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Research Paper

# Analysis of Memcapacitor Based Low Pass Filter

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***Abstract***—Discovery of memristor (memory resistor) element, which describes the relationship between electrical charge and magnetic flux and represents a two-terminal element whose resistance changes depending on the applied voltage, formed the basis of memristive systems. By associating the capacitor and inductor elements with the memristive systems, the working area of memristive systems has been expanded and the new memory circuit elements called memcapacitor (memory capacitor) and meminductor (memory inductor) have taken their place in the literature in addition to the memristor. The characteristic behavior of the memcapacitor shows the pinched hysteretic loop in the two state variables which are described as the electrical charge and the voltage. In this study, the memcapacitor element and its emulator circuit are considered for the analysis of a low-pass filter (LPF) circuit. Thus, the performance quality of the low-pass filter circuits with standard capacitor and memcapacitor is compared. As a result of the comparison, it was concluded that the low-pass filter circuit based on memcapacitor provides relatively better filtering performance than the classical filter circuit. In addition, it has been observed that the reactive power consumed by the memcapacitor is less than the reactive power consumed by the standard capacitor, as a result of the memcapacitor drawing less current from the circuit compared to the standard capacitor. These contributions offer promising results for future electronic studies.

***Keywords:*** Memristive systems, memcapacitor, low pass filter, performance comparison.

## 1. Introduction

In 1971, Prof Chua defined a new circuit element called memristor, considering the relationship between magnetic flux ($\varphi$, time integral of voltage) and electric charge ($q$, time integral of current) (Chua, 1971; Romero et al., 2019). The memristor produces a nonlinear relationship between the current ($i$) and voltage ($v$), where the memory effect is manifested by a characteristic pinched hysteresis loop in the voltage-current characteristics (Driscoll et al., 2010; Strukov et al., 2008). Memristor element has been used by researchers in many different areas in the literature due to its memory feature compared to standard resistance and its interesting nature (Gursul & Hamamci, 2019; Sahin et al., 2020;Yuet al., 2020; Gursul & Hamamci, 2021).

After the introduction of the memristor element, the concept of memristive elements was also generalized by Chua as memcapacitor and meminductor (Chua & Kang, 1976; Prodromakis et al., 2011; Pershin & Di Ventra, 2012). According to the relationships between different physical quantities schematized in Figure 1, the memcapacitor is expressed by the relation between the time integral of the electrical charge ($\sigma$) and the magnetic flux ($\varphi$), while the relation of the electrical charge ($q$) and the time integral of the magnetic flux ($\rho$) defines the meminductor. The ability to store energy in the form of an electric field for a voltage applied to the terminals of a memcapacitor is called memcapacitance and is denoted by $C_M$. The memcapacitance is given in equation 1.

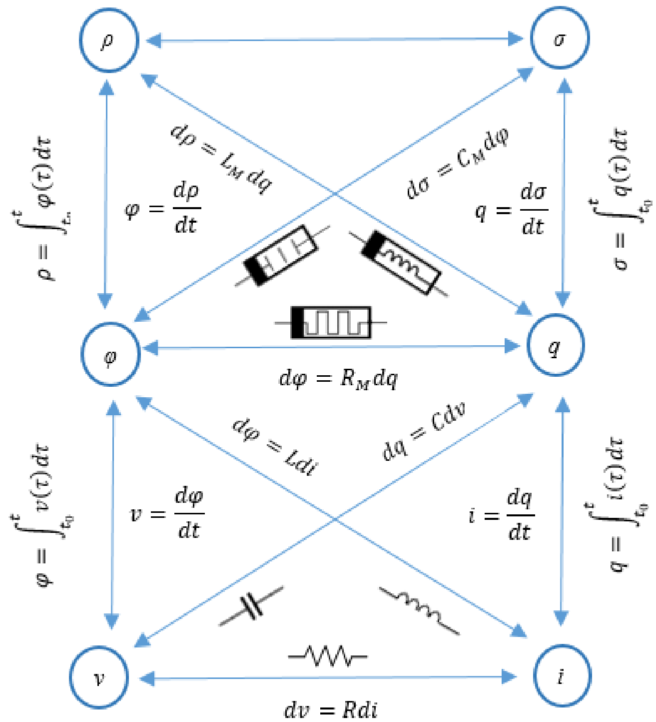


**Figure 1.** Basic electrical quantities and their relationships (Wang et al., 2012).

$$C_M = \frac{q(t)}{v(t)} = \frac{d\sigma}{d\varphi} \tag{1}$$

where

$$q(t) = \frac{d\sigma}{dt} \qquad v(t) = \frac{d\varphi}{dt} \tag{2}$$

Therefore, $\sigma$ and $\varphi$ shown in Figure 1 is given as

$$\sigma = \int_{t0}^{t} q(t)dt \qquad \varphi = \int_{t0}^{t} v(t)dt \tag{3}$$

The memcapacitor characteristics is based on the nonlinear relationship between magnetic flux and integral of electrical charge and hence it exhibits a pinched characteristic for a sinusoidal input as seen in Figure 2 (Sah et al., 2013; Liu & Iu, 2020; Romero vd., 2021). With the increasing frequency of the sinusoidal input, there is a decrease in the hysteresis field.

Memcapacitor can be considered as a passive circuit element like a standard capacitor, but its non-linearity and energy storage while keeping the signal in memory makes it different from a standard capacitor. The most distinctive feature of the memory capacitor is that it can store energy while keeping the applied signal in memory, and additionally it has a nonlinear characteristic. The memcapacitance value is determined by the slope of the $\varphi$-$\sigma$ curve. As mentioned above, $\varphi$ denotes magnetic flux and $\sigma$ the integral of electrical charge. The charge becomes zero when the voltage is zero as given in the memcapacitor characteristic. However, the fact that the current is zero at the beginning means that the charge will be zero, and thus it is understood that the memcapacitor element can store energy in a way that supports the above idea (Di Ventra et al., 2009).

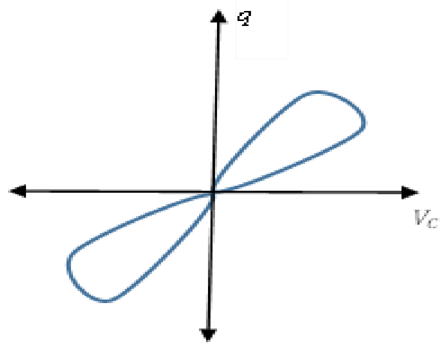


**Figure 2.** A general memcapacitor characteristic.

It is predicted that the use of memcapacitors in electrical and electronics circuits will bring significant gains, especially for memory operations. However, it is not yet commercially available. Therefore, in addition to the spice model (Biolek et al., 2009) suggested in the literature, many various memcapacitor emulators have been designed and reported (Fouda and Radwan, 2012; Abuelma'Atti and Khalifa, 2014; Yin et al., 2015). Due to its inherent memory and dynamic storage capabilities, the memcapacitor element is expected to occupy an important place in various science and technology fields such as non-volatile memories (Yu vd., 2020).

In this paper, a memcapacitor emulator circuit is considered and analyzed in Section 2. In the third section, the memristive low pass filter circuit is constructed by using the memcapacitor emulator instead of the standard capacitor. In the fourth section, a performance comparison of standard capacitor with memcapacitor is evaluated. Frequency characteristics of the low-pass filter circuits are obtained and compared the standard capacitor with memcapacitor in the Multisim spice program. In addition, the current values drawn from the circuit by the memcapacitor and the standard capacitor, as well as the consumed reactive power values are evaluated. In Conclusions Section, the main results of the study and its contributions to the literature are mentioned.

## 2. The Memcapacitor Emulator Circuit

The electrical circuits consisting of various electronic elements and having the characteristics of a memcapacitor are called memcapacitor emulators. In the literature, there are many memcapacitor emulators designed for application to different electronic circuits (Babacan, 2018; Gursul, 2021). In this study, a memcapacitor emulator designed by Yeşil & Babacan (2021), one of the emulators in the literature, is considered. In this circuit shown in Figure 3, two AD844 and one AD633 are used as active elements. AD844 consists of a CCII (second generation current conveyor) and a voltage buffer, while the AD633 is an analog multiplier. There are also three standard capacitors and a resistor in the circuit. The values of the passive elements used in the emulator are given as $C_1 = C_2 = C_3 = 1\mu$F and $R_1 = 500\Omega$.

The voltage and electrical load signals obtained when simulating the memcapacitor emulator in Figure 3 are shown in Figure 4.In the simulation, a voltage with the value of $V_1 = sin2\pi60t$ was applied to the emulator input.It has been observed that the obtained voltage and electrical charge signals take the zero value at the same times. Figure 5 gives the electrical charge-voltage characteristic of the memcapacitor at the frequency of 60 Hz. As can be seen, the obtained characteristic provides a double-leaf clover characteristic passing through the origin of the memcapacitor.

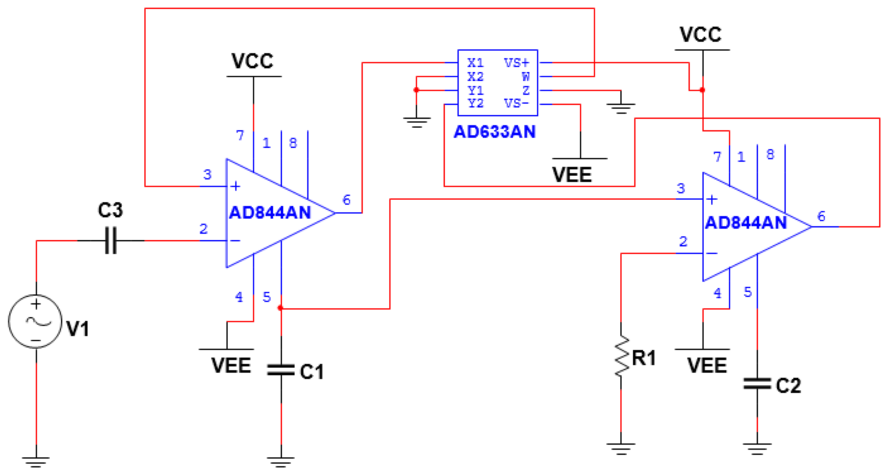


**Figure 3.** A memcapacitor emulator circuit (Yesil & Babacan, 2021).

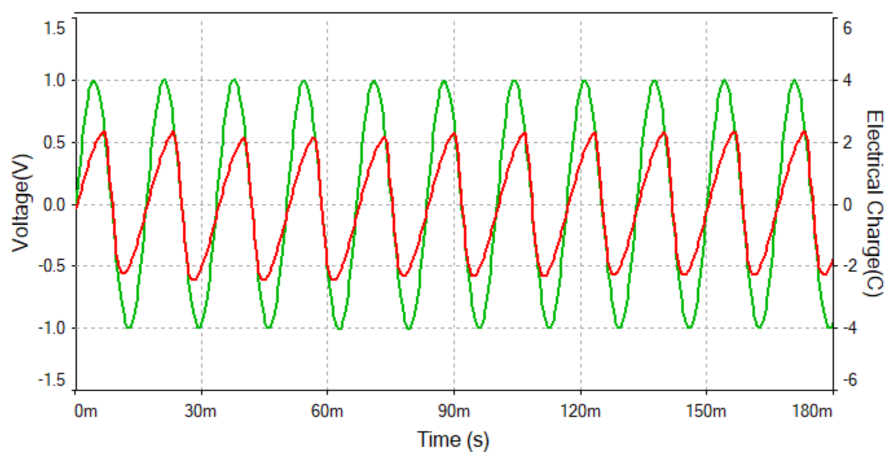


**Figure 4.**Voltage (green) and electrical charge (red) curves depending on time.

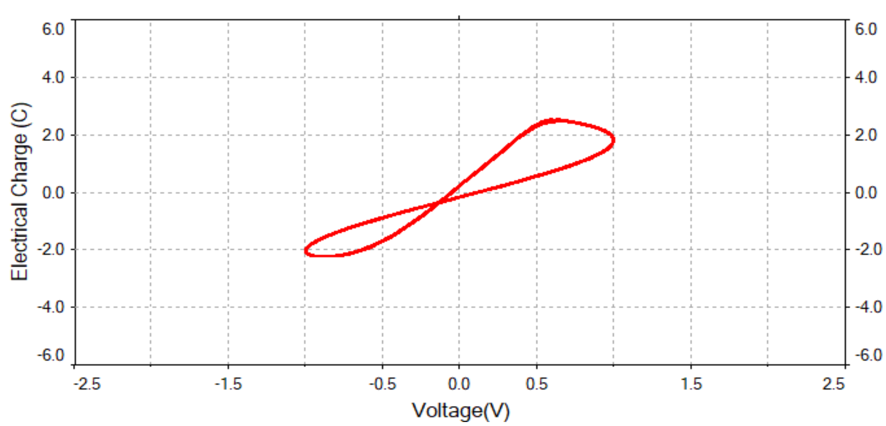


**Figure 5.** Hysteresis curve of the memcapacitor emulator

### 3. Active Low Pass Filter with Memcapacitor

In this section, an active low-pass filter, which is one of the most used circuits in the field of electronics, will be considered. The filter circuits are widely used especially in communication systems. The main task of an electronic filter is to transmit signals at desired frequencies and suppress signals at undesired frequencies. The first memristive element used by the researchers in the filter circuits is the memristor (Driscoll et al., 2010; Gursul & Hamamci, 2019).Similarly, the filter circuits with memcapacitors are among the topics in the literature (Arora & Niranjan, 2017; Li et al., 2017). An active low-pass filter circuit with the memcapacitor, which will be discussed in this study, is given in Figure 6, and the full form of this circuit with the memcapacitor emulator is presented in Figure 7. For the capacitor defined as $C_x$ in the circuit shown in Figure 6, a performance comparison was made for the filter circuit by first using the standard capacitor and then the memcapacitor.

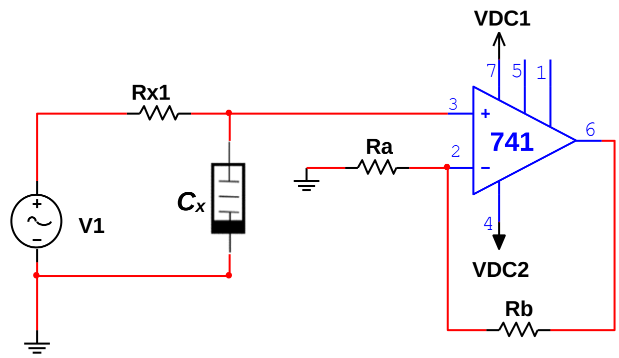


**Figure 6.** Low pass filter circuit with the memcapacitor.

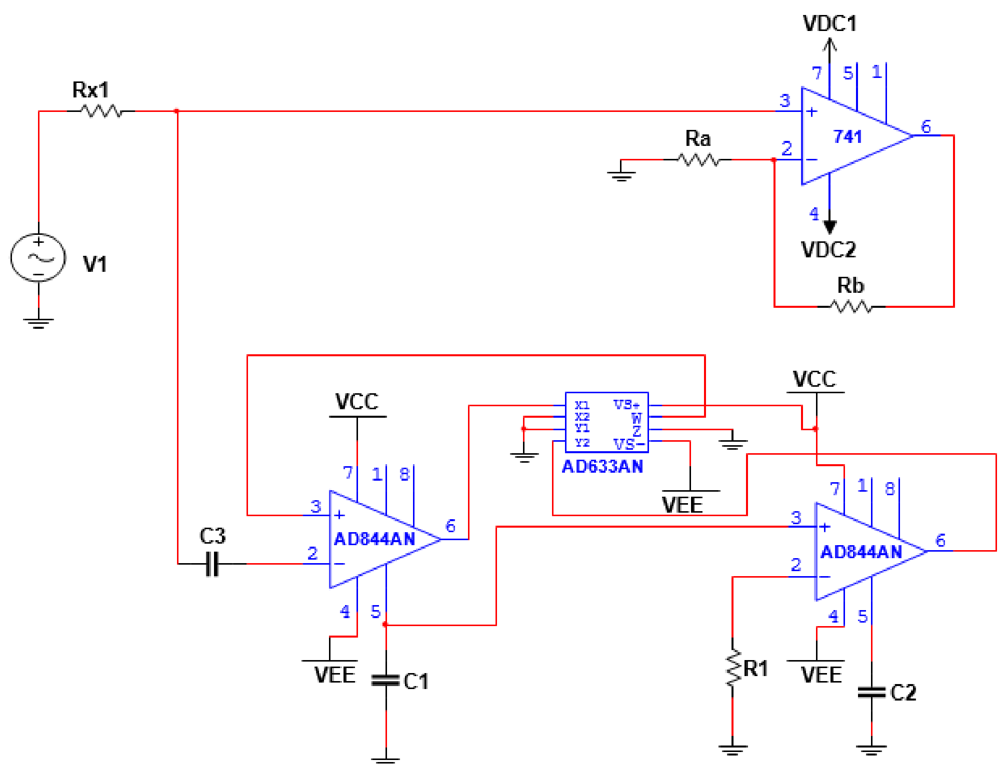


**Figure7.** Low pass filter circuit with memcapacitor emulator.

In the circuit in Figure 7, $R_{x1} = R_a = R_b = 1k\Omega$ and $C_x = 4.6\mu$F.The cut-off frequency of the circuit is calculated as $f = 34.5$ Hz using

$$f_c = \frac{1}{2\pi R_{x1} C_x} \tag{4}$$

The voltage gain of the circuit is determined as $A_v = 2$.

### 4. Performance Comparison of the Standard Capacitor and Memcapacitor

The results of the analysis made in this section are given in Figure 8 and Table 1. Figure 8 shows the voltage gain-frequency curves for the LPF with standard capacitor and memcapacitor. The analysis results show that the LPF circuit with memcapacitor has better signal suppression ratio than the classical LPF circuit, especially after the cut-off frequency. This analysis can be seen more clearly in the zoomed form where the values after the cut-off frequency.

Another analysis made in this study is the reactive power analysis. Reactive power is a power that the reactive element takes from the circuit and gives back, and it is actually a type of power that needs to be compensated because it causes fluctuations in the electrical network. Therefore, it is desirable that the amplitude of the reactive power be small. The reactive power values consumed by the standard capacitor and memcapacitor in the LPF circuit are given in Table 1. According to the reactive power parameter calculated with the formula $Q = -I^2 X_C$, it is concluded that the circuit with the memcapacitor consumes less reactive power and in this sense the performance quality is better.

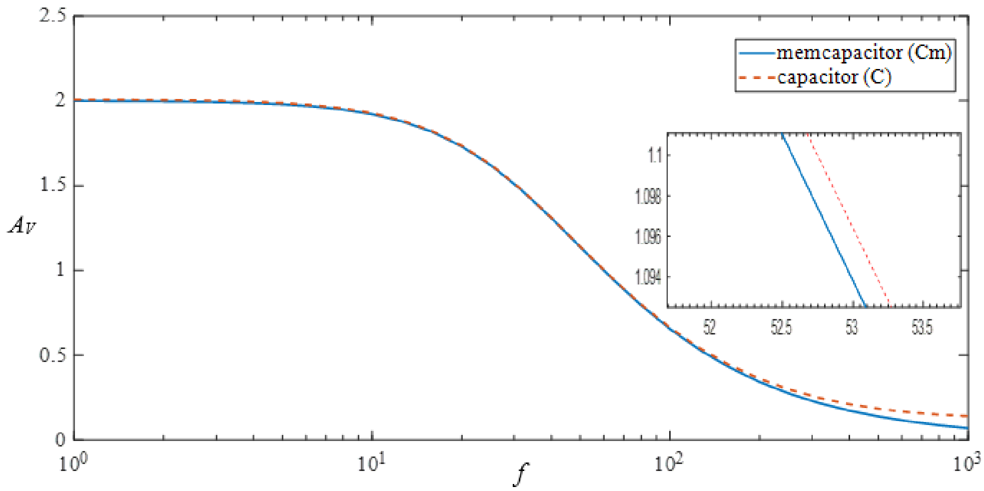


**Figure 8.** Voltage gain-frequency curves of the LPF circuits with standard capacitor and memcapacitor.

**Table 1.** Performance comparison of standard capacitor and memcapacitor for LPF circuit.

| Type of capacitor used ($C_X$ =4.6$\mu$F) | Current drawn | Reactive power |
|---|---|---|
| Standard capacitor | 945$\mu$A | –308.6$\mu$VAR |
| Memcapacitor emulator | 844$\mu$A | –246.5$\mu$VAR |

## 5. Conclusions

It is known that the purpose of a low pass filter circuit is to suppress signals after the cut-off frequency. From the analysis of the performances, it was noticed that by using a memcapacitor instead of the standard capacitor, it reacted slightly faster when it reached the cut-off frequency and this is closer to the ideal filter characteristics. In addition, it is obvious that the low reactive power consumed in a circuit will positively affect the performance of the circuit. Therefore the reactive power consumption, which is another analysis made in the study, showed that the use of memcapacitors increased the circuit quality. The circuit in which the memcapacitor is used consumes 20.12% less reactive power amplitude than the circuit in which the standard capacitor is used. The positive effects of the use of memcapacitors in the filtering ability and power consumption, which are important parameters in electronic circuits, are promising. It is thought that the use of memcapacitors in different circuits in the future will provide positive effects.

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