Noise effects on time delay reservoir computing using a single silicon microring resonator as real node

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Abstract

Time delay reservoir computing has gained considerable interest in recent years thanks to the hardware simplicity it requires. Instead of having several spatial nonlinear nodes connected, the reservoir nodes are time-multiplexed in the response of only one nonlinear node. In this work, we investigate time-delay reservoir computing in silicon photonics using a matrix of nonlinear nodes. In particular, we are studying the nonlinearity triggered by two-photon absorption in high-quality factor microring resonators (MRRs). Here we show that the nonlinearity of only one MRR exploited for computation makes the system more robust against noise.

Computing concept and architecture

- Numerical modelling of a single microring resonator subject to feedback as a real node.

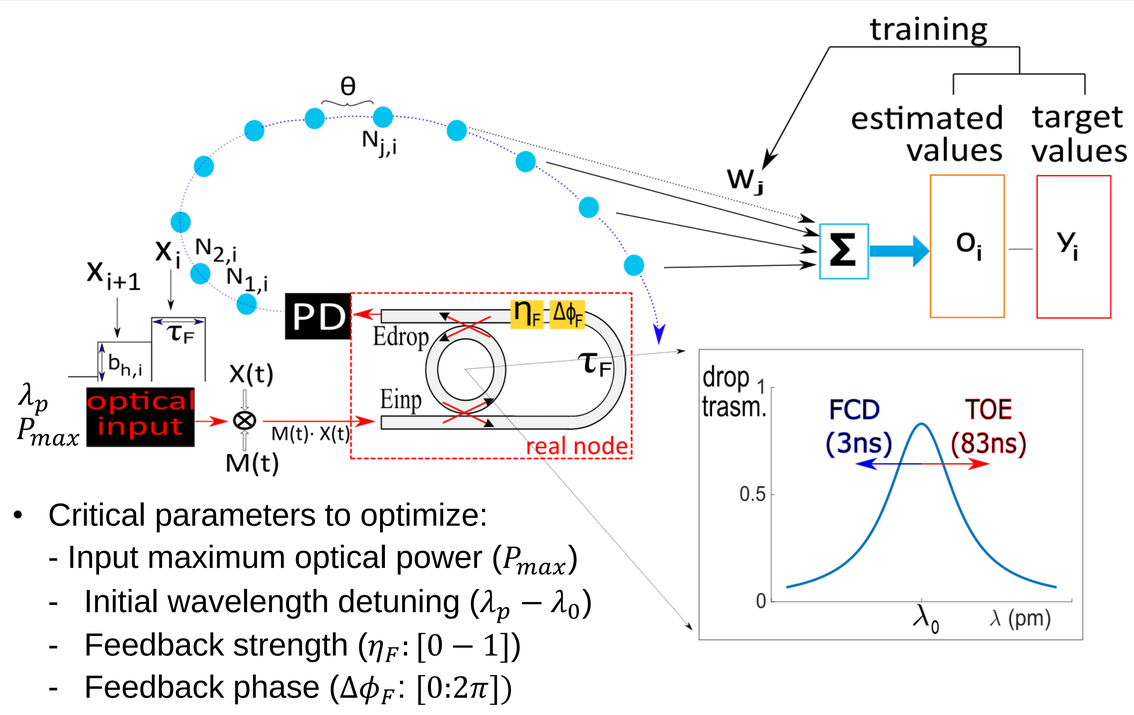
Principal properties:

- Recurrent neural network with fixed topology and connection strengths.
- Input nonlinear mapping into a higher dimensional space.
- Training applied only to the output weights.

Ingredients:

- Input time multiplexing.
- Mask signal (eventually needed to drive the real node in a transient dynamics).
- Nonlinear dynamics of one single node as a complex system (real node).
- Resevoir nodes time multiplexed in the real node response (‘virtual’).

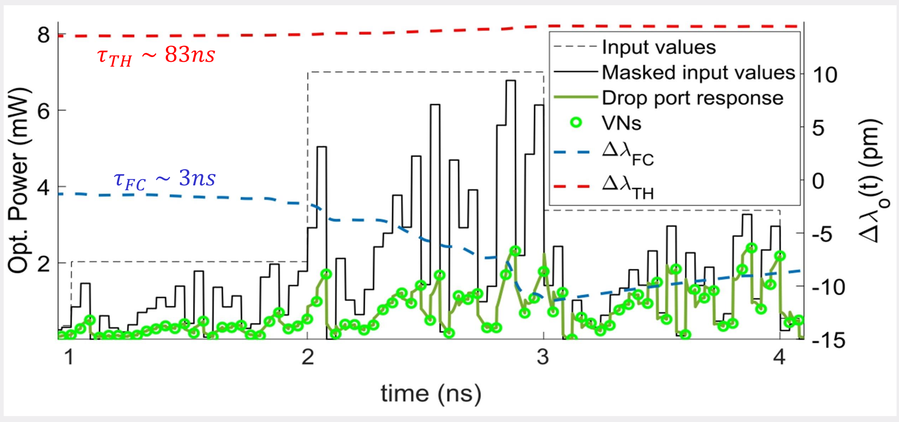
- Real node: Silicon MRR subject to optical feedback
- Nonlinearity exploited for computation:
  - Photodetection (PD) square law
  - MRR free carrier nonlinearity ($\tau_{FC} \approx 3ns$)
- Optical time-multiplexed input: X(t)
- Mask signal: M(t) ($\theta \approx 40ps$)
- MRR optical output: E_{drop}
- ● : sampled virtual nodes
- Network output: $o_i = \sum_i (W_j\, N_{j,i})$



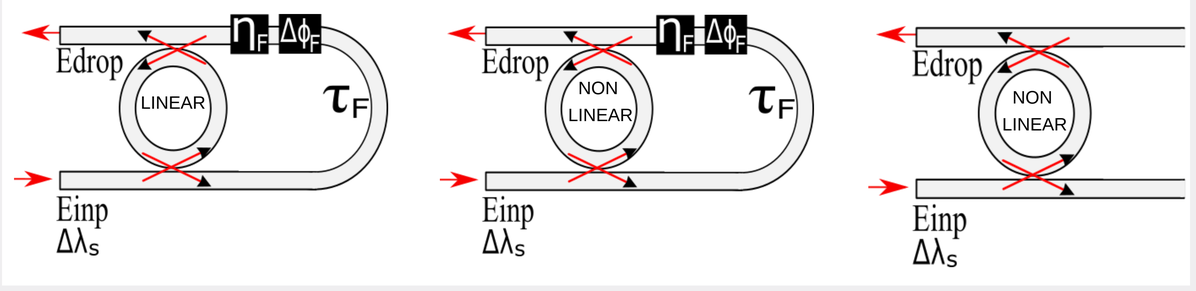
- Critical parameters to optimize:
  - Input maximum optical power (P_{max})
  - Initial wavelength detuning ($\lambda_p - \lambda_0$)
  - Feedback strength (η_F: $[0-1]$)
  - Feedback phase ($\Delta\phi_F$: $[0{:}2\pi]$)

Dynamics example

- By selecting $\tau_F \approx \tau_{FC}$, it’s possible to exploit the free carrier nonlinearity ($\Delta\lambda_{FC}$).
- Thermal nonlinear effects ($\Delta\lambda_{TH}$) are too slow compared to the optical input coding and do not contribute to the nonlinear transformation



Processing schemes

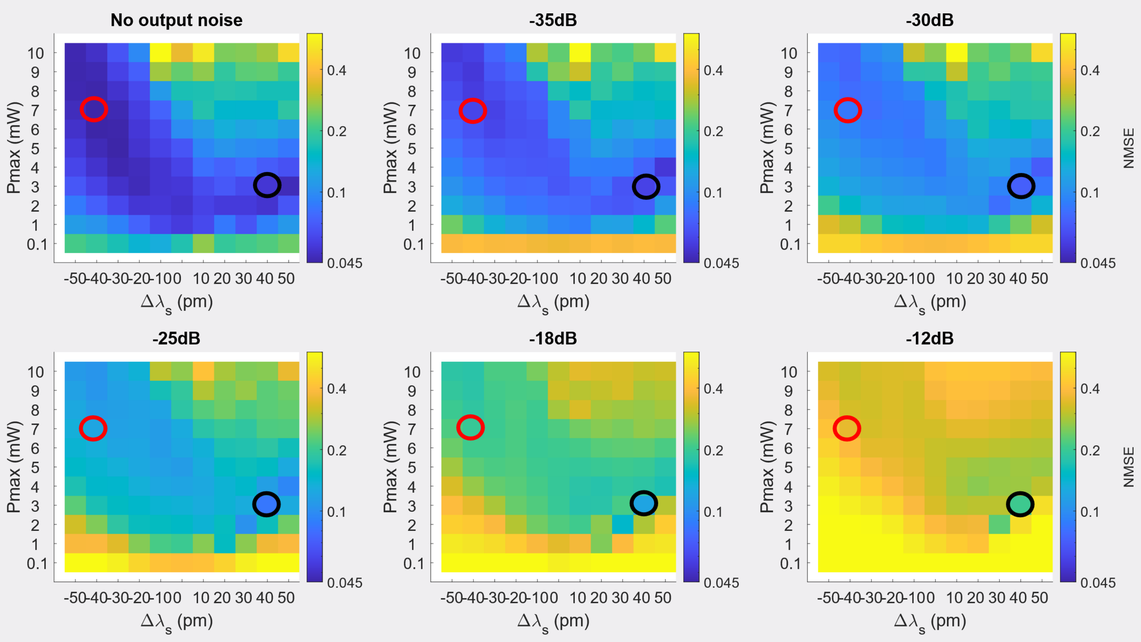


Linear memory capacity maximization.
Nonlinearity: photodetection

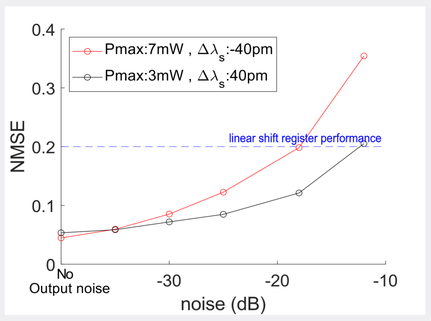
It exploits both the photodetection and the MRR free carrier nonlinearities.

MRR nonlinearity also exploited as source of nonlinear memory for the system.

Santa Fe time benchmark task vs output noise

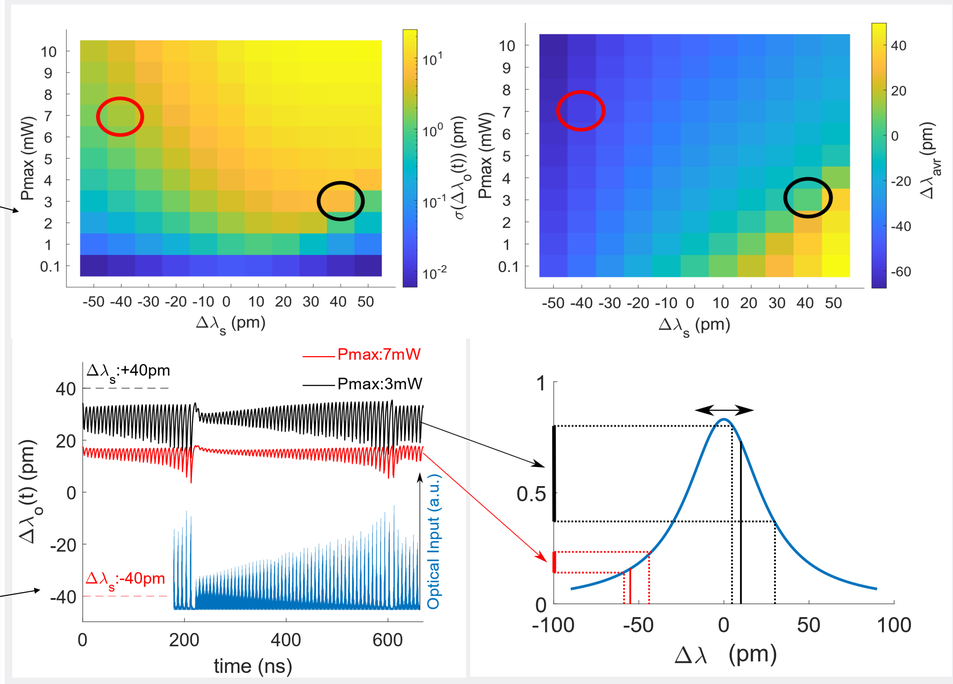


- Prediction task: $y_i = x_{i+1}$
- Gaussian white noise applied at the drop signal.
- Noise does not influence the MRR dynamics.



- Different robustness against noise

Exploited MRR nonlinearity



Discussion

- Three processing schemes appear available to better try to solve a task, which can include the feedback line and the MRR nonlinearity or not.
- Both the MRR and the feedback are memory sources of the system. The Santa Fe benchmark task is an example of memory demanding task where only the MRR free carrier nonlinear memory is sufficient for computation.
- Configurations exploiting (consistently) more the MRR free carrier nonlinearity are more robust against noise applied at the detected output signal.

References

W. Mass et al, ‘Real-time computing without stable states: a new framework for neural computation based on perturbations,’ Neural Comp.14 (11), 2531 (2002)
L. Appeltant et al, ‘Information processing using a single dynamical node as complex system,’ Nat. Commun 2 (1), 468 (2011)
G. Donati et al, ‘Microring resonators with external optical feedback for time delay reservoir computing,’ Opt. Express 30 (1), 522 (2022)