Araştırma Makalesi / Research Article

Memristor Based Filter Design and Implementation for ECG Signal

Muhammet Emin ŞAHİN[1], Barış KARAKAYA[2*], Hasan GÜLER[2], Arif GÜLTEN[2], Serdar Ethem HAMAMCI[3]

[1]Bozok University, Department of Electrical Electronics Engineering, Yozgat, Turkey
[2]Firat University, Department of Electrical Electronics Engineering, Elazığ, Turkey
[3]Inonu University, Department of Electrical Electronics Engineering, Malatya, Turkey
(ORCID: 0000-0001-7729-990X) (ORCID: 0000-0001-7995-390) (ORCID: 0000-0002-9917-3619) (ORCID: 0000-0002-9652-2625) (ORCID: 0000-0002-1868-6843)

Abstract
This paper presents memristor based filter implementation for a real time biomedical signal. The significance of this study is that the passive circuit element called memristor is completely linear in both experimental and simulation studies at high frequencies and becomes indistinguishable from normal resistance. The variation of the memristance value gives possibility to tune the cut-off frequency of the filter circuit. For this purpose, memristor based high-pass and low-pass filter circuits are constructed by simply replacing resistor with memristor emulator circuit in well-known R-C filter structures. The filter circuits are constituted on board and firstly sine wave is applied as input signal. Then, Electrocardiographic (ECG) signal is applied as input for M-C filter circuits. The results are obtained and analyzed in real-time. In the implementation stage of study, LabVIEW platform and DAQ card are used to obtain real-time data. The results show that memristor can be used quite easily to sort out biomedical signal processing applications and shows better performance.

Keywords: ECG, Filter, LabVIEW, Memristor.

Memristör Tabanlı Filtre Tasarımı ve EKG Sinyali için Uygulanması

Öz
Bu çalışma memristör tabanlı filtrenin gerçek zamanlı bir biyomedikal sinyal için uygulanmasını göstermektedir. Bu çalışmanın önemi, pasif bir devre elemanı olan memristörün yüksek frekanslarda hem deneysel hem de benzetim çalışmalarında tamamen doğrusal ve normal dirençten farksız olmasıdır. Memristans değerindeki değişim, filtre devresinin kesim frekansının ayarlanabilmesine olanak sağlamaktadır. Bu amaçla, sık kullanılan R-C filtre yapıları ile memristör tabanlı yüksek-geçiren ve alçak-geçiren filtre devreleri basitçe rezistör elemanı yerine memristör taklitçi devresinin yerleştirilmesiyle oluşturulmaktadır. Filtre devreleri board üzerinde kurularak ilk önce girişine sinüs işareti uygulanmaktadır. Ardından, Elektrokardiyogram (EKG) sinyali M-C filtrenin girişine uygulanmaktadır. Sonuçlar gerçek zamanlı elde edilip analiz edilmektedir. Çalışmanın uygulama aşamasında LabVIEW ara yüzü ve DAQ kartı kullanılmaktadır. Filtreleme işlemi sonucunda memristörün biyomedikal sinyal işleme uygulamalarında kolaylıkla kullanılabileceği görülmektedir.

Anahtar kelimeler: EKG, Filtre, LabVIEW, Memristör.

1. Introduction

For many years, only resistor, inductor and capacitor have been known as passive circuit elements. Memristor (contraction for memory–resistor) which is the fourth fundamental passive circuit element was theorized in 1970’s by L. Chua [1]. Memristor reveals the missing relation between charge flowing and flux across it. Although memristive behavior was reported in several publications, it was not until 2008 when Stanley Williams from the Hewlett-Packard scientific laboratories invented the first physical

[*]Sorumlu yazar: bkarakaya@firat.edu.tr
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prototype of the memristor which acts as a memristive solid state device [2, 3]. Memristor consists of two sub-layers of titanium dioxide, sandwiched among two platinum electrodes. The resistance of memristor changes due to the integration of current passing through on it. Therefore, memristor can be considered as a time varying resistor [4-6]. If the current flowing through the memristor is zero, summation of current passing through on it becomes constant. In this situation, memristive resistance remains unchanged. This property indicates that the memristor has non-volatile memory component [7].

Many research results and simulations from the memristor investigation have been made in the last few years. Memristor characteristic is suitable for both analogue and digital implementations. Analogue applications of memristor such as programmable amplifiers, oscillators, controllers and chaotic sources which have increased significantly have attracted many researchers attention recently [8].

Previously studied on memristor-based filter applications are remarkable application areas [8-12]. When voltage pulses are implemented the boundary between the doped and undopped regions of memristor, the equivalent resistance of the element changes. This event could be used in some adjustable circuits like electronic oscillators, amplifiers and filters.

In the present study, a memristor-based circuit including high-pass (HP) and low-pass (LP) filter characteristics are examined in real time results by using memristor emulator circuit which behaves like memristor. A series capacitor with a memristor emulator is used for high-pass and low pass filter. Then, a biomedical Electrocardiographic (ECG) signal is implemented these circuits to filter unwanted frequencies of the input signal. The main purpose of this study is to demonstrate real time implementation of memristor based filtering process using LabVIEW platform.

Herewith this introduction, TiO_2 memristor model and memristor emulator circuit are represented in Section 2. Moreover, memristor-based high-pass and low high-pass filter topologies are introduced, dynamical models are given and also their analytical models are derived. These models are modelled LabVIEW and Multisim platforms. ECG signal is applied to these filters. Results are represented in Section 3. At the end, final section concludes the paper.

2. Analysis of Methods

2.1. Memristor and its emulator circuit

The first physical model of memristor by HP is based on two regions of TiO_2 [6]. There is a two-layer thin film of TiO_2: One layer consists of intact TiO_2 and the other layer consists of TiO_{2-x}, which lacks of a small amount of oxygen. Figure 1 shows the structure of TiO2 memristor model. The boundary line between the TiO_2 and TiO_{2-x} layers moves when any voltage or current is implemented to the memristor. As a consequence, it is possible that resistance between two layers occurred by memristor is altered.

The formation of these thin-films TiO_2 memristor which is constituted by compressing between two platinum electrodes are set to show low and high resistances which are caused of a stoichiometric layer of TiO_2 and an oxygen deficient layer, respectively. Briefly, the resistance of film depends on the amount of its charges which might become the current direction reversed [1-6]. Figure 2 illustrates the two terminal basic memristor which has doped and undopped region. Device length and dopant region length are symbolized as *D* and *W*.

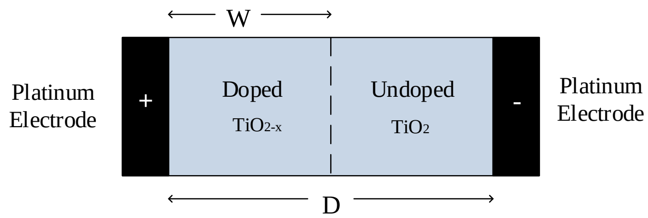

Figure 1. The formation of the TiO_2 memristor

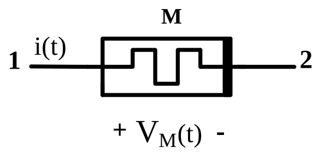

Figure 2. Memristor model with two terminals

The charge-flux relationship of memristor gives the memductance characteristic while the memristance (M) is obtained as electrical characteristic of memristor. Equation (1) shows the formula between electric charge (q) and magnetic flux (φ) of memristor. The memristance is the same as resistance, while resistive unit is shown as inverse of resistance unit. As it can be seen from equations given below (2) and (3), the memristor can be modelled in two ways as using relationship of flux with charge and charge with flux.

$$d\varphi = Mdq \tag{1}$$

$$W(\varphi) = \frac{dq(\varphi)}{d\varphi} \tag{2}$$

$$M(q) = \frac{d\varphi(q)}{dq} \tag{3}$$

In order to verify the previous argument and provide the memristor which is absent on the market commercially, emulator circuit of memristor is considered with its circuit simulation in this part.

A memristor emulator is memristive system and also represents the features of memristor. Chua described exactly this system and Figure 3 shows his memristor emulator circuit which has experimental flux integrator circuit and charge characteristics [4]. It consists of a large number of circuit elements and its application process seems time-consuming structure. Thereby, a model composing this emulator circuit in literature was used [13-15].

The memristor emulator circuit consists of seven resistors, one capacitor and an analogue multiplier AD633 symbolized as U2 in Figure 3. The values of resistors are $R_1 = R_3 = 33$ kΩ, $R_2 = R_4 = R_5 = R_7 = 470$ kΩ and $R_6 = 22$ kΩ. The value of capacitor is 100 nF.

Herewith, Figure 4 and 5 show the relation between current and voltage, and also between input voltage and output current in the emulator circuit at frequency of 20 Hz.

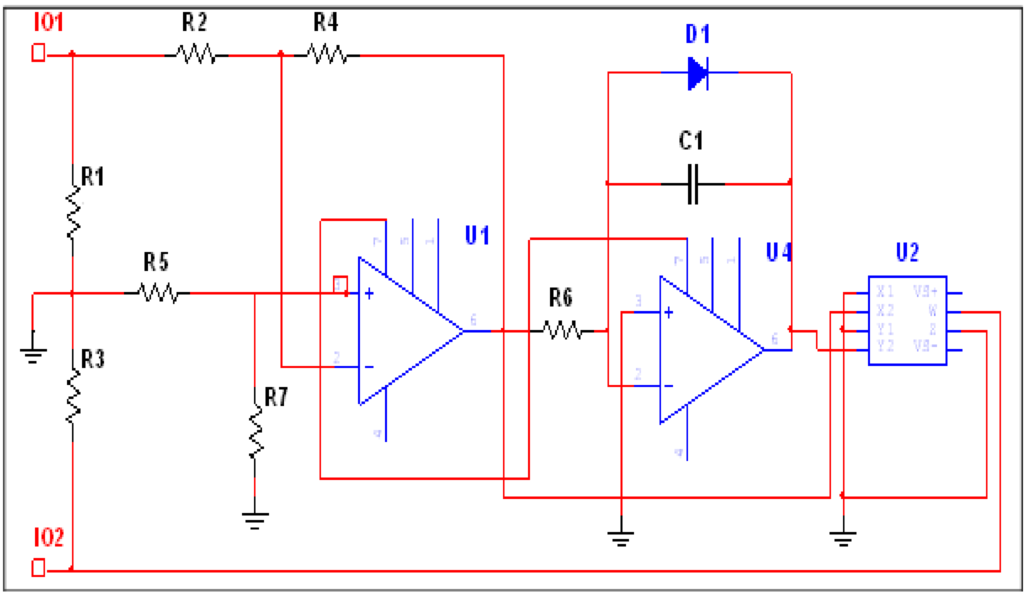

Figure 3. Memristor emulator circuit

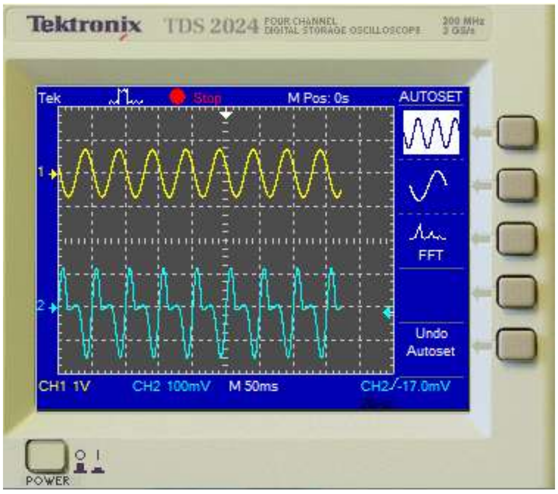

Figure 4. Input voltage and output current (f=20 Hz)

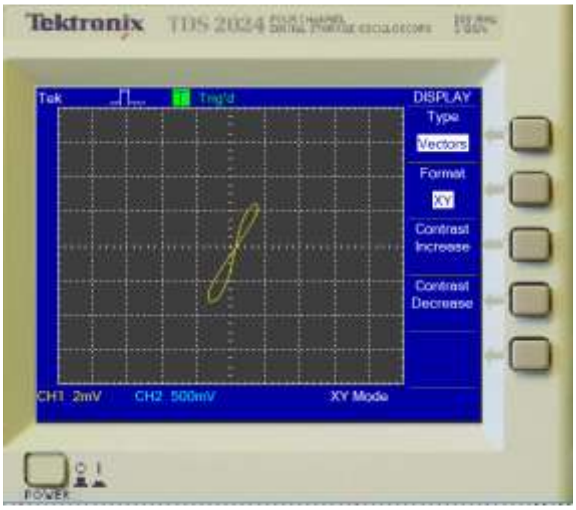

Figure 5. Relation between memristive current and memristive voltage

The presence of a pinched hysteresis was likely to be performed by the *i* - *v* pinched hysteresis loop characteristic. It is the most important feature of memristor. For this feature, Chua clearly emphasized that 'If it is pinched, it is a memristor' [14].

2.2. Memristor based filter structures

It is simply considered how to compose basic memristor based filter and it might be obtained by modifying well-known 1st-order both R-C (Resistor-Capacitor) high-pass and low-pass filter where its resistors are replaced with a memristor. The resultant circuitries mostly indicate an M-C (Memristor-Capacitor) high-pass and low pass filters. Passive first-order R-C filter is also called one pole filter [8, 16, 17].

Basically, a low pass filter enables to pass signals with a lower frequency and block the signals with high frequency while a high pass filter is exact opposite. The main point of study is that the memristance value can tune the cut-off frequency of filter structure. This property of memristor based filter circuit can demonstrate itself when the cut-off frequencies are determined. R-C low-pass, M-C low-pass, R-C high-pass and M-C high-pass filter circuits are given in Figure 6. (a), (b), (c) and (d), respectively. It is also clearly seen in the figure that M-C form of both filters are created by replacing linear resistor with memristor and taking account of polarity of the memristor.

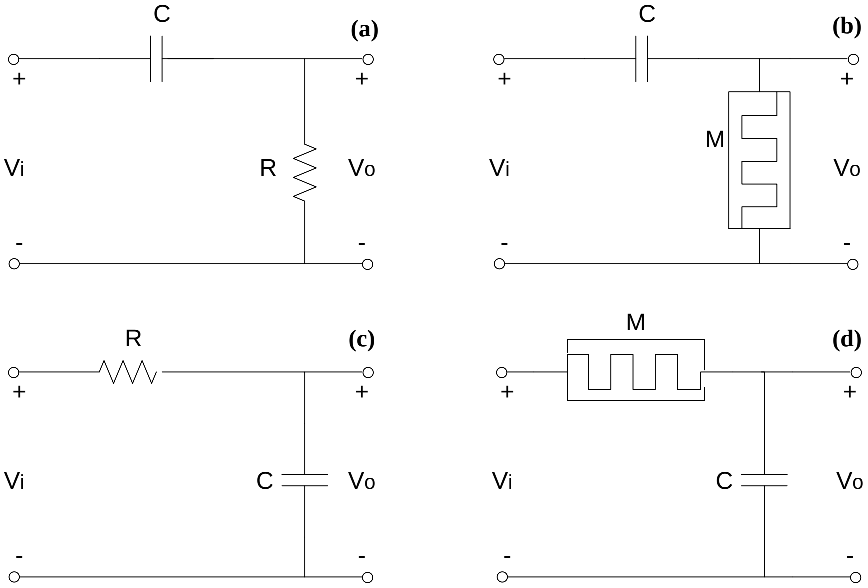

Figure 6. a) R-C high-pass filter, b) M-C high-pass filter, c) R-C low-pass filter d) M-C low-pass filter

The filter transfer functions and cut-off frequency are given equations below. The transfer function of low-pass R-C circuit is:

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{1/RC}{s+1/RC} \tag{4}$$

where, V_i is filter input voltage, V_o is filter output voltage. The cut-off frequency of R-C circuit can be represented as:

$$f_0 = \frac{1}{2\pi RC} \tag{5}$$

Phase function for R-C low-pass filter is:

$$\vartheta = -\arctan(2\pi fRC) \tag{6}$$

The transfer function of low-pass M-C circuit is:

$$H_{MC}(s) = \frac{1/MC}{s+1/MC} \tag{7}$$

The cut-off frequency of M-C circuit can be expressed as:

$$f_0 = \frac{1}{2\pi MC} \tag{8}$$

Generally, the simplest R-C high-pass is analysed as the ratio of output voltage to input voltage which is named as transfer function in s-domain:

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{s}{s+1/RC} \tag{9}$$

Phase function for R-C high-pass filter is:

$$\vartheta = \frac{\pi}{2} - \arctan(2\pi fRC) \tag{10}$$

The transfer function of high-pass M-C circuit is:

$$H_{MC}(s) = \frac{s}{s + 1/MC} \tag{11}$$

The transfer functions can be enlarged by using Laplace expression of memristance which is depicted in [18] as follow.

$$Z(s) = M\left[1 + \frac{w_M^2}{2\left(s^2 + sw_M + w_M^2\right)} - \frac{w_M^2}{2\left(s^2 - sw_M + w_M^2\right)}\right] \tag{12}$$

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{1/\left(M\left[1 + \frac{w_M^2}{2\left(s^2 + sw_M + w_M^2\right)} - \frac{w_M^2}{2\left(s^2 - sw_M + w_M^2\right)}\right]\right)C}{(s+1)/\left(M\left[1 + \frac{w_M^2}{2\left(s^2 + sw_M + w_M^2\right)} - \frac{w_M^2}{2\left(s^2 - sw_M + w_M^2\right)}\right]\right)C} \tag{13}$$

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{s}{(s+1)/\left(M\left[1 + \frac{w_M^2}{2\left(s^2 + sw_M + w_M^2\right)} - \frac{w_M^2}{2\left(s^2 - sw_M + w_M^2\right)}\right]\right)C} \tag{14}$$

The transfer function of low-pass M-C circuit can be transformed as depicted in [18] and the transfer function of high-pass M-C circuit can be transformed as depicted in [18]. The transfer functions structures are the same as R-C filter circuits. These similar properties can be used for filtering applications with memristor emulator circuit. In the literature, there are remarkable studies about filtering applications using memristor [19-21]. Memristance has adjustable value and varies regarding to its applied energy. Therefore, the cut-off frequency in memristive filter applications is tunable [20].

2.3. ECG signal

The Electrocardiographic (ECG) signal is nothing but the recording of the heart electrical activity. ECG signal is frequently exposed to noise from various resources such as 50/60 Hz power line interference, motion artefact from the electrode–skin interface, muscle activities etc. [22].

In this study, memristor based low-pass and high-pass filters are used to eliminate noise of raw ECG signal data. The reason of selecting ECG signal is that ECG signal has very low amplitudes and it is very hard to eliminate unwanted frequencies. The raw ECG signal data is obtained from FBI open ECG system. The data is created with LabVIEW platform and converted to analogue data.

3. Experimental Setup and Results

In the implementation stage of study, memristor behavior was examined. Memristor emulator circuit was set up on board. The input voltage was arranged as 100 mV sine signal and 20 Hz frequency. The x-y form of the input voltage and output current signal is given in Figure 7. It can be derived that emulator circuit acts as memristor in real time application. The results show that emulator circuit works as desired.

This circuitry was managed to constitute M-C low-pass and high-pass filter structure by connecting capacitor before emulator circuit for low-pass filter and after emulator circuit for high-pass filter structure like Figure 6.(b) and (d) respectively. The capacitor value is set to 1 μF for both filter circuits. Figure 8 illustrates the input signal and output signal of M-C low-pass filter while Figure 9 illustrates the same signals for M-C high-pass filter structures. The input signals are at the bottom of scope screens.

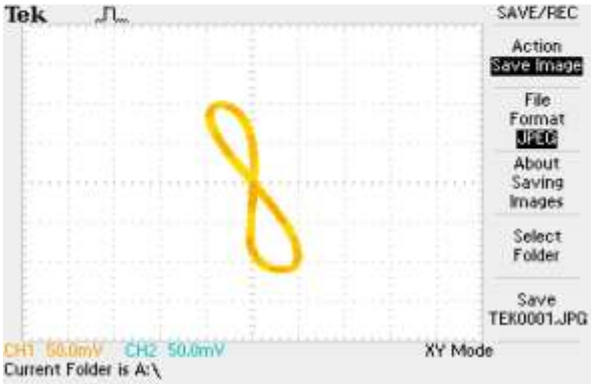

Figure 7. The x-y form of input voltage and output current of emulator circuit

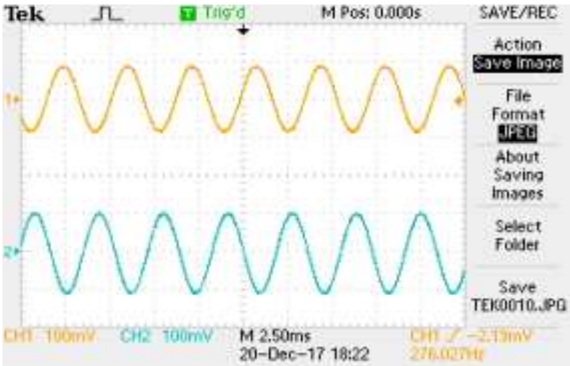

Figure 8. The input and output signals of M-C low-pass filter circuit

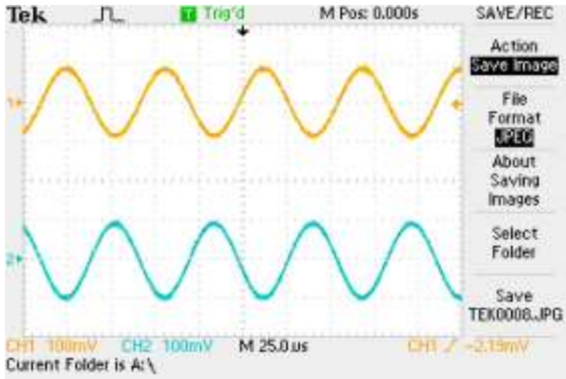

Figure 9. The input and output signals of M-C high-pass filter circuit

In the ECG signal filtering stage of study, ECG signal data [23] is extracted from a text file by using LabVIEW platform. Also, the ECG data is normalized to -1.5 to 1.5 in amplitude. The normalized ECG signal is applied to the memristor based high-pass and low-pass filters via LabVIEW NI 6009 DAQ card, respectively. Figure 10 illustrates the normalized ECG signal. ECG signal is applied to memristor based high-pass after than low-pass filter circuits respectively. The capacitor value is 1 µF. The critical frequencies are determined as 15.1 Hz for high-pass filter and 31.8 Hz for low-pass filter. The last outcome signal of filtering process is sent to DAQ card and the filtered signal is submitted in Figure 11.

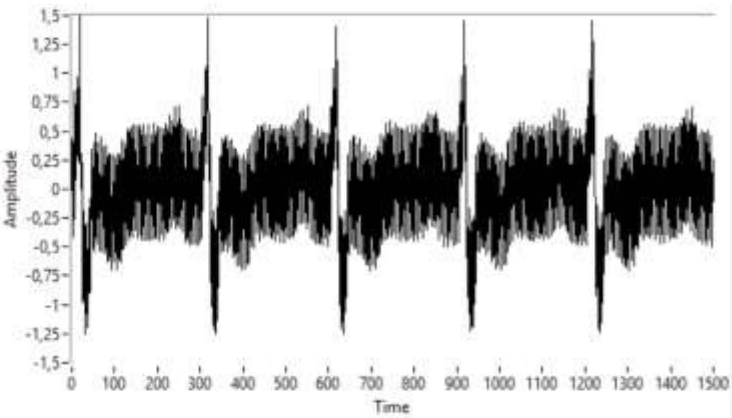

Figure 10. The normalized ECG signal

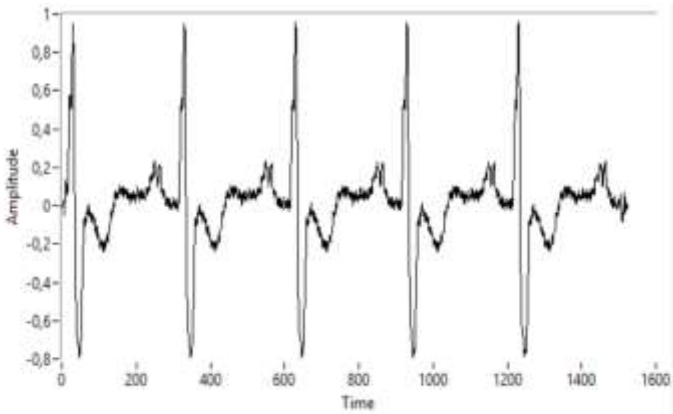

Figure 11. The filtered ECG signal

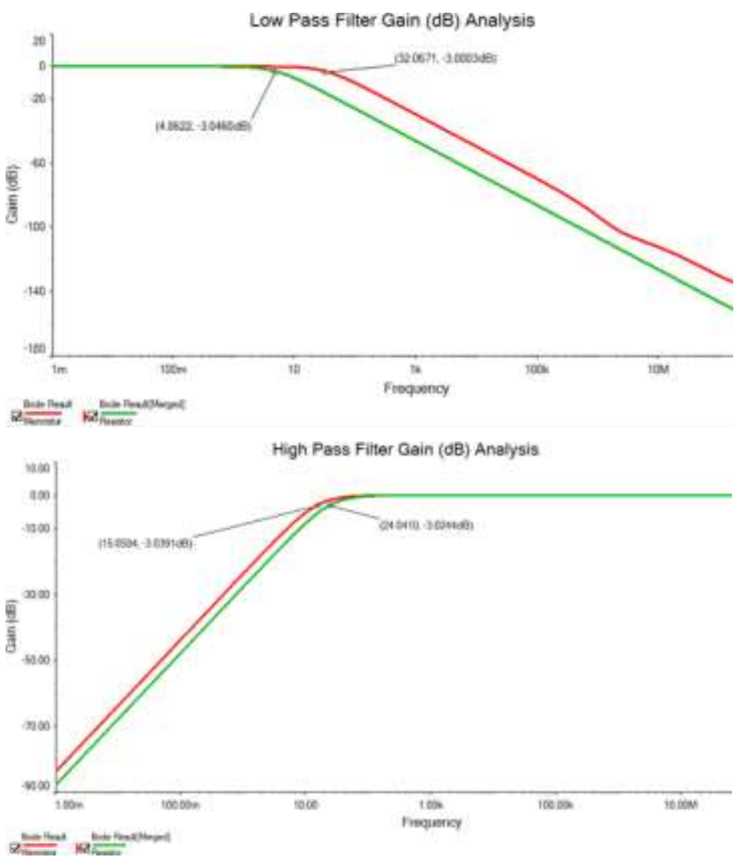

Figure 12. Comparison of gain responses of filter structures

In addition to these results, in order to demonstrate how effectively memristor can be used in filtering applications, frequency and magnitude responses of filter structures designed in this study are given with Bode plots by using Multisim platform. The Bode results indicates that the memristor emulator circuitry can be successfully used instead of resistance. Also, memristor based filter structures gives better response rather than resistor based filters at the meaning of gain values of cut-off frequency region. Figure 12 shows bode gain plots for low and high pass filter respectively.

4. Conclusion

In this study, memristor is used instead of resistor in memristor emulator circuit while creating low-pass and high-pass filters. The behavior and effects of the memristor in these filter circuits is investigated for filtering biomedical signal. ECG signal is firstly filtered by memristor based high-pass and low-pass filters and then results are analyzed. Thus, it is understood from the results that the memristor based high-pass and low-pass filters provide the same filtration effects like R-C filters. Also, these filters can behave as a viable replacement for the resistors. It is possible to say that the implementation of memristor in conventional circuits and new applications will increase day by day. Furthermore, the variation of the memristance value gives possibility to tune the cut-off frequency of the filter circuit. This study can also be performed for other memristor models such as non-lineer dopant drift memristor emulator.

Author's Contributions

All authors performed the experiments and took role on writing the manuscript.

Statement of Conflicts of Interest

No potential conflict of interest was reported by the authors.

Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics.

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