**Challenge #28: Model and Simulate a Memristor**

**Learning Goal:**To understand how memristors work and model their behavior using a nonlinear dopant drift model in Python. Specifically, simulate the Biolek/Joglekar-based memristor and visualize its dynamic I-V characteristics.

**Objective**

* Implement a computational model of a memristor.
* Reproduce and visualize the characteristic *pinched hysteresis loop* in the I-V curve.
* Understand how state variables like doped region width x(t) and memristance R(t) evolve over time.

**Model Overview**

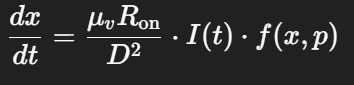
We used the **Biolek SPICE model** (2009) which builds on the **HP memristor** physics. It models the memristance R(t)R(t)R(t) as:



Where:

*  is the normalized width of the doped region.
* R*on*​, R*off*​ are resistance limits for fully doped/undoped states.
* The **Joglekar window function** is used to handle boundary conditions and nonlinearity:  
  

The dopant drift differential equation:



**Simulation Setup**

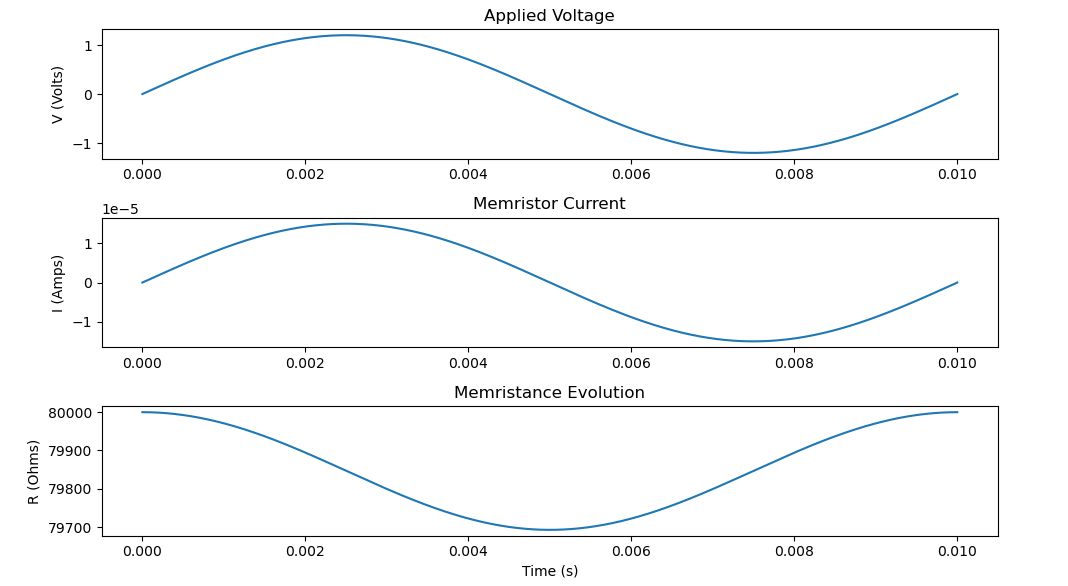
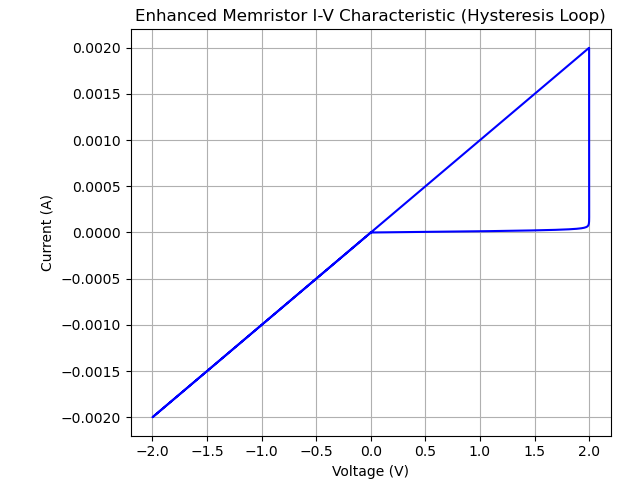
| **Parameter** | **Value** |
| --- | --- |
| R*on* | 1 kΩ |
| R*off* | 100 kΩ |
| R*init*​ | 80 kΩ |
| D (film width) | 10 nm |
| μ*v* |  |
| p (window power) | 10 |
| Voltage Input | 2V peak, 1 Hz sine wave |
| Simulation Time | 1 second |
| Time Step | 100 μs |

**Python Implementation**

The memristor was modeled in Python using NumPy arrays and a numerical Euler integration scheme. The full code included state evolution, current computation, and window function handling. The result is a step-by-step evolution of the memristor’s behavior under voltage stimulation.

**Results**

1. Enhanced I-V Characteristic: Pinched Hysteresis Loop

* The loop is *pinched* at the origin — a key signature of memristors.
* The loop's width reflects **state-dependent resistance**: the more the state x(t) evolves during the input cycle, the wider the hysteresis.
* Using higher nonlinearity (p = 10) and low-frequency excitation (1 Hz) enabled this strong nonlinear behavior.
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**Conclusions**

* The **Biolek memristor model** with the **Joglekar window function** is effective for capturing memristive behavior.
* The **pinched hysteresis loop** confirms memory-dependent dynamics and nonlinear resistance evolution.
* Simulation reveals how memristors could serve as hardware synapses, storing weight as resistance.