Passive Fully Floating Emulator of Memristive Device for Laboratory Experiments

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Abstract: - A simple emulator of memristive system, containing only passive electronic components, namely resistors, capacitor, and no-DC biased transistor is described. Unlike other hitherto published emulators it does not exploit DC power supply. Moreover, it provides effective emulation of grounded as well as floating memristive systems. The circuit idea enables interesting experiments, demonstrating the well-known fingerprints of memristive systems such as the pinched v-i hysteresis loops.

Key-Words: - Memristive system, passive system, floating two-terminal element, pinched hysteresis loop.

1 Introduction

The paper [1] by the Hewlett-Packard researchers, announcing the manufacture of a nano-device resembling the memristor [2], sparked worldwide interest in memristive systems [3], inaccurately designated as memristors, which are currently considered the revolutionary components for the computer industry and also analog applications. Since commercial samples are not currently available, various emulators have been designed for experimenting with these perspective devices, on both analog and hybrid principles [4-15]. All of them suffer from the following drawback: They employ active electronic components, which require DC supply sources, even if a passive memristive system is emulated. This entails other disadvantages, for example a large influence of the parasitic properties of the active building blocks (such as offset and drift, limited bandwidth, low dynamic range of voltages and currents, etc.) on the operation of the emulated system, as well as serious problems when emulating floating two-terminal devices.

On the other hand, several papers describe the experimentally well-established manifestations of memristive systems, particularly the pinched hysteresis loops, for some passive systems whose framework has been well-known for many years (various types of bulbs or discharge lamps [16], radio detector called cat’s whisker used as the first radio detector [17], etc.) or for systems with accidentally revealed memristive behavior (diode bridge with LCR filter [18]). Experiments with “Home-made memristors“ [19], [20] are based on the idea from [17] that memristive effects are associated with imperfect electric contact.

As emphasized in [21], “the current textbooks will have to be revised to include the memristor and the new paradigm it represents for electronic circuit theory”. It is underlined in [22] that “the most valuable applications of memristors will most likely come from some young student who learns about these devices and has an inspiration for something totally new”. The memristive emulators can serve as a good input gate into this exciting research area for such students which like the laboratory experiments. However, the emulators must be of a simple construction such that its analysis can easily result in a definite understanding of the key principle of the operation of the memristive system.

The objective of this paper is the synthesis of a passive memristive system from commonly available electronic components. The synthesis will start from equations that define the memristive systems and thus the principle of the operation of the emulator will be obvious, together with its parameters, advantages and limitations.

2 Memristors and memristive systems

The general first-order voltage-controlled memristive system is described by its port equation (1) and state equation (2) [3]

$$i = g(x, v)\, v\,, \tag{1}$$

$$dx/dt = f(x, v)\,, \tag{2}$$

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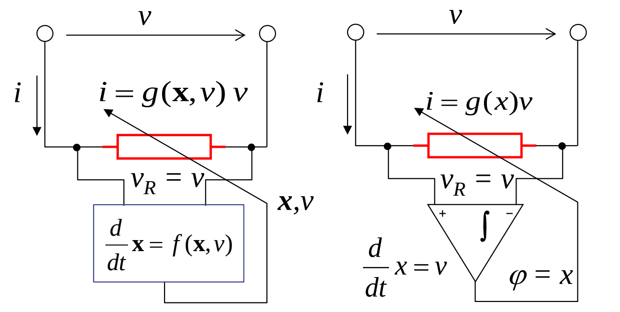
where v and i are the voltage and current of the memristive port, respectively, x is the internal state variable, and g and f are nonlinear functions of the state variable and the voltage, respectively. The function g represents the conductance, or memductance, which can be dependent on both the voltage (the sign of nonlinearity) and the state (the sign of memory effect). The block diagram corresponding to Eqs. (1), (2) is shown in Fig. 1 (a).



(a) (b)

Fig. 1. Block diagrams of (a) general memristive systems, (b) ideal memristors.

The memristor, in the sense of its axiomatic definition [2] (today frequently denoted as ideal memristor), is a special case of the memristive system (1), (2), with its conductance being dependent only on the internal state, and the differentiation of the state variable with respect to time being equal to the voltage, or, in other words, the state variable is equal to the integral of the voltage, which is the flux φ [2] (also see Fig. 1 (b)):

$$i = g(x)\, v, \qquad (3)$$

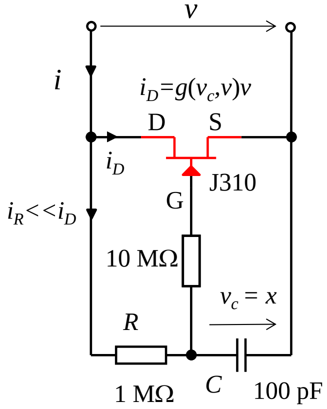
$$dx / dt = v. \qquad (4)$$

Since the memductance depends on the internal state, the memristive systems exhibit the *v*-*i* pinched hysteresis loop, which is the most widely known fingerprint of these systems. It is also known that memristors and memristive systems can be either passive or active, and that the sufficient condition of the passivity is the nonnegative memductance. A special attribute of the memristor (3), (4) is that it is a fundamental circuit element which cannot be substituted by any combination of other fundamental elements (R, L, C). The controlled sources do not fall into this category, and thus they can be used for the construction of memristor emulators via active blocks working on the principle of controlled sources (for example operational amplifiers).

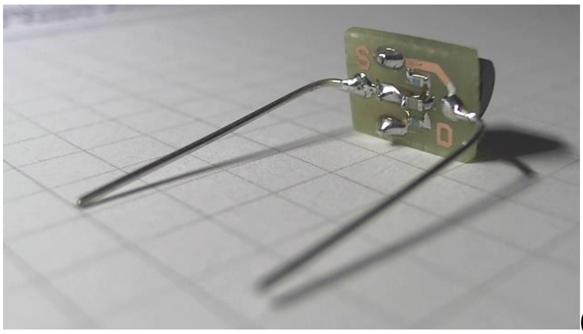
As regards the memristors (3), (4), it is obvious from (4) that the ideal integrator needs to be implemented for their emulation. However, this is impossible without active electronic elements. From the opposite point of view, if only passive elements are available for implementing the emulator, it is possible to realize a certain subclass of the general memristive systems (1), (2), whose behavior, under specific conditions, can approach the behavior of the ideal memristors.

3 Synthesis of memristive system

The proposed schematic and the physical implementation of passive circuit emulating the memristive system are shown in Figs. 2 (a) and (b), respectively.



(a)



(b)

Fig. 2. Emulator of the passive memristive system, (a) schematic, (b) implementation.

The schematic starts from the block diagram of a general memristive system in Fig. 1 (a) for the case of one-dimensional state vector **x,** having an ambition to emulate, within a certain accuracy, also the behaviour of ideal memristor in Fig. 1 (b). The RC cell with the output v_C operates as passive lossy integrator with the cutoff frequency $f_C=1/(2\pi RC) \approx$ 1592 Hz. For frequencies above this value, the characteristics of this circuit approximate the characteristics of ideal integrator, when the voltage v_C corresponds to the integral of the port voltage

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v and thus the state variable x in Eq. (4). This voltage is concurrently the voltage across the JFET terminals G and S, which controls the transistor conductance between the terminals D and S. If this conductance were independent of the voltage v, then the circuit could implement the memristor (3), (4). The resistor in series with the gate G increases its resistance and galvanically separates the gate from the output of the RC cell.

As shown hereinafter, the circuit in Fig. 2 (a) in fact emulates a more general memristive system (1), (2). It is a consequence of the non-ideal passive integrator and specific nonlinear characteristics of the transistor.

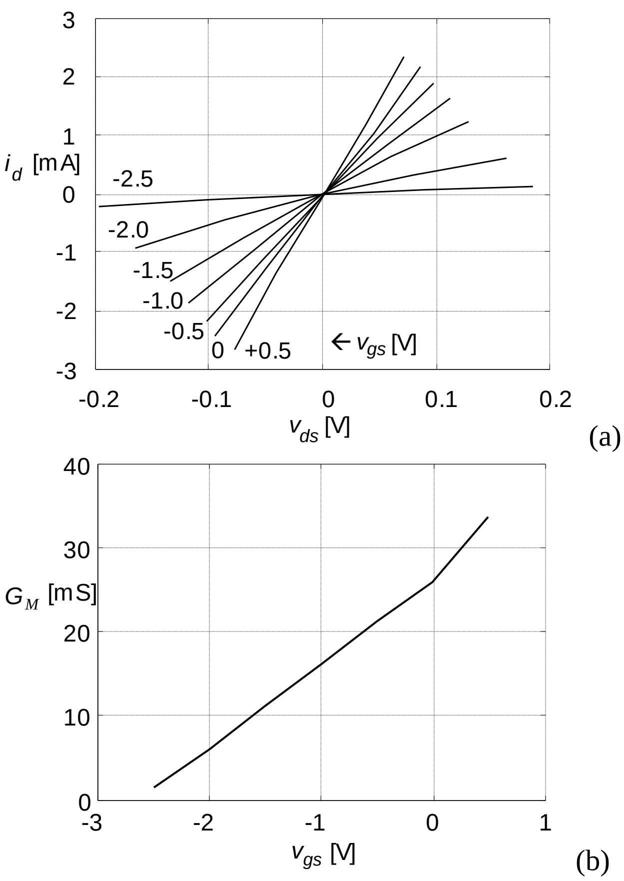

Fig. 3. Measured characteristics of the transistor J310 [15]: (a) $i_d(v_{ds})$ for constant voltage v_{gs}, (b) $G_M(v_{gs}) = di_d/dv_{ds}$ for $v_{ds} = 0$.

The measured nonlinear DC characteristics of the transistor J310 are shown in Fig. 3 [15]. As is obvious from Fig. 3 (b), this JFET can be used as an electronically controlled conductor. Figure 3 (a) reveals that for a fixed voltage v_{gs} the conductance is not constant but depends on the voltage v_{ds}, which is a sign of the memristive system (1), not the memristor (3). Eq. (3) will therefore be fulfilled only for a small swing of v_{ds} around zero when the nonlinearities of the characteristics do not take effect.

Consider that the characteristics of the transistor from Fig. 3 (a) are represented by the equation

$$i_d = g(v_{gs}, v_{ds})v_{ds}. \quad (5)$$

Concrete analytic forms of Eq. (5) of various complexities, resulting from the physical nature of the operation of JFET, are well known [24], but they are irrelevant to the subsequent analysis. Considering the identities $x = v_c$, $v = v_{ds}$, taking into consideration the differential equation of the RC cell in Fig. 2 (a) and its high impedance level when the current through this cell can be neglected in comparison with the current i_d, the mathematical model of the circuit in Fig. 2 (a) can be rewritten in the form

$$i = g(x, v)\, v\,, \quad (6)$$

$$\frac{d}{dt}x = \frac{1}{RC}(v - x) \quad (7)$$

A comparison with Eq. (1) and (2) leads to the conclusion that the circuit in Fig. 1 can serve as the emulator of memristive systems.

A comparison with Eq. (3), (4) yields that the circuit in Fig. 2 (a) can successfully mimic the ideal memristor if two conditions are fulfilled simultaneously:

1) The memductance is independent of the voltage v (thus a small voltage swing).
2) The state variable must be negligible compared to the voltage v (this will be fulfilled for relatively high signal frequencies when the passive integrating RC cell will show adequate attenuation).

4 Demonstration of the emulator behavior

Figure 4 presents experimental results when the emulated system is excited by a generator of sinusoidal voltage with 3V amplitude and varying frequency.

It is obvious from the results that the hysteresis is negligible for a low frequency (10 Hz) because the RC cell does not cause any significant phase shift between the port voltage and the state voltage (v_C), the latter controlling the transistor.

The memory effect is evident for 100 Hz, but the loop is not symmetrical. It points to the fact that the emulated system is not an ideal memristor.

(a)

(b)

(c)

(d)

Fig. 4. Measured pinched hysteresis loops of the memristive system from Fig. 2 (a) under its sinusoidal excitation with an amplitude of 3 V and frequencies of (a) 10 Hz, (b) 100 Hz, (c) 1 kHz, and (d) 10 kHz. The current (vertical axis) was sensed via a voltage drop at 10 Ω resistor in series with D-S junction of JFET.

One reason is the non-ideal operation of the integrator, whose cutoff frequency is one order higher than the frequency of the signal. The loop is already almost symmetrical for 1 kHz. When increasing the frequency up to 10 kHz, one can observe the well-known fingerprint of memristive systems: the area of the hysteresis loop diminishes towards zero if the frequency increases ad infinitum.

5 Conclusions

The proposed emulator of memristive systems has the following advantages:

(i) It is built from components that do not use power supplies.
(ii) It naturally emulates both grounded and floating two-terminal devices.
(iii) It does not labour with the well-known drawbacks of emulators built up from active devices (signal limitations, offset and drift issues, parasitic nonlinear distortion coming from OpAmp nonidealities, etc.).
(iv) It can be manufactured as a small two-terminal device, ready for laboratory experiments.
(v) The frequency band of gradual disappearance of the hysteresis effects can be changed via adjusting the time constant of the RC cell.

In order to increase the accuracy of modeling ideal memristors, further research will focus on the linearization of the element implementing the memductance, and also on the modification of the integrating cell.

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