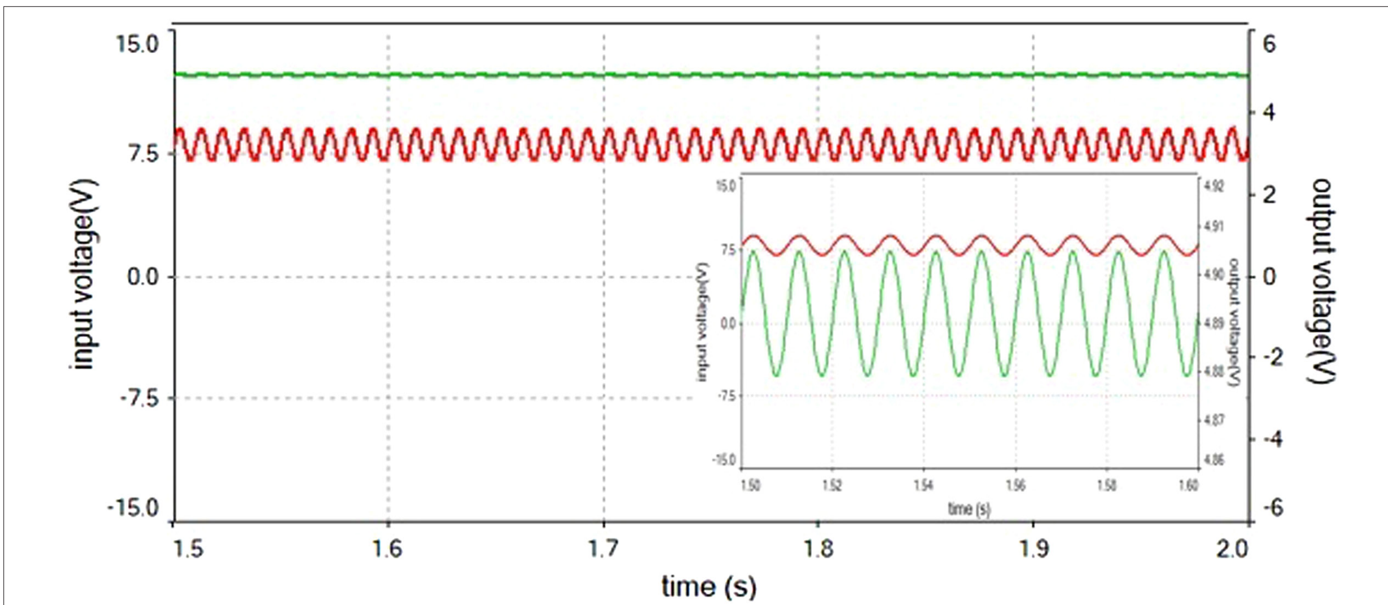

Fig. 9. Input (red) and output (green) voltages of the memristive voltage regulator and their zoomed views.

30.8% less power than the resistive one. In addition, in the memristive oscillator circuit, the oscillating signal starts at about 4 ms and reaches a steady state around 15 ms, while in the resistive oscillator circuit the signal starts at about 200 ms and reaches a steady state around 230 ms. This means that the operational speed in the memristive oscillator circuit is approximately 15 times faster than in the resistive oscillator circuit. In the voltage regulator circuit, voltage regulation and power consumption were chosen as the test parameters. It has been observed that the memristive circuit provides a voltage regulation with approximately 22.05% less oscillation than the resistive circuit. In addition, 24.52% less power consumption was observed in the memristive regulator circuit compared to the resistive regulator. The results obtained for both circuits strengthen the idea that memristiveness contributes to the efficiency of electronic circuits. Thus, it is seen that the memristor can be used in various other circuit applications with different properties. As a continuation of the study, it is aimed to develop new circuits with a wider operating range than the emulator circuits available in the literature in the future and to apply them to electronic circuits.

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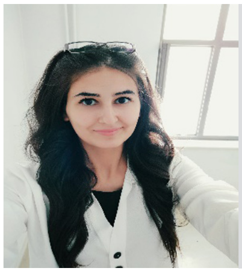

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