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Design of the floating-type memristor emulator and its circuit implementation

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Abstract: Memristor is a kind of nonlinear resistance with memory ability. The resistance of the memristor changes depending on the charge quantity or the magnetic flux passing through it. As a basic two-terminal device, the memristor should be connected with other electronic devices in any form and not limited to the grounding-type. In this paper, a new memristor emulator is proposed based on HP memristor model and then a floating-type memristor emulator is designed. Finally, the corroding physical circuits are built to verify the correctness of the design.

Keywords: memristor emulator; grounding-type memristor; floating-type memristor; software simulation; physical circuit

I. Introduction

In 1971, Professor Chua predicted according to the symmetric relations between the four basic circuit variables (charge, flux, voltage and current) that there exists a fourth fundamental two-terminal circuit element (except to resistor, capacitor and inductor) characterized by a relationship between charge and flux linkage, named memristor [1]. In 2008, the HP lab has successfully made the memristor device [2] using nano-material. And from then on the related researches to the memristor begun to get people's attention. As nano-technology have many shortcomings such as the high cost, difficult to realization and other deficiencies, the memory device is now a product only in the laboratory environment and its commercialization needs a long way to go. Therefore, designing the emulation of the memristor according to the actual electrical characteristics has a very important significance and practical value.

Nowadays, a lot of essays reported the SPICE model of memristor [3-7]. These models can be used to simulate the voltage and current curve of the memristor, but it is not the physical circuit which can be realized physically. That is to say, these models can not be apply to specific circuits neither be used to experimental study. To end this, researchers have designed many equivalent circuit models [8-11] and circuit emulators [12-13]. For example, Bao Bocheng [9] designed two kinds of equivalent circuits of the magnetic-control memory devices according to the quadratic form and cubic form model respectively. Muhammad [13] designed a new type of memristor emulator and analyzed its application in digital modulation. Daniel [14] designed another type of memristor emulator which can simulate the behavior of the TiO_2 memory device and was built by the existing devices. Then the author analyzed the electrical characteristics of the two or more memory devices with the same or different polarity in series, parallel and mixed.

The circuit emulators designed by the above essays can only be connected to other circuits in grounding-type. However, as a basic two terminal device, the memory device should be connected with other electronic devices in any form and not limited to the grounding-type. So the suspending-type (same as “floating-type”) of the memory device is need to be studied and researched. In paper [15], through analysis of memconductor, the author designed the floating-type emulator of memconductor, and analyzed its filtering characteristics. In paper [16], the author realized the simulator of the grounding type at first. Then, in the case of constant circuit topology, the grounding resistance can be transformed into floating memristor, floating memconductor and floating meminductor by means of access to different property elements to the circuit topology.

In my paper, based on the above literature, a new type of floating-type of memristor emulator is designed by using a small amount of components. And then the software simulation is carried out. Finally, the physical circuit is built.

II. Realization of the memristor emulator

2.1 Realization of the grounding-type memristor emulator

Literature [16] shows that the HP model can be expressed by the following formula:

$$R_m(t) = R_{OFF}(1 - k \cdot q(t)), \tag{1}$$

Where $k = \mu_V R_{ON} / D^2$.

According to the mathematical model of the HP memristor, we achieve a grounding type circuit of the memristor emulator using the current feedback operational amplifier and analog multiplier, as you can see in figure 1. Where chip U1 and U2 are current feedback operational amplifiers AD844AN, and chip U3 is analog multiplier AD633JN. The port characteristics of AD844AN is given by

$$v_x = v_y, i_y = 0, i_z = i_x, v_w = v_z. \tag{2}$$

Analyzing the circuit in Figure 1，chip U1 is current voltage converting circuit，and the output voltage is given by

$$v_{1out}(t) = R_1 i_{\text{in}}(t). \tag{3}$$

Chip U2 constitutes an integral circuit, and its output voltage is given by

$$v_{2out}(t) = \frac{1}{C}\int i_C(t)dt = \frac{1}{C}\int \frac{v_{1out}(t)}{R_2}dt. \tag{4}$$

According to the input and output of AD633JN, the output voltage of the chip U3 is given by

$$v_w = \frac{(v_{x1} - v_{x2}) \cdot (v_{y1} - v_{y2})}{10} + v_z. \tag{5}$$

$$v_{3out} = -\frac{1}{10} v_{1out}(t) v_{2out}(t). \tag{6}$$

The output voltage of the chip U3 feedback to the Y port of the chip U1, due to the X port and Y port of AD844AN are the same voltage (“ virtual short”), so there is

$$v(t) - v_{3out}(t) = i_{\text{in}}(t) R_s. \tag{7}$$

Substituting(3),(4) and (6) into (7)

$$v(t) = v_{3out} + i_{\text{in}}(t)R_s \;= i_{\text{in}}(t)\left(R_s - \frac{R_1^2}{10R_2C} q(t) \right). \tag{8}$$

So the resistance of the memristor is given by

$$R_m = R_s\left(1 - \frac{R_1^2}{10R_sR_2C} q(t) \right). \tag{9}$$

Make

$$R_s = R_{OFF}, \qquad k = \frac{R_1^2}{10R_sR_2C}. \tag{11}$$

Therefore the proposed model of the memristor emulator can correctly simulate the HP memristor which was described by formula (1).

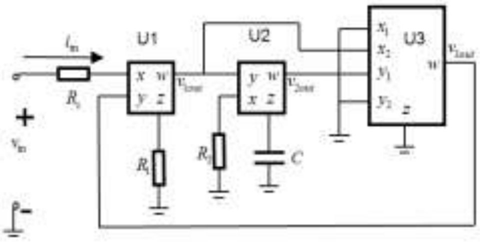


Fig.1 Grounding-type HP memristor emulator

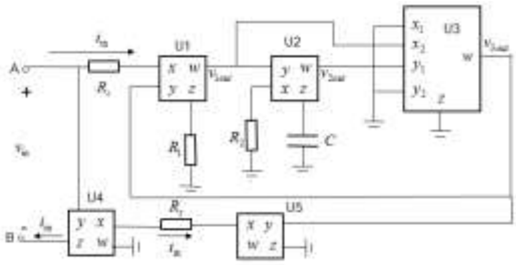


Fig.2 Floating-type HP memristor emulator

2.2 Realization of the floating-type memristor emulator

On the basis of Figure 1, adding two AD844 chips to realize the voltage to current conversion, the emulator can realize the HP memory of the floating ground connection, as shown in figure 2.

Analyze each port of the chip U4, we have $v_x = v_y = v_A = v(t)$. similarly analyze the chip U5, we obtain $v_x = v_y = v_{3out}(t)$. The X ports of the chip U4 and U5 were linked by a resistance R_s, thus the current of the X port of the chip U4 is given by

$$i_x = \frac{v(t) - v_{3out}(t)}{R_s} = i_{\text{in}} \tag{12}$$

So $i_z = i_x = i_{\text{in}}$. Meanwhile, the chip U4 have $v_B = v_z = v_w = 0$. Therefore both A and B ports of the emulator's input are an input voltage of two-terminal network, so to achieve the floating ground connection.

Thus the memory device can be directly connected to other circuits without grounding limit.

III. Multisim software simulation analysis

In order to verify the correctness of the proposed emulator, this paper uses the circuit simulation software ("Multisim") to simulate. Simulation analysis to the grounding type memristor was shown in Figure 1. The current feedback circuit uses the chip AD844AN, and the analog multiplier uses the chip AD633JN, meanwhile the bias voltage is $\pm 15V$. Circuit parameters set to $C = 220nF$, $R_s = 16k\Omega$, $R_1 = 4k\Omega$, $R_2 = 5k\Omega$ 。

The input voltage amplitude is $V_{PP} = 5V$, and the voltage frequency is equal to the 40Hz, 200Hz, 100Hz respectively. Using sine wave to drive the simulator, and getting the characteristic curve of the memristor shows in Figure 3.

Then the input sine wave signal frequency set to $f = 40Hz$, and the amplitude is equal to 2V, 3V, 5V respectively. Getting the characteristic curve of the memristor shows in Figure 4.

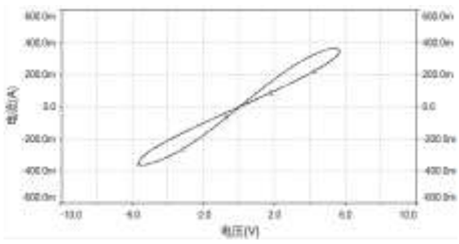
This is a good way to verify the three essential characteristics of the memory device:

1. The memristance varies with the voltage of input signals, showing a helical shape of "8" hysteresis loop.
2. The nonlinearity decreases with the increasment of the frequency of the input signal, and when the frequency reaches a large value the memristor becomes a linear resistor.
3. And the nonlinearity also changes with the amplitude of the input signal. For the magnetic-controlled memristor, the input voltage is greater, the less nonlinearity; for the charge-controlled memristor, the input current is bigger, the less nonlinearity.

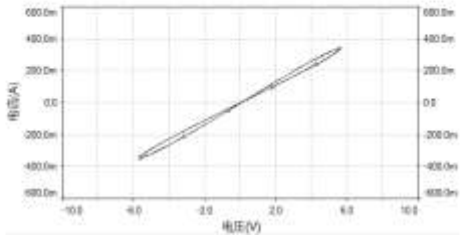
The HP memristor belongs to charge- controlled memristor, so the input current is bigger, the nonlinearity is small. And when the current is large enough the memristor becomes a linear resistor. While the current and voltage is in inverse proportion, the higher the voltage, the smaller the current. So the increasing voltage in Figure 4(a), (b) and (c) shows that the current is reduced.

From the above analysis and Figure 3, 4 can be drawn that the design of the memristor emulator in my paper can be very good to meet the memristor's three nature characteristics, namely, the design of the emulator is successful!

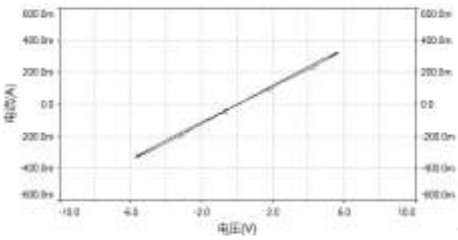
Similarly, simulation to the floating-type emulator has the same properties. Figure 4 shows the voltage vs. current curve of the floating-type emulator with the input amplitude is 4V and the signal frequency is 40Hz. Because the space is limited, other graphics will not be given.



(a)

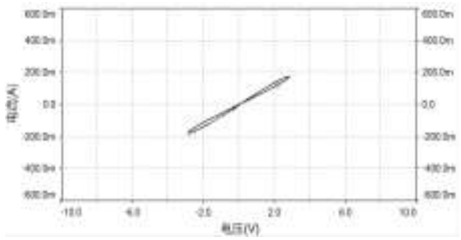


(b)

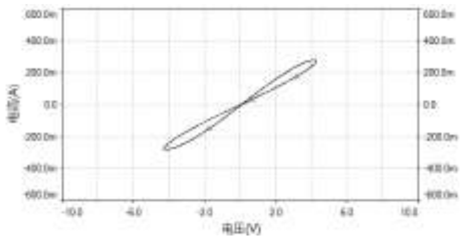


(c)

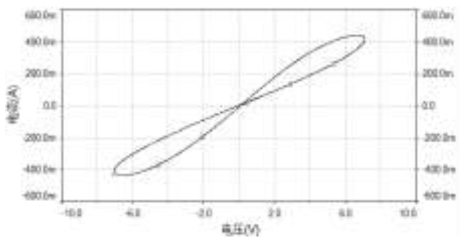
Fig.3 V-I curve of the grounding-type memristor emulator with different input frequency (a) 40Hz (b) 100Hz (c) 200Hz



(a)



(b)



(c)

Fig.4 V-I curve of the grounding-type memristor emulator with different input voltage (a) 2V (b) 3V (c) 5V

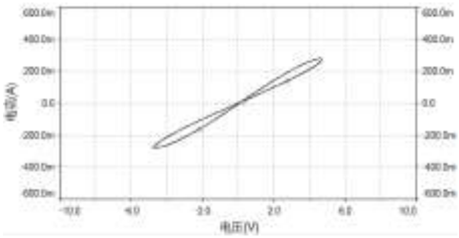
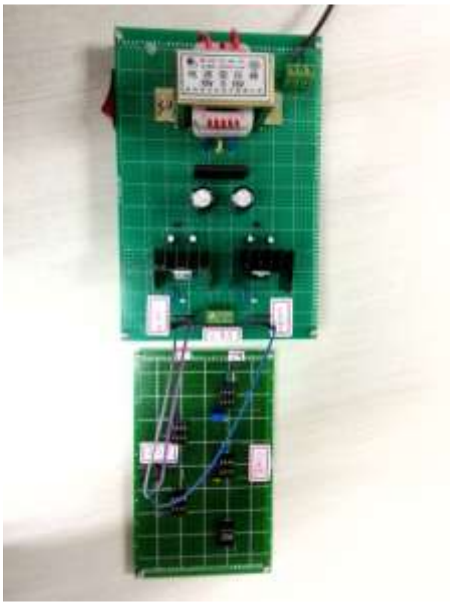


Fig.5 V-I curve of the floating-type memristor emulator memristor

IV. Physical circuits of the memristor

Using conventional elements to construct the floating-type memristor, as shown in Figure 2, we got the physical circuits shown in Figure 6(a). And the voltage vs. current curve shows in Figure 6 (b).Because the space is limited, other graphics will not be given.



(a)

(b)

Fig.6 (a) physical circuits of the floating-type memristor (b) V-I curve of the floating-type memristor

V. Conclusion

In this paper, the design of the memory device can be realized by ordinary active devices. Based on the model of the grounding-type memristor emulator, the author designed a floating-type memristor emulator. The simulation results are in agreement with the theoretical results of the two models, and meet the three essential laws of the memristor. Finally, two kinds of physical maps are given in the paper. The simulation results are also verified by the simulation results which reverified the correctness of the design of the circuit simulator. Because of its non-grounding limitation the potential application of the floating-type of memristor is more extensive .

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