

# Paper: Time-Dependent Nanoparticle Networks

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## 1. Introduction & Literature Review

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- **Background on Time-Independent Nanoparticle Networks:** Recap of equilibrated studies and static nonlinearity.
- **Neuromorphic-Computing Context:** Dynamical response, memory, fading-memory, kernel richness; examples from reservoir computing and spiking networks.
- **Gap & Objectives:** Need for quantitative dynamical characterization under time-varying drive; role of two-type disorder in tuning time scale, nonlinearity, and memory.

## 2. Model & Simulation Tool

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### 2.1. Network Geometry & Disorder

- 2D lattice with fixed inter-particle spacing.
- Two NP types: Diameter of a NP defined as  $d_i = N(\mu_{d_i}, \sigma_{d_i}^2)$ , with  $\mu_{d_i} \in \{d_1, d_2\}$  and  $\sigma_{d_i} = 0$  by default.
- Two Junction types: Resistance of a junctions defined as  $R_i = N(\mu_{R_i}, \sigma_{R_i}^2)$ , with  $\mu_{R_i} \in \{R_1, R_2\}$  and  $\sigma_{R_i} = 0$  by default.

### 2.2. KMC with Floating Output & Time-Dependent Boundaries

- Original KMC summary and modifications:
  - Floating output node.
  - Time-stepped boundary voltages for input and optional controls.
- Event rates and charge updates under time-dependent boundaries.

## 3. System Characterization

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### 3.1. Transient (Step) Response & Tunable Time Scales

- **Protocol:** Single voltage step, record NP and Output potentials.
- **Large Output Capacitance Study:**
  - Vary  $C_{ext} > C_{NP}$  to shift  $\tau$  into ms regime.
- **Metrics:** Exponential fits to extract  $\tau$ ; plots of  $\tau$  vs.  $C_{ext}$  and NP/junction types.

### 3.2. Frequency Response & Hammerstein Approximation

- **Protocol:** Sinusoidal sweep  $f_0$  from  $f_{min}$  to  $f_{max}$ .
- **Metrics:** Gain  $|H(f)|$ , phase  $\varphi(f)$ , quasi-static plateau and roll-off.
- **Modeling:** Fit to Hammerstein block model (static nonlinearity + linear filter).

### 3.3. Nonlinearity & Total Harmonic Distortion

- **Protocol:** Sinusoidal sweep  $f_0$  from  $f_{min}$  to  $f_{max}$ .
- **Metrics:** THD vs. frequency, and NP/junction configuration.

### 3.4. Memory Effects

- **Multi-Pulse Protocol:** Two step pulses separated by  $\Delta t$ ; quantify second-response attenuation.
- **Optional Noise Protocol:** White-noise drive; compute short-term memory kernel or autocorrelation decay.
- **Figure:** Memory metric vs.  $\Delta t$  and NP/junction configuration.

## 4. Parametric Control via Additional Electrodes

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- **8-Electrode Extension:** 1 input, 1 floating output, 6 fixed-bias controls.
- **Protocol:** At given  $f_0$  random control voltages or just varying two representative controls for heatmaps.
- **Studies:**
  - Control-bias effects on  $\tau$ .
  - Control-bias effects on THD/nonlinearity.

## 5. Conclusions & Outlook

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- Summary, Applications, Neuromorphic Computing context
- Key takeaways and directions for future work.

## Supplementary

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- **RC-Ladder Analogy:**
  - 1D NP string vs. classical RC ladder.
  - $\tau$  and  $|H(f)|$  comparisons.
- **Raw output traces and model-fit residuals.**