Verilog-AMS-POM: Verilog-AMS Integrated Polynomial Metamodeling of a Memristor-Based Oscillator

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Abstract

A two-level framework for memristor based mixed-signal design exploration is proposed. First, a Verilog-A memristor model is proposed which is not source-type dependent and has an advantage over existing SPICE memristor models. Second, a POlynomial Metamodel integrated Verilog-AMS (Verilog-AMS-POM) is proposed to enable fast circuit-accurate system-level design exploration of memristor based circuits and systems. A memristor based programmable Schmitt trigger oscillator is proposed as a case study. The coefficients of determination of the proposed metamodels are greater than 0.99 and the RMSE are less than 0.09. Verilog-AMS-POM simulation achieve a over 30,000X speedup compared to SPICE based simulations.

The Proposed Memristor Model

$$V_M = [R_{on}x + R_{off}(1-x)]I_M$$

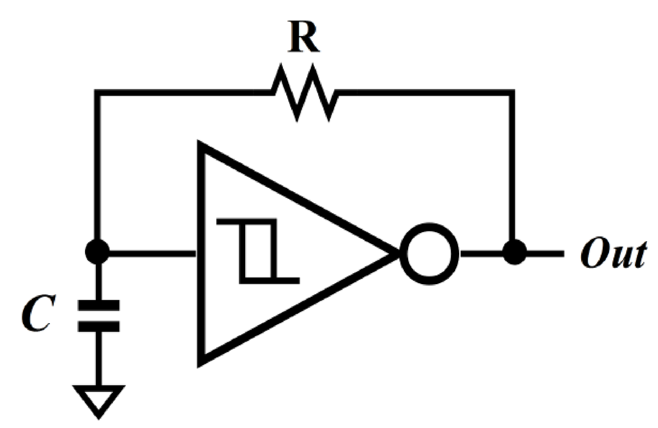
$$\frac{dx}{dt} = \begin{cases} \mu_v \frac{V_p}{D^2} e^{\frac{R_{on}}{V_p} I_M} & \text{if } V_M \geq V_p, \\ \mu_v \frac{V_n}{D^2} e^{\frac{R_{on}}{V_n} I_M} & \text{if } V_M \leq V_n, \\ \mu_v \frac{R_{on}}{D^2} I_M & \text{otherwise.} \end{cases}$$

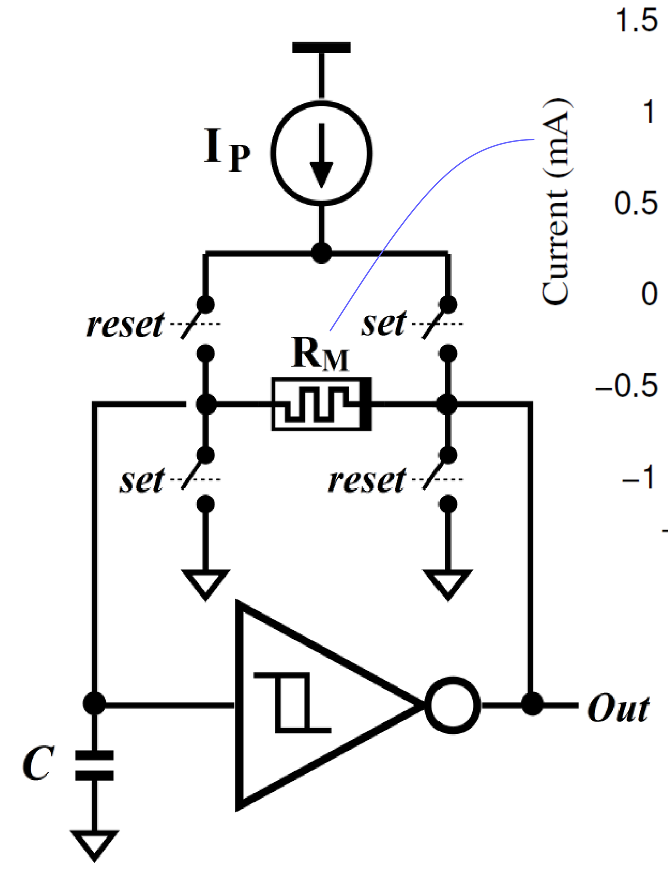
- Based on the coupled variable-resistor model
- Modified memristor dynamic according to an exponential dopant drift model
- The model is implemented in Verilog-A
- No hard-switching issue
- Circuit parameters are retained

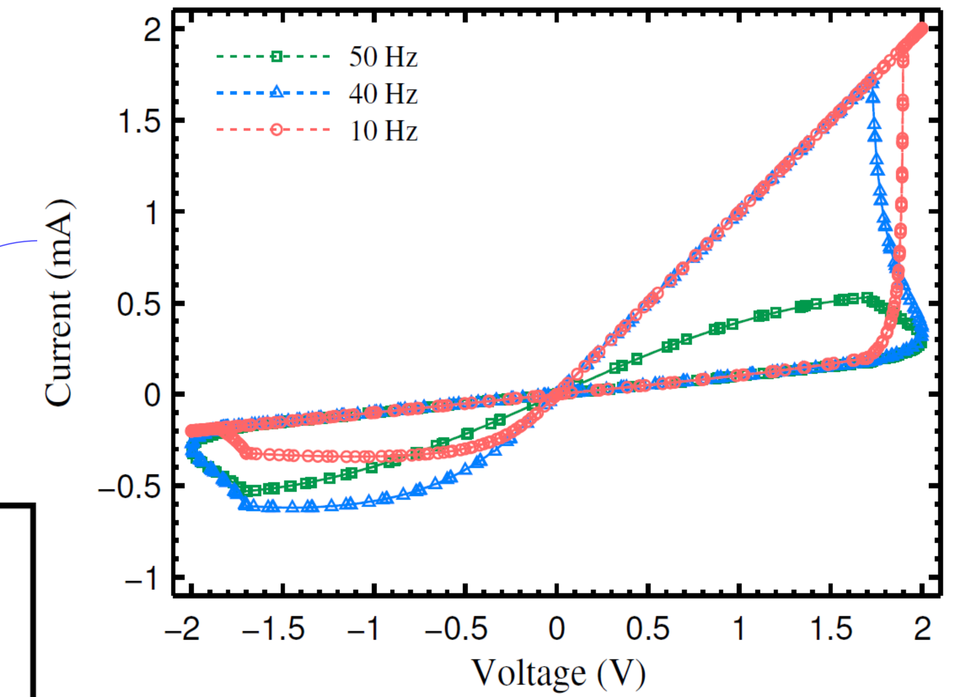
$$f_o = \frac{1}{t_1 + t_2}$$

$$t_1 = RC \cdot \ln\left|\frac{V_{SH}}{V_{SL}}\right|$$

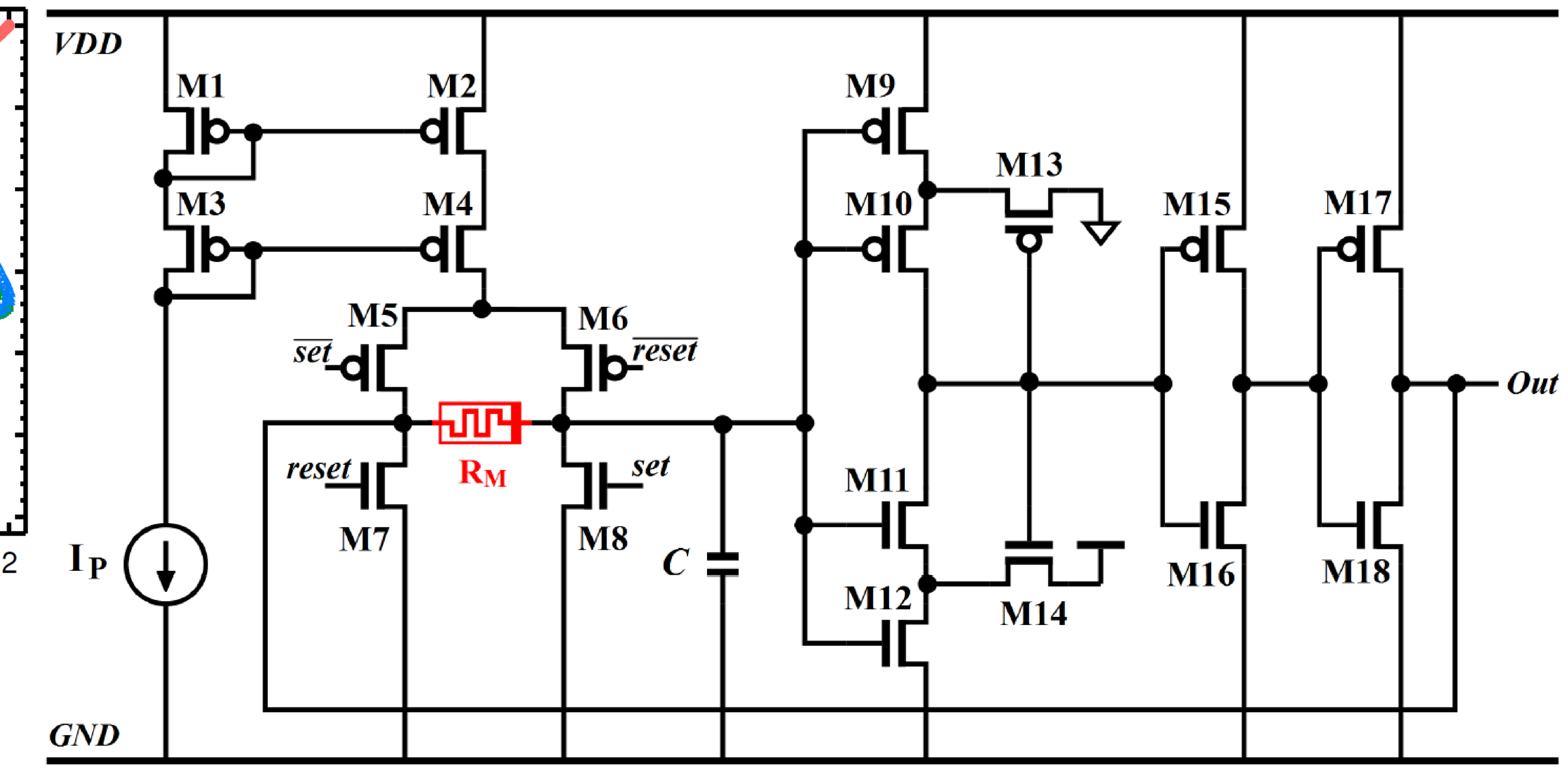
$$t_2 = RC \cdot \ln\left|\frac{V_{DD} - V_{SL}}{V_{DD} - V_{SH}}\right|$$







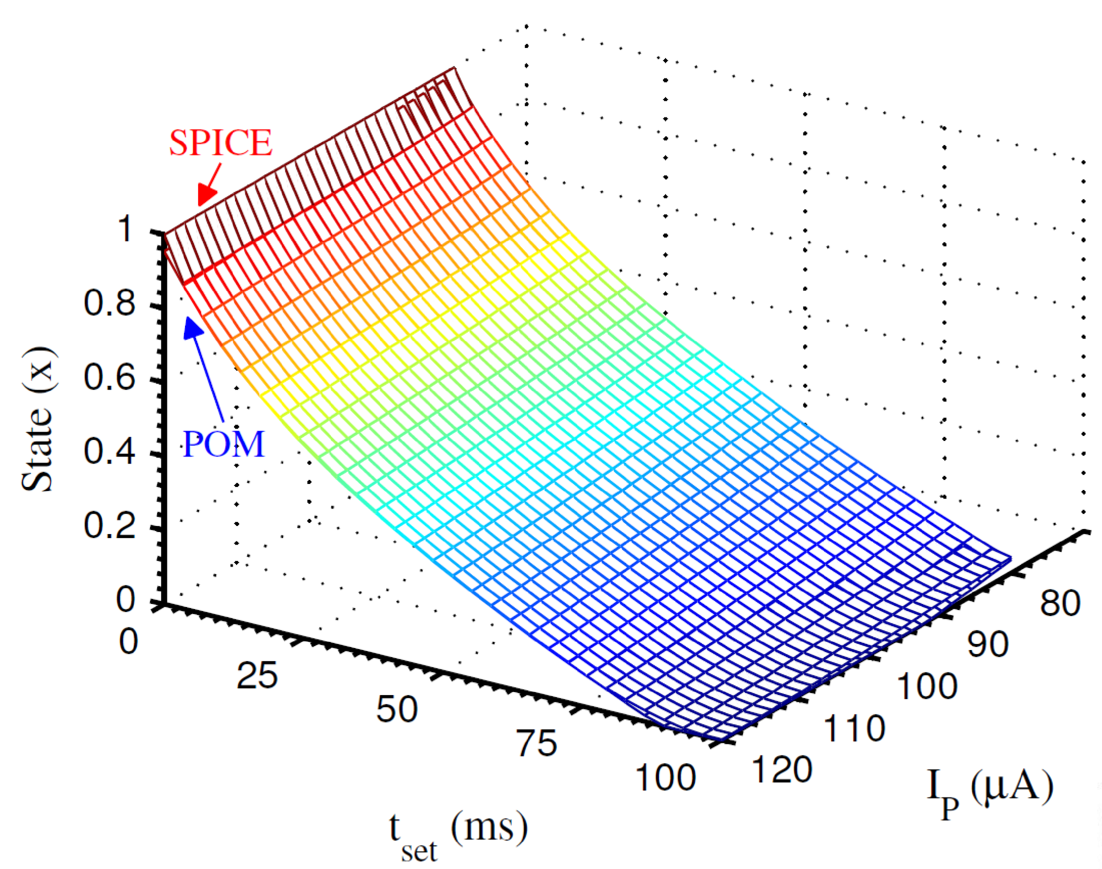
CMOS Realization



Polynomial Metamodeling

$$f_{POM}(\mathbf{v}) = \sum_{i=0}^{N_B-1} \beta_i \prod_{j=0}^{N_D-1} v_j^{p_{ij}}$$

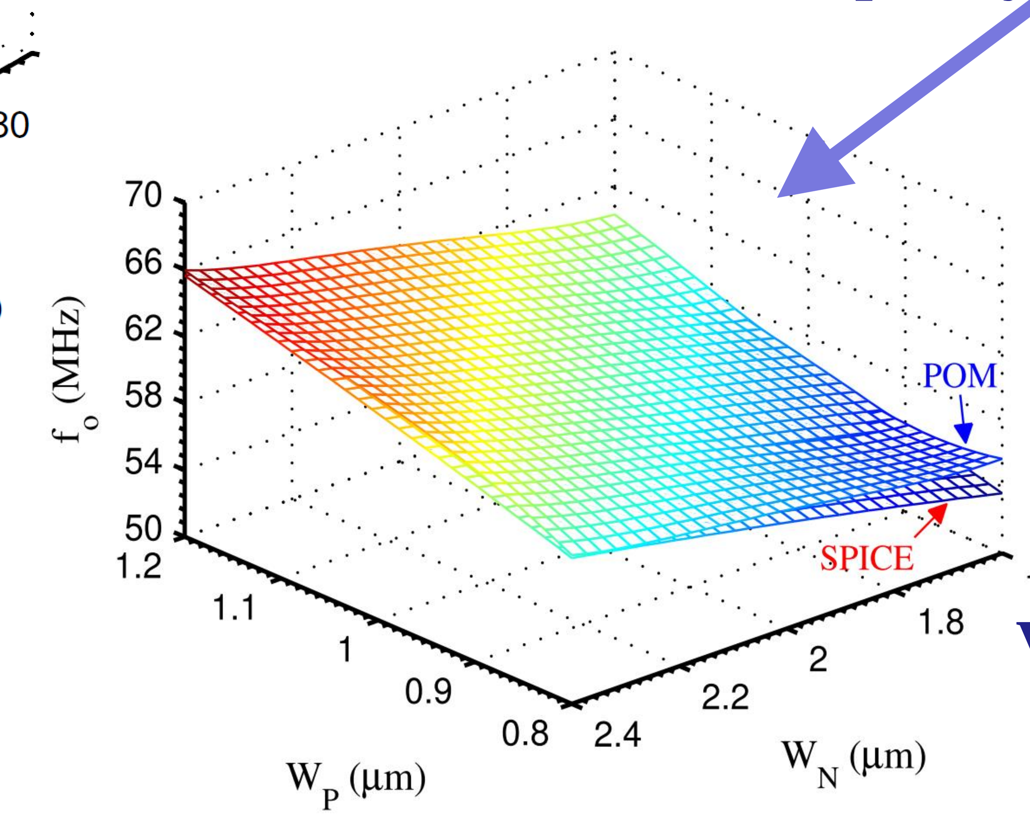
Memristor state



Verilog-AMS Integration

Verilog-AMS Module

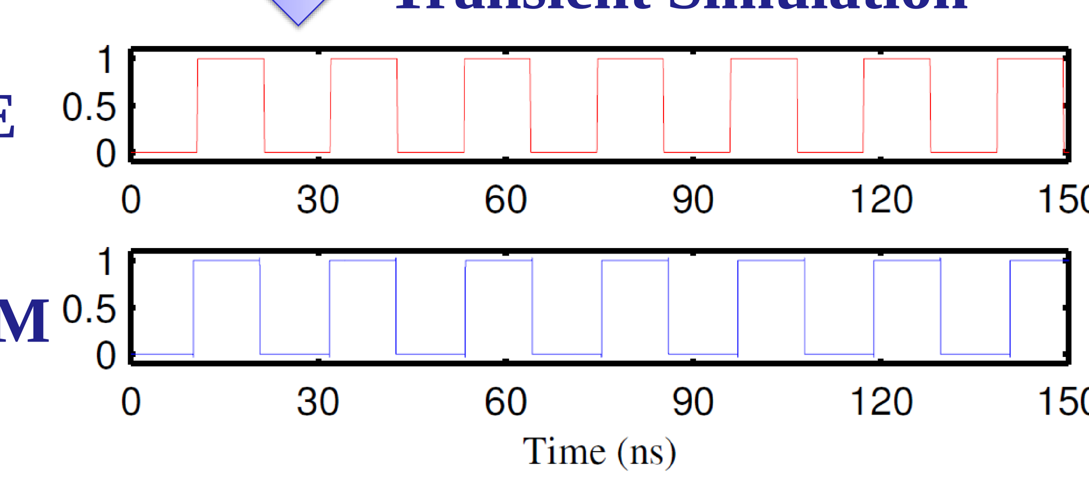
Oscillation frequency



Transient Simulation

SPICE

Verilog-AMS-POM



Oscillator Design

- Schmitt trigger oscillator topology is used
- Programmability is introduced by replacing the resistor with a memristor
- The design is realized in a 90 nm CMOS process with a 1-V supply

Polynomial Metamodeling

- Design Variables include transistor widths, Ron, Roff, etc.
- 2nd order polynomials
- Outputs are memristor state and oscillation frequency
- A 500-sample training set
- A 500-sample verification set

Verilog-AMS Integration

- Verilog-AMS-POM: the two polynomial metamodels are integrated into a Verilog-AMS module
- Verilog-AMS-POM vs SPICE: Over 30000× simulation speedups were observed

Conclusion

- The proposed memristor device model retains circuit parameters
- The polynomial metamodels created for the memristor based oscillator are accurate and efficient
- Verilog-AMS-POM drastically boosts the simulation speed.

DESIGN AUTOMATION CONFERENCE

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