İSTANBUL UNIVERSITY CERRAHPAŞA

RESEARCH ARTICLE

Electrica 2020; 20(1): 81-85

Pavlov's Dog: A Simple Circuit Implementation using a Volatile Memristor

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Cite this article as: Orman K. Pavlov's Dog: A Simple Circuit Implementation using a Volatile Memristor. *Electrica*, 2020; 20(1): 81-85.

ABSTRACT

Memristors are electronic devices, which are widely used in neuromorphic circuit design, because they exhibit some superior properties such as memory and nonlinear behavior. Previous nonvolatile memristor-based associative learning, which is a type of learning mechanism using circuits, has not taken into account the time interval between neutral stimulus and its effect on the circuit, after a long time-lapse. In this paper, a volatile memristor is used instead of a fully nonvolatile memristor in an effort to provide the sensitivity required for the time interval between applied pulses. Also, compared with previous studies, the response of the volatile memristor-based circuit is sensitive to additional input applied pulses. All simulations presented in this work were successfully carried out.

Keywords: Memristor, volatile, associative learning

Introduction

Memory-resistor (i.e., memristor), is a fourth generation passive circuit component, which provides the linkage between flux and charge. This new circuit component exhibits pinched hysteresis voltage-current relationship, when a sinusoidal signal is applied. It also exhibits the nonvolatile memory effect and its memristance depends on the applied signal direction [1, 2]. The memristance decreases, when a current flows in the forward direction, and increases, when a current flows in the reverse direction. In 2008, Stanley Williams and coworkers from Hewlett-Packard Company announced the physical implementation of a memristor using a TiO_2 sandwich structure [3]. After the fabrication of memristor [3], many memristor models/emulators were developed by researchers [4-12] to deal with its fabrication difficulties. Each emulator has its own advantages compared to other emulators.

Memristors can be used in various applications, such as neuromorphic electronics, and provide significant advantages. Associative learning, which is a type of important learning activity, is a classic conditioning process. Pavlov's Dog experiment can be used as an example to understand the learning mechanism. Some researchers have designed memristor-based associative learning circuits in an effort to demonstrate the Pavlovian conditioning process [13-16]. However, some very important associative learning mechanism properties were not taken into account, when using these circuits. These are: 1.The response of the circuit remains active even after a long time has elapsed. However, time has a direct effect on Pavlov's Dog salivation and therefore, the circuit should not give any response. 2. After the learning of Pavlov's Dog behavior, salivation starts to decrease, when the applied sequential signals "lack food." To overcome these two problems, an electronically controllable volatile memristor was used instead of the nonvolatile memristor in an effort to obtain a circuit response close to the real associate learning mechanism.

In this paper, a volatile memristor-based associative learning circuit was implemented. Compared with previous studies the circuit response is very close to the real learning mechanism.

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Received: 31 December 2019

Accepted: 06 January 2020

DOI: 10.5152/electrica.2020.19085

The time-lapse and many ring pulses "lack food" after the learning mechanism is removed or the learning process is reduced. Previous studies do not take into account these two important properties. The problem can be solved using a volatile memristor and by controlling its volatility property. All simulations were successfully performed using TSMC CMOS (Taiwan Semiconductor Manufacturing Co., Hsinchu, Taiwan,) *0.18 μm* process parameters.

Memristor Circuit Emulator

The memristor circuit emulator used in this work is shown in Figure 1. This emulator has been designed by Babacan et al. [11]. The designed circuit exhibits floating and nonvolatile characteristics. The memristor consists of one multi-output Operational Transconductance Amplifier (OTA), two resistors, and one capacitor. The capacitor provides the volatile characteristics of the circuit. Since memristors are nonlinear circuit componets, a multiplier was used to provide the nonlinear behavior of the memristor. In this way, the voltages on the capacitor and resistor are multiplied and connected to the negative terminal of the OTA. The resistor, which is connected to the other output terminal of the OTA, controls the memristance variation range. Another resistor was attached to the capacitor, which was connected to the output terminal of the OTA. This resistor was used in the circuit to convert the nonvolatile memristor to a volatile one. If the charging mechanism of the circuit can be controlled, the volatility of the memristor can also be controlled.

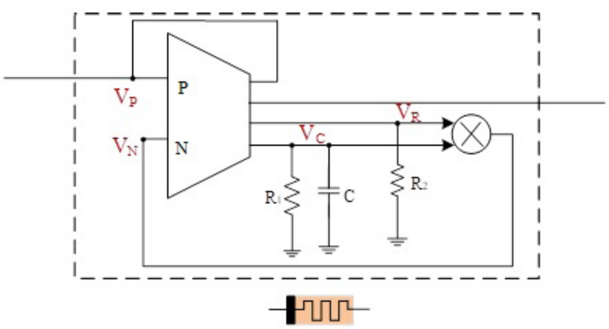

Figure 1. OTA-based memristor emulator circuit. Here, R1=94 MΩ, R2=1 kΩ, C=10 nF, gm=100 uS. (Dimensions: 117x67 mm (96x96 DPI))

The pinched hysteresis voltage-current relationship, which is the key feature of volatile memristors, is shown in Figure 2a. Here, the amplitude of the applied voltage is *1V* and the frequency is *1 kHz*. In Figure 2b, the memristance variation is shown for *100 Hz*, *1V* pulses. The memristance increases during pulses and starts to decrease between pulses.

Associative Learning using a Volatile Memristor

Associative learning is a type of learning activity. The famous Pavlov's Dog experiment can help to understand this classical conditioning example. First, the Pavlov's Dog experiment process is summarized. Pavlov showed some food to his dog and the dog began to salivate. Then, Pavlov rang a bell each time he showed the food to his dog. After a few trials, the dog began to salivate each time Pavlov just rang the bell. Previous memristor-based associative learning circuit designers focused on only these two properties: 1. Salivation begins when food is shown. 2. After a few trials, the dog begins to salivate every time it listens to the bell's ring once the learning activity is completed [13-16]. However, in reality, the dog does not salivate after a long time has elapsed or if food is not given after the bell's ring. In particular, the dog begins to forget salivation after

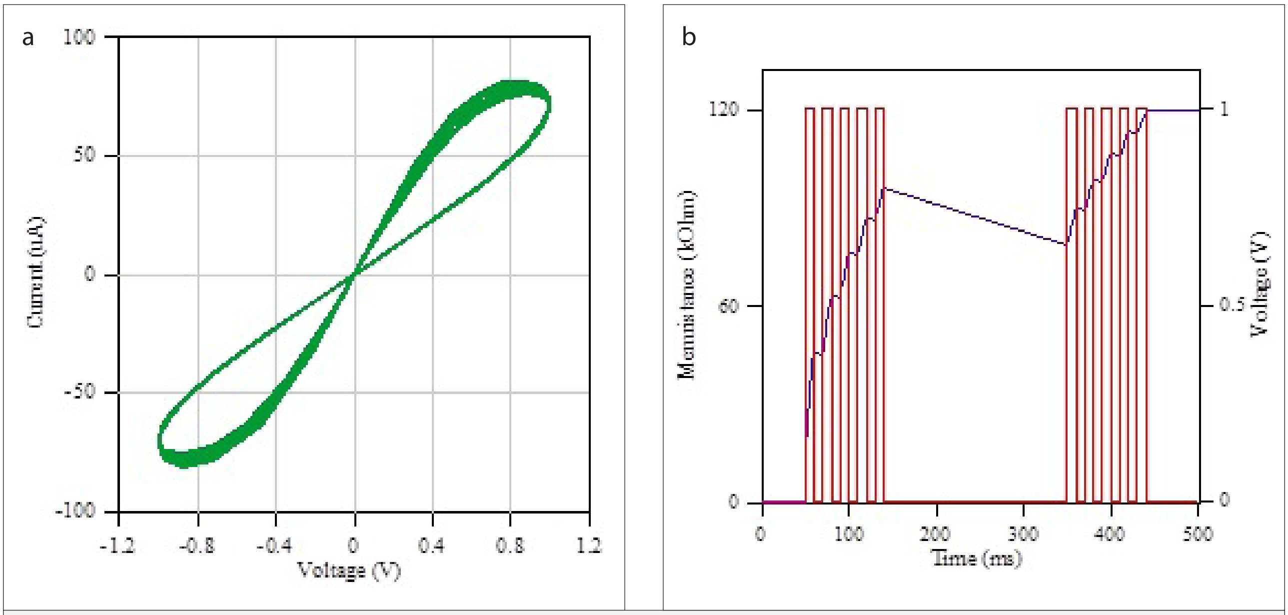

Figure 2. a, b. Voltage-current relationship, when a sinusoidal signal is applied. (Dimensions: 69x67 mm (96x96 DPI)) (a). Memristance variation, when positive 1V pulses are applied. (Dimensions: 77x65 mm (96x96 DPI)) (b)

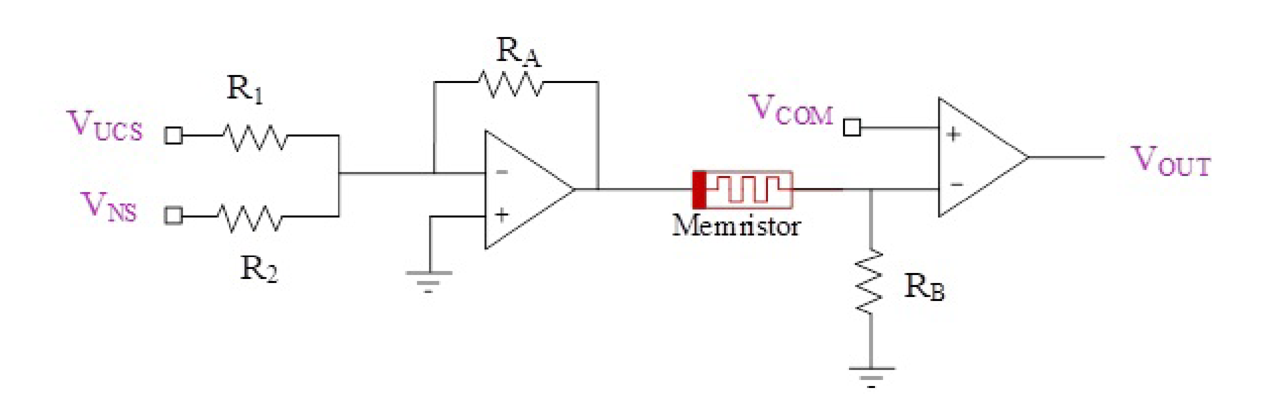

Figure 3. Memristor-based associative learning circuit [15-16]. (Dimensions: 160x51mm (96x96 DPI))

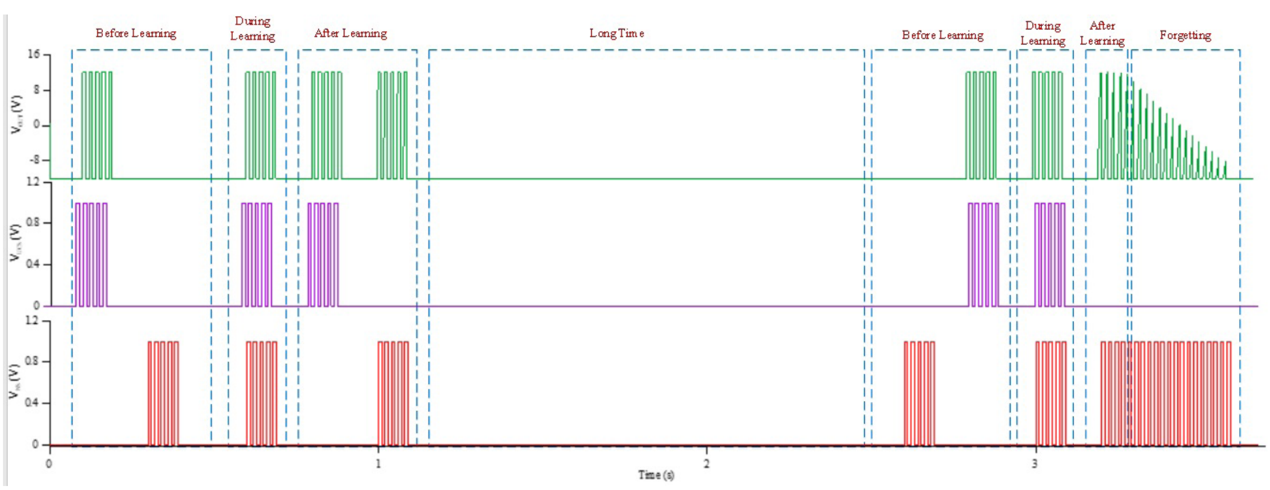

Figure 4. Response of the memristor-based learning circuit before learning, during learning, after learning, and during forgetting. (Dimensions: 356x132 mm (96x96 DPI))

the bell has been rung a few times. Therefore, previous studies [13-16] have been missing a point because they disregard the above mentioned mechanism. Moon and coworkers [15] and Babacan and Kacar[16] presented an associative learning circuit, which is shown in Figure 3. This circuit uses fabricated and floating current source (FCS)-based nonvolatile memristors, respectively. The circuit has an unconditioned stimulus (UCS) and a neutral stimulus (NS) to represent food and bell inputs, respectively.

A volatile memristor was used instead of a nonvolatile memristor in the associative learning circuit. Here, the volatility property is very important because it enables the control of the capability of learning and the forgetting speed. The circuit response, when pulses are applied before learning, during learning, after learning, and during forgetting are shown in Figure 4.

Before the learning stage, the circuit's output becomes positive or zero, when input signals are applied only to the unconditional stimulus input or only to the NS input, respectively. During the learning stage, signals are applied to both inputs and thus, the circuit produces a positive output. After the learning stage, the circuit has learned and can give positive response when signals are applied to both inputs seperately. Time directly affects the memory property of the circuit. Thus, the circuit does not produce any output, when a signal is applied only to the NS input. The learning process requires that an output signal is obtained, when a signal train is applied to the NS input. However, if the signal train is applied to the NS input of the circuit a zero output is obtained. This situation can be related to the Pavlov's Dog salivation, which starts to decrease, when the bell rings repeatedly.

Conclusion

Previous studies on associative learning do not take into account the time-lapse and the unnecessary NS effect. According to the Pavlov's Dog experiment, dog's salivation starts to become zero, when NS is not applied after a long time-lapse or any food is not given after several rings of the bell. This work was focused on these missing properties and the problem was solved using only a volatile memristor instead of a nonvolatile memristor. The nonvolatile memristor used was converted to a volatile memristor by attaching a resistor. The volatility of the memristor is very important for tuning the relationship between learning and forgetting speeds. Simulation results were obtained using TSMC CMOS *0.18 μm* process model parameters, which are compatible with the associative learning theory.

Peer-review: Externally peer-reviewed.

Conflict of Interest: The author have no conflicts of interest to declare.

Financial Disclosure: The author declared that the study has received no financial support.

References

1. L.O. Chua, "Memristor - the missing circuit element", IEEE Trans Circuit Theory, vol. 18, pp. 507-19, 1971. [CrossRef]
2. L.O. Chua, Kang S.M, "Memristive devices and systems, Proceedings of the IEEE, pp. 209-23, 1976. [CrossRef]
3. D.B. Strukov, G.S. Snider, D.R. Stewart, R.S. Williams, "The missing memristor found", Nature, vol. 453, pp. 80-83, 2008. [CrossRef]
4. Z. Biolek, D. Biolek, V. Biolkova, "SPICE model of memristor with nonlinear dopant drift", Radioengineering, pp. 210-214, 2009.
5. H. Kim, M. Sah, P. Yang, C.S. Cho, L.O. Chua, "Memristor emulator for memristor circuit applications", IEEE Trans Circuits Syst, vol. 59, no. 10, pp. 2422-31, 2012. [CrossRef]
6. S. Kvatinsky, E.G. Friedman, A. Kolodny, U. C. Weiser, "TEAM: Threshold adaptive memristor model", Circuits and Systems I: Regular Papers, IEEE Transactions vol. 60, no. 1, pp. 211-21, 2013. [CrossRef]
7. A. Yesil, Y. Babacan, F. Kacar, "A new DDCC based memristor emulator circuit and its applications", Microelectronics Journal, 2014. [CrossRef]
8. C. Sanchez-Lopeza, M.A. Carrasco-Aguilar, C. Muniz-Montero, "A 16 Hz-160 kHz memristor emulator circuit", AEU-International Journal of Electronics and Communications, pp. 1208-19, 2015. [CrossRef]
9. Y. Babacan, F. Kacar, "Floating Memristor Emulator with Subthreshold Region", Analog Integrated Circuits and Signal Processing, pp. 1-5, 2016. [CrossRef]
10. Y. Babacan, F. Kacar, K. Gurkan, "A Spiking and Bursting Neuron Circuit Based On Memristor", Neurocomputing, pp. 86-91, 2016. [CrossRef]
11. Y. Babacan, A. Yesil, F. Kacar, "Memristor emulator with tunable characteristic and its experimental results", AEU-International Journal of Electronics and Communications, pp. 99-104, 2017. [CrossRef]
12. C. Sanchez-Lopeza, L.E. Aguila-Cuapio, "A. 860 kHz Grounded Memristor Emulator Circuit", AEU-International Journal of Electronics and Communications, 2017. [CrossRef]
13. M. Ziegler, R. Soni, T. Patelczyk, M. Ignatov, T. Bartsch, P. Meuffels, H. Kohlstedt, "An Electronic Version of Pavlov's Dog", Advanced Functional Materials, vol. 22, no. 13,pp. 2744-9, 2012. [CrossRef]
14. Y.V. Pershin, M. Di Ventra, "Experimental demonstration of associative memory with memristive neural networks", Journal Neural Networks, vol. 23, pp. 881-6, 2010. [CrossRef]
15. K. Moon, S. Park, J. Jang, D. Lee, J. Woo, E. Cha, S. Lee, J. Park, J. Song, Y. Koo, H. Hwang, "Hardware implementation of associative memory characteristics with analogue-type resistiveswitching device", Nanotechnology, Vol. 25, No. 49, 2014. [CrossRef]
16. Y. Babacan, F. Kacar, "FCS Based Memristor Emulator with Associative Learning Circuit Application", U-JEEE, vol. 17, no. 2, pp. 3433-7, 2017.

Kamil Orman received B.Sc., degrees in Electrical and Electronics Engineering at Selcuk University in 1996. He received his Msc., and Ph.D.degree in Electrical and Electronics Engineering at Atatürk University in 2008 and 2018 respectively. His main research interests are control systems, nonlinear control, algorithms, robotic systems and unmanned vehicles. He is currently working as a assistant proffessor in the Computer Engineering department of the Erzincan Binali Yıldırım University.