Simulation and Experimental Demonstration ofLow-/High-Pass Filter using Memristors

Khushwant Sehra[1], Gaurav K. Shakya[2], Poonam Kasturi[3],
Mamta A. Wagh[4], Manoj Saxena[5],*
[1,2,3,5]Department of Electronics,[4]Department of Mathematics
Deen Dayal Upadhyaya College, University of Delhi
*saxenamanoj77@gmail.com

ABSTRACT

'Filter' as the name suggests means sifting out required information from a mixture of unwanted ones. Filters are the electronic circuits which are employed to carry out this action. They are widely used for signal processing to enhance and reinforce the required component out of the unwanted ones. This paper focuses on the implementation of some common filters such as the low pass and high pass filters using Memristors and their simulation in NI Multisim. A comparison is then presented between the traditional and the implemented circuits.

Keywords: Chua's Circuit, Loading Effect,Memristor, Multisim

INTRODUCTION

Memristor was first postulated by Prof. Leon Chua in the year 1971, as the missing non-linear two terminal passive device relating magnetic flux and electric charge. The memristor behaves like a non-linear resistor having 'memory', as its present state is dependent upon the history of the current that has passed through it previously and in what direction. In addition, it was subsequently found that the memristor at higher frequencies behaves like a normal resistor so can be used in place of traditional resistors. This paper focuses on discovering the effects of replacing resistors with memristors in the filter circuits.

Filters are the electronic circuits that are used mainly for signal processing to enhance the required frequency components while attenuating the other ones. In this paper, memristor based low pass and high pass filtercircuits have been designed and their experimental electrical characteristics are in close proximity to the simulated results obtained using NI Multisim. The op-amp realization of memristor used for simulation of these filters are based on (1).

METHODOLOGY

Op-amp realization of the non-linear diode has been employed in this paper for the implementation of memristor-based filters. This realization is based on a Voltage

Controlled Voltage Source (VCVS) wherein the op-amp is assumed to operate in an ideal condition so that its output is a function of its input differential voltage. Kennedy(1) makes use of off-the-shelf components to realize the Chua'sdiode (2) which are summarized in (Table-I).

Table – I Components used for realizing Chua's Diode

S.No.	Components		Units
1	Dual BiFet Op-amp AD712AH		2
2	Resistors –		
	$22\text{k}\Omega(\pm\,5\%, 0.25W)$		2
	$3.3\text{k}\Omega\;(\pm\,5\%, 0.25W)$		1
	$2.2\text{k}\Omega\;(\pm\,5\%, 0.25W)$		1
	$220\Omega\;(\pm\,5\%, 0.25W)$		2

The components listed above in (Table-I)are used for realizing one diode only. Apart from these, 1μF capacitor is also used in designing the high pass and low pass filters.

Low Pass Filter – First Order: This filter simply passes all the signals having frequencies below a reference frequency known as the cut off frequency and provides a 20dB/decade roll off, where cut off frequency is given by Equation-1. Analysis of Memristor – Capacitor filter circuits employing HP memristor has been carried out by HasanSozen *et. al.*(3).

$$f_{cut\,off} = \frac{1}{2\pi RC} \qquad\qquad ..(1)$$

The traditional low pass filter consists of a section ofa resistor and a capacitor as shown in FigureI(a). The input is provided between the free resistor terminal and ground. The output is taken across the capacitor as depicted. The capacitor, at low frequencies provides high impedance (capacitive reactance $X_c = \frac{1}{j\omega C}$) where, $\omega = 2\pi f$so that the input signal takes the alternative low impedance path and reaches the output terminal. However, at higher frequencies the reactance of capacitor decreases ($X_c \propto \frac{1}{f}$) as a result, the circuit thus filters out high frequency signal to ground.In the memristor based low pass filter, resistor is replaced by memristor which is implemented using the Chua's diode. The input is fed to the memristor terminal while the output is taken across the capacitor.The proposed circuit using memristor is shown in (Figure I(b)).
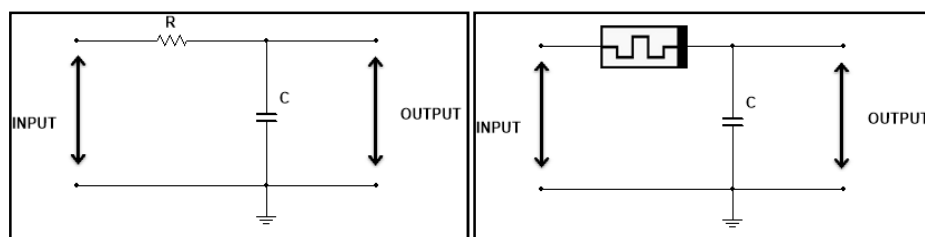

Figure I (a) RC circuit for first order low pass filter (b) Schematic of memristor based first order low pass filter.(Input is a Sine Wave having V_{p-p} = 8.6 Volts)

The circuit has been simulated using NI Multisim(4) and the results have been verified experimentally. The simulated circuit which performs the filtering action is depicted in (FigureII).
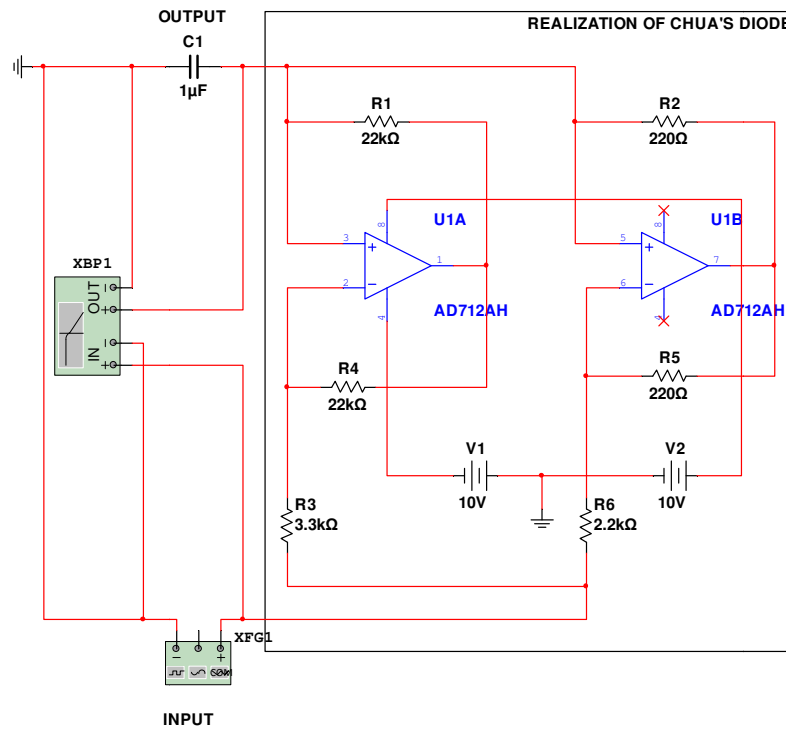

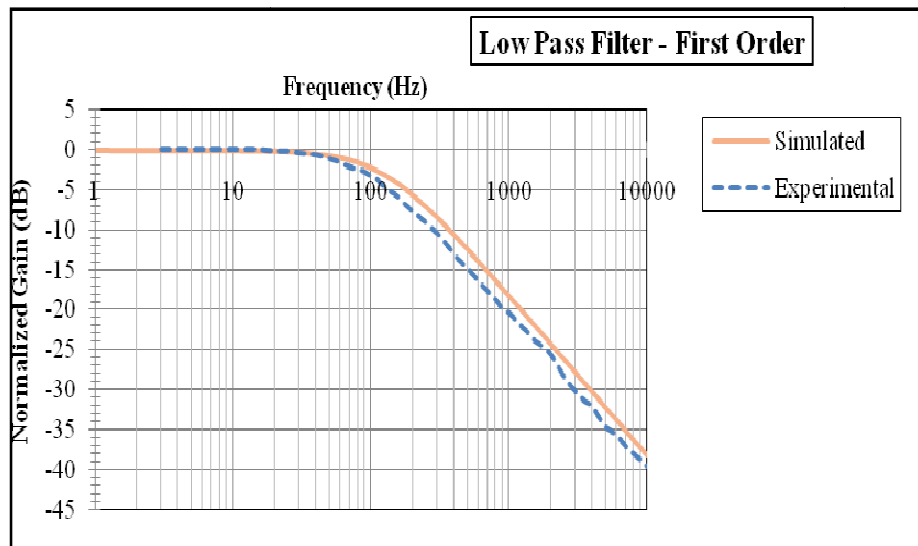Figure-II Schematic of memristor implementation of first order low pass filter.

Figure-III Frequency response of memristor based first order low pass filter – simulated and experimental.

Table–II 1st Order Low Pass Filter Parameters

Parameters	Experimental	Simulation
Cut-off	$\approx 95\ Hz$	$\approx 119.4\ Hz$

| **Roll Off** | $\approx 17.21 dB/decade$ | $\approx 17.24 dB/decade$ |

The frequency response of Memristor– Capacitor first order low pass filter as shown in (Figure III) brings forth the fact that the circuit actually is attenuating the higher frequency components, while the lower ones are passed through unaltered.The cut off frequency and roll off so obtained experimentally, as shown in (Figure IV (a) & (b), was ~95Hz and ~17.21dB/ decade respectively (Table II). The circuit thus mimics the Resistor – Capacitor based low pass filter.

Low Pass Filter–Second Order: This filter simply passes all the signals having frequencies below a reference frequency known as the cut off frequency and provides a 40dB/decade roll off, where cut off frequency is given by Equation-2.
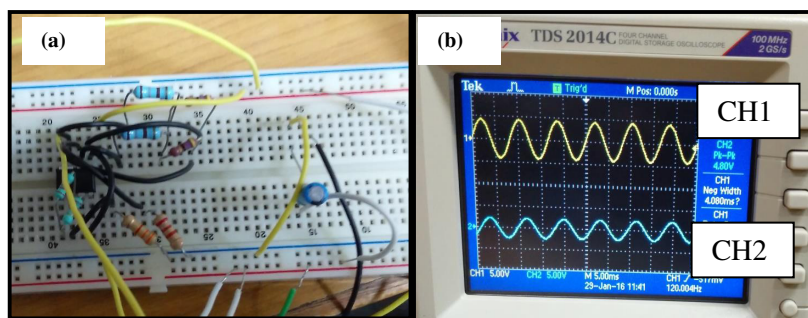
$$f_{cut\,off} = \frac{1}{2\pi RC} \qquad\qquad ..(2)$$

Figure-IV(a)Memristor based first order low pass filter hardware setup. (b)Waveforms from the hardware setup[Input: CH1 (Yellow), Output: CH2 (Blue)].

The traditional second order low pass filter consists of twosections of resistor and capacitor. The input is provided between the free resistor terminal and ground while the output is taken across the capacitor.Similarly in case of memristor based second order filter, another section of MC is added, and the output is taken across the second capacitor as shown in (Figure V(a)). These types of filters provide a higher attenuation to higher order frequency signals.The proposed circuit using memristor is shown in (Figure V(b)).

The circuit has been simulated using NI Multisim and the results have been verified experimentally as well. The simulated circuit which performs the filtering action is depicted in (Figure V (b)). Each hierarchical block in (Figure V (b)) is a realization of Chua's diode which is represented as in (Figure VI).
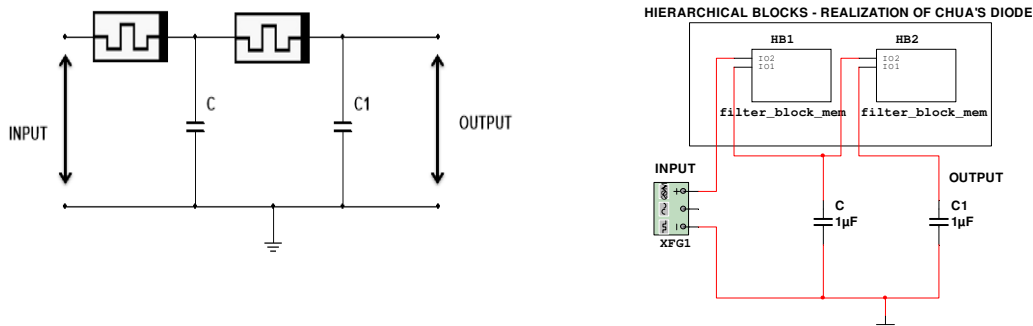

Figure-V(a) Schematic of memristor based second order low pass filter and (b) its implementation in NI

Multisim using op-amp equivalent circuit for memristor.(Input is a Sine Wave having $V_{p-p} = 8.6$ Volts)
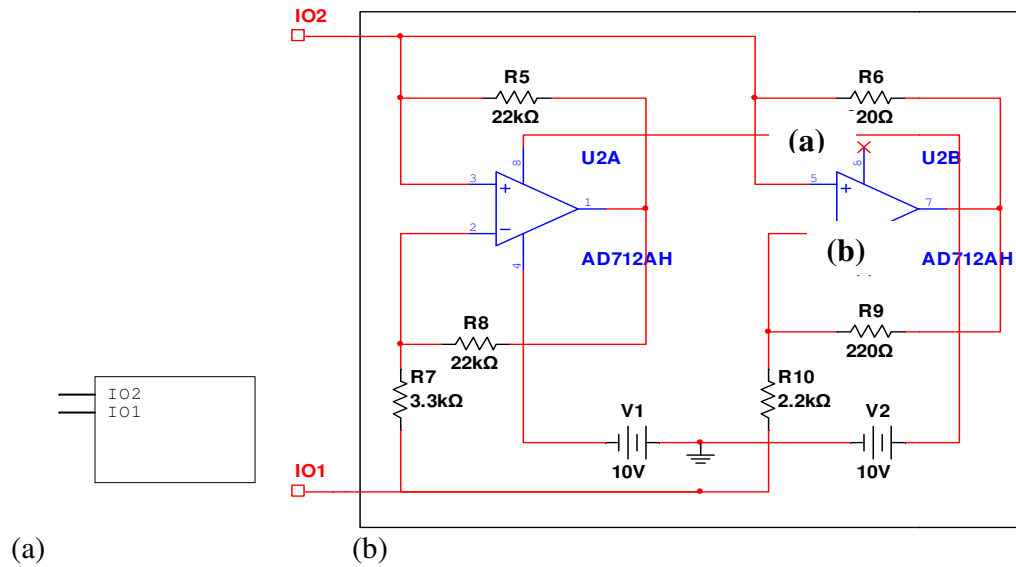

(a)   (b)

Figure-VI(a) Hierarchical block employed in simulation circuit (b) Internal circuit of the hierarchical block.
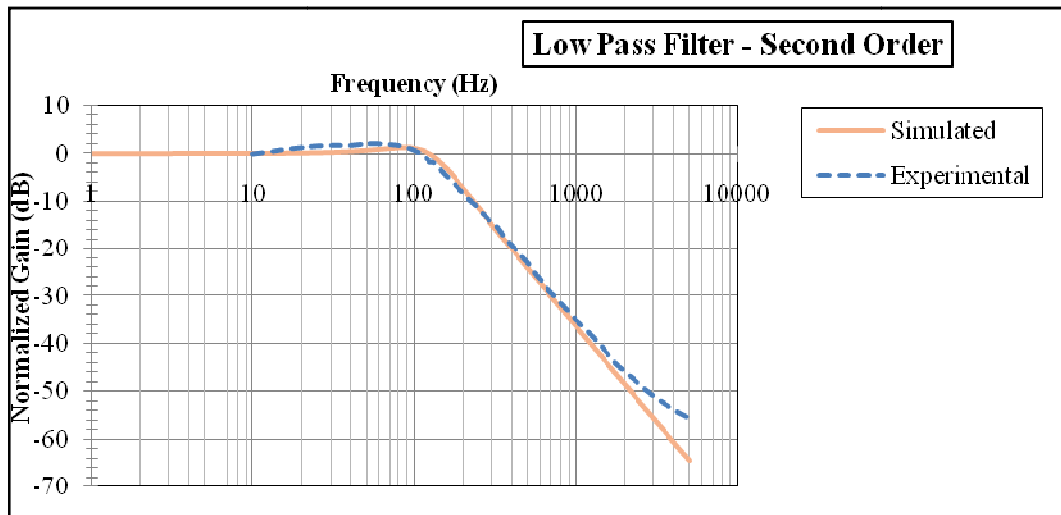

Figure-VII Frequency response of memristor based second order low pass filter – simulated and experimental.

As is evident from (FigureVII),the second order memristor based filteras shown in (Figure VIII (a) & (b)) provides a higher attenuation to the unwanted frequencies, and thus the gain rolls off at the rate of $\sim$38dB/decade(Table-III).

Table – III 2nd Order Low Pass Filter Parameters

Parameters	Experimental	Simulation
Cut-off	$\approx 145\ Hz$	$\approx 154.4\ Hz$
Roll Off	$\approx 38.2 dB/decade$	$\approx 38 dB/decade$

102

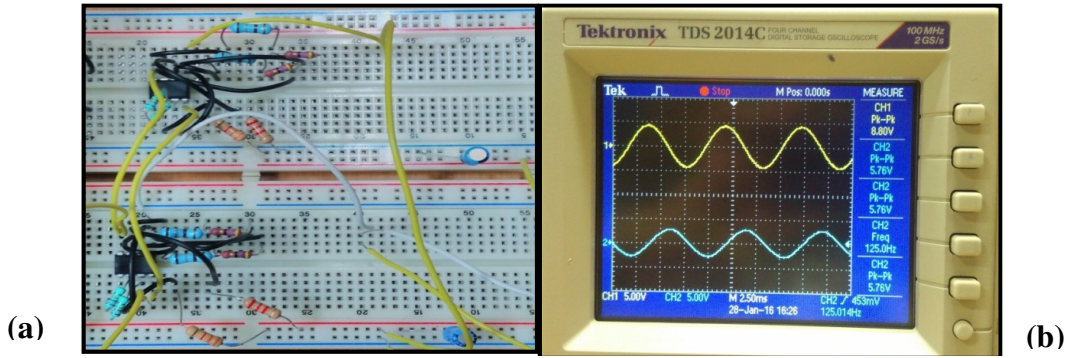**(a)**   **(b)**

Figure-VIII (a) Memristor based second order low pass filter hardware setup. (b) Waveforms from the hardware setup [I/p: CH1 (Yellow), O/p: CH2 (Blue)].

High Pass Filter – First Order: This filter simply passes all the signals having frequencies above a reference frequency known as the cut off frequency and provides a 20dB/decade roll off, where cut off frequency is given by Equation-3.

$$f_{cut\,off} = \frac{1}{2\pi RC} \qquad\qquad\qquad ..(3)$$

The traditional first order high pass filter consists of a section of a resistor and a capacitor as shown in (FigureIX(a)). The input is provided between the free capacitor terminal and ground. The output is taken across the resistor as depicted in (Figure IX (a)). The capacitor, at low frequencies provides high impedance (capacitive reactance $X_c = 1/_{j\omega C}$) so that the low frequency input signals are highly attenuated.

However, at higher frequencies the reactance of capacitor ($X_c \propto 1/_f$)decreasesand therefore, the high frequency signal passes through unaltered.The circuit then performs filtering action by attenuating the lower frequency signals and passing the high frequency signals through it.In this case too, resistor is replaced bymemristor that is implemented bythe Chua's diode.

The input is fed to the capacitor terminal while the output is taken across the memristor as in (Figure IX (b)).The proposed circuit using memristor is shown in (Figure IX (b)).
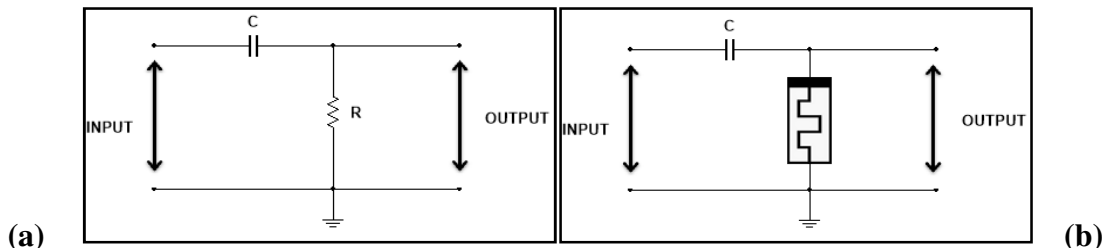

(a)   **(b)**

Figure-IX (a)RC circuit for First Order High Pass Filter(b)Schematic of memristor based first order high pass filter. [Input is a Sine Wave having V_{p-p} = 8.6 Volts]

The circuit has been simulated using NI Multisim and the results have been verified experimentally as well. The simulated circuit which performs the filtering action is depicted in (Figure X).
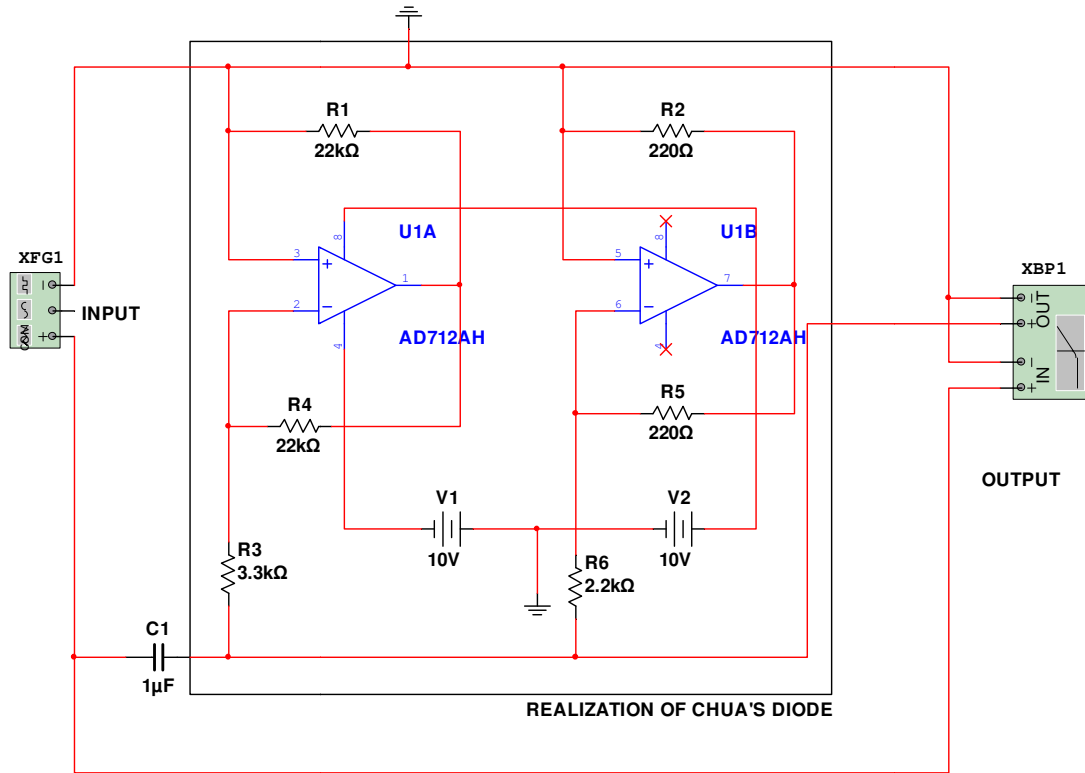
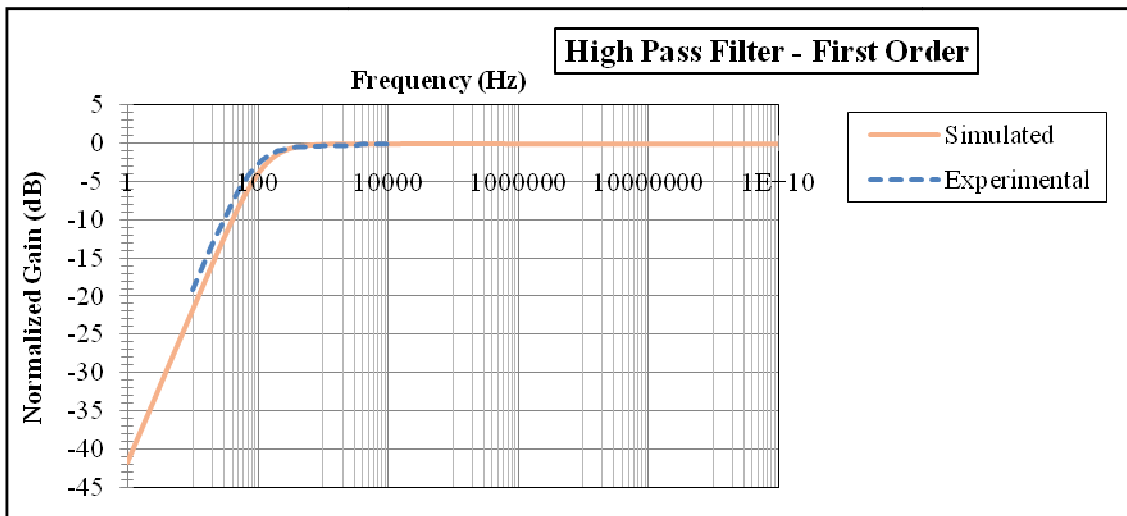Figure-X Schematic of memristor implementation of first order high pass filter.

Figure-XI Frequency response of memristor based first order high pass filter – simulated and experimental.

Table– IV First Order High Pass Filter Parameters

Parameters	Experimental	Simulation
Cut-off	$\approx 95.3 Hz$	$\approx 123.8\ Hz$
Roll Off	$\approx 16.3 dB/decade$	$\approx 16.9 dB/decade$

The frequency response of Memristor - Capacitor high pass filter as depicted in (Figure XI (a) & (b)), shows that the circuit indeed is performing the filtering action by attenuating the lower order frequencies whilst allowing the higher ones to pass through it and reach the output terminals.The cut off frequency and roll off so obtained experimentally was ~95.3Hz and ~16.3dB/ decade respectively (Table-IV). The circuit thus mimics the Resistor – Capacitor based high pass filter.
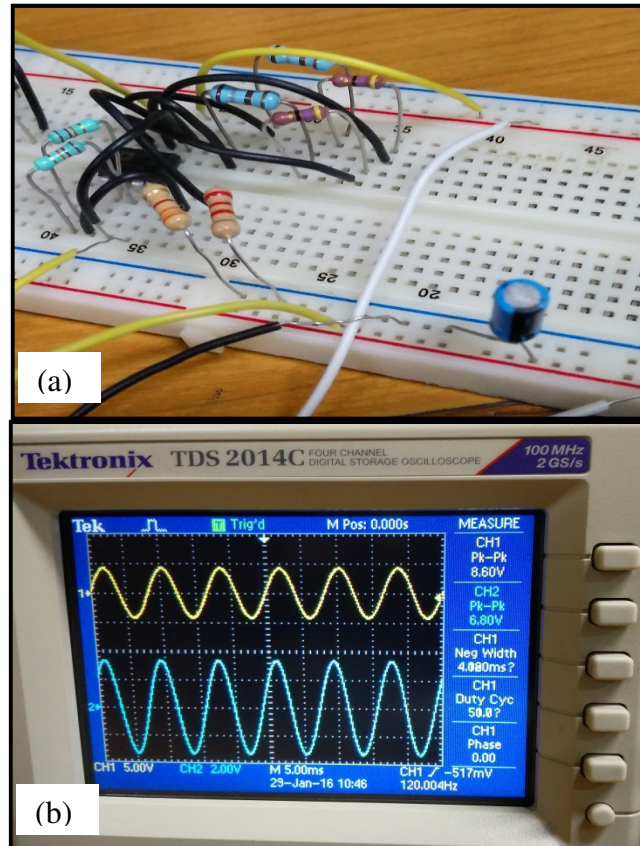

Figure-XII(a) Memristor based first order high pass filter hardware setup. (b)Waveforms from the hardware setup [Input: CH1 (Yellow), Output: CH2 (Blue)].

High Pass Filter – Second Order: This filter simply passes all the signals having frequencies above a reference frequency known as the cut off frequency and provides a 40dB/decade roll off, where the cut off frequency is given by Equation-4.

$$f_{cut\ off} = \frac{1}{2\pi RC} \qquad\qquad .. (4)$$

The traditional second order high pass filter consists of another section of a capacitor and resistor. The input is provided between the free capacitor terminal and ground while the output is taken across the resistor. In case of memristor based second order filter, another section of CM is added as shown in (Figure XIII(a)). The output is taken across the second memristor, where it is seen that the arrangement provides a higher attenuation to the lower order frequency signals. The proposed circuit using memristor is shown in (Figure XIII (b)).
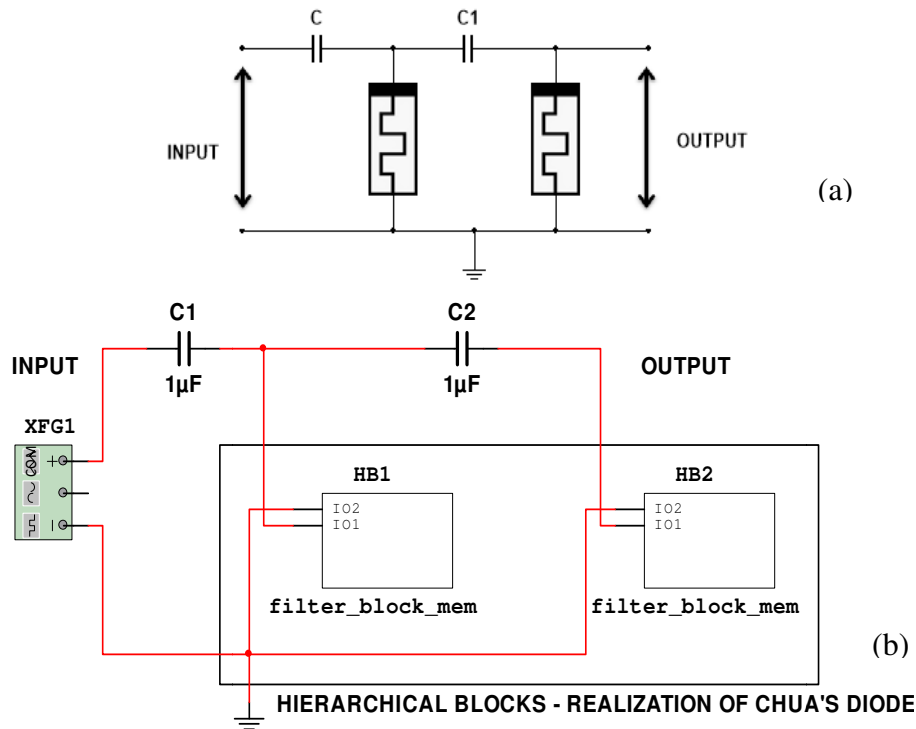
Figure-XIII(a) Schematic of memristor based second order high pass filter and (b) its implementation in NI Multisim using op-amp equivalent circuit for memristor. [Input is a Sine Wave having V_{p-p} = 8.6 Volts]

The resulting frequency response of the circuit is depicted in (FigureXIV).
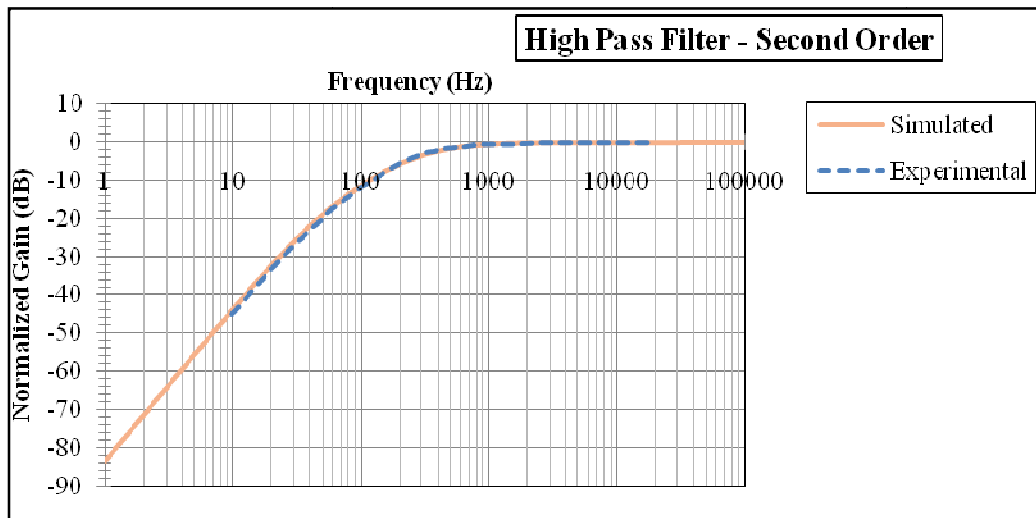

Figure-XIV Frequency response of memristor based second order high pass filter – simulated and experimental.

The frequency response of memristor based second order high pass filter as demonstrated experimentally in (Figure XV (a) & (b)) highlights that when the output is taken across the memristor, the roll off as shown in (Table V) so obtained is not what one expects in a general second order filter system. This is due to the low resistance offered by memristor and as a result when output is being taken across it, the situation is similar to the one when a low impedance load is connected to a circuit

having higher total impedance. Due to this parallel combination, the effective impedance drops critically. As a result, the memristor draws more current and causes a greater voltage drop in the circuit.

Table –V 2nd order High Pass Filter Parameters

Parameters	Experimental	Simulation
Cut-off	$\approx 310.5 Hz$	$\approx 336.7\ Hz$
Roll Off	$\approx 24.23 dB/decade$	$\approx 22.31 dB/decade$

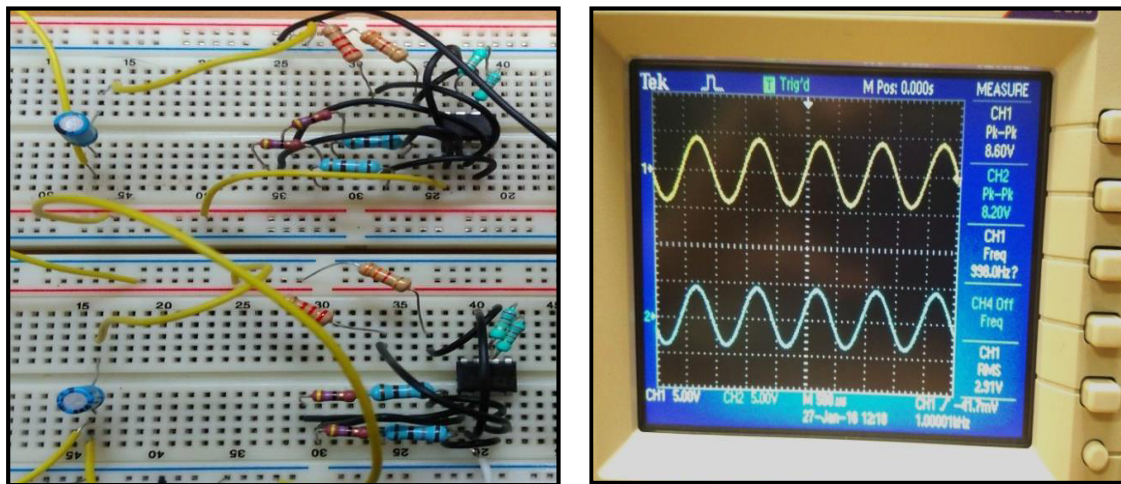Figure-XV(a) Memristor based second order high pass filter hardware setup. (b)Waveforms from the hardware setup [Input: CH1 (Yellow), Output: CH2 (Blue)].

RESULTS

The simulation and experimental results carried out are within limits of permissible error. It is observed that the memristor based filters provide the same filtering effect as that of RC filters and can act as a viable replacement for the resistors.

CONCLUSIONS

This paper was focused on the implementation of memristors in common filters. It was observed that though the simulated and experimental results are in agreement, when output is being taken across memristor in high pass filters, due to low resistance offered by memristor (~1326.3 Ω), loading effect can be observed due to which the ideal 20dB and 40dB roll-off are not achieved in the first order and second order systems. Thus, a new model for memristor is to be developedto account for the loading effect.

ACKNOWLEDGMENTS

REFERENCES

1. Kennedy, M.P.(1992). Robust opamp realization of Chu'a circuit *Frequenz* Vol: pp. 46(3-4): (66–80).

2. Chua,L.O. (2007). Chua circuit*Scholarpedia* Vol: pp. 2(10):1488.

3. Sozen,H., Cam,U.(2014). First-Order Memristor-Capacitor Filter Circuits Employing HpMemristor*Journal of Circuits, Systems, and Computers* Vol: pp. 23(8):(1450116).

4. NI MultisimEducation Edition Version 13.0, Serial No.: M79X04290