Programmable Résistors : Model and Applications

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***Abstract*— In this paper, we present the model of programmable resistors based-on memristor component. We also show the interest to use programmable resistor in the case of analog electronic circuits. In the first of paper, we present the memristor. In fact before 1971, the passive electrical components is limited to three: resistor, capacitor and inductor. In 1971, Chua predicts the existence of a fourth element that links the charge to the magnetic flux. After a discussion on the modeling of memristor and critics of the scientific community about the existence of the memristor and its modeling, in the second part, we will present Matlab simulation results of HP lab model. We will also show the interest of using memristor in analog electronic circuits through a programmable resistor model.**

***Index Terms*— Programmable resistors, Memristor, modeling, programmable resistor applications.**

I. INTRODUCTION

The memristor, or memory resistor, is a two-terminal passive electronic component. It was introduced in 1971, by Professor Chua, in an article of the IEEE journal Transaction on Circuit Theory [1]. Chua noted that there are four different mathematical relations connecting of the three passive electrical components: resistor, capacitor and inductor. The physical variables allowing the relation between these three components are: current, voltage, electrical load and magnetic flux. These relations are deduced from Faraday's law. Chua compared the above model to Aristole's model of matter. Thus, depending on the above model he saw a striking resemblance and predicted the existence of the fourth electrical component called memristor, which link the electrical charge to magnetic flux.

II. MEMRISTOR MODELING

A. *Discussion on the modeling of memristor*

Two pairs of equations define the memristor: electrical load control and the magnetic flux control [1].

For electrical load control:

$$v(t) = M\big(q(t)\big)i(t) \qquad (1)$$

$$M(q) = d\varphi(q)/dq$$

For magnetic flux control:

$$i(t) = W\big(\varphi(t)\big)v(t) \qquad (2)$$

$$W(\varphi) = dq(\varphi)/d\varphi$$

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According to the mathematical relations, the electrical resistance of the memristor is not constant but depends on the current that had previously circulated through the device. In 1976, L. Chua introduced dynamic equations to define a memristive system with the property of "pinched hysteresis loop" between current and voltage [2] [3]. According to Biolek, this footprint of the memristif is "self crossing" which corresponds to a cross with coordinates (0 : 0) [4].

In 2008, an HP lab manufactures the first memristor component with layers of TiO_2 between two layers of Pt [5]. HP also introduces a mathematical model of component operation. The scientific community in several points has criticized this model:

- The use of the term "Fourth Component" is questioned [6][7][8][9]. Some experimental evidence contradicts the generalization of Chua, since a non-passive nanobattery effect is observable in the resistance switching memory [10].

- Williams argued that MRAM, phase change memory and RRAM were memristor technologies [11]. Some researchers have argued that biological structures such as blood [12] and skin [13] [14] fit the definition. Others have argued that the memory device developed by HP Labs and other forms of RRAMs were not memristors but rather part of a larger class of variable resistor systems [15]. Thus, the broader memristor was an unjustifiable scientific position for patents [16].

- In 2011 and in 2012, Meuffels indicates the existence of an erroneous hypothesis concerning the ionic conduction [11][17]. This error is the result of shortcomings in the electrochemical modeling presented in the HP Lab article.

- Meuffels and Soni also revealed an important inconsistency: If a current-controlled memristor with the property of non-volatility exists, its behavior would violate the Landauer principle: minimal amount of energy required to change the "information" states of a system [6] [3]. Indeed, the storage of nonvolatile information requires the existence of energy barriers. In the opposite case, the system would arbitrarily oscillate from one memory state to another just under the influence of thermal fluctuations. Di Ventra and Pershin finally adopted this criticism in 2013 [7].

A. *Memristor modeling*

As discussed previously, there is no scientific consensus regarding the definition of the memristor as well as its modeling. Thus, in this article as the first approach, we have chosen to use the HP Labs model to define the operation of a memristor. Our objective being twofold: this model will enable us to simulate the variation of the memristor value as a function of the voltage as well as the "pinched hysteresis loop" characteristic between current and voltage. It will also allow us to show the interest of the memristor in analog electronics through its use in a number of typical circuits.

The HP model's is based on the "modulation" of the size of the doping zone w of the memristor between the value R_{on} and R_{off} as a function of the electrical loads (current) that runs through the component.

$$M(q) = R_{off}\left(1 - \frac{\mu_v R_{on}}{D^2} q(t)\right) \qquad (3)$$

$$w(t) = \mu_v \frac{R_{on}}{D} q(t)$$

With $M(q)$, the instantaneous value of the memristor, w the size of the doped zone, D the total size of the doped zone, μ_v the mobility of the electric charge.

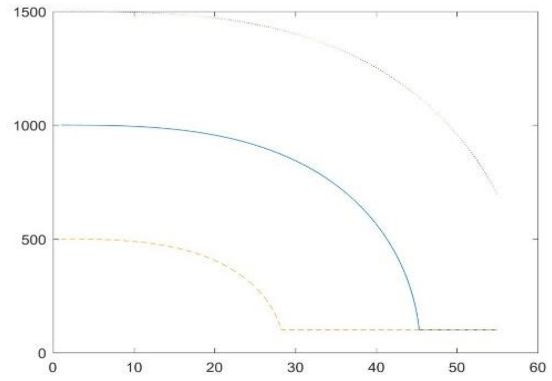


Fig. 1 The transient response of the memristor value under ramp input source $v(t)=tV$, for different initial value: 500, 1000 and 1500 Ω

Fig.1 illustrates the change of the memristor value versus time under rampe input voltage source, for three initial values 500, 1000, 1500 Ω and R_{on} , R_{off} are fixed to 100, 16000 Ω. Also as see on fig1, the low value of memristor is limited to R_{on}.

As discussed before, the footprint of the memristor appear under sinusoidal input. Thus, the "pinched hysteresis loop" between current and voltage is shown in Fig.2. For this simulation, we choose the electrical load control.

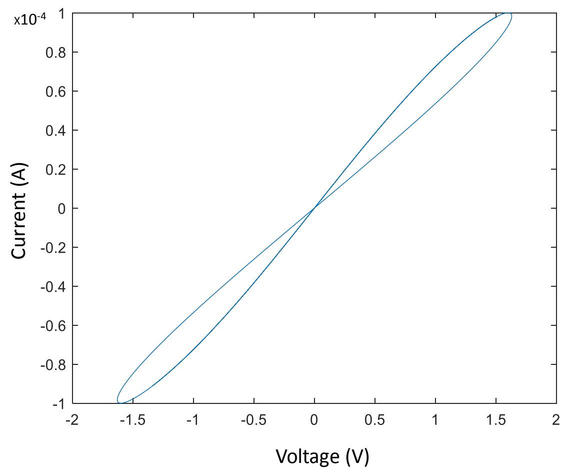
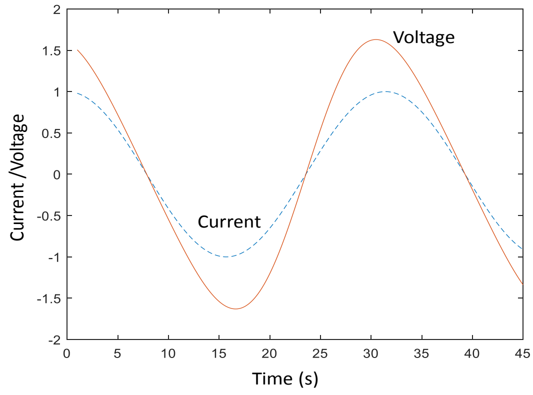
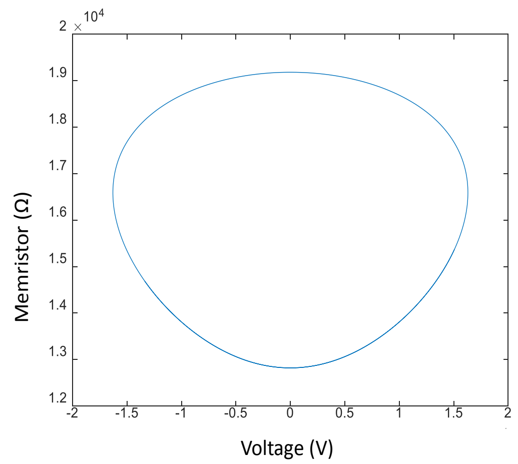


Fig.2 Pinched hysteresis loop appear between current and voltage for sinusoidal input with frequency $f=0.1$ Hz

In Fig. 3 show, respectively, variations of current and voltage versus time (a). Note that 10^{-4} multiply values of current. Fig. 3 (b) illustrate the variation of memristor versus voltage.



(a)



(b)

Fig. 3 Variations of current and voltage versus time (a) and memristif values versus voltage (b)

III. PROGRAMMABLE RESISTORS

In this section, we will present two examples of programmable resistor applications in analog electronic circuits.

First, we introduce a model of programmable resistor that is built using a memristor as shown in Fig. 4. This programmable resistor consists of a memristor, two switches (S1 and S2) for programming the desired resistance value on the memristor, a programming voltage generator. Both capacitors (C1, C2) allow DC decoupling of the memristor. The programmable resistor will be connected to the analog circuit between the points A and B.

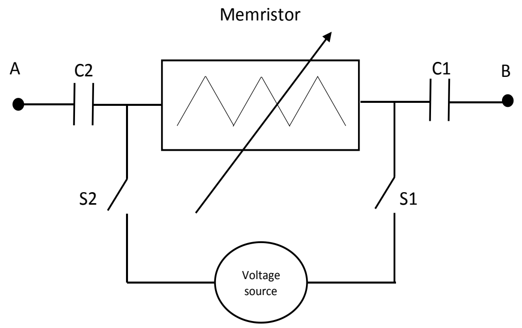


Fig. 4 Programmable resistor

To illustrate the use of the programmable resistor, we will use it in an amplifier circuit and a second-order bandpass filter.

The chosen amplifier is an instrumentation amplifier widely used in analog electronics. Fig. 5 shows the circuit and the evolution of the gain as a function of the value of the programmable resistor.

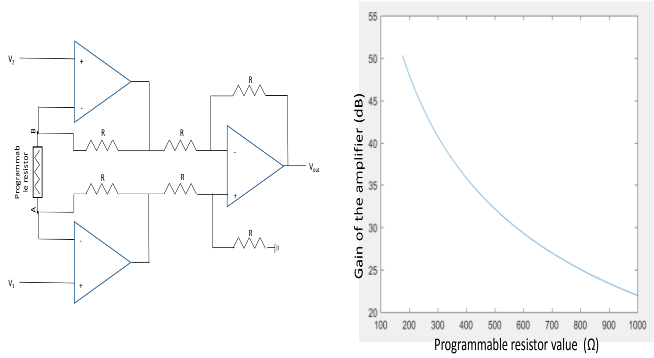


Fig. 5 Schematic of the instrumentation amplifier and evolution the gain versus value of the programmable resistor

Fig. 6 shows the evolution of the high and low cut pulsations in the case of a second-order band pass filter.

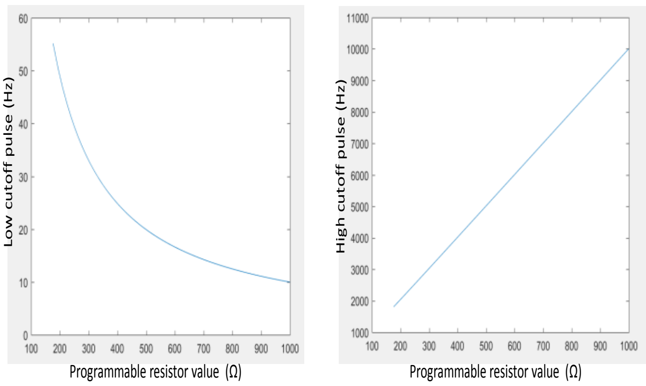


Fig. 6 High and low cut pulsations versus programmable resistor values.

Fig. 7 shows the Bode diagram of the filter when the value of the programmable resistor is set to 1000 Ω

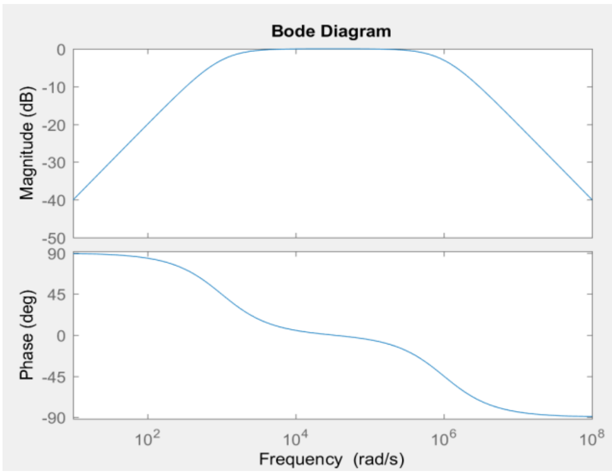


Fig. 7 Bode diagram of filter

The results obtained for both applications (amplifier and filter) show a real interest in using the memristor-based programmable resistors. Indeed, it is easy to obtain different functional characteristics of analog circuits with a programming of the value of the memristor.

IV. Conclusion

In this article, we discuss the modeling of memristors and define the programmable resistors model and their interest in analog electronic circuits.

In the first part of the article, we presented the principle of memristors developed by Professor Chua. We also presented the model developed by HP lab. A discussion showed the different points of view and the mistrust of the scientific community on the existence of the memristor as well as on its modeling.

In the second part, we modeled the memristor using Matlab software. We have shown the current-voltage characteristic, which is the fingerprint of a memristor device, in the case of a sinusoidal polarization. After, we developed the circuit of a programmable resistor based-on memristor component.

The interest to use the programmable resistors in analog electronic circuits is show through two examples. Indeed, it is easy to obtain different functional characteristics of analog electronic circuits with a programming of the value of the memristor.

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