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An Operational Transconductance Amplifier-based Memcapacitor and Meminductor

Yunus Babacan

Department of Electrical and Electronics Engineering, Erzincan University School of Engineering, Erzincan, Turkey

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ABSTRACT

Previous studies have focused on the new mem-elements after the experimental realization of memristor which is the the fourth passive circuit element. This research presents a simple operational transconductance amplifier (OTA)-based memcapacitor and meminductor emulator circuit that does not comprise a mutator circuit. Each emulator was verified using the LTspice simulation program, and the simulation results were found to be compatible with the characteristic behaviors of the memcapacitor and meminductor.

Keywords: Memcapacitor, meminductor, emulator, OTA

Introduction

Leon Chua postulated the existence of a new basic passive circuit element, called the memristor, defined by a constitutive relationship between flux and charge linkage [1,2]. Researchers did not focused on the new element until fabricated a solid state implementation of the memristor [3]. The *n*-th order mem-elements are presented in the reference [4]. The mem-elements such as memcapacitor and meminductor attract interest therefore various SPICE models/circuits of memcapacitor and meminductor were showed by many researchers [5-10].

In this letter, Operational Transconductance Amplifier (OTA) based very simple memcapacitor and meminductor emulators that do not require any mutator to transform from memristor to memcapacitor or from memristor to meminductor is presented. The features of the proposed memelements are demonstrated via circuit simulations.

Memcapacitor Emulator Circuit

Current-mode structures have very low power consumption property (memristive elements have very low power consumption). For this reason OTA which is current mode circuit element is suitable for emulator design. The proposed memcapacitor circuit is shown in Figure 1. One output terminal of OTA is connected to the positive input terminal to provide resistive behaviour. Another terminal is connected to the C_2 capacitor to obtain memory effect of the proposed emulator. Negative input terminal of the OTA is connected to the voltage source which depends on the multiplication of the C_2 capacitor voltage and its integral [8]. The C_1 capacitor is initial capacitor of the proposed emulator.

Sinusoidal 100 mV input signals with various frequencies are applied to the input of the memcapacitor emulator and voltage-charge curves are obtained as shown in Figure 2a. The Figure 2b shows the input voltage-time and charge-time graphics.

Address for Correspondence:
Yunus Babacan

E-mail:
ybabacan@erzincan.edu.tr

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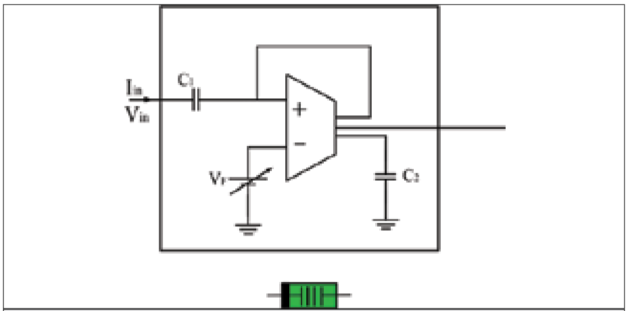

Figure 1. Memcapacitor emulator circuit based on OTA. Here C1=1nF, C2=1pF, gm=3mS

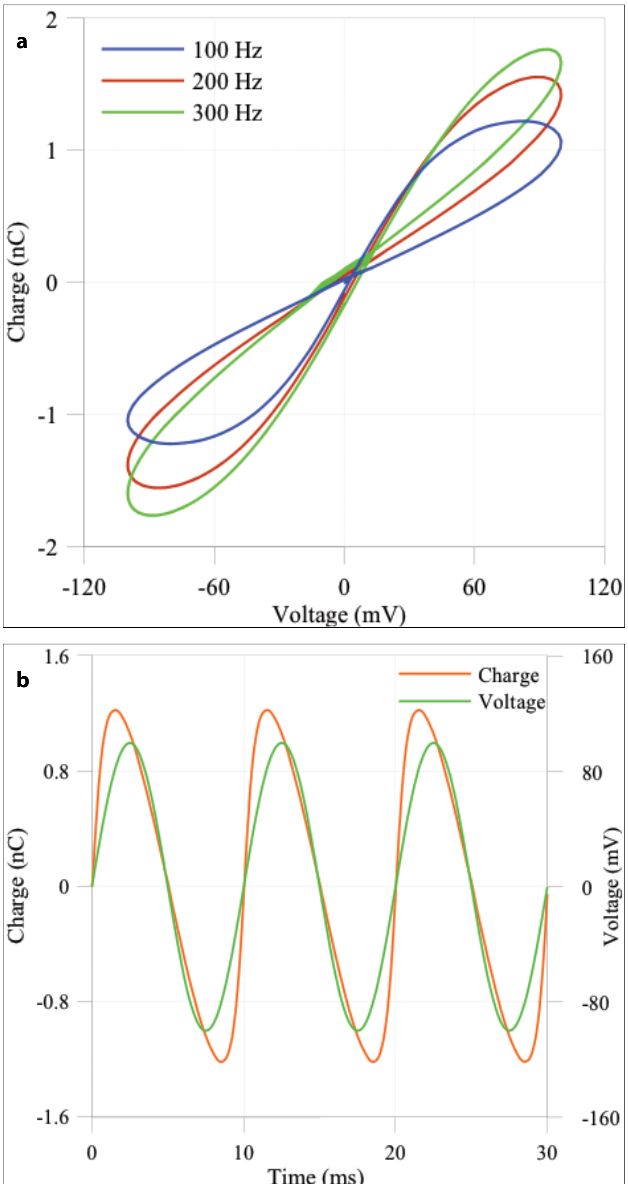

Figure 2. a,b. Simulation results under sinusoidal inputs for memcapacitor. a) Voltage-current relationship with various frequencies. b) Charge and input voltage of memcapacitor

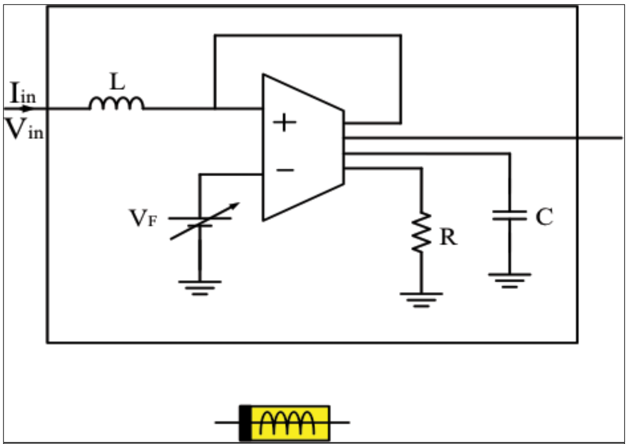

Figure 3. Meminductor emulator based on OTA. Here L=100 mH, C=1pF, R= 1 kΩ, gm=30 μS

The input current is given by:

$$I_{in} = C_1 \frac{d(V_{in} - V_F)}{dt} \quad (1)$$

This equation can be rewritten as below:

$$\frac{q(t)}{C_1} + V_F = V_{in} \quad (2)$$

$$V_F = V_{C2}\int V_{C2} = \frac{q(t)}{C_2^2}\int q(t)\,dt, \; (q(t) = C_2 V_{C2}) \quad (3)$$

q(t) is variable part of the proposed circuit that is why VF changes and provides the memcapacitive behaviour of the proposed emulator circuit.

Meminductor Emulator Circuit

Similar circuit topology used for meminductance design as shown in Figure 3. Negative input of the OTA is derivative of the multiplication of the resistor and capacitor voltages. One output of the OTA is connected to the its input to provide the resistive behaviour. The voltages on the capacitor and resistor provide the memory effect and inductance change ranges respectively.

The proposed meminductance emulator is operated under 100 nA sinusoidal input currents with 100, 300, 500 Hz respectively. Meminductor behaves frequency-dependent characteristic as shown in Figure 4a. The flux and current waveforms cross zero levels as shown in Figure 4b. Namely phase difference is zero between the both signals that is why hysteresis effects can be seen in current-flux relationship.

The fundamental relationship between flux and current is:

$$\varphi(t) = \int (V_{in} - V_F)dt = L\,i(t) \quad (4)$$

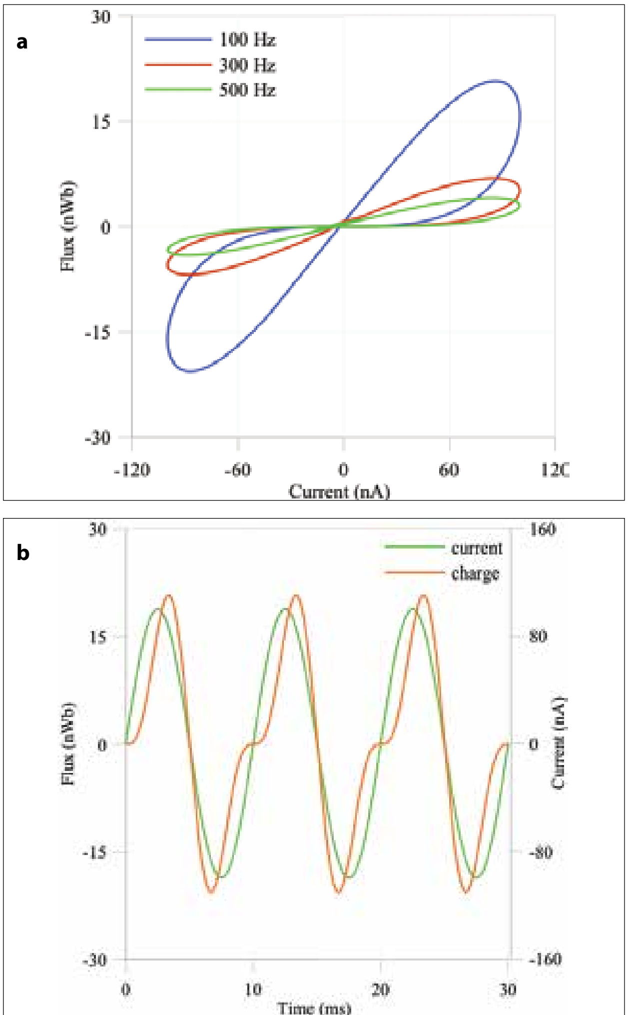

Figure 4. a,b. Various curves for meminductor emulator circuit. a) Hysteresis loops under periodic sinusoidal current input. b) Flux and input current of meminductor

The V_A voltage equals to the multiplication of resistor and capacitor.

$$V_A = V_R x V_C \quad (5)$$

Here:

$$V_R = I_{in}(t) x R \text{ and } V_C = \frac{q(t)}{C} \quad (6)$$

Negative input of the OTA,

$$V_F = \int V_A dt = \int \left(\frac{q(t) R I_{in}(t)}{C} \right) dt \quad (7)$$

Equation (4) and (7) can be rearranged:

$$\varphi(t) = \left[L + \frac{q(t)R}{C} \right] I_{in}(t) \quad (8)$$

The flux change of the proposed circuit can be seen from equation (8) and the inductance changes according to the $\frac{q(t)R}{C}$.

Conclusions

Simple OTA based memcapacitor and meminductor emulator circuits are presented. Many memcapacitor and meminductor circuits or models consist of memristor element but proposed emulator is designed without any memristor circuit or models. Emulators which have no memristor circuit or models become more effectively according to the memristor based mem-elements so the proposed emulators are suitable for memcapacitor and meminductor based circuit applications. And also these emulators have simple structures. The behaviours of the proposed memelements are demonstrated via circuit simulations and all results compatible with previous studies.

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Yunus Babacan received B.Sc., M.Sc. degrees in Electrical and Electronics Engineering at Atatürk University, 2008 and 2011 respectively. He received his Ph.D. degree in Electrical and Electronics Engineering at Istanbul University in 2016. His main research interests are memristive systems, analog circuit design and memristor based biological circuit/system design. He is currently working as an assistant professor at the Electrical and Electronics Engineering department of Erzincan University.