The Design of Memristor Based High Pass Filter Circuit

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***Abstract*— Many researchers accept to memristor as fourth basic circuit elements in literature. The missing linkage between charge and flux is provided by a device which is memristor. The memristor ("memory resistor") is formally defined as a two-terminal element in which the magnetic flux between the terminals is a function of the amount of electric charge that has passed through the device. It is predictable that memristor-based analog filters will provide different features from other circuit devices. In this paper, we use an emulator circuit which seems memristors property basic to explain the high pass filter with memristor. Firstly, an emulator existing in literature is used fort his application. Then, memristor-based high pass analog filter is modeled, filter waveforms and performance analyzed in time and frequency with simulations. Circuit gain and phase results are explained. These results obtained in this study can be used in the design of memristor-based high pass filter.**

Keywords— memristor; emulator; filter; multisim;

I. Introduction

Leon O. Chua presented a new work where the fourth passive two-terminal electrical component – memristor was described in 1970s [1]. Memristor was introduced in the field of circuit design in 2008. The Stanley William's group from Hewlett-Packard (HP) has built a nano-scale TiO_2 device which is nonvolatile and exhibits synaptic characteristics [2-4].

Circuit theory has the basic elements; current, voltage and magnetic flux. There is a relationship among them. Resistor, capacitor, and inductor which are three of them define the three basic devices. However, the relation between the charge and the flux and the device which describes it was unknown. This situation is inspired to Leon Chua for discovering of the fourth fundamental element memristor which describes the above missing relation between charge and flux [1]. They show that memristor should represent the relation between electric charge (q) and magnetic flux (φ).

$$\partial\emptyset = M\partial q \quad (1)$$

Memristor has drawn the worldwide attention after HP released its invention and after this year many studies are made very different fields. Because of such unusual features of the memristor, many scientists had started to implement the memristor for analog and digital information processing applications. Others have applied memristive devices as resistive switching devices for memory and logic applications. Under sinusoidal signals, memristive devices, are the *pinched* hysteresis loop in the current versus voltage. Owing to these event, the resistance of the memristor depends upon the past history of the input current or voltage. This phenomenon which is the analog signal storing capability of the memristor is very important in neuromorphic applications [3-6].

Commercially available memristors are not expected to seem in the near future due to the cost and technical difficulties in fabricating nano-scale devices, although immense interest among scientists on the memristor. Thus, we need circuit replacements which behave like memristors to make real-world application circuits which exploit memristor's potentials and features. Some research groups presented spice macro models which are useful for explaining and simulating memristor [7-14].

In this paper, we propose memristor based high pass filter and study its characteristics. The analysis and simulation results of memristor based circuit are based on charge controlled memristor emulator that presented in [8]. The organization of the paper is as follows. Section 2 briefly explains details of memristor. In Section 3 memristor based high pass filter is studied. Section 4 gives the simulation results for high pass filter circuits. In Section 5 the conclusion of this study is given.

II. MEMRISTOR

The structure of the TiO_2 memristor are shown Fig. 1 [3]. In the TiO_2 memristor, a thin titanium dioxide TiO_2 layer and a thin oxygen-poor titanium dioxide TiO_2 layer are sandwiched between two platinum electrodes. The TiO_2 layer and the TiO_2 layer are referred to as undoped, and doped layers, respectively.

When a voltage or current is applied to the memristor, the dividing line between the TiO_2 and TiO_2 layers shifts as a function of the applied voltage or current. As a result, the memristor resistance between the two electrodes is changed. The structure of these thin-film titanium dioxide memristors are set to become a stoichiometric layer of titanium dioxide (low resistance) and an oxygen deficient layer (high resistance) sandwiched between two platinum electrodes. *D* is the length

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of the device and w is the length of the doped region. In short, the resistance of the film is relying on how many charges have been input from a specific direction whilst the current direction could be change reversed [1-4].

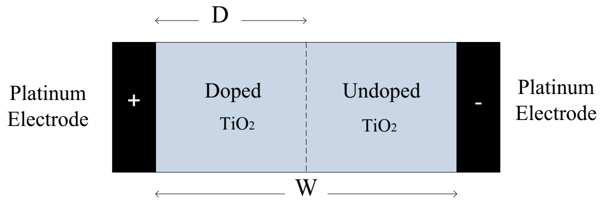

Fig. 1. The structure of the TiO_2 memristor

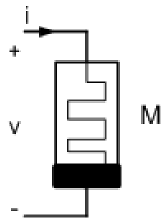

Fig. 2. Memristor model which has two terminals

To validate the previous discussion and due to the absence of physical commercially memristors, this section discusses emulator circuits followed by circuit simulations.

A memristor emulator is memristive system and move memristor-like properties at the same time. This system complies with the definition given by Chua [2]. This circuit is shown Fig. 3 Chua's circuit emulator has using experimental flux integrator circuit-circulation and charge characteristics. Chua's emulator circuit consist of many elements and application appears time-consuming. Thus, we use a model which is limited from this emulator circuit in literature [9-12].

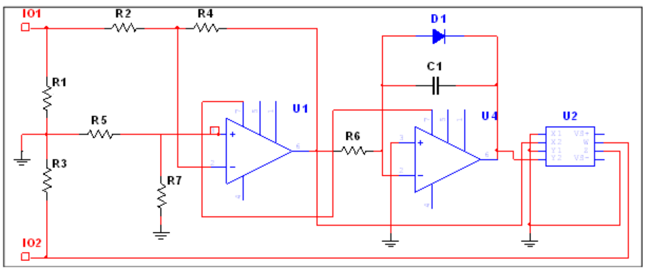

Fig. 3. Emulator circuit of memristor

III. MEMRISTOR BASED HIGH PASS FILTER

We consider a modified version of the basic first order R-C (Resistor-Capacitor) high-pass filter, where the resistor is replaced by a memristor. The resulting circuit, usually referred to as an M- C (Memristor-Capacitor) high-pass filter, where V_i and V_o respectively, denote the filter input and output voltages. Passive first-order R-C filters with one resistor and one capacitor are also called one pole filters [15-17].

Low-pass filters behave in opposite way, when high-pass filters pass high frequency and blocks low frequency signals. R-C high-pass and M-C high-pass filters are shown in Fig. 4 (a) and 4 (b), respectively. By changing the linear resistor with memristor and considering also polarity of the memristor, M-C form of these filters are obtained as depicted in Figure 4 (b).

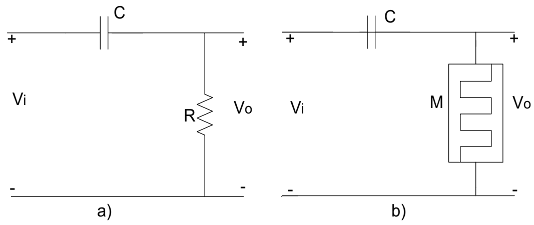

Fig. 4. a) RC high pass filter b) MC high pass filter

$$H_{MC}(s) = \frac{MCs}{MCs + 1}$$

$$f_0 = \frac{1}{2\pi RC}$$

A MC high pass filter was constructed by connecting a memristor and a 1 μF capacitor in series. The transfer function of the circuit was measured using a network analyzer with Multisim bode diagram. Then we made co-simulation from Multisim to LabVIEW.

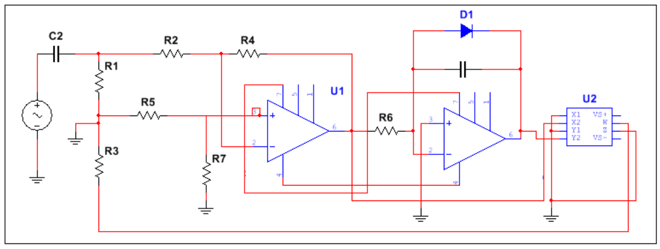

Fig. 5. MC high pass filter circuit

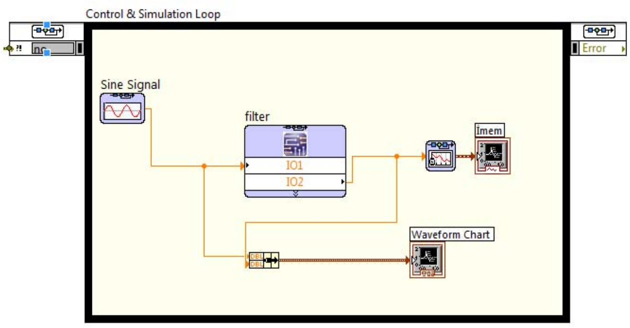

Fig. 6. Multisim LabVIEW co-simulation

IV. SIMULATION RESULTS

The emulator of memristor is modelled with Multisim and the desing is showed in Fig. 3. Emulator circuits seem memristor behavior. Resistors ordinary seem linear relationship between current and voltage, so this results a straight line in I-V graph of an ordinary resistor. However, memristors has hysteresis curves for I-V characteristic. Since memristors are not voltage storage devices, the voltage must be equal to zero when the current is zero. This situation causes, zero pinched hysteresis loop in I-V curve of the memristor. As observed above that there are two straight line segments in the curve. We set a relation between LabVIEW and Multisim and observe the results of LabVIEW. These results are given Fig. 7 shows the LabVIEW simulation result of I_{mem}-V_{mem} relation of emulator circuit. Also, Fig. 8 illustrates the Multisim results I_{mem}-V_{mem} relation of emulator circuit.

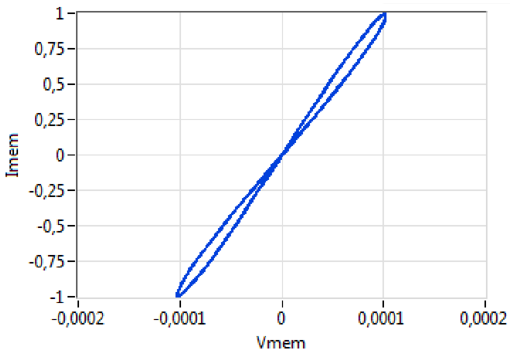

Fig. 7. LabVIEW simulation result Imem-Vmem relation of emulator circuit

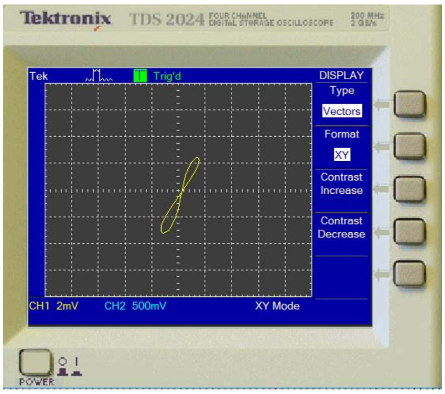

Fig. 8. Multisim simulation result Imem-Vmem relation of emulator circuit

A behavioral model of a memristor are developed at device level using the Multisim by following the mathematical equations presented previously. The reason of preferring the Multisim program is its graphic based structure and the ease provided to user in constituting interface [16-19]. We research TiO_2 memristor model to make it easy to comprehend and ready to be used in memristive systems.

In order to investigate the memristor effect on high pass filter classical RC high pass filter and memristor based high pass filter are simulated using Multisim program. The memristor model parameters given in similar study are used.

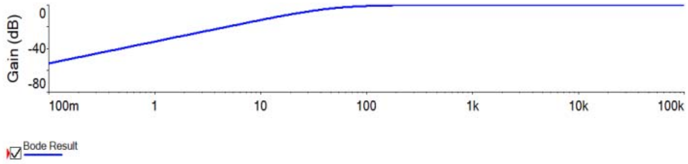

Fig. 9. RC filter gain (dB) graph

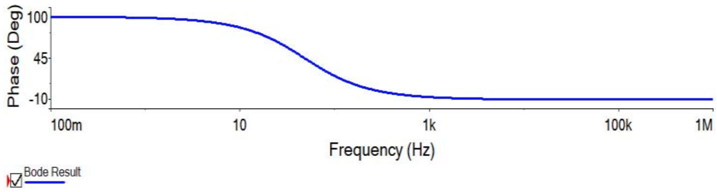

Fig. 10. RC filter phase graph

Fig. 9 and 10 show RC high pass filter gain and phase graph, respectively. The capacitor value is taken as 1 uF for the two simulated circuits while the resistor value for classical RC circuit is selected as 3.3k Ω. The theoretical cut off frequency of resistor based circuit is found as 49.88 Hz. Time domain simulation results of resistor and memristor based circuits for input voltage with 0.05 V amplitude and 60 Hz frequency. It is seen from figure difference between phase degrees and amplitude value of the circuits' outputs due to memristor variation. Fig. 11 and 12 show MC high pass filter gain and phase graphs, respectively.

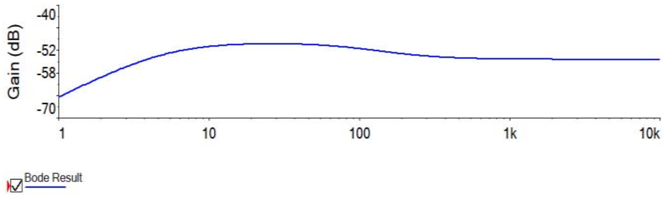

Fig. 11. MC filter gain (dB) graph

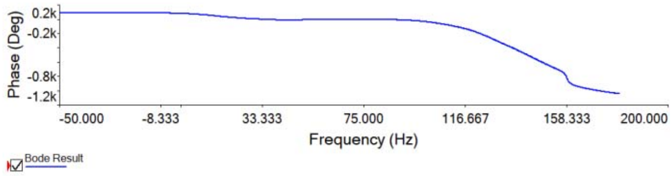

Fig. 12. MC filter phase graph

Fig 13 and 14 illustrate input voltage and output current of emulator circuit at frequency 60 Hz and Input voltage and output current of emulator circuit at frequency 5k Hz, respectively. We see that if we increase the frequency of input signal, memristor behavior as a resistor.

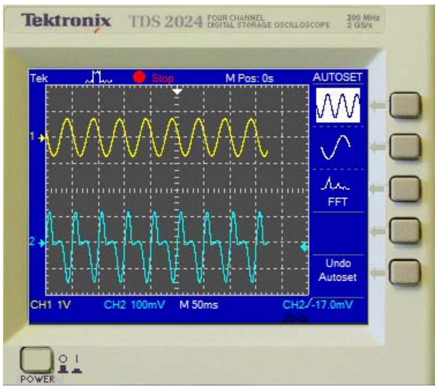

Fig. 13. Input voltage and output current of emulator circuit at frequency 60 Hz

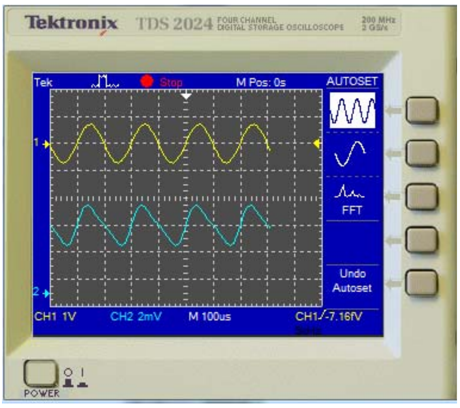

Fig. 14. Input voltage and output current of emulator circuit at frequency 5k Hz

V.CONCLUSION

In this paper, resistor in RC high pass filter circuit is replaced with memristor. The theoretical analysis on the effect of using memristor in place of a resistor are described mathematically and verified by Multisim and LabVIEW simulation results. It is observed from simulation results that the cut off frequency of the filter circuit gain is similar to each other. However, M-C circuit behavior like band-pass filter after a value. The effect of input frequency for memristor based high pass filter is examined.

Although a memristor is not available as a separate component in market yet, simulation results and analytical models of memristor-based circuits obtained using memristor models available in literature can be used to explain how to design memristor-based filters.

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