International Conference on Computer Engineering, Information Science & Application Technology (ICCIA 2016)

Responses to Stimulating Signals of Memristive Circuit Based On LC Contour

Yujie Cao [a], Shuai Ye [b]

College of Electronic Science and Engineering, Nanjing University of Posts and Telecommunications, Nanjing, 210046, China

[a]b13020110@njupt.edu.cn, [b]b13020114@njupt.edu.cn

Abstract. As typical memory elements, memristor and memcapacitor have attracted much attention. In this work, we investigate the characteristics of the voltage controlled memcapacitor. Furthermore, the memristive circuit which is based on LC contour and consists of memcapacitor and memristor is also researched and we find that it can also simulate the amoeba's learning behavior. In particular, the circuit in this paper can respond to periodic signals with different frequencies more than once which may make the further simulation and investigation in neurography and bionics more efficiently.

Keywords: Memristor; Memcapacitor; Memristive circuit with LC contour.

1. Introduction

Memory effect is a universal phenomena in materials, devices, complex circuits, systems and especially in biology. To simulate the memory phenomena of biological process by existed circuit and system has always been a significant topic in neural network, bionics and artificial intelligence. Chua proposed a fundamental memory element called memristor which can memorize the amount of charge flowing through it in 1971[1]. Later, in 1976[2], he extended this concept to a more comprehensive memory system. Although these concepts have been put forward about four decades ago, the realization of the device has not come out until 2008[3].

Strukov *et al* at Hewlett-Packard lab found out that, the vacancies of oxygen will move under the bias voltage, and hence change the resistance distribution of the material TiO_{2-x}, in which vacancies of oxygen act as the donor centers. Especially for the nano-size materials, the electric field will be enhanced tremendously and the field will be strong enough to make the ion immigrate. Based on the sandwich structure, the HP-device can perform a pinched *v*-*i* hysteresis behavior, which is believed as the typical properties of the memristor.

The applications were also explored by many research groups in the fields of neural networks [4], quantum dynamics of circuits [5], programmable analog ICs [6] and polymer nanodevices [7]. Using memristive circuit with LC contour, Pershin *et al* simulated the amoeba's learning behavior [8]. In their model, the circuit can memory the periodic voltage impulses and change the state. Although, the proposed circuit can only respond to one particular periodic signal with definite frequency. The later work presented by them showed that, a set of LC contours or a single memcapacitor-based adaptive contour can respond to different frequencies, but the change of the state can only occur once, which means that the state will not change even when the second stimulating signal comes[9].

In this paper, we describe the model of memcapacitor firstly, and then, we investigate the characteristics of the voltage controlled memcapacitor. Moreover, the memristive circuit based on LC contour and its responses to stimulating signals are researched. Ultimately, we have a brief conclusion of this paper.

2. Models of Memcapacitor

Two types of memristor have been recognized, charge controlled and flux controlled. Similarly, according to its electric constraint relation, memcapacitor can also be divided into two categories, namely voltage controlled and charge controlled. A voltage controlled memcapacitor is defined by[10]:

$$Q(t) = C(x, V_C, t)V_C(t) \tag{1}$$

$$\dot{x} = f(x, V_C, t) \tag{2}$$

In the above two formulas, $V_C(t)$ is the voltage drop through memcapacitor at time t and $Q(t)$ represents the stored charge of memcapacitor. Additionally, C is the memcapacitance which is determined by the state variable x of the system.

Likewise, a charge controlled memcapacitor can be defined by the following formulas:

$$V_C(t) = C^{-1}(x, Q, t)Q(t) \tag{3}$$

$$\dot{x} = f(x, Q, t) \tag{4}$$

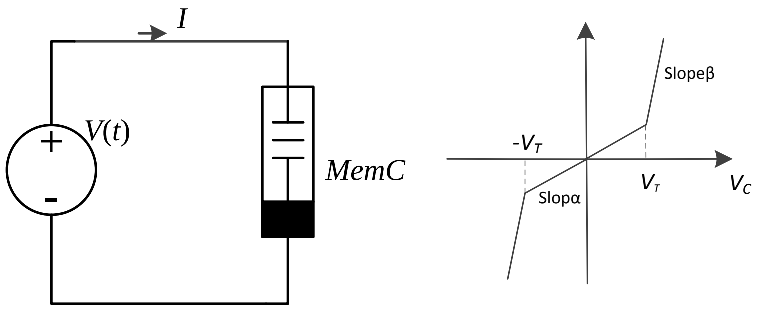
Here, we launch research on a simple model of memcapacitor which is shown in Fig. 1(a). Supposing C=x, the relationship between variables which change over time can be expressed by the formula which is defined by Eq. 6.

$$C = x \tag{5}$$

$$\dot{x} = (\beta V_C + 0.5(\alpha - \beta)[|V_C + V_T| - |V_C - V_T|]) \times \theta(x - C_1)\theta(C_2 - x) \tag{6}$$

In Eq. 6, V_C is the voltage drop through memcapacitor, the value of which is $V_C = Q/C = V(t) = V_0 sin(2\pi f t)$, V_0 is the amplitude and f is the frequency of the voltage source. V_T is the threshold voltage, α is the slope when $|V_C|<V_T$, β is the slope when $|V_C|>V_T$, θ is the step function, C_1 and C_2 represent the minimum value and maximum value of memcapacitance respectively. The piecewise linear curve of the memcapacitor is displayed in Fig. 1(b).

In this paper, we investigate the characteristics of memcapacitor based on the model of the voltage controlled memcapacitor.



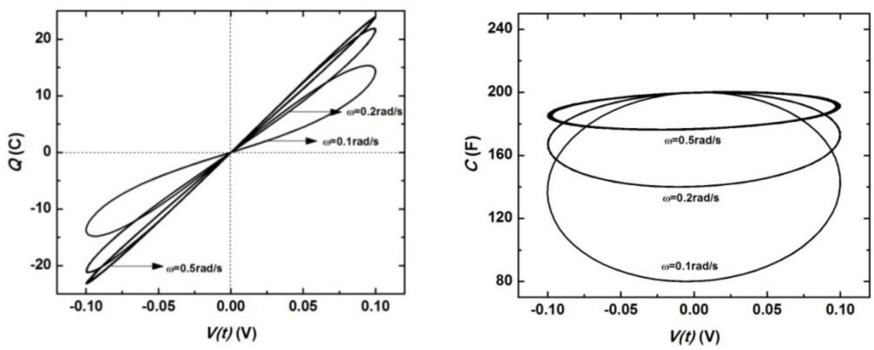
(a) (b)

Fig.1(a) Model of the voltage controlled memcapacitor; (b) Characteristic of memcapacitor.

3. Results and Discussion

3.1 Characteristics of memcapacitor

First of all, we discuss the characteristics of Q-V and C-V for a memcapacitor. We model and simulate a memcapacitor system by using Matlab. The applied voltage is described as $V(t) = V_0 sin(2\pi f t)$ and the selection of parameters are α=20$F/(Vs)$, β=40$F/(Vs)$, V_T=0.5V and V_0=0.1V. The results of simulation are shown in Fig. 2.



(a) (b)

Fig.2(a) Q-V curves and (b) C-V curves of memcapacitor with different frequencies

Fig.2 (a) is the piecewise linear Q-V curve of memcapacitor. From Fig.2 (a), we can find that the Q-V curve is a pinched hysteresis. When the applied voltage is zero, the stored charge of the memcapacitor is zero as well. Moreover, the characteristics of memory devices are closely related to the frequency of the external stimulating signal. Hence, we change the frequency of the applied voltage and find that when the frequency changes, the change of *Q-V* characteristics is very obvious, and that is to say, the pinched hysteresis curve becomes weaker with increasing the input signal frequency. Similarly, it can be seen from Fig.2 (b) that with the frequency increasing, the range of the memcapacitance decreases instead.

3.2 Memristive circuit based on LC contour and responses to stimulating signals

Since memory elements have numerous fantastic characteristics, some research groups have begun to explore memory elements' applications in memory circuit, neurology and bionics. Pershin *et al* have reported that only using a resistor, a capacitor, an inductor and a memristor can simulate the amoeba's learning behavior. The memristance will increase in the case of periodic stimulating signals and can memorize the circuit state as well.

Based on their research, we replace the capacitor with a charge controlled memcapacitor and the specific circuit is shown in Fig. 3.

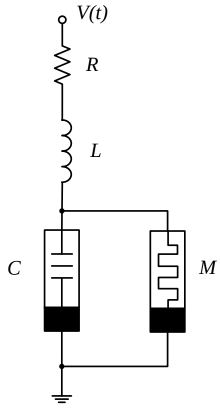


Fig.3 Memristive circuit with memcapacitor and memristor.

In this circuit, we select a charge controlled memcapacitor which can be described as:

$$C = \gamma Q = \gamma \int i_C(t)\, dt \tag{7}$$

Assume that the voltage drop through the memcapacitor is *V*, the total current flowing through the circuit is as follows:

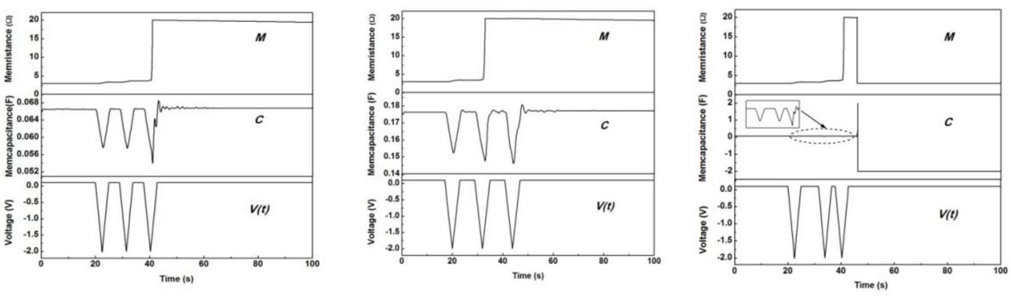
$$I = i_R = i_L = i_C + i_M = C\frac{dV}{dt} + V\frac{dC}{dt} + \frac{V}{M} \tag{8}$$

After that, we can attain the relationship of the circuit according to Fig.3:

$$V(t) = V_R + V_L + V = RI + L\frac{dI}{dt} + V \tag{9}$$

Put Eq. 7 and Eq. 8 into Eq.9, and then, select partial parameters as follows: resistance R=1Ω and inductance L=1H. Simultaneously, we choose a memristor with the piecewise linear model and the parameters are: α=0.01$\Omega/(Vs)$, β=100$\Omega/(Vs)$, V_T=1.5V.

Apply periodic stimulating signals with T=8.9s, T=11.9s and an aperiodic signal, respectively. Meanwhile, through choosing different initial values of memcapacitor, we get simulation results which are shown in Fig. 4.



(a) (b) (c)

Fig.4 Diagrams of circuit responses to periodic and aperiodic signals.

It can be seen that for periodic signals, memristance increases rapidly due to the appropriate selection of memcapacitor's initial value, which is to say, the circuit state has changed. On the contrary, if the stimulating signal is aperiodic, although the value of memristance jumps when the second negative triangular wave arrives, it still returns to the original value when the third wave the period of which is not the same as before arrives. Generally speaking, memristance does not change significantly.

Therefore, similar to the results of Pershin *et al*'s research, the memristive circuit which is based on LC contour and consists of memcapacitor and memristor can also simulate the amoeba's learning behavior. It is worth mentioning that the circuit in this paper can respond to periodic signals with different frequencies more than once which will make our further simulation and investigation in neurography and bionics more efficiently.

4. Conclusion

In general, it is suggested that the memristive circuit which is based on LC contour and consists of memcapacitor and memristor can respond to periodic signals with various frequencies more than once and it can also simulate the amoeba's learning behavior. This finding may have potential applications in neurography and bionics.

References

[1]. Chua L O. Memristor - the missing circuit element [J]. IEEE Transactions on Circuit Theory, 1971, 18(5): 507-519.

[2]. Chua L O, Kang S M. Memristive devices and systems [J]. Proceedings of the IEEE, 1976, 64(2): 209-223.

[3]. Strukov D B, Snider G S, Stewart D R, Stanley Williams R. The missing memristor found [J]. Nature, 2008, 453: 80-83.

[4]. Pershin Y V, Di Ventra M, Experimental demonstration of associative memory with memristive neural networks [J]. Neural Networks, 2010, 23(7): 881-886.

[5]. Scarpa G, Russer J A, Lugli P, et al. Quantum dynamics of circuits with memory capacitors and inductors[C]. Electromagnetics in Advanced Applications (ICEAA), 2012:614-617.

[6]. Shin S, Kim K, Kang S M. Memristor application for programmable analog ICs [J]. IEEE Transactions in Nanotechnology, 2011, 10(2): 266-274.

[7]. Zhitenev, N. B, Sidorenko, A. Tennant, D. M. &Cirelli, R. A. Chemical modification of the electronic conducting states in polymer nanodevices [J]. Nature Nanotechnology. 2007, 2, 237-242.

[8]. Pershin Y V, Fontaine S L, Di Ventra M. Memristive model of amoeba learning [J]. Physical Review E, 2009, 80: 021926(1) - 021926(6).

[9]. Fabio Lorenzo Traversa, Yuriy V. Pershin, Massimiliano Di Ventra. Memory models of adaptive behavior [J]. Transactions on Neural Networks and Learning Systems. 2013, 24(9): 1437-1448.

[10]. Di Ventra M, Pershin Y V, Chua L O. Circuit Elements with Memory: Memristors, Memcapacitors, and Meminductors [J]. Proceedings of the IEEE, 2009, 97(10):1717-1724.