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Simulation of Logic Gates with Memristor

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ABSTRACT

A memristor is a memory resistor that behaves analogously, that is, its resistance can be programmed between two states with minimum resistance and maximum resistance, and the values are stored until the next programming voltage is applied. As a property of the material, this element will show itself when materials and devices in nanometer dimensions are used. A circuit with a memristor can have advantages such as better performance, fewer components, and, on the contrary, it has a lower chip level and lower power consumption. The memristor resistance depends on the integral portion of the input given to its terminal, while the variable resistor depends on the instantaneous value of the input. The memristor is a neutral member of the circuit and has two terminals that can maintain a functional relationship between current over time and voltage over time. While examining the characteristics of the memristor, the types of memristors and the characteristic of memristor hysteresis were also investigated in this study.

Key words: memristor, non-volatile memory, hysteresis.

INTRODUCTION

In the field of electronic circuits, the three basic elements of resistance, capacitor, and inductor played a major role, so that they form the main body of the circuits in most electrical circuits in the fields of power, electronics, and telecommunications. These elements have characteristics in terms of four variables: voltage, current, electric charge, and magnetic flux. In other words, the degree of resistance of the element can be calculated from its current-voltage characteristic, the amount of inductance of the element can be calculated from the voltage-electric charge characteristic and the degree of the capacitance of a device from can be calculated its current-magnetic flux characteristic. Mr. Chua first introduced the mathematical model of Memristor in 1971, and in 2008 HP Laboratory developed a physical model of the device based on its mathematical model [1-2]. Features of this device are the ability to create in nano-dimensions, variable resistance, the ability to maintain the last resistance after the voltage applied to it, and the characteristic of historic current-voltage, which makes it a good option in making RAM, low power computers, non-volatile memory, logic gates and participation in biological processes and artificial intelligence. Consequently, designing memristor-based circuits and optimizing them to increase the density of boards and increase numerical calculations, have always been considered by researchers in this field.

Memristor is the fourth basic element after resistors, inductors, and capacitors that can be implemented in nanoscale and due to compatibility with CMOS technology, it can be replaced with transistors (which take up a lot of space). This dual-base element with its current-voltage characteristic can show the behavior of a non-volatile resistor memory and show a special function in solving complex real-world problems in the processor of analog computers [3]. Synaptic memristor connections have been able to significantly reduce the power of neuromorphic processors [4]. The lack of electrical elements capable of mimicking biological synapses has created challenges for complex and compact brain-shaped systems [5]. In this regard, the use of memristor crossbar networks in the absence of a transistor can be an effective step in creating complex neural networks. In these networks, memristors form a computational framework in which information storage and processing are combined [6-7].

Though memristor-based logic circuits have created new opportunities in the discovery of advanced computing architectures by replacing conventional integrated circuits, a standard method has not yet been developed for designing memristor-based logic circuits and it is not clear which method can be most effective in designing these circuits.

Memristor-based logic and computational circuits have different divisions. *CMOS / Memristor Hybrid Circuits*: These circuits are a combination of Memristor with CMOS circuits, they have a threshold in creating Boolean logic and logical calculations [8-9]. *IMPLY circuits*: In this method, Boolean functions are calculated using logical reset and imply operators [10-11]. *All memristor circuits*: In these circuits, Boolean functions are realized only by all memristor circuits [12]. *Circuits with programmable connections*: These circuits use programmable memory crossover networks with nanowires [13-14].

Memristor has been used in all these circuits in two different ways. In one method, logic values are expressed using voltage levels (for example, a voltage of 5 volts represents logic and a voltage of zero volts represents a logic zero). In this method, memristors in the role of switches create the ability to create FPGA-like architectures or logic calculators in the form of logic gates [15-16]. Therefore, the purpose of this study is to investigate the simulation of logic gates with memristor.

Theoretical foundations of research

Memristor

Memristor, or the fourth major element of the circuit, was theoretically proposed in 1971 [17] but was not physically built. In 2008, Stanley Williams et al. built a memristor at the nanoscale in Hewlett-Packard or HP Company, thus, Memristor was fully introduced.. This element will show itself as a property of matter when materials and devices in nanometer dimensions are used. The more researchers work with devices on a smaller scale, the more they will see strange behaviors due to the memristor effect in these devices. [18]. A memristor is an element that has analogous behavior, i.e. its resistance can be programmed between two states with minimum resistance and maximum resistance, and values up to actions, and the values are stored until the next programming voltage is applied.

Memristor-based memories can reduce power consumption and provide high reliability as well as reversibility for a data center in the event of a power outage. Other applications of memristor technology include the development of computer systems that interact with events similar to those of the human brain. The result of this application can lead to the advancement of modern face recognition technology. Likewise, it can enable security and confidential devices that detect a particular set of biometric features of a particular person to gain access to personal information or enable a device to learn based on experience. Other applications include the following:

The memristor consists of a two-layer titanium oxide thin-film TiO2 film, sandwiched with a thickness of D, between two nano-platinum connections. A layer is impure with high oxygen and transformed into a low-resistance semiconductor. The remaining area is not impure and has high strength (Figure 1).

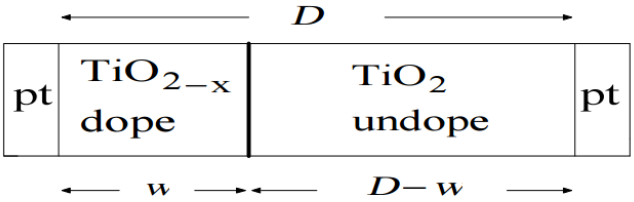

Figure 1: Memristor physical model

In [2], a high-pass filter and an amplifier are designed and simulated using a memristor. In this circuit, the memristor is used as the negative feedback element and the capacitive-resistance filter is used as the input impedance in the amplifier topology. In this research, it has been shown that an adjustable gain can be designed using a memristor.

In [4], an adjustable filter is made by placing a memristor in a capacitive inductor circuit. This circuit is adjusted based on its input waveform, frequency, and quality factor (Q factor). Passive elements are only used in this circuit and can be used in biological applications. A schematic of an adjustable RmLC memory filter is shown in Figure 2a. Memory capacitor is also derived. Figure 2 b shows the small-signal transmission function and circuit time series are shown in Figure 2 c.

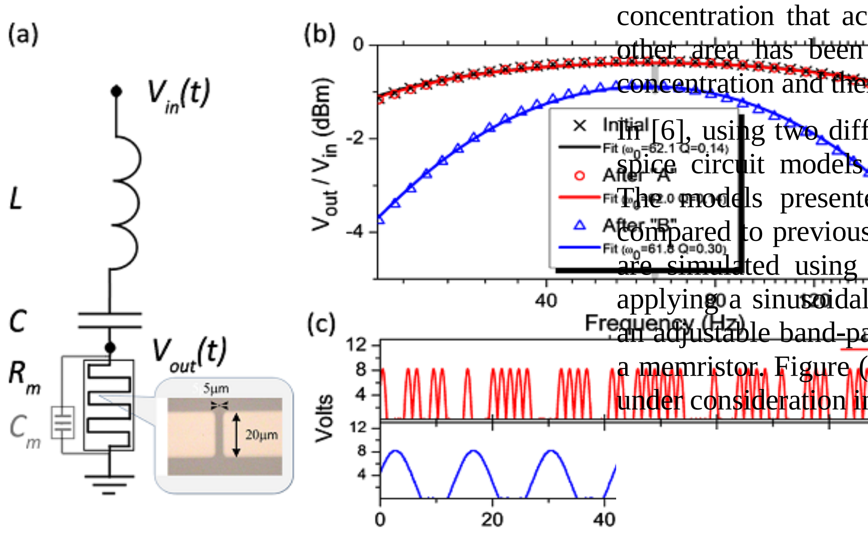

Figure 2: Memorization circuit is shown in [4].

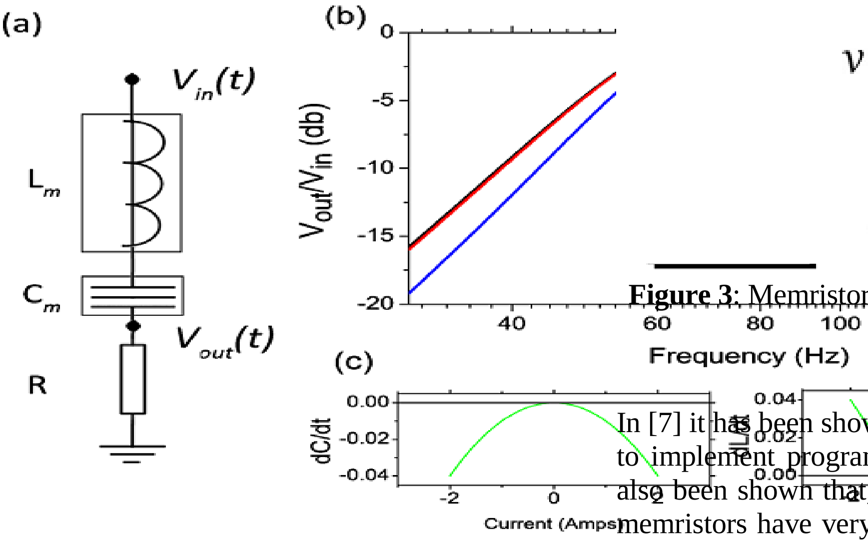

Figure 2: RmCmL circuit offered in [4]

In [5], a SPICE model for memristor is proposed. The proposed model is evaluated by simulating simple circuits and comparing them with experimental results. Via the offered model, different circuits can be designed with a memristor. In this paper, two circuits are designed and simulated with memristors. One is a low-pass filter circuit in which a memristor is connected with a series resistor, and one is an integrator circuit in which a memristor and an operational amplifier are used. It has also been revealed that the memristor can be used as an inductor in analog circuits. Consequently, in addition to the inductor property, its size is much smaller than ordinary inductors. In the SPICE model presented in this paper, a thin semiconductor layer with two regions is considered for a memristor. One area has a high impurity concentration that acts as a small resistor, and the other area has been slightly impure via impurity concentration and therefore it has a larger resistance.

In [6], using two different types of integrators, two spice circuit models for memristor are presented. The models presented in this paper are simpler compared to previous models. Different memristors are simulated using the proposed models and by applying a sinusoidal voltage source. In this paper, an adjustable band-pass filter is also designed using a memristor. Figure (3) shows the memristor model under consideration in [6].

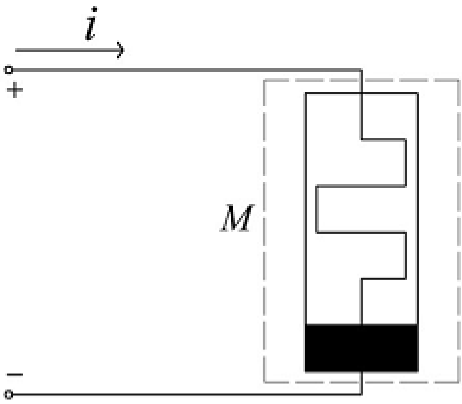

Figure 3: Memristor model under consideration in [6]

In [7] it has been shown that memristors can be used to implement programmable analog circuits. It has also been shown that, unlike conventional resistors, memristors have very slight parasitic effects. In the current paper, a programmable differential amplifier is designed using a memristor. Figure (4) shows the programmable amplifier circuit proposed in [7] using the memristor

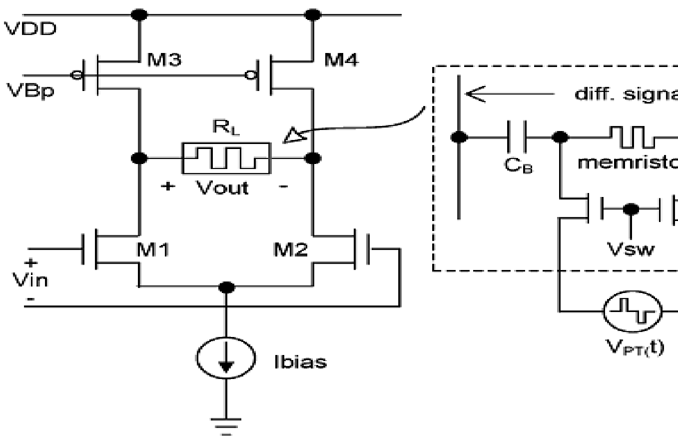

Figure 4: Programmable amplifier circuit proposed in [7] using memristor

In [8], multi-valued logic circuits are designed using memristors. Because memristors have different values of resistance, different logic levels can be generated with them. With this idea, in this article, an array of memristors is used to build a multi-value memory system. In [9], a new logic circuit is designed using a memristor. In this paper, using a memristor, XOR gates are designed with a new structure as well as a multiplier. In [10], a memristor simulator is presented that simulates the behavior of a TiO_2 memristor. Furthermore, two or more memristor simulators can be connected in series, in parallel, or combination with the same or opposite polarizations.

In [11], the existing memristor models have been studied with Matlab software. To predict the behavior of memristor devices three different models of memristor have been studied in this paper. In [12], using a titanium dioxide memristor, a variable gain amplifier is designed. The circuit is analyzed regarding voltage and load-controlled memristor models. The analysis includes a demonstration of the general harmonic distortion theory for the amplifier. The circuit is simulated with SPICE software. In [13], using memristor, random access memory is designed with resistive random access memory (RRAM). This paper also reports the transient behavior of memristors. A transient orbital model is also provided for the memristor and it is simulated with the H simulator SPICE.

In [14], it is stated that memristors are new devices that can be used in applications such as memory, digital and analog circuits, and nervous systems. Various memristor technologies such as ReRAM, MRAM, and PCM are offered. This article describes different memristor models and provides a Verilog model for them. In [15], a decoder is designed based on memristor. In this paper, first, the memristor characteristics are analyzed and modeled with HSPICE and then the decoders are designed based on NOR and their performance is compared with memristors performance. Experimental results and analysis show that the design presented in this paper is correct.

In [16], describes the structure and basis of the operation of the William Memristor. In this paper, the described analysis considers the linear drift model of William Memristor. A Simulink circuit model with memristors is attained using Kirchhoff's voltage law and formula. The basic results achieved in MATLAB and Simulink are presented graphically. In [17], a simple and general model is presented based on boundary conditions for memristor. The design and analysis procedures of the different circuits that include memristors are also presented. This paper proposes a two-port model for memristor. In [18], a SPICE memristor simulator is offered based on a new improved nodal analysis that can support unusual state variables such as memristor impurity ratios. With this simulator, the memristor can be expressed as a state matrix. By simulating a circuit containing 32 by 32 memristors, it is shown that the simulation with the model proposed in this paper takes 40 times less time than previous simulators. In [19], an analog model is presented based on light-dependent resistance for the memristor. This model can be divided into two parts: a control circuit and a variable resistor. The model based on light-dependent resistance can be used in both simulation and fabrication for later memristor applications. Mathematical models that describe the behavior of the device have also been deduced.

Types of memristors

1. Spintronic memristor

Yiran Chen and Xiaobin Wang (2009) described three possible examples of magnetic memristors. In one of the three examples, the resistance created by the rotation of electrons in one part of the device pointer in a different direction from the other parts of the "field wall" creates a boundary between the two states. Electrons moving towards the device have a special spin that causes a change in the magnetic state of the device. The magnetic alteration, in turn, causes the field wall to move and the resistance of the device to change. This work has received a lot of attention in the electronic press, including interviews on the IEEE spectrum.

2. Magnetic resistance of rotational torque transmission

Magnetic resistance of rotational torque transmission is a well-known instrument that shows memristor behavior. The resistance depends on the direction of relative rotation between the two sides of the magnetic tunnel junction. This in turn can be controlled by the torque induced by the current through the connection. However, the length of the current through the connection determines the amount of current required. For example, the electric charge charged in this way is the main variable. Furthermore, MgO-based magnetic tunnel connections show memristor behavior based on oxygen vacancies drift inside the insulation MgO layer (resistive switching). Thus, the combination of spin-torque and resistive switching naturally results in a second-order master system with W = (WI, W2) in which WI represents the magnetic state of the magnetic tunnel connection and W2 represents the resistance state of the MgO barrier. Note that in this case the current is controlled in the WI switch (rotational torque is due to the high current density) while in the W2 switch the voltage is controlled.

3. Spin memristor systems

The mechanism of memristor behavior in such a structure is entirely based on the degree of rotation of the free electron, which makes it easier to control ion transport in nanostructures. When the external control parameter (such as voltage) changes, the electron spin polarization adjustment is delayed due to the propagation and relaxation processes created by the waste. This result is predicted in the study of rotational extraction at the semiconductor / ferromagnetic interface but is not described in terms of memristor behavior. On a short time scale, these structures behave almost like an ideal memristor. This results in the expansion of a wide range of semiconductor spintronic applications as well as the use of memristor systems.

Characteristic of memristor hysteresis

Memristor manifests very interesting nonlinear specifications. This nonlinear characteristic makes the memristor a special case of a wide range of dynamic systems called memristor systems. Among the specifications of memristor systems, the frequency response of the Lissajous shape to the sinusoidal input is also interesting. This curve is hysteretic and when the frequency increases to infinity, the Lissajous curve shrinks and tends to be a smooth line passing through the origin. This indicates that the hysteretic effect in the memristor system decreases with increasing frequency and eventually becomes a pure resistance system. This is shown in Figure (5).

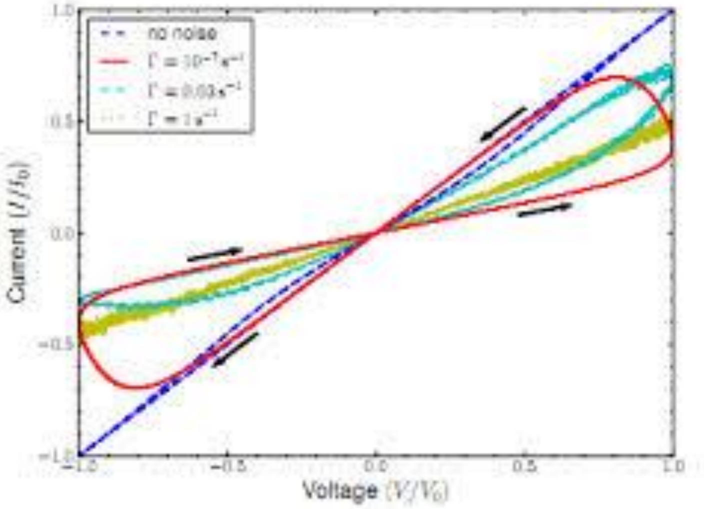

Figure 5: Frequency response of the Lissajous Memristor curve

Each memristor memory cell in the transistor memory structure uses a transistor to access it and separate it from the cells in the other rows. The structure of such memory is plotted based on the NOR and NAND arrays in Figure (6).

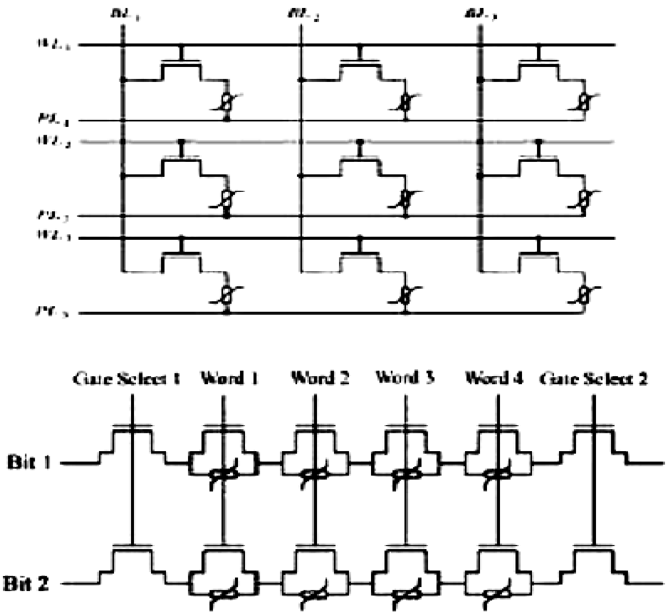

Figure 6: Memristor memory structure based on transistor cells in the form of NOR (up) and NAND (down) arrays

In a crossbar cell, the memristor switching material with the ability to configure arrays of cross metal electrodes is located (Figure 7). Each batch of these materials is used as a memory cell at intersections.

Since switches are dual-terminal components, the entire crossbar structure is an inactive array.

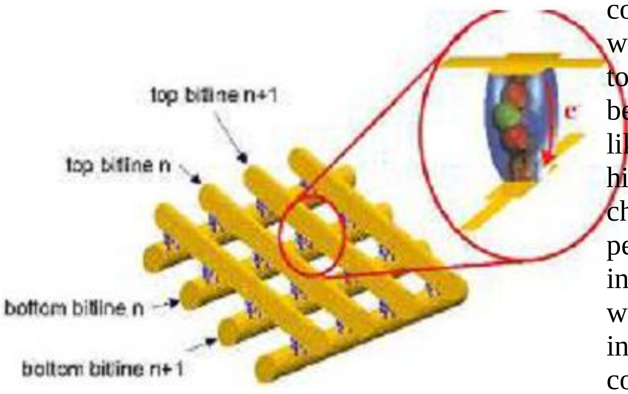

Figure 7: Memristor switching material configurable between arrays of cross metal electrodes in a crossbar cell

Conclusion

A memristor is a memory resistor that behaves analogously, i.e. its resistance can be programmed between two modes with minimum resistance and maximum resistance, and the values are stored until the next programming voltage is applied. This element will show itself as a property of the material when materials and devices are used in nanometer dimensions. A circuit that includes a memristor can have advantages such as better performance, fewer components, and, equally, a lower chip level and power consumption.

Random-access memory or RAM is inherently erased after a power outage. However, in 1971 the idea of preserving memory was theoretically introduced, and this phenomenon was realized in 2008. A memristor or memory resistor is an electrical member with two terminals in which a functional connection is established between an electric charge and a magnetic flux. When current enters the device from one direction, the electrical resistance increases, and when current enters from the opposite direction, the resistance decreases. But when the current stops, this component of the circuit maintains the last resistance it had, and when the load current starts again, the resistance of the circuit will be the same as the last time of operation. As long as the current diagram remains in a certain range over time, this device is a resistance operator with almost linear resistance. Memristor was theoretically formulated and named by Chua in an article published in 1971. In 2008, a team at HP Lab officially announced the production of a variable-based thin-film memristor. This means that the memristor can be used in nanoelectronic memory and neomorphic computer structures.

In the 1971 paper, Leon Chua came up with a concept between resistor and inductor-capacitor and was inspired by a simple and basic idea similar to a tool like a memristor. Though the relationship between voltage and current in a memristor is not like a linear variable resistor, other scientists before him expressed nonlinear relationships for electric charge and flux, but Chua's theory was more pervasive. The memristor resistor depends on the integral portion of the input given to its terminal, while the variable resistor depends on the instantaneous value of the input. Then, this component of the circuit recalls the amount of current flowing through it, it was discarded by Chua as a memristor. In other words, the memristor is a neutral member of the circuit and has two terminals that can maintain a relationship between the function of current in time and voltage in time. The diagram of this function is called memristance and is similar to a variable resistance. Batteries also have memristance but are not neutral. The definition of a memristor is based specifically on the main variables of the circuit, namely current and voltage, and their relationship to time, just like resistors, capacitors, and inductors. Unlike these three circuit components (resistor, inductor, and capacitor) which can have constant values concerning time, the memristor relation is nonlinear and can be expressed as a function of the circuit variable, i.e. net load current. There is no such thing as a standard memristor. As an alternative, any device that plays a functional role in expressing voltage in terms of current or vice versa is a type of simple resistor memristor.

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