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A new Circuitry Design for Memristor Realization

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Abstract– This paper proposes new designs on the building blocks, namely the reflector and the scaler, in the design framework proposed by Leon Chua, which is used for implementing memristor in electronic circuits. Simpler and more robust designs are reported, and their functions are well demonstrated with circuit simulations.

1. Introduction

The recent development of memristor has aroused a lot of interest, thanks to the realization of memristor based on a thin film of titanium dioxide found by HP in 2008 [12]. The term, memristor, was firstly proposed by L.O. Chua in [3, 4] more than forty years ago, defining a component presenting a missing relationship between charge and magnetic flux linkage. Due to the distinct characteristics of memristor, many potential applications have recently been suggested, including variable gain amplifier [14], adaptive filter [5], memory [6, 7, 10], chaos generation [8, 13], just to name a few.

In the last few years, many efforts have also been paid to identify the memristance properties [1, 2, 12]. Similar trials have been observed for developing same property by means of simple electronic circuits. However, it is noticed that many designs only focus on the differential equation without consider the physical nature [9], while some designs require special analogue function, such as divisor, for implementation [11].

In this paper, we are interested in the design framework proposed in [3, 4], where a memristor is considered as a two-port network. The design is achieved by cascading three kinds of two-port networks, namely, the mutator, the reflector and the scaler, so that the function of memristor can be obtained. The major advantages for this framework are that it is a general design and different kinds of memristors can be implemented.

In the original design [3, 4], a relatively complicated circuits based on transistor and diodes have been suggested for the reflector and the scaler. It consequently introduces a limited operational range of the designed memristor and also hinders its practical applications.

Our objective in this paper is to improve the circuit implementations of the reflector and the scaler so that a more effective design of memristor can be obtained. The organization of the paper is as follows: In Sec. 2, an overview of the circuitry realization of memristor is provided. New designs for the reflector and the scaler are then described in Sec. 3, while some simulation results are also given to justify the functions of the proposed circuits. Finally, conclusions are drawn in Sec. 4.

2. Circuit of Memristic Function

Figure 1 depicts the block diagram for a memristor proposed in [3, 4].

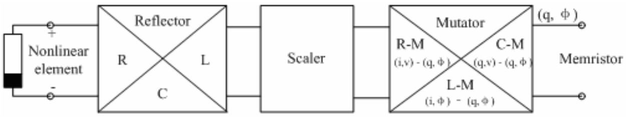


Fig. 1 Realization of memristor

The mutator, the reflector and the scaler given in Fig. 1 are all active two-port networks and their functions are briefly summarized as below:

1. A reflector is to rotate the *v-i* (voltage-current) characteristics with any desired angle.
2. A scaler is to scale up or down the *v-i* characteristics.
3. A mutator is to transform a nonlinear network element into another type. There are basically three kinds of mutators, namely R-M**,** C-M and L-M mutator.

By cascading a reflector, a scaler and a mutator, it is possible to obtain memristic characteristics at the output port by connecting a nonlinear element at the input port.

Referring to the designs given in [3, 4], it is noticed that the electronic circuit for mutator is simple and effective, but that for reflector and scaler are complicated. A number of transistors and diodes have been used and hence the voltage and frequency operational ranges are limited. Therefore, in the next section, some improvements in the designs of reflector and scaler are proposed so that a more effective realization of memristor becomes possible.

3. New Design

3.1. Design of Reflector

As mentioned before, the function of reflector is to modify the *v-i* characteristic, which can be described by the following transformation:

$$\begin{cases} v_1 = (\cos 2\theta)\, v_2 - (\sin 2\theta)\, i_2 \\ i_1 = (\sin 2\theta)\, v_2 + (\cos 2\theta)\, i_2 \end{cases} \tag{1}$$

where $0 < \theta \le 180^{\circ}$ and, “1” and “2” at the subscript indicate the input and output ports, respectively.

Based on (1), one can obtain the T-parameters matrix [Wiki] as follows:

$$T = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos 2\theta & \sin 2\theta \\ \sin 2\theta & -\cos 2\theta \end{bmatrix}, \qquad (2)$$

while the corresponding Y-parameters matrix [Wiki] can then be derived as:

$$Y = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} \frac{D}{B} & \frac{-\det(T)}{B} \\ \frac{-1}{B} & \frac{A}{B} \end{bmatrix} \qquad (3)$$

where $\det(T)$ is the determinant of T. Therefore,

$$Y = \begin{bmatrix} -\cot 2\theta & \csc 2\theta \\ -\csc 2\theta & \cot 2\theta \end{bmatrix} \qquad (4)$$

and Fig. 2 depicts the equivalent circuit for T.

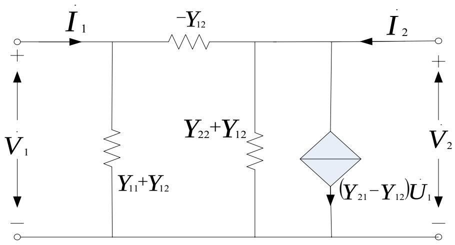


Fig.2. Equivalent circuit of Y-parameters matrix

Based on Fig. 2, it is possible to have a reflector designed as shown in Fig. 3, where R_1=Rcotθ, R_2=Rtanθ, R_3 = –Rsin2θ, and K=2csc2θ/R.

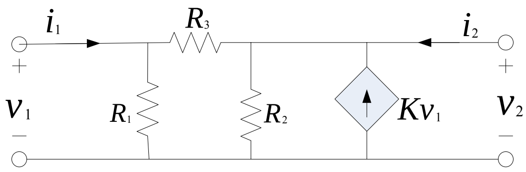


Fig.3. Circuitry for reflector with $0 < \theta \le 90^{\circ}$

The negative resistor is implemented by an operational amplifier circuit (LM324 is used and the voltage sources is ±15V), and the voltage-control current source (VCCS) can be realized as shown in Fig. 4.

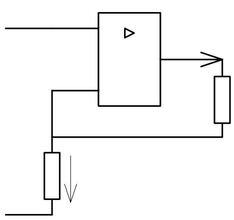


Fig.4. Circuitry of VCCS

Figure 5 depicts the entire design. To have a rotation of 30 degrees on the *v-i* characteristics, the following resistances are used:

R_1=1.732kΩ; R_2=577Ω; R_{d1}=2.4MΩ; R_{d2}=3.3MΩ; R_{d3}=R_{d4}=220kΩ; R_{d5}=R_{d6}=20MΩ; R_{n1}=R_{n2}=20MΩ; R_{n3}=866Ω; R_8=R_9=20MΩ;

and the gain of the VCCS is computed as K=0.002308.

The circuit is simulated by Multisim[1], and the *v-i* characteristics of v_1 and v_2 are given in Fig. 6 (a) and (b), respectively. It can be clearly observed that a rotation of 30 degrees in the *v-i* curve is obtained.

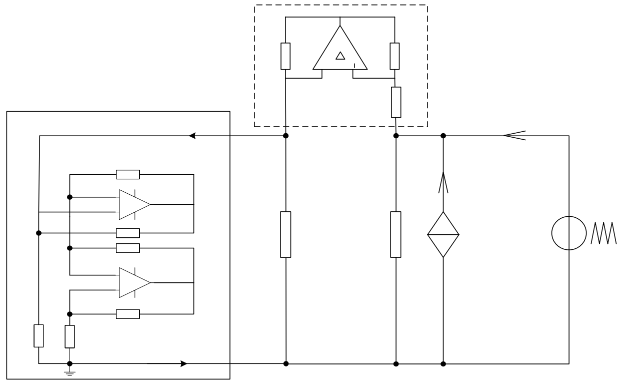
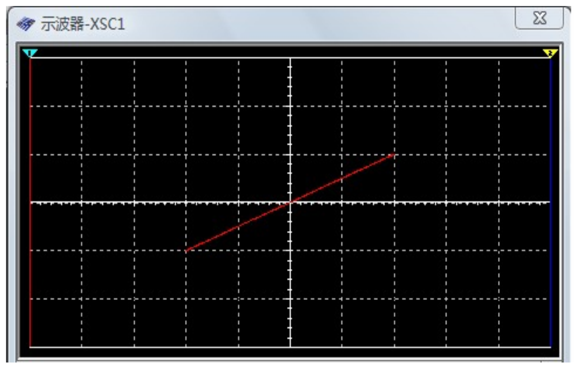
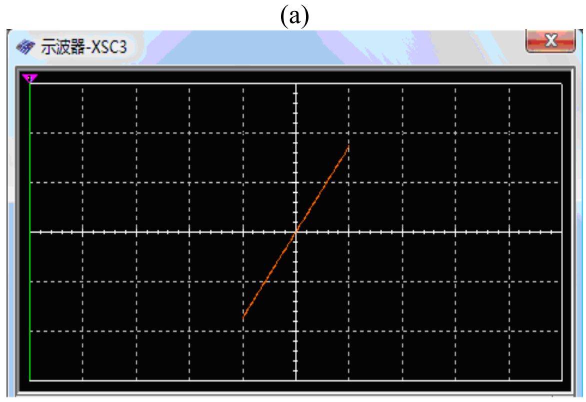


Fig. 5. Electronic circuits showing a reflector with nonlinear resistor connected at Port 1.



(a)



(b)

Fig. 6. The *v-i* characteristics of (a) v_1 (b) v_2

One of the advantages for the newly proposed reflector is that the angle of rotation can be easily adjusted by

[1] Multisim is a circuitry simulation tool designed by National Instruments Ltd.

simply changing the values of R_1, R_2, R_3 and K. Figure 7 shows another example with a rotation of 120 degrees where R_1=–577Ω, R_2=–1732Ω, R_3=866Ω and K=–0.0023.

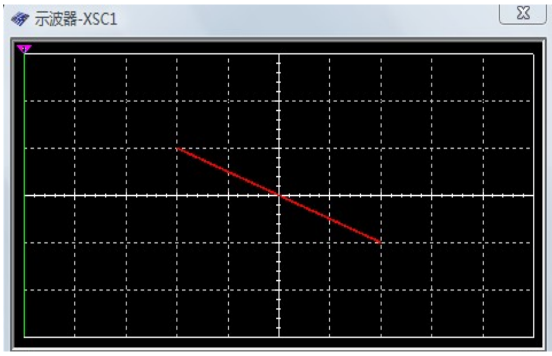


Fig. 7. The *v-i* characteristics of v_2 after rotating the *v-i* characteristics of v_1 by 120 degrees using the reflector.

Remark 1: All the simulations are carried out with an input frequency of 1KHz. Limited by the frequency response of the operational amplifier, the *v-i* characteristics may be distorted if a very high frequency signal is inputted.

3.2. Design of Scaler

As explained in [3,4], the function of a scaler is to rescale the input signal so that the operational range can be matched to the dynamical ranges of the components. Its function can then be characterized by the below transformation:

$$\begin{cases} v_1 = v_2 \\ i_1 = -k i_2 \end{cases}, \tag{5}$$

where the negative sign indicates the difference in the directions of i_1 and i_2.

Based on (5), it is noticed that, if a resistance load is connected to Port 1, a negative resistance will be obtained at Port 2. Therefore, the scaler is closely related to the design of negative resistor, and it can be realized by the circuit as depicted in Fig. 8.

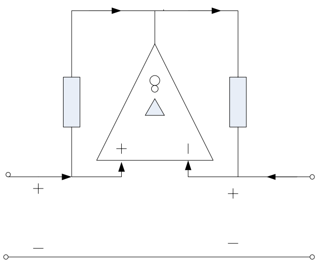


Fig. 8. Circuitry realization for a scalar

Assuming a neglected biasing input currents, i.e. $I_5 \approx 0$ and $I_6 \approx 0$, one has

$$V_1 = V_2 \tag{6}$$

$$I_1 = \frac{V_1 - V_0}{R_1} \tag{7}$$

$$I_2 = \frac{V_2 - V_0}{R_2} \tag{8}$$

From (6)-(8), one obtains

$$\frac{I_1}{I_2} = \frac{V_1 - V_0}{V_2 - V_0} \times \frac{R_2}{R_1} = \frac{R_2}{R_1} \tag{9}$$

and hence $k = \frac{R_2}{R_1}$.

Consider a negative resistor R_L connected to the output port, one has:

$$I_2 = \frac{-V_2}{R_L} \tag{10}$$

The input impedance of the two port network is then derived as:

$$Z = \frac{V_1}{I_1} = \frac{V_2}{\frac{R_2}{R_1} I_2} = \frac{V_2}{\frac{R_2}{R_1} \times \frac{-V_2}{R_L}} = -R_L \times \frac{R_1}{R_2} \tag{11}$$

Similarly, assuming that a load resistor R_L is connected to the input port, the output impedance can be derived as:

$$Z = \frac{V_2}{I_2} = \frac{V_1}{\frac{R_1}{R_2} I_1} = -R_L \times \frac{R_2}{R_1} \tag{12}$$

Figure 9 depicts the entired circuitry design and the function is simulated by Multisim based on the following resistance values:

R_1=2MΩ; R_2=1MΩ; R_4=R_7=220KΩ; R_5=3.3MΩ; R_6=2.4MΩ; R_8= R_9=20MΩ;

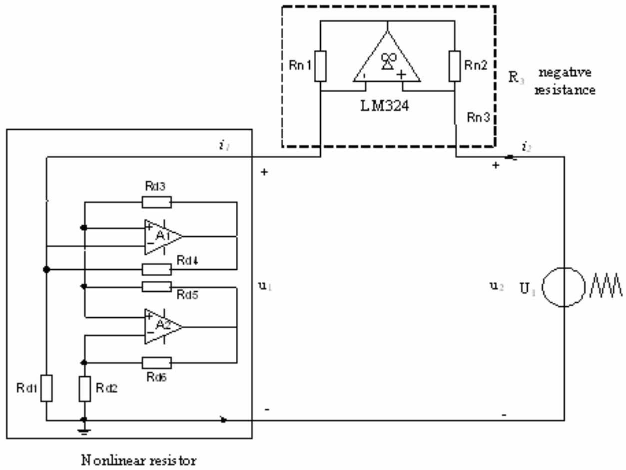
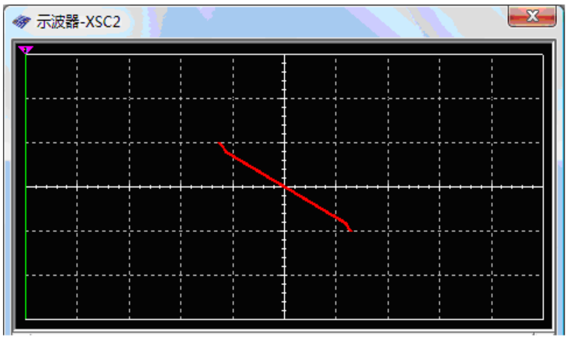


Fig. 9. Electronic circuits showing a scalar with nonlinear resistor connected at Port 1.

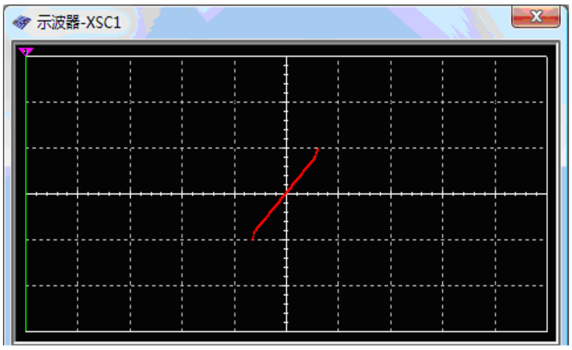
The *v-i* characteristics of v_1 and v_2 are given in Figs. 10 (a) and (b), respectively. As a remark, the ratio of R_1 and R_2 gives K=0.5.

When different K is used, for example, K=2 (R_1=1MΩ and R_2=2MΩ), the v-i characteristics of v_2 is changed as shown in Fig. 11.

Remark 2: Similarly, all the simulations are carried out with an input frequency of 1KHz. Distortions on the *v-i* characteristics at the output port are noticed if signal of high frequency is inputted.



(a)



(b)

Fig. 10. *v-i* characteristics of scaler (a) v_1 (b) v_2 with load R_L and $K=R_2/R_1=0.5$

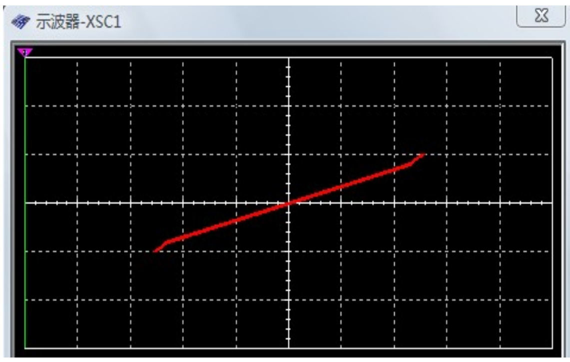


Fig. 11. *v-i* characteristics of v_2 of a loaded scaler and $K=2$

4. Conclusion

This paper improves the two major design blocks for the realization of memristor, based on the implementation method proposed in [3, 4]. New electronic circuits using operational amplifiers are given to implement the functions of a reflector and a scaler. The correctness of the designs is varified by circuit simulations.

Acknowledgments

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