DESIGN AND EXPERIMENTAL VALIDATION OF A PIEZOELECTRIC RESONANT MEMS PHASE COMPARATOR

Mathieu Gratuze and Frédéric Nabki*
École de Technologie Supérieure, LaCIME, Montréal, Québec, Canada

ABSTRACT

In this paper the design and experimental validation of the performances of a piezoelectric resonant microelectromechanical systems (MEMS) phase comparator is presented. Compared to the traditional integrated circuits, the potential benefits of a MEMS phase comparator include a low power consumption, higher sensitivity, higher selectivity and improved robustness. The design and experimental validation of a resonant MEMS phase comparator are presented. The operation of this resonant MEMS phase comparator is experimentally validated at a frequency of 108 kHz. This work is expected to lead towards the development of new applications for MEMS devices.

KEYWORDS

Piezo-eletricity, Phase Comparator, Phase Detector, MEMS, Resonator, Signal Processing, PiezoMUMPS.

INTRODUCTION

Signal processing can be achieved using micro-electro-mechanical systems (MEMS), as various instances have been proposed, including band pass, high pass and low pass filters, and resonators. Phase comparators are critical building blocks of various electronic systems, one of the most famous one being the phase-locked loop (PLL). They can also be encountered in diverse applications, such as motor control, radar and telecommunication systems, servo mechanisms, demodulators, clock and data recovery circuits (CDRs).

From a practical point of view, phase detectors can be divided into two main classes: linear phase detector and binary phase detector [1]. In the case of a linear phase detector, the transfer function is somewhat linear between the output and the input phase error, while binary phase detector produces an error signal that corresponds to the sign of the instantaneous phase error.

However, to the authors' best knowledge, literature on MEMS phase comparators is limited to the work of I. Dunk et al.[2], and that of J. Han et al. [3].[2] claims a device with the potential for higher sensitivity, higher selectivity, faster lock time, low power consumption and improved robustness. It makes use of Huygens Synchronization, the mechanical phenomenon behind the synchronization of two hanging pendulums. The work of J. Han et al. [3] consists in a power combiner with a thermoelectric power sensor to achieve a broadband MEMS phase comparator, at a much higher frequency (i.e. from 8 GHz to 12 GHz). However, this comes at the cost of a large power consumption (up to 1 W) [3].

This work targets a simpler structure to implement a piezoelectric resonant MEMS phase comparator: a simple clamped-clamped beam. Accordingly, the contributions of this work is the design and experimental validation of a piezoelectric resonant MEMS phase comparator.

THEORY AND OPERATION

The studied phase comparator MEMS resonator in this paper is a simple clamped-clamped beam with two electrodes each covering one half of the beam. The dimensions of the simulated MEMS are presented in detail in Table. The materials height and dimensions are consistent with the ones available in the commercial PiezoMUMPs process from MEMSCAP (Crolles, France), since this process is used for the fabrication of the prototypes in this work.

Table 1: Overview of the dimensions of the beam.

Parameter	**Value**
Length of the beam (um)	800
Width of the beam (um)	100
Separation between the electrodes (um)	5

It is well known electrode placement has an impact on the behavior of a MEMS resonator. Thus, two electrodes each covering one half of the beam have been used to either excite the mode shape of the first eigen mode (if the two excitation signals are in phase) or the mode shape of the second eigen mode (if the two excitation signal are in phase opposition). Thus, two excitation signals (F_{S1} and F_{S2}) have been defined:

$$F_{S1}(t) = A \sin(2\pi f_e t) \tag{1}$$

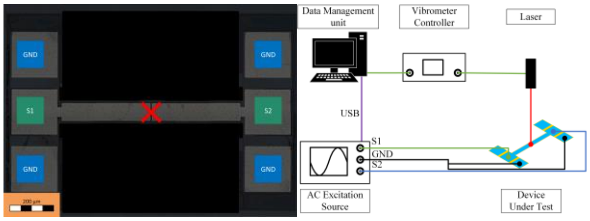
$$F_{S2}(t) = A \sin(2\pi f_e t + \Delta\varphi) \tag{2}$$

Where, A is the amplitude of the excitation signal in V, f_e is the frequency of the excitation signal in Hz, and $\Delta\varphi$ is the phase difference between the two signals.

FABRICATION AND EXPERIMENTAL RESULTS

The piezoelectric resonant MEMS phase comparator has been fabricated using the PiezoMUMPs process from MEMSCAP and a micrograph is shown in Fig.1a.

A laser vibrometer from Polytec, (Irvine, CA, USA) is used for experimental measurement. The test setup is presented in Fig.1b. Excitation of the resonant MEMS phase comparator is provided using a function generator type AFG3252 from Tektronix, (Beavertown, Or, USA) which can provide dual output signals with a controllable phase difference. Channels 1 and 2 are respectively connected to S1 and S2 pads which are shown in Fig.1a while the beam is grounded.



(a) (b)

Figure 1: (a) Micrograph of the fabricated resonant MEMS phase comparator, both electrodes are clearly identified along with the central (red) measurement point. (b) Schematic of the test bench.

Considering that that the resonant MEMS phase comparator will be excited by an excitation signal containing a single frequency, the recommendations made in [4] have been followed and the resonant MEMS phase comparator has been characterized using a pulsed sweep type excitation. The resulting frequency response is shown in Fig.2. It should be noted that when amplitude of the excitation is relatively large a non-linearity appears.

Table 2, show the good agreement between the measured

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resonant frequency of the resonant MEMS phase comparator and the simulated behavior using COMSOL Multiphysics.

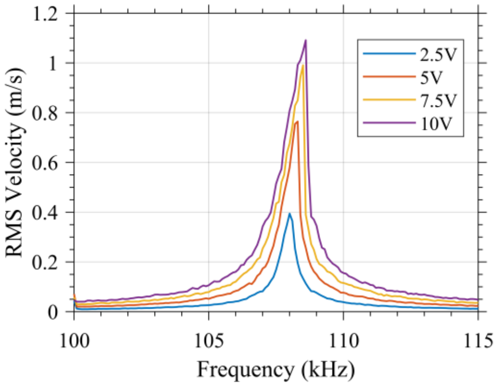


Figure 2: Measured RMS velocity of the central point of the resonant MEMS phase comparator (Δφ=0°)

Table 2: Summary of the characteristics of the resonances when the amplitude of the excitation signal is equal to 10 V_{pp}.

Parameter	**Value**
Simulated Resonant Frequency (kHz)	103.4
Measured Resonant Frequency (kHz)	108.6
Operating Bandwidth (kHz)	107.5-108.75

Afterwards, the phase difference, when keeping the amplitude and frequency of the excitation constant has been varied in the interval 0-360°. The influence of such variation is shown in Fig.3. It is clear to see that the RMS velocity of the central point can be used as a proxy to measure the phase difference between F_{S1} and F_{S2}

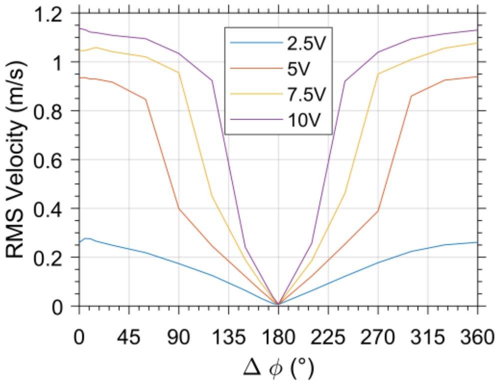
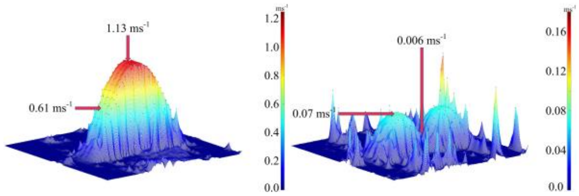


Figure 3: Influence of the variation of Δφ on the measured RMS velocity of the central point (f_e = 108 kHz)

To validate the operating principle of the resonant MEMS phase comparator, the heat map of the RMS velocity of the resonant MEMS phase comparator has been measured when , *Δφ* is set to 0° (see Fig. 4a) and when *Δφ* is set to 180° (see Fig. 4b).

It can be noted that the relationship between the RMS velocity *Δφ* is not linear. Still, it is possible to estimate the amplitude of the RMS velocity of the central point as a function of *Δφ:*

$$V_{pred}(\Delta\varphi) = |V(\Delta\varphi=0|A_{meas})\,\sin(\Delta\varphi/2)| \qquad (3)$$



(a) (b)

Figure 4: Visualization of the heat map of the RMS velocity of the resonant MEMS phase comparator, with A=10V, fe=108kHz and (a) Δφ equal to 0° (b) Δφ equal to 180°.

where *V(Δφ=0 | Ameas)* is the measured RMS amplitude of the velocity of the measurement point as extracted from Fig. 2. This allows the determination of r^2, the squared Pearson product moment correlation between the estimation and the experimental results, this is shown in Table 3. The good agreement between estimation and measurement shows that the calibration of the resonant MEMS phase comparator will be simplified as it is not necessary to measure the value for all the values of *Δφ*. Nevertheless, it should be noted that the current operation of the phase comparator doesn't allow the determination of which signal comes first.

Table 3: Overview of performances the fitting function, f_e=108kHz.

Amplitude of the excitation (V)	**Measured rms velocity when Δφ=0° (ms^{-1})**	**r^2**
2.5	0.28	0.9951
5	0.94	0.9344
7.5	1.07	0.9685
10	1.13	0.92

CONCLUSION

In this paper the design and experimental validation of a piezoelectric resonant MEMS phase comparator was presented. The reported results show its potential for the development of integrated MEMS phase comparator.

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CONTACT

*M. Gratuze; tel +1 438 728-8549 , mathieu.gratuze@etsmlt.ca