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FCS Based Memcapacitor Emulator Circuit

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ABSATRACT: In this paper we have designed a grounded memcapacitor emulator which is a part of memristive system providing a nonlinear relationship between Charge and Voltage. The Floating Current Source (FCS) possesses a low power consumption feature, has been utilized for the memcapacitor emulation. In this study, a memcapacitor emulator is designed utilizing discrete circuit elements. The proposed emulator circuit exhibits a simple design consisting of MOSFETs and capacitors. The emulator performance is verified theoretically, and computer simulations and results are discussed here.

Keywords: Memcapacitor, FCS, Emulator

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INTRODUCTION

Memristor is a semiconductor that connects a resistor, capacitor, and inductor to make the fourth new type of element. Its resistance is named as memristance that differs as a function of flux and current. Memristance is charge dependent resistance and have the unit of the Ohm. Leon Chua mathematically expressed memristor utilizing the relation between flux and charge (Chua et al., 1971; Chua et al., 1976). After this expression, Stanley Williams and his team fabricated first physical memristor (Strukov et al., 2008). The physical production of memristor attracted the attention of the scientific world leading to increase studies in this field (Abdallah et al., 2011; Kolka et al., 2012; Kim et al., 2012; Williemas et al., 2013; Kvatinsky et al., 2013). The main reason of this interest is because of the memristor's permanent memory feature as well as nonlinear resistance and great operation performance (Babacan et al., 2017). In 2009, the memristive concept was implied to memcapacitor and meminductor which also exhibits nonlinear characteristic and memory like memristor (Ventra et al., 2009).

The memcapacitors defined by the charge-voltage relationship can be developed from a memristor with a mutator. They are also one of the fundamental circuit elements, which are the generalizations of ordinary capacitors with nonlinearity and immediate responses. This new element, memcapacitor, provides connection between the second derivative of voltage and first derivative of current with nonlinearity and memorial behavior. In other words memcapacitors are high-orders circuit elements so brings new possibilities new nonlinear circuit design. Memcapasitors, has the potential applications in nanoscale devices that can store data without power source.

In this paper, we designed memcapacitor emulator circuit using floating current source (FCS) structure which is current mode and require low power consumption. The emulator circuit is designed and simulated with LTspice program, the unlicensed computer software. The performance of this simple circuit design has been verified theoretically and by comparison with previous studies. It is believed that this study will encourage future studies to design more power efficient and simple memristor/memristor based circuits for practical usage.

MATERIALS AND METHODS

Memcapacitor Emulator Circuit

Memcapacitor is one of the last elements of the mem-system with current source based and low power consumption characteristic (Babacan et al. 2017). In this paper, a memcapacitor emulator circuit is proposed employing FCS due to its low power requirement. In this study, the current mode FCS circuit design proposed by Arbel and Goldminz is utilized, shown in Figure1, for memcapasitor emulator circuit (Arbel et al., 1992). In this design, the difference between input voltages of FCS (VP, VN) is transferred to output as a current. In case of VP voltage is greater than VN voltage, FCS output current is positive. Otherwise, if VN voltage is greater than VP voltage, then FCS output current is negative.

According to the Ohms' law;

$$I_2 - I_1 + (I_{XN} + I_{XP}) = 0 \quad (1)$$

$$I_2 = I_1 \quad (2)$$

$$I_{XP} = -I_{XN} \quad (3)$$

Where I_1 and I_2 are bias currents, I_{XN} and I_{XP} are FCS output currents.

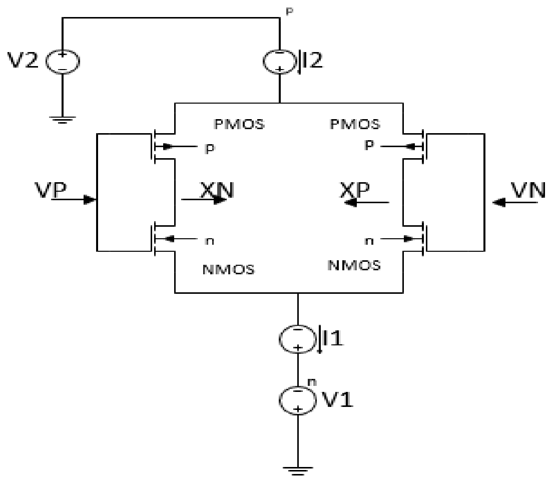

Figure 1. FCS Circuit. PMOS *L*=1µm, *W*=8 µm and NMOS *L*=1 µm, *W*=2, (V2=+0.9V, V1=-0.9V, I_2=+0.9µA and I_1=-0.9µA)

Employing the aforementioned FCS, the memcapacitor emulator circuit is design and shown in Figure 2. In this design, V1 is input voltage, C2 is initial capacitor, C1 is connected to the FCS output to generate memory, and the other FCS output is connected to the FCS positive input to create resistive behavior. V_A input voltage is equal to product of C1 capacitor voltage and its voltage integral. This product is the one provides non-linear characteristic in emulator circuit.

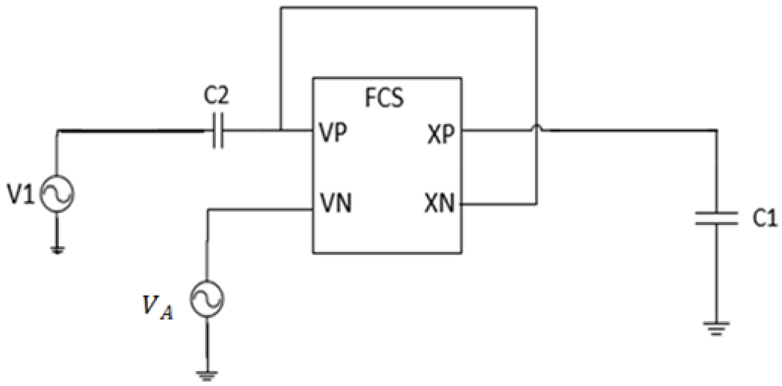

Figure 2. Memcapacitor emulator circuit. (C1=100pF, C2=1nF and V1=100mV)

$$V_A = V_{C1} \int V_{C1} \quad (4)$$

$$V_A = \frac{q(t)}{C1} \int \frac{q(t)}{C1} d(t) \quad (5)$$

$$V_A = \frac{q(t)}{(C1)^2} \int q(t) d(t) \quad (6)$$

As can be seen from the equations above, the voltage V_A shows a nonlinear change with respect to the charge q(t). In equation 6, q(t) is a control parameter which provides memcapacitor characteristic to emulator. Therefore, due to the dependency of V_A to the charge q(t), it is clear to say that the emulator is a charge-controlled circuit.

RESULT AND DISCUSSION

Simulation results

The proposed design is simulated in order to validate the theoretical outcome. Figure 3 shows the charge and voltage hysteresis loop of design. In a range of ±100mV input voltage, the output has been also analyzed for frequencies of 1Hz, 3Hz, 5Hz and 7Hz to see the dependency of frequency. It is known that the mem-elements have non-linear characteristic at low frequency but at high frequency they lose their non-linearity characteristic and they behave like linear elements (Babacan et al.,2017; Karakulak et al., 2011). This theorem explains the hysteresis behaviors towards frequency in Figure 3 as the input voltage alternates between +100mV and -100mV. As can be seen in the figure, regardless of frequency, it is clear that the emulator Memcapacitor exhibits capacitive effect. Even though the hysteresis loop is non-linear at low frequencies it is gradually becoming linear with the increase in frequency. In other words, three important things can be understand from frequency depended pinched hysteresis loop: 1. The element has zero phase shift, 2. the element has memorial behavior, 3. The element exhibits nonlinear behavior.

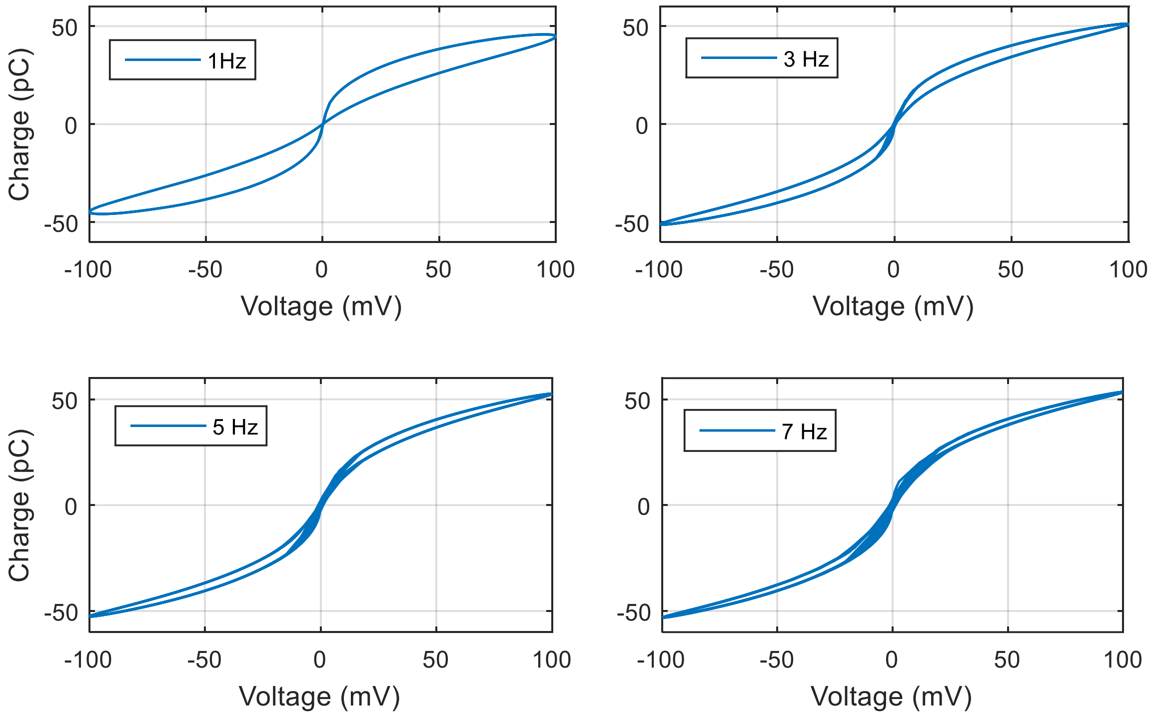

Figure 3. Memcapacitor emulator hysteresis loop at frequencies of 1, 3, 5 and 7Hz.

The time domain simulation of is also performed and presented in Figure 4. It is seen from the figure that as the input voltage cycling between ±100mV, the charge that measure from C1 is following the voltage move until C1 gets fully charged. When the capacitor is fully charged, the charge level is linear until the input voltage begins to drop. Memcapacitors should have zero phase shift between charge and voltage so we wanted to show this property. As shown in Fig. 4., there is no phase shift between charge and voltage.

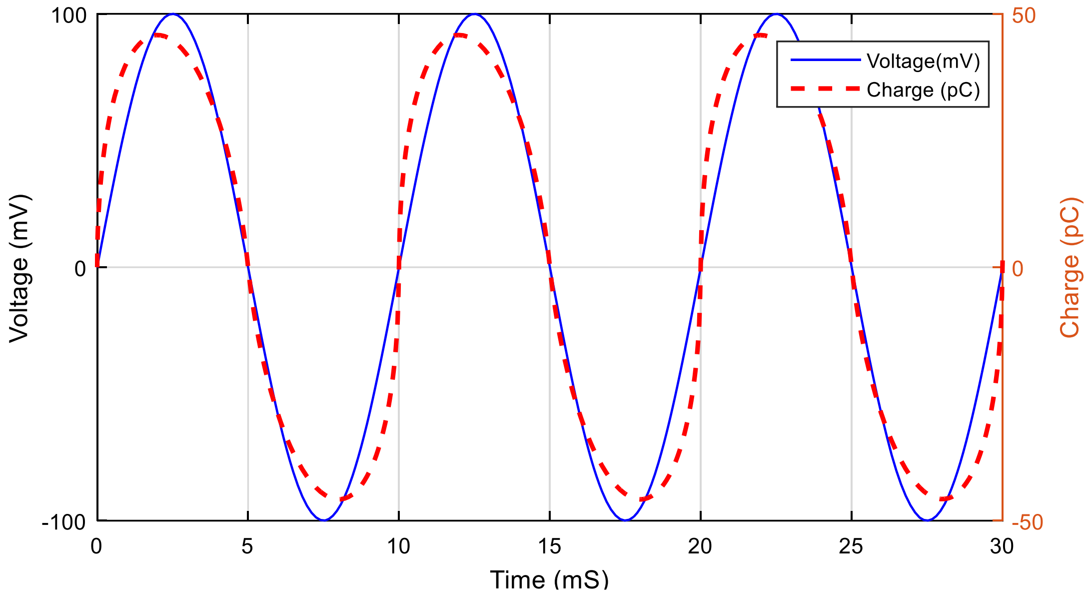

Figure 4. Memcapacitor emulator charge and voltage

Pulse train is applied to the proposed circuit to show its non-volatile behavior. So we applied positive and negative pulses to investigate the non-volatility behavior. Five positive and negative voltage pulses are applied to the input terminal of the circuit to verify the non-volatile memory effect of the emulator. As shown in Figure 5, positive and negative pulses are applied to the input terminal to test the memorial property of the proposed circuit. VA voltage is multiplication of the voltage on the capacitor and integral of the capacitor voltage. This multiplication provides nonlinearity of the circuit. The memorial effect is obtained using capacitor. It can be seen from Fig.5. charge increases during the pulses and there is very little change during pulse interval. The similar state can be seen when applied negative input pulses and it can be say that charge decreases when applied negative pulses. Charge becomes nearly the same between applied pulses. In other words, the proposed circuit have memory and store charge as shown in Fig.5.

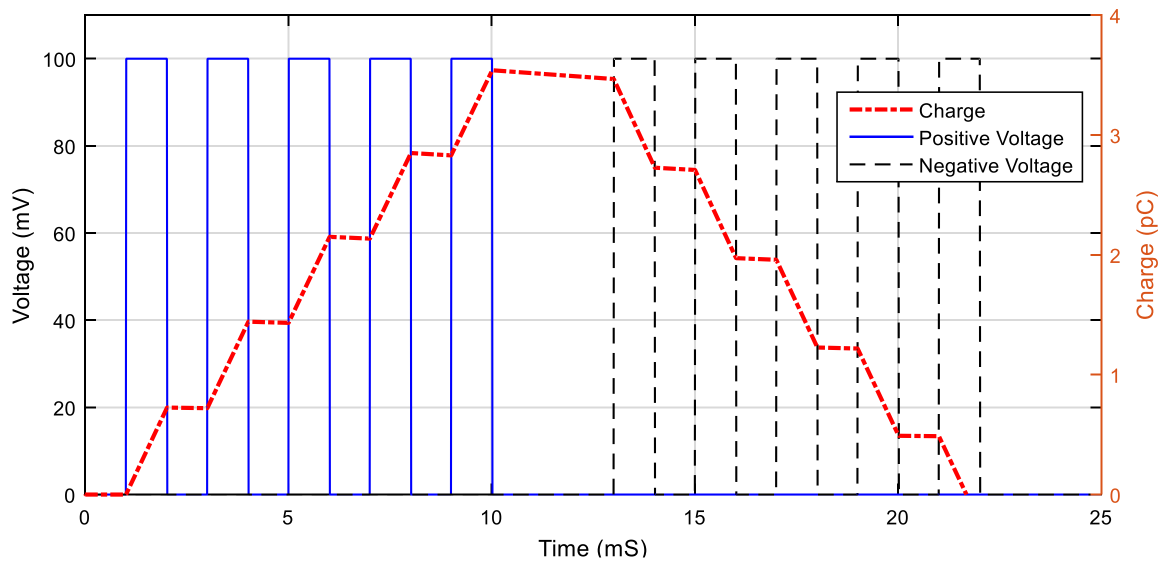

Figure 5. Charge change when applied positive and negative pulse train.

In summary, it needs to be noted that, when no voltage applied to the emulator, during the time between two sets of pulses, the Charge shows a slide decrease. This decrease is due to the MOSFET leakage current. If this leakage can be also controlled, then the control of the emulator memory can be possible.

CONCLUSIONS

In this paper, we designed a new memcapacitor emulator circuit based on current mode FCS structure. As it is expected, the Voltage-Charge relation became hysteresis and with the frequency it became linear. The applied pulses showed that the Charge does not change over time and it changes during the applied input pulse duration. Therefore, it is believed that, the proposed emulator design can shed light on the more practical and simpler circuitry for the emerging mem-system technology.

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