Experimental control of laser optical spikes via direct current modulation

C Quintero-Quiroz[1], Taciano Sorrentino[1], Andrés Aragoneses[1],
J Garcia-Ojalvo[2], M. C. Torrent[1], Cristina Masoller[1].

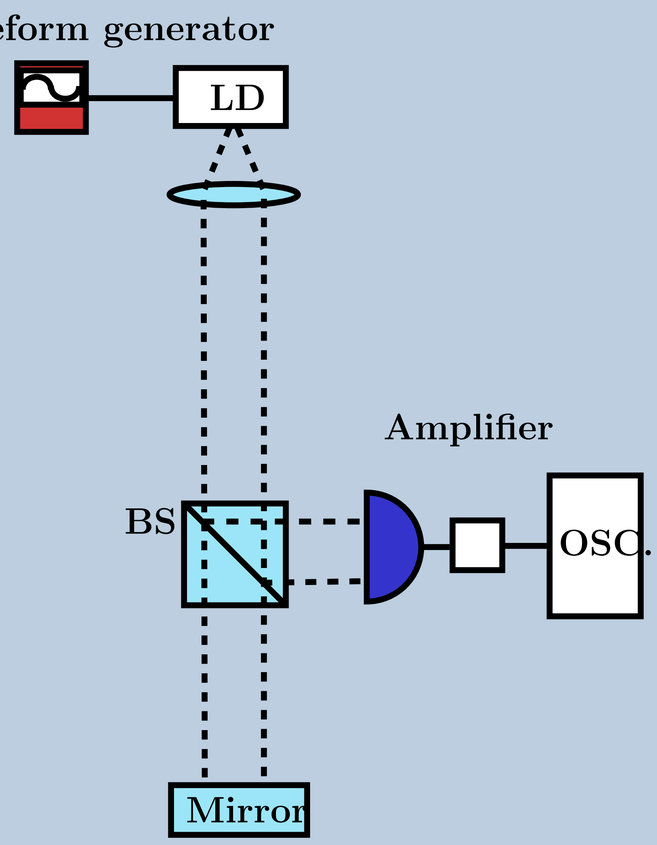
[1]Departament de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya, Colom 11, Terrassa, 08222 Barcelona, Spain

[2]Department of Experimental and Health Sciences, Universitat Pompeu Fabra, 08003 Barcelona, Spain

Abstract

We study experimentally the symbolic dynamics of a stochastic excitable optical system with external periodic forcing. Specifically, we consider a semiconductor laser with direct current modulation which operates in the low-frequency fluctuations (LFFs) regime induced by self time-delayed optical feedback.
In this regime the laser intensity displays sudden and apparently stochastic dropouts that resemble neuronal spikes. We analyze experimentally recorded time-series of intensity dropouts using a symbolic method that allows to uncover serial correlations in the dropout sequence [1, 2]. By converting the sequence of inter-dropout intervals in a sequence of symbolic ordinal patterns [3], we analyze the symbolic language of the laser in a three-dimensional parameter space defined by the pump current dc value, the modulation amplitude and the modulation frequency. We aim at identifying clear transitions to an entrained dynamics that is controlled by the external forcing.

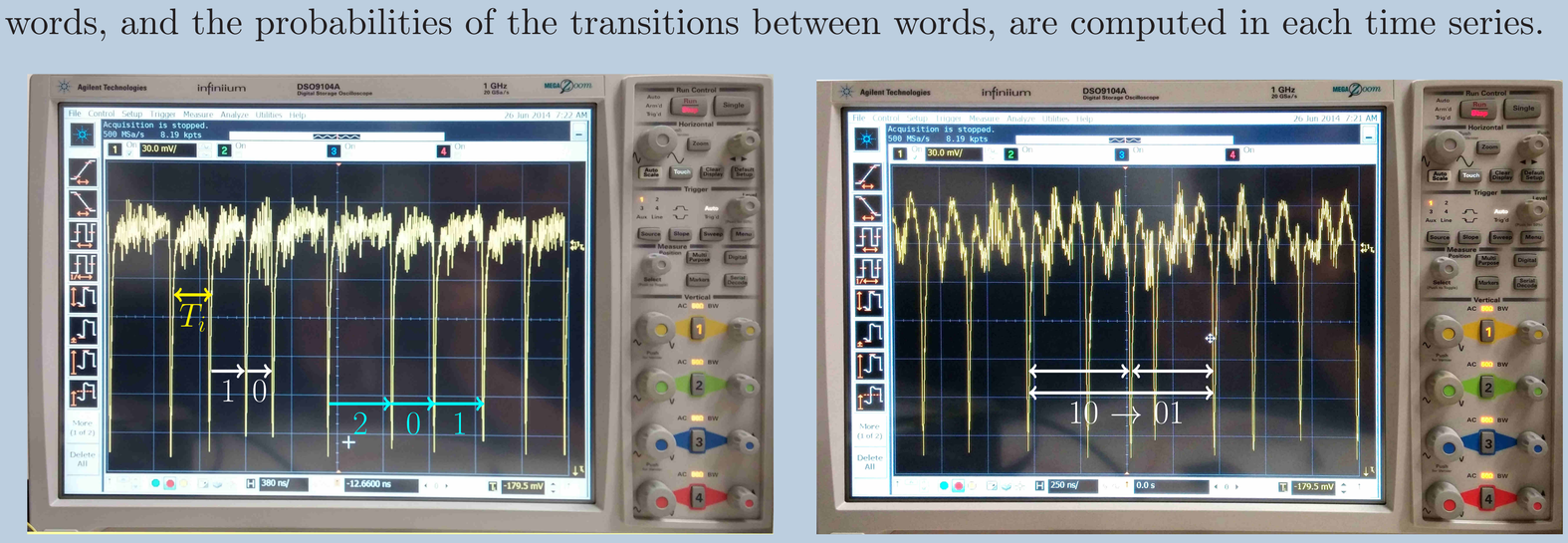
Experimental Setup



Experimental setup for 650 nm laser (SONY SLD1137VS). LD stands for laser diode, BS for a (50/50) beamsplitter and OSC for oscilloscope. 7% threshold reduction. Time delay $\sim$ 5ns.

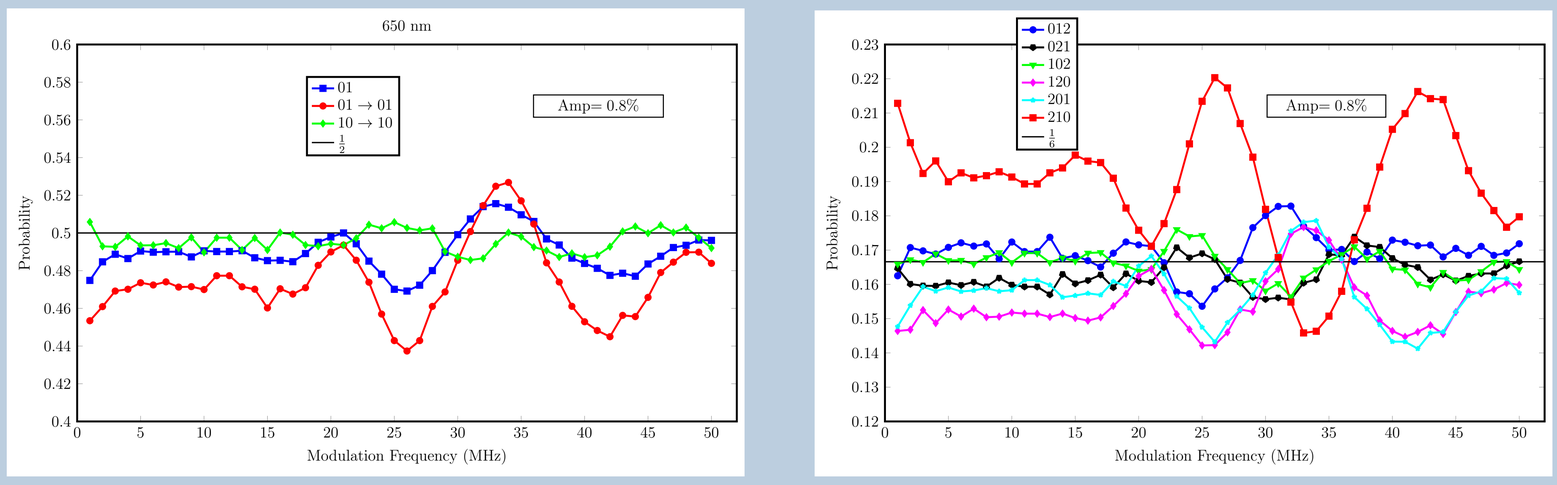
Ordinal Analysis Method

The experimental sequences of inter-dropout intervals (IDIs) are analyzed by means of ordinal analysis [3], in which the IDI sequence is transformed into a sequence of ordinal patterns (OPs), also referred to as words. Words of length D are defined by considering the relative length of D consecutive IDIs.
For $D = 2$ there are two OPs: $\Delta T_i < \Delta T_i + 1$ gives word 01 and $\Delta T_i > \Delta T_{i+1}$ gives word 10; for $D = 3$ there are six OPs: $\Delta T_i < \Delta T_{i+1} < \Delta T_{i+2}$ gives
012, $\Delta T_{i+2} < \Delta T_{i+1} < \Delta T_i$ gives 210, etc.
The words are formed by consecutive nonsuperposing IDIs. Then, the probabilities of the different words, and the probabilities of the transitions between words, are computed in each time series.

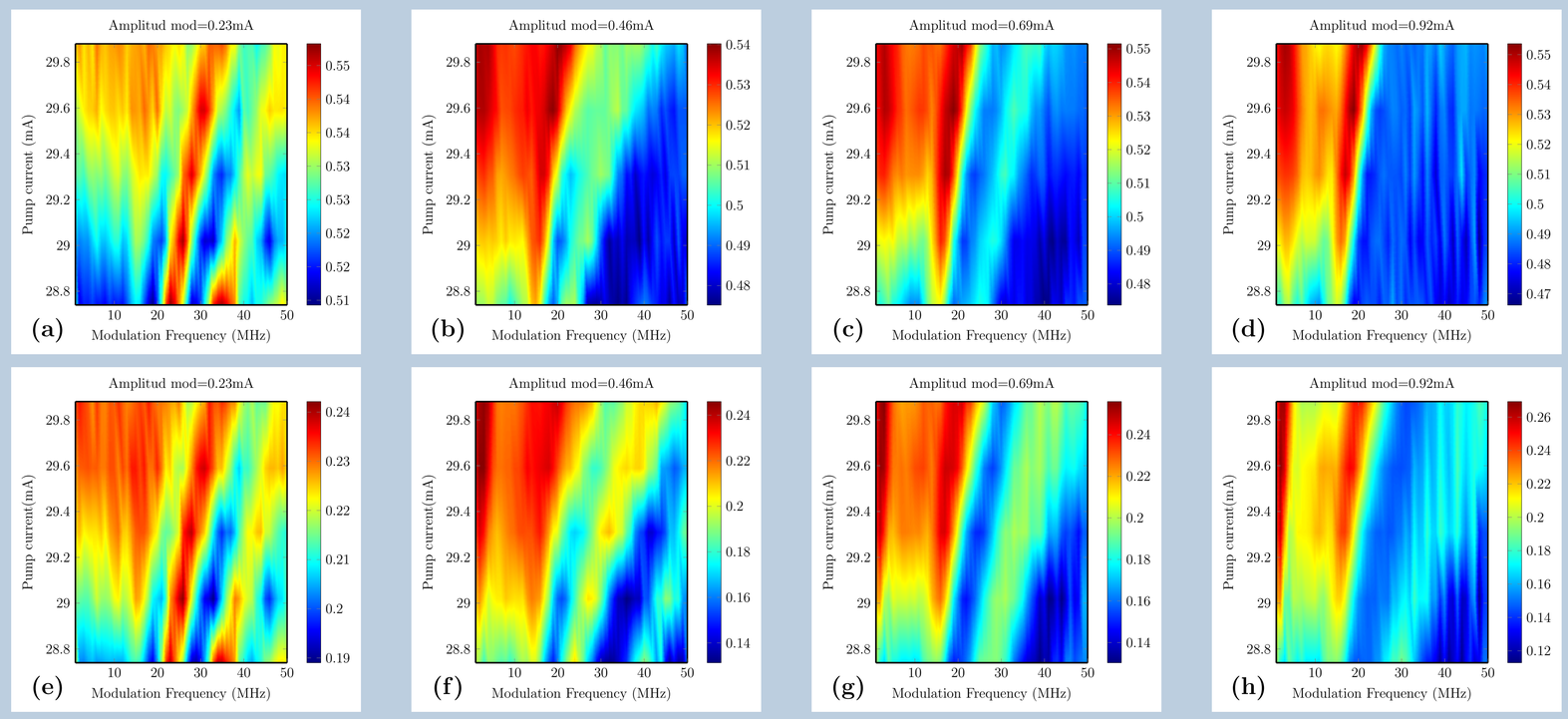


Examples of words for D=2 and D=3 (left).Transition between the words "10" and "01" (right).

Results



Word probabilities and transition probabilities for D=2 (left) and word probabilities for D=3 (right), for varying modulation frequency. The dc value of the pump current and the modulation amplitude are 28.74mA and 11.50mA respectively.



Probability of the word "10" for D=2 (a-d) and probability of the word "210" for D=3 (e-h), varying the pump current dc value and the modulation frequency, each frame is for a fixed modulation amplitude.

Conclusions

We have presented a preliminar analysis of the symbolic dynamics of modulated LFFs and we have detected clear transitions in the probabilities of the symbolic patterns which are induced either by the variation of the modulation frequency or by the variation of the laser pump current (which in turn varies the natural frequency of the optical spikes). These transitions could be related to different locking regions.

References

[1] Andrés Aragoneses, Nicolás Rubido, Jordi Tiana-Alsina, M. C. Torrent and Cristina Masoller, *Sci. Rep.* **3**, (2014).

[2] Andrés Aragoneses, Taciano Sorrentino, Sandro Perrone, Daniel J. Gauthier, M. C. Torrent, Cristina Masoller, *Opt. Express* **22**, 4705 (2014).

[3] Christoph Bandt, Bernd Pompe. *Phys. Rev. Lett.* **88**, 174102 (2002)

Acknowledgements

Supported by the European Commission through the FP7 Marie Curie Initial Training Network 289146, NETT: Neural Engineering Transformative Technologies.