

On The Realization of Memristor Based RC High Pass Filter

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Abstract

In 1971, Prof. Leon Chua proposed and described memristor which defines the relationship between flux and charge. Stanley Williams and his group realized a practical device that fulfills the memristor properties. In this paper, a memristor based high pass filter is presented. A comparative analysis between resistor and memristor based high pass filters is performed. The cut off frequency dependency of the high pass filter with memristor configuration is investigated. SPICE simulation results which are obtained using a memristor SPICE model with nonlinear dopant drift are included to verify theoretical analyses. The effect of change in the input frequency and initial condition of the length of doped region on the cut off frequency of the given high pass filter is investigated. The memory effect of memristor is represented by simulation results.

1. Introduction

In 1971 Prof. Leon Chua proposed and described the fourth passive element, which he called memristor. It behaves like a nonlinear resistor with memory and defines the relationship between flux and charge. [1].

On May 1, 2008, Stanley Williams and his group at HP laboratories announced the first experimental realization of memristor in nanoscale device form by using a very thin film of titanium dioxide (TiO₂) sandwiched between two platinum contacts [2].

The memristor has begun to receive a great interest in designing analog circuit since the announcement of its HP realization. The transmission characteristics of noninverting op amplifier circuit based on memristor with different memristor models is investigated [3, 4]. A multilevel memory is obtained by using memristor [5]. Yenpo, et al, characterized the memristor properties for using it in high density electrically programmable nonvolatile memory applications [6]. In order to reduce the signal processing power Witrisal used memristors in an ultra-wideband (UWB) [7]. Memristor based fine resolution programmable resistor is proposed and used in a programmable gain amplifier [8]. Varghese and Gandhi designed memristor based differential amplifier [9]. Pershin and Ventra proposed a memristor emulator and used it in several memristor based analog application [10]. A linearized controls analysis of memristors is presented in [11]. Wien oscillator circuit uses memristor device is presented its characteristic is studied [12, 13]. Bayat and Shouraki proposed memristor based basic analog

arithmetic circuits [14]. Several SPICE macromodels have been proposed in the literature [15-18] to describe memristor behavior and design new circuits.

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 that presented in [2]. The organization of the paper is as follows. Section 2 briefly explains details of HP 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 is given.

2. TiO₂ Memristor Model

The HP memristor comprises of very thin film of titanium dioxide (TiO₂) which is sandwiched between two platinum (Pt) contacts with length of D. TiO₂ film consists of two regions; one with oxygen vacancies with length of w and the other with insulating TiO₂ with length of D-w. There is a TiO₂ junction where one side is doped has low resistance R_{ON}, and the other side is un-doped has high resistance R_{OFF}. The total resistance of the device is the series of doped and un-doped regions resistances.

Supplying the memristor with an external bias voltage v(t) moves the boundary between two regions according to its polarity. The voltage-current relationship for memristor is given by (1) [2].

$$v(t) = (R_{ON} \frac{w(t)}{D} + R_{OFF} (1 - \frac{w(t)}{D}))i(t) \quad (1)$$

In case of R_{ON} << R_{OFF} the memristance expression for HP memristor can be obtained as;

$$M(q) = R_{OFF} (1 - \frac{R_{ON}}{\beta} q(t)) \quad (2)$$

where $w(t) = \mu_V \frac{R_{ON}}{D} q(t)$ μ_V is the average drift velocity and has the units cm²/sV, D has the units m, and q(t) is the total charge passing through the memristor device.

3. Memristor Based High Pass Filter

The resistor in RC high pass filter given in Figure 2a is replaced with a memristor as shown in Figure 2b. In this work

we investigate the effect of memristance variation on cut off frequency of memristor based high pass filter.

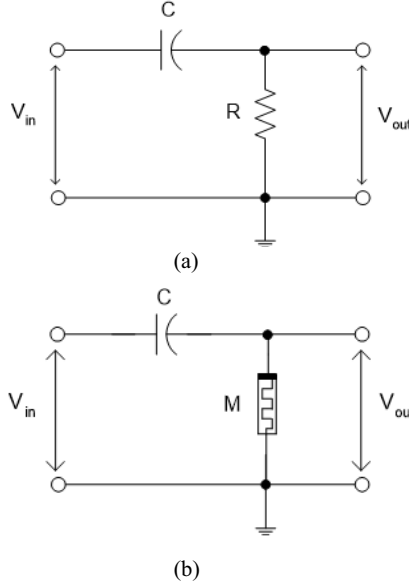


Fig. 1. (a) The simplest RC high pass filter. (b) High pass filter with memristor configuration.

In this paper R_M and V_M denotes the resistance of the memristor and the amplitude value of the voltage across the memristor respectively. Talukdar et al. say from simulation results in case of giving a sinusoidal waveform as input voltage, R_M will oscillate across R_{avg} and give memristor resistance for sinusoidal input voltage as [19];

$$R_M = R_{avg} \pm \Delta R_M \sin(\omega t + \varphi) \quad (3)$$

where ΔR_M denotes the amplitude of sinusoidal resistance variation across R_{avg} . The magnitude peaks of the resistance in (3) can be written as;

$$R_{max,min} = R_{avg} \pm \Delta R_M \quad (4)$$

As expressed in [12] the amplitude of sinusoidal variation of R_M (ΔR_M) for linear dopant drift model can be given as;

$$\Delta R_M = \frac{V_m k (R_{OFF} - R_{ON})}{2\pi R_{INIT} f_M} \quad (5)$$

where $k = \mu_v R_{ON} / D^2$ and f_M is the voltage frequency across the memristor device. It is evident from (5) that ΔR_M is inversely proportional to f_M . It means, increasing f_M will cause a small variation, whereas decreasing it will cause high variation across R_{avg} .

Routine analysis of the simplest RC high pass filter yields the transfer function as;

$$\frac{V_{out}}{V_{in}} = \frac{s}{s + 1/RC} \quad (6)$$

The cut off frequency of the RC circuit can be written as;

$$f_o = \frac{1}{2\pi RC} \quad (7)$$

The transfer function and the cut off frequency for memristor based filter circuit can be given by the following equations.

$$\frac{V_{out}}{V_{in}} = \frac{s}{s + 1/R_M C} \quad (8)$$

$$f_o = \frac{1}{2\pi RC} \quad (9)$$

Using (4) transfer function and cut off frequency of the circuit can be given as;

$$\frac{V_{out}}{V_{in}} = \frac{s}{s + 1/(R_{avg} \pm \Delta R_M)C} \quad (10)$$

$$f_{o,M} = \frac{1}{2\pi(R_{avg} \pm \Delta R_M)C} \quad (11)$$

It is evident from (3) that the resistance swing of memristor depends on voltage frequency and amplitude across the device. Hence, the cut off frequency for memristor based filter depends on the input voltage frequency and amplitude.

4. Simulation Results

In order to investigate the memristor affect on high pass filter classical RC high pass filter and memristor based high pass filter are simulated using PSPICE program. In simulations PSPICE model of memristor for nonlinear dopant drift which has been proposed in [16] is used. The memristor model parameters given in same study are used; $R_{INIT}=80 \text{ K}\Omega$, $R_{ON}=1 \text{ K}\Omega$, $R_{OFF}=160 \text{ K}\Omega$, $D=10 \text{ nm}$, $\mu V=10 \text{ Fm}^2/\text{sV}$, $p=10$ where R_{INIT} and p parameters denotes the initial resistance and exponent of window function respectively.

The capacitor value is taken as 100 nF for the two simulated circuits while the resistor value for classical RC circuit is selected as 80 K Ω . The theoretical cut off frequency of resistor based circuit is found as 19.89 Hz. Time domain simulation results of resistor and memristor based circuits for input voltage with 10 V amplitude and 20 Hz frequency is given in Figure 2. It is seen from figure difference between phase degrees and amplitude value of the circuits' outputs due to memristor variation.

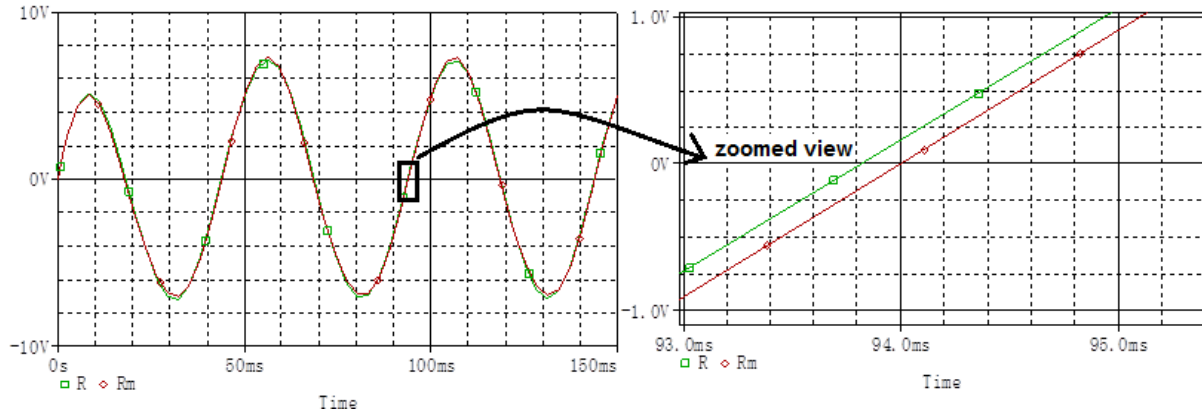


Fig. 2. Simulated output voltages of resistor and memristor based circuits for input voltage with 10 V amplitude and 20 Hz frequency.

The application an external voltage across memristor device for a period of time changes the memristance value continuously in accordance with frequency and amplitude values of applied voltage. When the applied voltage is removed the final memristance value becomes the initial memristance value for next voltage application. Therefore, the memristor may have different R_{INIT} values at each time voltage applied across it.

at each time voltage applied across its terminal. As it is seen from Figure 3 memristor based circuit has different magnitude response for every R_{INIT} parameter value. The change of R_{INIT} value of the used memristor, causes the output voltage of memristor based circuit to follow up the curve that belongs to the final R_{INIT} value. This also demonstrates the memory effects of memristor. It is obvious from the figure that the cut off frequency of the circuit is inversely proportional to R_{INIT} parameter.

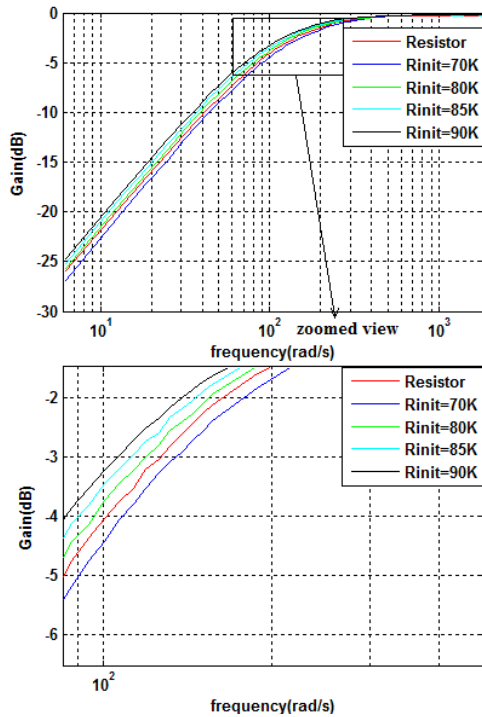


Fig. 3. Magnitude response of resistor and memristor based circuits.

Figure 3 shows the simulated magnitude response of resistor and memristor based high pass filters. The memristor based circuit is simulated for different R_{INIT} parameter values. The length of the doped region determines the memristor initial resistance. Hence, the memristor may have different R_{INIT} values

5. Conclusions

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 PSPICE simulation results. It is observed from simulation results that the cut off frequency of the filter circuit can be tuned by setting the R_{INIT} parameter of memristor device. The effect of input frequency for memristor based high pass filter is examined. It is shown that from simulation results, memristor based circuit will have different magnitude response for every R_{INIT} value. Magnitude response of the memristor based high pass circuit follows up the curve that belongs to final R_{INIT} value. This indicates the memory effects of memristor. The effect of different R_{INIT} parameter for cut off frequency is presented with simulation results. It is observed increasing R_{INIT} value reduces the cut off frequency of the filter circuit due to it directly effects R_M .

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