DSTA 2021
dys-ta.com
16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Active MEMS Amplifier for Improved Signal-to-Noise Ratios

STEFANIE GUTSCHMIDT[1*], SEIGAN HAYASHI[1], NICHOLAS LAM[1], CLAUDIA LENK[2]

1. Mechanical Engineering, University of Canterbury, Christchurch, New Zealand
2. Department of Micro- and Nanoelectronic Systems, TU Ilmenau, Germany [0000-0002-3040-1265]
* Presenting Author [0000-0002-1528-809X]

Abstract: The idea of using feedback mechanisms to adaptively amplify signals beyond the linear range is inspired by the human cochlea. The considered active composite MEMS (micro-electromechanical systems) oscillator amplifies input signals distinctively using its passive, active nonlinear, and Hopf dynamics. The amplification level is solely determined by the mechanical properties of the device and the input stimulus strength, making use of the system's complex dynamics. One of the key outcomes of our work is that we can demonstrate amplitude-dependant amplification, which can be likened to the compressive nonlinearity seen in the cochlea. Our comprehensive dynamic and stability analyses are accompanied by experimental validations of new findings, including an evaluation of technological feasibility.

Keywords: active MEMS sensor, signal-to-noise ratio, nonlinear compressive amplification

1. Introduction

The human cochlea is an impressive example of a biological sensor. The cochlea's remarkable dynamic range, highly tuneable sensitivity and nonlinear compressive amplification properties are attributed to its underlying active nature [1, 2]. Theoretical and experimental attempts to create an artifical device include active oscillators with different feedback mechanisms [1], diverse nonlinear systems [1, 3] and operation near bifurcation points such as a Hopf [4]. This novel work explores the dynamics of a self-sensing and self-actuating MEMS oscillator [5] subject to external stimuli and feedback mechanisms (see Fig. 1). Our investigations focus on the amplification properties of the MEMS oscillator operated at selected parameter tuples. Furthermore, selected theoretical findings are validated experimentally and technological feasibility of parameter ranges is discussed.

2. Model

We consider a single MEMS cantilever (Fig. 1) with integrated sensing and actuation capabilities [5]. Based on our previous work [6], the analysis is carried out with a simplified modal representation of the first vibration mode

$$\ddot{q}_w + \delta\dot{q}_w + q_w = \alpha q_\theta + \kappa_{ext}, \tag{1}$$

$$\dot{q}_\theta + \beta q_\theta = \gamma i^2\,, \tag{2}$$

where q_w and q_θ are the non-dimensionalised mechanical and thermal variables of the system. Parameters $\alpha, \beta, \gamma, \delta$ are integration constants originating from a modified Ritz discretization [6] and κ_{ext} being the external stimulus.

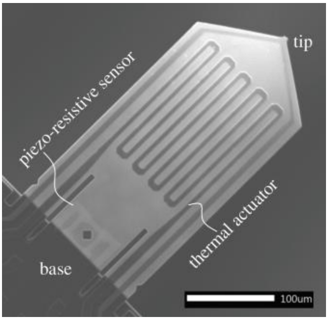

Fig. 1. SEM picture of MEMS sensor. (Taken with JEOL JSTM-IT300)

A feedback mechanism is introduced by means of the thermal actuator as $i = \tanh(i_{DC} + a q_w)$, where i_{DC} is an offset current, which controls control equilibrium states and a is the feedback strength.

3. Results and Discussion

Figure 2 depicts relevant equilibrium states of the system and associated gain properties for a range of feedback values and input strengths. In this brief discussion we highlight the different dynamics of three system configurations. The passive system (black) exhibits a constant gain of 38.42 dB at resonance for any input amplitude and feedback parameter. In contrast, the gain of the active, nonlinear system (blue) is dependent on input amplitude. As a result, the system is capable of demonstrating amplitude-dependant amplification, which can be likened to the compressive nonlinearity seen in the cochlea [2-3]. Certain equilibrium states also feature a Hopf bifurcation (purple), exhibiting another range of gain properties available with this system. Input amplitudes encompassing a parameter range of 10^{-7} to 10^{-3} yield a maximum gain of 76 dB near the Hopf-point at $a = 2.7$ for even a non-optimised system.

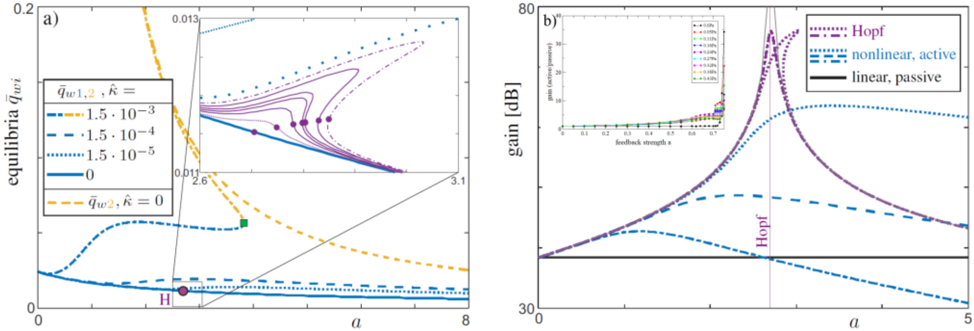

Fig. 2. Simulated behaviour of the MEMS system for different feedback strengths and varying stimuli; a) equilibrium states, b) associated gain properties; insert: initial experimental investigations showing gain at Hopf point.

4. Concluding Remarks

A novel adaptable MEMS sensor with self-sensing/-actuation capabilities has been presented whose complex nonlinear dynamics gives rise to much improved amplification properties. Initial theoretical gain characteristics, which have also been qualitatively validated experimentally (see insert of Fig. 2b), suggest very promising amplification and signal detection properties, even in noisy environments (not directly shown here but observable in Fig. 2b)). A more detailed and satisfying discussion of our new findings in addition to a discussion on the technological feasibility is included in the full paper.

References

[1] Joyce B.S., Tarazaga P.A. (2015) *Smart Mater. Struct.*, **24**, 094004.
[2] Neely S. T., Rasetshwane D.M. (2017) *J. Acoust. Soc. Am.*, **142**(4).
[3] Hudspeth A.J. (2008) *Neuron.*, **59**(4): 530-545.
[4] Hudspeth A.J., Jülicher F., Martin P. (2010) *J. Neurophysiol.*, **104**: 1219-1229.
[5] Ivanov T, Gotszalk T, Grabiec P, Tomerov E, Rangelow IW (2003) *Microelectron. Eng.*, **67**: 550-556.
[6] Roeser D., Gutschmidt S., Sattel T., Rangelow I.W. (2016). *J. Microelectromech. Syst.*, **25**: 78-90.