DOI 10.5162/EUROSENSORSXXXVI/PT1.41

On the Tunability of Resonant MEMS Sensor Subject to Blue Sideband Excitation

Erion Uka[1], Chengqi Lin[2], Jianlin Chen[2], Yuan Wang[3], Chun Zhao[1]
[1] School of Physics, Engineering & Technology, University of York, York, YO10 5DD, UK
[2] School of Microelectronics, Shanghai University, Shanghai, China
[3]Institute of Microelectronics, University of Macau, Zhuhai, China

erion.uka@york.ac.uk

Summary:

This work describes a new method and parameters by which the amplitude-frequency characteristics and sensitivity of a resonant MEMS sensor subject to the recently proposed blue sideband excitation (BSE) can be tuned. We show that the sensitivity of the BSE-based resonant MEMS sensor can be improved by 3 times via suppressing the intrinsic Duffing nonlinearity coefficient of the resonator. This paves the way for a new paradigm for highly sensitive and programmable multi-mode MEMS sensors.

Keywords: MEMS, resonant sensor, blue-sideband excitation (BSE), tunable sensitivity, multi-mode

Background

A new scheme of operating resonant MEMS sensors via blue-sideband excitation (BSE) has been proposed recently. As illustrated in Fig. 1, unlike the conventional direct driving method, the excitation frequency is at the sum of those of two modes of interest. The advantage of this new method is improving the sensitivity [1], circumventing the issue of feedthrough capacitance, as well as the capability of simultaneously detecting multiple parameters, e.g., acceleration and temperature [2]. These warrant further explorations of this newly emerging method, and this paper reports a new method to further improve the sensitivity towards realizing a new class of highly sensitive and programmable multi-mode MEMS sensors. In addition, as hypothesized in [1], the amplitude-frequency (A-f) effect in BSE (distinguish from the A-f effect in Duffing nonlinearity) can degrade the noise performance of resonant MEMS subject to BSE when operated in a closed-loop configuration. Here we report that the A-f effect in BSE can also be tuned with the same approach, thereby leading to a noise reduction in a closed-loop configuration.

Description of the New Method or System

The device-under-test for this work is a baseline double-ended tuning fork, as shown Fig. 2. The device is fabricated using the commercially available SOIMUMPS process, with a thickness of 25 µm. The device is placed in a vacuum chamber (pressure of 50mTorr) for characterizations. The bias voltage is generated using a DC power supply (Keysight EDU36311A). An additional DC voltage (V_{offset}) is applied to function as a proxy for stiffness perturbations experienced when operating the device as an accelerometer. The V_{offset} voltage, along with the BSE drive signal, $v_{actuate}$, is generated using an MFLI lock-in amplifier by Zurich Instruments. The motional current (i_{mot}) is converted to voltage using a custom-made transimpedance amplifier, the output of which is then fed to the MFLI. The tests were conducted in an open-loop configuration.

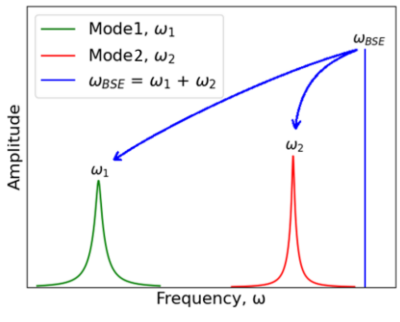

Fig. 1. Illustration of the blue-sideband excitation regime where the driving signal frequency is the sum of the resonant frequencies of modes 1 and 2.

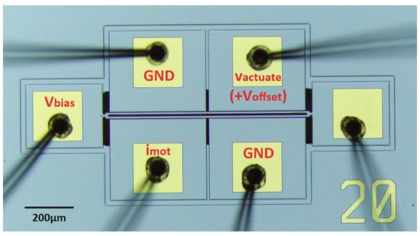

Fig. 2. Optical image of the MEMS resonator with length 830 µm, width 8 µm and thickness 25 µm.

DOI 10.5162/EUROSENSORSXXXVI/PT1.41

Results

The measured resonant frequencies are 106.452kHz (Q-factor: 13k) for Mode 1 and 110.602kHz (Q-factor: 51k) for Mode 2. Simulated mode shapes are shown in Fig. 3.

Fig. 3. Mode shapes of Mode 1 and 2.

It is known that the Duffing nonlinearity coefficient of the resonator can be tuned by adjusting V_{bias}, i.e., nonlinearity softening. Based on this, we show that the nonlinear relationship between the BSE frequency and the output amplitude of Mode 2 (A-f effect in BSE) can also be tuned (see Fig. 4.). This is supported by our simulation by tuning the intrinsic Duffing nonlinearity coefficient only (See Fig. 5). We note that this can also be used to improve the sensitivity of such a resonant sensor.

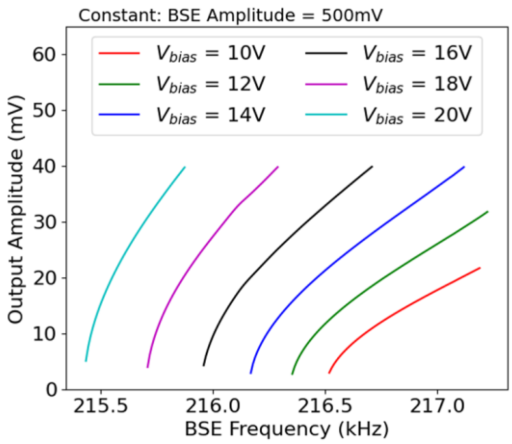

Fig. 4. The nonlinear relationship between output amplitude and BSE frequency of mode 2 for a range of bias voltages.

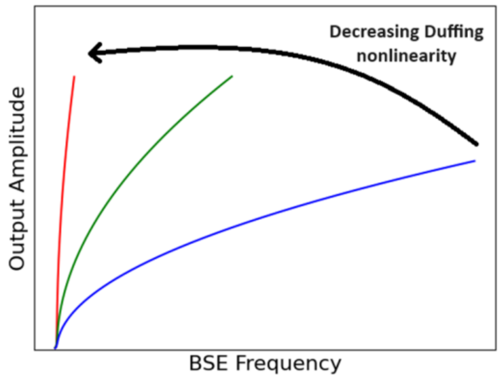

Fig. 5. Simulated results from the numerical model of the system. The results show that the nonlinear relationship between output amplitude and BSE frequency of mode 2 can be tuned by changing the intrinsic Duffing nonlinearity.

To obtain the sensitivity, the BSE drive signal is maintained at a constant, and the BSE frequency is tuned such that the output amplitude of Mode 2 is kept at 5mV, and the sensitivity figure is shown in Fig. 6. From the sensitivity results, it can be observed that by changing the V_{bias} from 10 V to 16 V, the sensitivity can be improved from 1.19 mV/V to 5.85 mV/V, a 4.9-fold increase. This demonstrates the feasibility of the new approach towards realizing a highly sensitive and programmable multi-mode sensor.

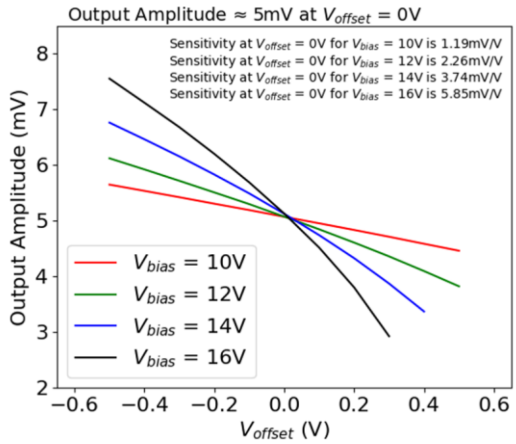

Fig. 6. The relationship between output amplitude and V_{offset} of mode 2 for a range of bias voltages for output amplitude = 5mV at V_{offset} = 0V setpoint, as well as the sensitivity values extracted at V_{offset} = 0V setpoint with different V_{bias} voltage, i.e., different Duffing nonlinearity coefficients

Conclusions

From the results obtained thus far, we confirmed the feasibility of our new approach by improving the sensitivity as well as the A-f effect in BSE (distinguish from the A-f effect in Duffing nonlinearity) via tuning the intrinsic Duffing nonlinearity coefficient of the resonator. We anticipate that the results can be extremely useful in realizing a new class of highly sensitive and programmable multi-mode resonant sensors subject to BSE. Ongoing experiments are focusing on obtaining more data at different operating points, e.g., the output amplitude of 10 mV, as well as the noise characterizations. We aim to show the efficacy of the method in not only improving the sensitivity but also the noise.

References

[1] L. Xu, J. Xi, L. Gao, F. Li, J. Pi, C. Li, K. Wang, X. Xiong, Y. Wang, H. Liu, X. Zou, C. Zhao, A closed-loop system for resonant MEMS sensors subject to blue-sideband excitation, *Journal of Microelectromechnical Systems,* 31.4, 690-699 (2022); doi: 10.1109/JMEMS.2022.3183021

[2] J. Xi, L. Xu, Y. Wang, H. Liu, X. Xiong, X. Zou, C. Li, F. Hu, C. Wang, M. Kraft, C. Zhao, Multiple Parameter Decoupling for Resonant MEMS Sensors Exploiting Blue Sideband Excitation, *Journal of Microelectromechnical Systems,* 32.5, 426-436 (2023); doi: 10.1109/JMEMS.2023.3293464