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VTEAM – A General Model for Voltage Controlled Memristors

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Abstract*— Memristors are novel electrical devices used for a variety of applications including memory, logic circuits, and neuromorphic systems. Memristive technologies are attractive due to the nonvolatility, scalability, and compatibility with CMOS. Numerous physical experiments have shown the existence of a threshold voltage in some physical memristors. Additionally, as shown in this paper, some applications require voltage controlled memristors to operate properly. In this paper, the Voltage ThrEshold Adaptive Memristor (VTEAM) model is proposed to describe the behavior of voltage controlled memristors. The VTEAM model extends the previously proposed TEAM model, which describes current-controlled memristors. The VTEAM model has similar advantages to the TEAM model: it is simple, general, and flexible and can characterize different voltage controlled memristors. The VTEAM model is accurate (below 1.5% in terms of relative root mean squared error) and computationally efficient as compared to existing memristor models and experimental results describing different memristive technologies.

Index Terms—**Memristive systems, memristor, SPICE, MATLAB, resistive switching, ReRAM.**

I. INTRODUCTION

Memristors are passive two-port elements with a variable resistance. For ideal memristors, as originally suggested by Chua in 1971 [1], the resistance depends directly on the charge passing through the device, or alternatively, on the integral over time of the applied voltage across the device (*i.e.*, flux). Memristive devices, originally defined by Chua and Kang [2], are an extension of the memristor definition, where the resistance depends on a state variable (or a set of state variables). While discussions exist in the literature concerning the specific definition of memristors [3], [4], [5], in this paper the term 'memristor' is used to describe both ideal memristors and memristive devices. Emerging nonvolatile memory technologies (*e.g.*, Resistive RAM, Phase-Change Memory, and Spin-Transfer Torque Magnetoresistance RAM) are considered as memristors [4]. Memristors can also be used for other attractive applications, such as logic circuits [24] and neuromorphic systems.

Numerous memristor models have been proposed. Some of the models do not exhibit a threshold [6], [7], [8]; hence, the resistance of the device changes for any applied voltage (or current). Recently, the TEAM model [9] has become widely used due to the simplicity, generality, accuracy, and low computational complexity. The TEAM model relies on a threshold current, where the resistance changes only for currents above a certain level. Experimental data of some memristive devices show, however, the existence of a threshold voltage rather than threshold current. Furthermore, certain memory and logic applications require memristors with a threshold voltage to operate properly.

Hence, a memristor model with the advantages of the TEAM model (*i.e.,* general, simple, and sufficiently accurate) and exhibiting a threshold voltage is desirable. In this paper, VTEAM, a novel memristor model that satisfies these requirements, is presented. The VTEAM model has sufficient accuracy (below 1.5% in terms of relative root mean squared error) as compared to existing memristor models and experimental results of different memristive technologies.

The rest of the paper is organized as follows. Motivation for a threshold voltage and applicability to various circuits are demonstrated in Section II. In Section III, the VTEAM model is described. A comparison between the VTEAM model and previously proposed models, including experimental results, is presented in Section IV. The paper is summarized in Section V.

II. MOTIVATION FOR THRESHOLD VOLTAGE

The authors previously proposed the TEAM model [9], which is inspired by the Simmons tunnel barrier model [8]. The TEAM model is based on a threshold current. The resistance of the memristor does not change for currents below a certain threshold current. Experiments on several types of memristive devices, however, have shown the existence of a threshold voltage (*e.g.,* [6], [18], [23]), as illustrated in Figure 1 for different memristors. Furthermore, a memristor with a threshold voltage is more appropriate than a threshold current for certain logic and memory applications, as demonstrated in subsections IIA and IIB for, respectively, memory and logic.

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