

# A Versatile Memristor Circuit Emulator for Nanoscale Thin-film TiO<sub>2</sub> Using Discrete-electronic Components

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## Extended Abstract

The successful fabrication of a real nanoscale thin-film TiO<sub>2</sub> memristor from Hewlett Packard (HP) Laboratories has greatly re-energized the interests of researcher in memristor and its future promising applications, especially in nanoscale era because of the limitations in CMOS technology [1]. Many works have started to utilized memristor in diverse nanoscale areas; especially non-volatile random access memory (ReRAM) and neuronmophic synaptic networks [2]. However, the solid memristor devices are not expected to be available in the near future because of the technical difficulties involved in the nanoscale fabrications. Therefore, a replacement which behaves like a real memristor device is urgently needed to allow researchers to study the practical application of memristors. In this study, we present a memristor emulator circuit which can correctly mimic the behaviour of the real nanoscale TiO<sub>2</sub> thin-film memristor device from HP Labs. Additionally, the proposed emulator can also show various i-v hysteresis characteristics as observed at different dimensions of real memristor devices. The proposed emulator is a flux-controlled memristor emulator which originally reported in [3] based on a third-order polynomial function of flux-charge ( $q = \alpha\phi + \beta\phi^3$ ). The emulator circuit is constructed using off-the-shelf electronic devices with two operational amplifiers U1 and U2; two multipliers U3 and U4; one capacitor C and six resistors R, R<sub>1</sub>, R<sub>2</sub>, R <sub>$\alpha$</sub> , R <sub>$\beta_1$</sub> , and R <sub>$\beta_2$</sub> . The success of constructing a controllable memristor emulator of HP TiO<sub>2</sub> memristor was confirmed by both of numerical simulation and laboratory experiment. The numerical analysis of the proposed scheme is firstly performed with an equivalent mathematical modelling in Matlab. The value of  $\alpha$  and  $\beta$  in the nonlinear flux-charge function were chosen for identifying the model parameters of electronics elements in the emulator in order to observe the typical i-v hysteresis loop of the real memristor. Different i-v shape of the emulator circuit was obtained by changing coefficients  $\alpha$  and  $\beta$  in the nonlinear cubic polynomial. The emulator circuit was finally implemented on the prototype print circuit board (PCB) for the experimental observation of the memristive behaviour as well as the controllability using simple electronics devices such as AD633 multipliers; HA17741 amplifiers. Three potentiometers were used for R <sub>$\alpha$</sub> , R <sub>$\beta_1$</sub> , and R <sub>$\beta_2$</sub>  to control the memristive behavior of the proposed memristor emulator. Measurements of the controllable PCB-type memristor emulator were performed using oscilloscopes for the observation of its characteristics. All of the gained results from simulation and measurements were highly matched with the real thin-film TiO<sub>2</sub> memristor presented in [1]; thus, the proposed memristor emulator is recommended as the foundation for understanding and design different emulators for nanoscale TiO<sub>2</sub> thin-film memristors at the Laboratory level to engineers and scholars who cannot access memristor fabrication technology but want to studies memristor-based related.

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