Noise on Resistive Switching: a Fokker-Planck Approach

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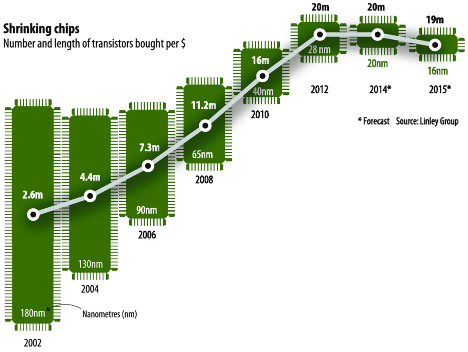
Motivations

- Higher circuit densities lead to smaller signal-to-noise ratios
- There is a prominent role of noise in electronic circuits



But noise... might not be harmful, after all

- Stochastic resonance
- Dithering
- Synchronization
- ...

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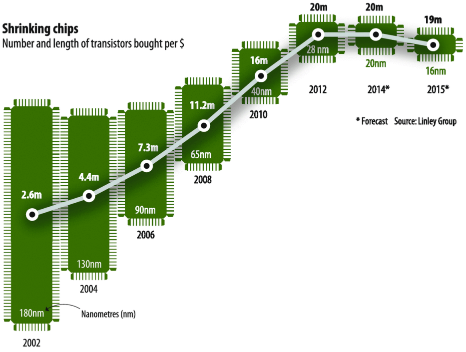

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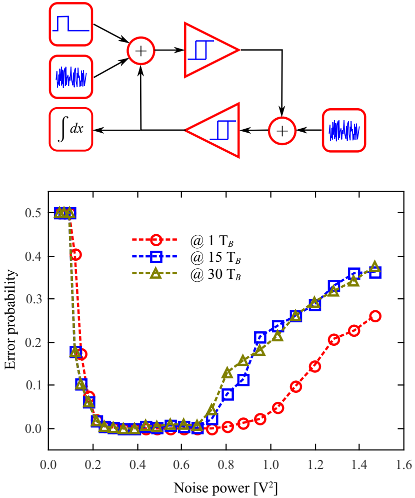
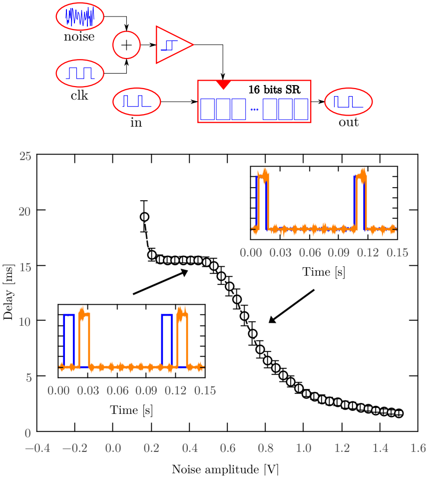
Storage and transmission assisted by noise



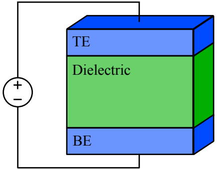
[Patterson *et al.* Physica A, 2010]

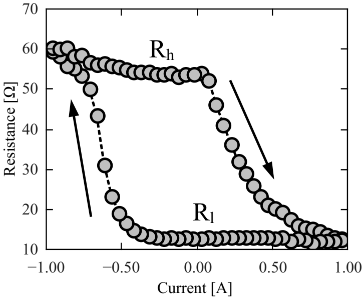


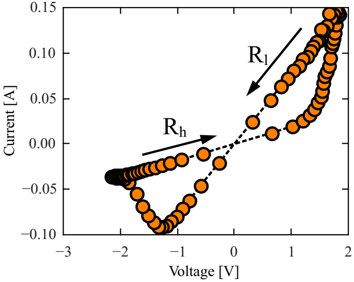
[Pessacg *et al.* CNSNS, 2015]

Resistive Switching

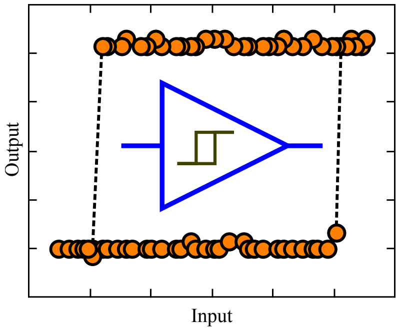
- Change of resistance under the action of an external field
- First reported in 1962 by Hickmott
- Binary oxides, transition metal oxides, organic materials, *etc.*
- Potential application of RS in the area of non-volatile memories

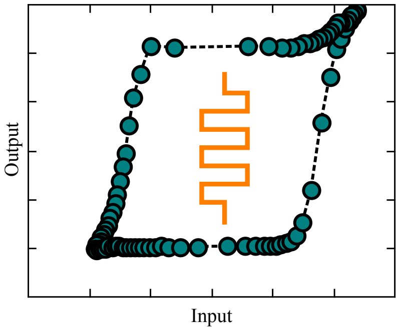






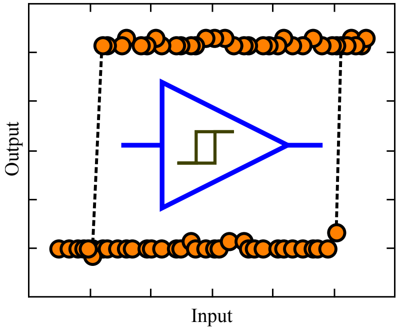
Motivation: Hysteretic device

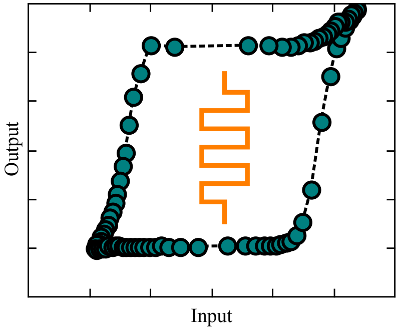




What is the role of noise in such a system?

Motivation: Hysteretic device





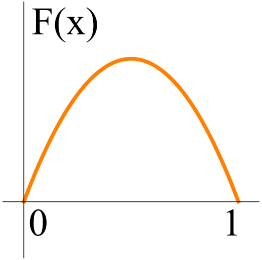
What is the role of noise in such a system?

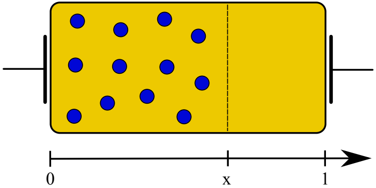
Numerical model

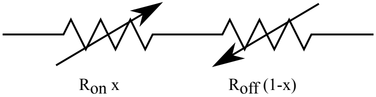
$$v(t) = R(x)i(t)$$

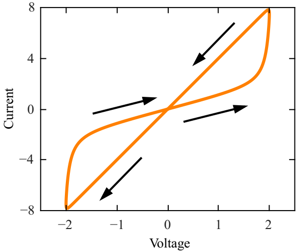
$$\frac{dx}{dt} = F(x)i(t)$$

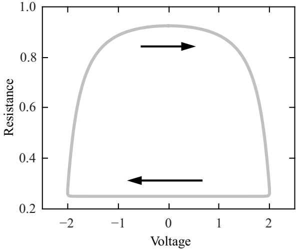
$$R(x) = (1 - \delta R\, x)$$











[Strukov *et al*. Nature, 2008]

Noise in resistive switching

PHYSICAL REVIEW E **85**, 011116 (2012)

Stochastic memory: Memory enhancement due to noise

Alexander Stotland and Massimiliano Di Ventra
Department of Physics, University of California–San Diego, La Jolla, California 92093-0319, USA
(Received 25 April 2011; revised manuscript received 2 October 2011; published 10 January 2012)

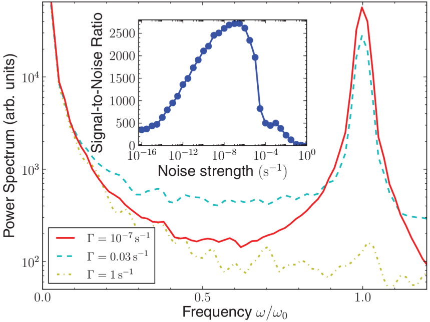
There are certain classes of resistors, capacitors, and inductors that, when subject to a periodic input of appropriate frequency, develop hysteresis loops in their characteristic response. Here we show that the hysteresis of such memory elements can also be induced by white noise of appropriate intensity even at very low frequencies of the external driving field. We illustrate this phenomenon using a physical model of memory resistor realized by TiO_2 thin films sandwiched between metallic electrodes and discuss under which conditions this effect can be observed experimentally. We also discuss its implications on existing memory systems described in the literature and the role of colored noise.

DOI: 10.1103/PhysRevE.85.011116 PACS number(s): 02.50.Ey, 05.40.Ca, 73.23.−b, 85.40.Qx

Internal noise

$$\frac{dx}{dt} = F(x)i(t) + \eta(t)$$

$$\langle \eta(t)\eta(t')\rangle = \Gamma\delta(t-t')$$



Fokker-Planck equation

Langevin: Stochastic differential equation

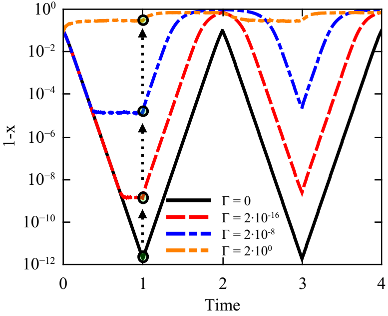
$$dx = F(x)\, i(t)\, dt + \sqrt{\Gamma} dw$$

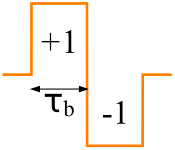
F-P: Partial differential equation

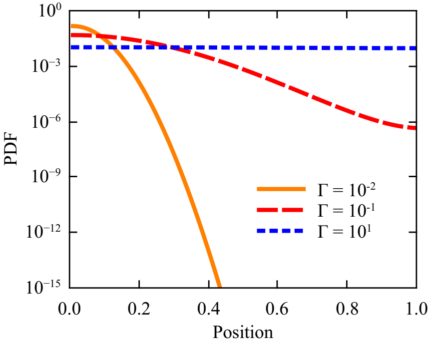
$$\frac{\partial}{\partial t} p(x,t) = -\frac{\partial}{\partial x} \{F(x)\, i(t)\, p(x,t)\} + \frac{\Gamma}{2} \frac{\partial^2}{\partial x^2} p(x,t)$$

- w: Wiener process
- $F(x)\, i(t)$: drift coefficient
- $\sqrt{\Gamma}$: diffusion coefficient

Results: Influence of internal noise







$$P_s(x) \propto \exp\left\{ \frac{2}{\Gamma} \int_x v(\tau_b) \frac{F(y)}{R(y)} dy \right\}$$

As Γ increases the PDF broadens

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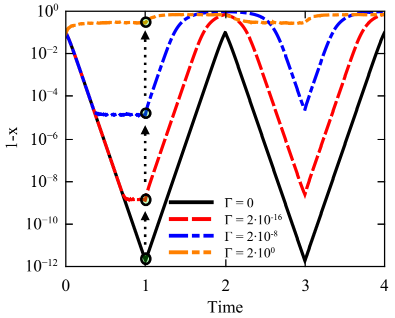

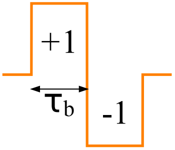

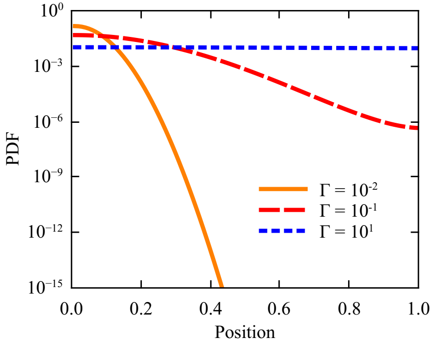

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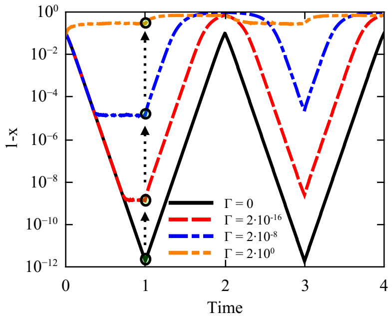
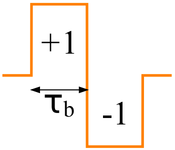
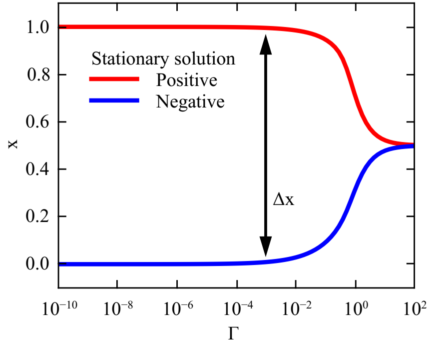


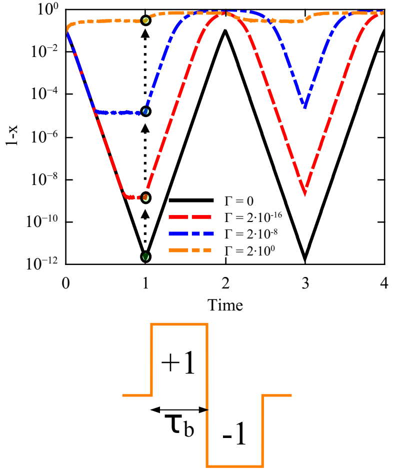


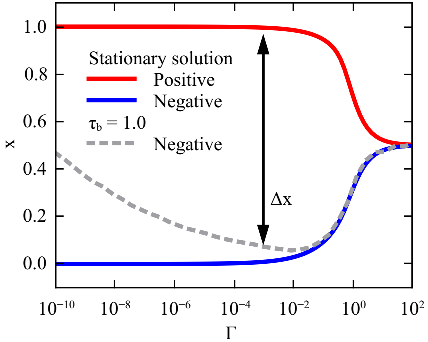


$$\Delta R \propto \Delta x$$

The stationary solution is not reached for every τ_b

Results: Influence of internal noise





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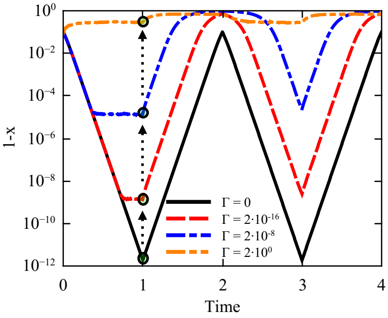
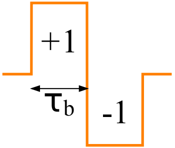
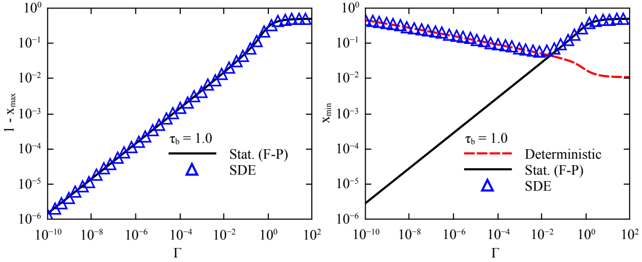
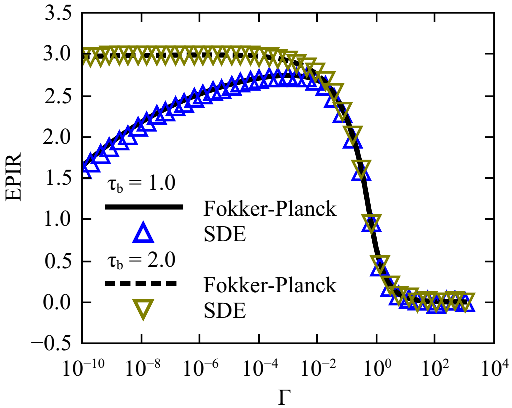






- **Low noise amplitude** → Deterministic evolution
- **High noise amplitude** → Evolution constrained by noise

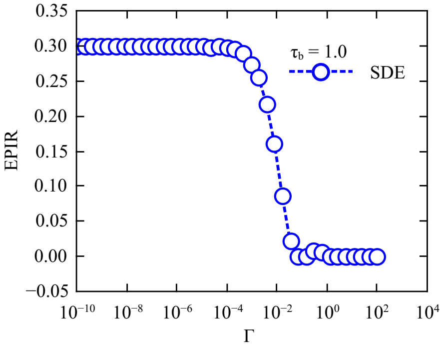
Results: EPIR



$$\text{EPIR} = \frac{R_h - R_l}{R_l}$$

- Internal noise enhances the EPIR ratio for a given initial condition and pulsewidth
- Good agreement between SDE & the F-P approach

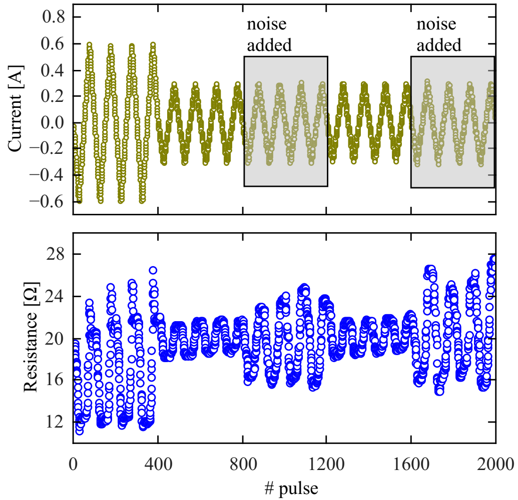
Results: Influence of external noise

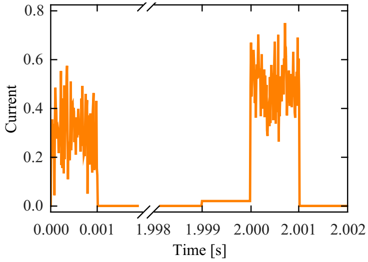


$$\frac{dx}{dt} = \frac{F(x)}{R(x)}\left(v(t) + \eta(t)\right)$$

- External noise only has the effect of degrading the EPIR ratio
- Same results with the Fokker-Planck approach... (see **UPON2015** extended abstract)

But... experimental results





External noise **does** enhance the resistive contrast!

[Patterson *et al.* PRE, 2013]

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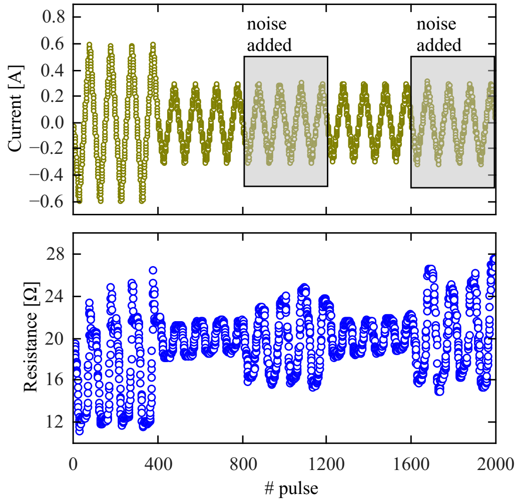

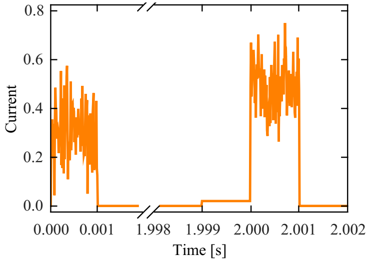

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Conclusions & open questions

Conclusions

- Internal noise enhances the contrast between resistive states in a non-harmonic signal
- We introduced a Fokker-Planck approach to study the effect of internal noise
- We provide an alternative explanation by means of this approach
- We found that external noise has only the effect of degrading the resistive contrast

UPON question: What is the role of external noise in RS?

Does it

- enhance ion migration?
- promote conductive filaments creation?

Thank you for your kind attention!