Stochastic Resonance with an Integrated Nano-Electro-Mechanical Photonic Crystal Membrane

Avishek CHOWDHURY[1], Sylvain BARBAY[1], Marcel CLERC[2], Isabelle ROBERT-PHILIP[1], Rémy BRAIVE[1,3*]

[1] Centre de Nanosciences et de Nanotechnologies, CNRS, Univ. Paris-Sud, Université Paris-Saclay, C2N Marcoussis, 91460 Marcoussis, France

[2] Departamento de Fısica, Facultad de Ciencias F´ısicas y Matem´aticas, Universidad de Chile, Casilla 487-3, Santiago, Chile

[3] Université Paris Diderot, Sorbonne Paris Cité, 75207 Paris Cedex 13, France

[*] remy.braive@lpn.cnrs.fr

In a large number of experiments or devices, noise is usually viewed as an undesirable disturbance, hindering the measurement sensitivity or device performances. In some circumstances however, noise-induced phenomena can help, as in the case of stochastic resonance whereby a weak coherent signal, compared to the barrier height of a double-well potential, gets amplified resonantly by application of external noise. Stochastic resonance occurs in a wide class of nonlinear systems, in neurobiology [1], mesoscopic physics [2], photonics [3], atomic physics [4], mechanics [5, 6]...

If a weak periodic forcing is applied to the oscillator, the initially symmetrical double-well potential gets tilted asymmetrically up and down, periodically raising and lowering the potential barrier. Although the periodic forcing is too weak to let the membrane switch periodically from one potential well into the other one, noise-induced hopping between the potential wells can become synchronized with the weak period forcing. This time coincidence takes place when the average waiting time between noise-induced interwell transitions is comparable with half the period of the periodic forcing. Thus stochastic resonance corresponds to the noise-assisted amplification of a weak coherent input that is too feeble to induce hopping between the two stable states.

It has been mainly reported in non-linear systems driven by a coherent signal together with an additive noise, more scarcely a multiplicative noise. We report here on stochastic resonance in a bistable device with the assistance of such a non-linear noise.

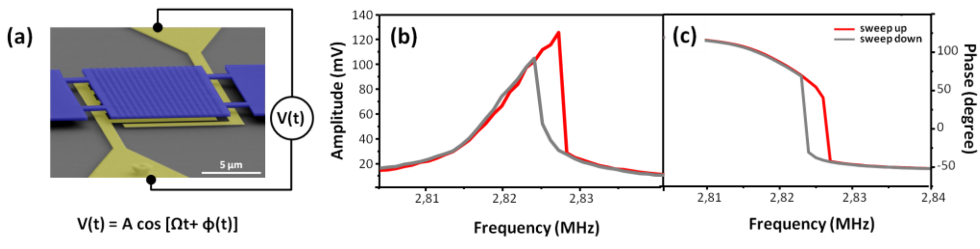

Fig. 1. (a) S.E.M. image of the suspended photonic crystal membrane (in blue) above the interdigitated electrodes (in yellow). By applying an AC voltage V(t), the amplitude (b) and the phase (c) are recorded across the fundamental mechanical resonance of the photonic crystal oscillator by sweeping the driving frequency Ω up and down. Thus a bistable region is observable.

Our mechanical resonator consists of an InP suspended membrane with a thickness of about 260 nm and a 10×20µm² surface (Fig. 1a). Holes are drilled on in the membrane to perform a perfect photonic crystal used as a reflector at normal incidence for the probe laser. A coherent weak signal is introduced by applying a modulated electrostatic force on the membrane and driving its out-of-plane motion. This force is generated by applying an AC-bias at the frequency inside the hysteresis region (Fig. 1b-c), on integrated interdigitated electrodes placed underneath the membrane at a distance of

about 400 nm (Fig. 1a). In the same manner, phase noise is added on the AC applied voltage, which is proportional to the actuation force. Last, the mechanical response of the membrane is probed optically in an interferometric testbed, in which the membrane is used as one of the end mirrors. With an actuation strong enough, the oscillator can enter in a non-linear regime and exhibits bistability (Fig. 1b-c).
In order to match the time coincidence conditions, an in-depth characterization of these time-scales is performed on the device.

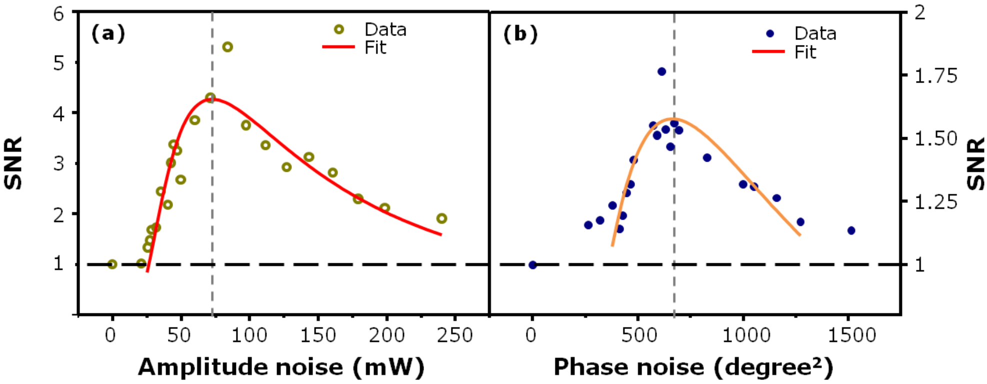

Fig. 2: Signal to Noise Ration (SNR) normalized with respect to no noise intentionally induced either in amplitude (a) or in phase (b)

Thus, we were able to demonstrate stochastic resonance with phase noise in a non-linear oscillator, consisting of a nano-electromechanical device with an amplification of a factor 1.75. In addition to that and thanks to numerical simulations, we show that phase noise has to be taken into account as a multiplicative noise to reproduce experimental results. At the same time, pure amplitude noise stochastic resonance has also been investigated and could simply be understood with additive noise. To enhance amplification with phase, alignment of the modulation along the preferential path between the two states in the potential could be a solution.
Such stochastic resonance obtained by assistance of phase noise may enable various noise-aided applications, including signal transmission telecommunication with intensively used Phase Key Shifting protocol, or metrology with improved detection in noise-floor limited systems.

References

[1] S. Bezrukov and I. Vodyanoy, *Noise-induced enhancement of signal transduction across voltage-dependent ion channels*, Nature vol. 378, pp. 362-364, 1995

[2] A. Hibbs *et al*, *Stochastic resonance in a superconducting loop with a Josephson junction*, J. Appl. Phys. vol. 77, pp. 2582, 1995

[3] S. Barbay, G. Giacomelli and F. Marin, *Stochastic resonance in vertical cavity surface emitting lasers*, Phys. Rev. E, vol. 61, pp. 157, 2000

[4] D. Wilkowski *et al*, *Instabilities in a magneto-optical trap: Noise-induced dynamics in an atomic system*, Phys. Rev. Lett. vol. 85, pp. 1839, 2000

[5] F. Mueller *et al*, *Optomechanical stochastic resonance in a macroscopic torsion oscillator*, Phys. Rev. A vol. 79, pp. 031804, 2009

[6] W. Venstra et al, *Stochastic switching of cantilever motion*, Nat. Comm. vol. 4, pp. 2624, 2013