Parametric Amplification and Stochastic Resonance in Bio-Inspired Hair Flow Sensors

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Inspired by crickets and its perception for flow phenomena (figure 1), artificial hair flow sensors have been developed successfully in our group [1]. The realization of array structures and improvement of fabrication methodologies have led to better performance, making it possible to detect and measure flow velocities (illustrated in figure 2) in the range of sub-mm/s [2]. To improve the performance of these artificial hair flow sensors even further, we will make use of non-linear effects. In nature a wide range of such effects exist (filtering, parametric amplification, etc.) and can give a rise in sensitivity, dynamic range and selectivity.

Parametric amplification is one of these effects and can be considered as adaptation of the sensor performance. By controlling the mechanical properties of the hair sensory system in time, a non-linear dynamical system can be obtained. Such a non-linear system can be configured in such a way, that one improves the performance of the system. Carr et al. [3] showed that with the right choice of parameters the input is amplified by the system compared to the case without parametric amplification. Generally, with a well-defined configuration one can achieve filtering and selective gain of the system. In our case we will modulate the torsional spring stiffness of the system in time (see figure 3b), and with the appropriate pump amplitude, frequency and phase we are able to improve the gain of the flow velocity input signal, which is confirmed by numerical analysis (see figure 3a).

Another interesting non-linear effect for performance improvement is stochastic resonance. This principle is based upon stochastic concepts and consists of adding noise to a weak sub-threshold signal, in order to lift it over a specific barrier or threshold. With the right amount of noise added to a sub-threshold harmonic signal, the resulting transitions will lead to a quasi-periodic signal, containing information about the sub-threshold signal [4]. It turns out that within a small band of added noise the Signal-to-Noise Ratio (SNR) of the system is improved, which has been experimentally determined for crickets by Levin and Miller [5], given in figure 4a. We want to take a similar approach for our artificial hair sensory system, in order the further increase its perception for low flow velocities. Numerical analysis by simulations confirms the existence of stochastic resonance (figure 4b).

In conclusion, by introducing non-linear effects to our artificial hair sensory system, we are able to increase the performance of these sensors even further. Both parametric amplification and stochastic resonance prove to be useful mechanisms for improving the flow perception of the sensory system.

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References

[1] M. Dijkstra, J. J. van Baar, R. J. Wiegerink, T. S. J. Lammerink, J. H. de Boer, and G. J. M. Krijnen. “Artificial sensory hairs based on the flow sensitive receptor hairs of crickets”. *Journal of Micromechanics and Microengineering*, **15**:S132–S138, 2005.

[2] C. M. Bruinink, R. K. Jaganatharaja, M. J. de Boer, J. W. Berenschot, M. L. Kolster, T. S. J. Lammerink, R. J. Wiegerink, and G. J. M. Krijnen. “Advancements in technology and design of biomimetic flow-sensor arrays”. In *22nd IEEE International Conference on Micro Electro Mechanical Systems (MEMS 2009), Sorrento, Italy*, number CFP09MEM-USB, pages 152–155, Piscataway, January 2009. IEEE Computer Society Press.

[3] D. W. Carr, S. Evoy, L. Sekaric, H. G. Craighead, and J. M. Parpia. “Parametric amplification in a torsional microresonator”. *Applied Physics Letters*, **77**(10):1545–1547, September 2000.

[4] T. Wellens, V. Shatokhin, and A. Buchleitner. “Stochastic Resonance”. *Reports on Progress in Physics*, **67**:45–105, 2004.

[5] J. E. Levin and J. P. Miller. “Broadband neural encoding in the cricket sensory system enhanced by stochastic resonance”. *Letters to Nature*, **380**:165–168, March 1996.

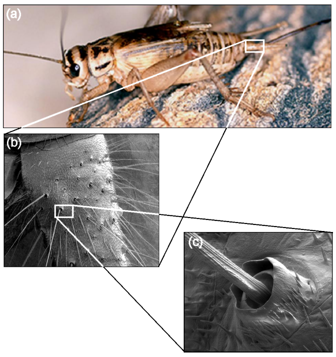


Figure 1: Flow perception by crickets.

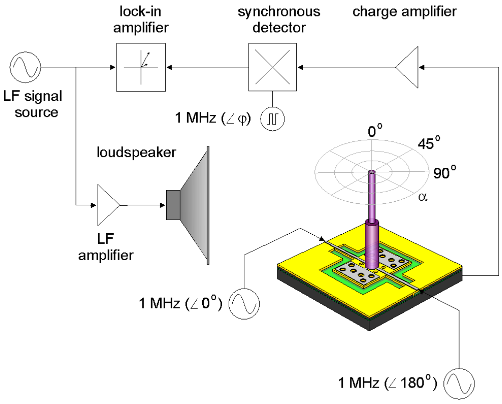
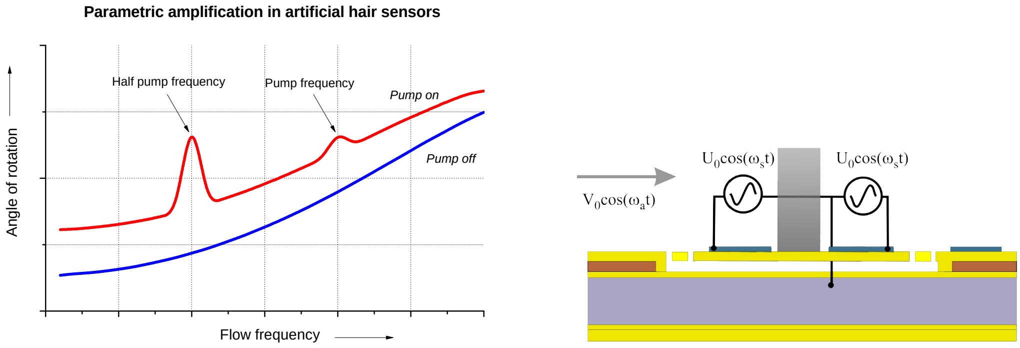


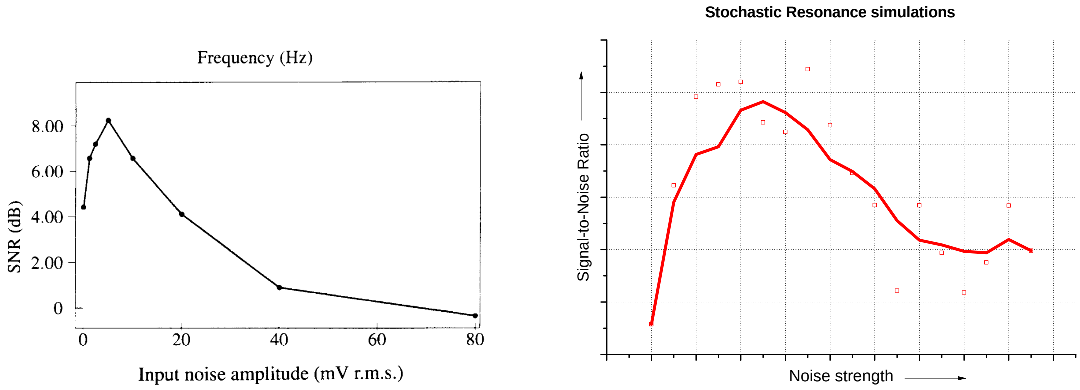
Figure 2: Performing flow measurements with artificial hair flow sensors.



(a) Numerical analysis for variable flow frequencies.

(b) Modulating the torsional spring stiffness in time.

Figure 3: Parametric amplification in artificial hair sensors.



(a) Experimentally improved SNR for crickets by Stochastic Resonance [5].

(b) Numerical analysis for variable noise strength.

Figure 4: Stochastic resonance in artificial hair sensors.