ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Procedia Chemistry 1 (2009) 1131–1134
Procedia Chemistry
www.elsevier.com/locate/procedia

Proceedings of the Eurosensors XXIII conference

VHF band-pass filter based on a single CMOS-MEMS double-ended tuning fork resonator

J. L. Lopez[a], J.Verd[b], A. Uranga[a], G. Murillo[a], J. Giner[a], E. Marigó[a], F. Torres[a], G.Abadal[a], N. Barniol[a]*

[a]*Departament of Electronic Engineering, Universitat Autònoma de Barcelona, Bellaterra 08193, Spain*
[b]*Electronic Systems Group, Universitat de les Illes Balears, Palma de Mallorca 07122, Spain*

Abstract

This paper presents a single Double-Ended Tuning Fork (DETF) MEMS resonator-based band-pass filter fabricated on a commercial standard CMOS technology. The accurate design of this resonator demonstrates the ability to perform filtering without the need of coupling multiple resonators. The main characteristic is to define the out-of-phase mode resonance frequency of the DETF smaller than the in-phase mode frequency. The electrical characterization shows that this stand-alone band-pass filter presents a 44.4MHz central frequency with a 0.6% bandwidth in air.

Keywords: Microelectromechanical Systems (MEMS), CMOS, Filter, CMOS-MEMS, RF-MEMS, Tuning fork MEMS, band-pass filter.

---

1. Introduction

Typical filter implementations are based on electrical [1] or mechanical [2, 3] coupling of two or more resonators to provide the required band-pass for filter applications, which can decrease the fabrication process throughput.

The main idea behind this work is to use a resonator that inherently presents two near frequency resonance modes [4] in order to create the filter band-pass.

Similar concept (and structure) was employed by Yan et al. but using phase inversion [5] to obtain that filter shape. This technique, however, presents two important drawbacks: 1) a dual supply is required to obtain the phase inversion and 2) because the biasing of the electrodes, AC coupling (i.e. a capacitor) is required to isolate subsequent electronics from the typically high DC values required by MEMS structures. These coupling capacitors would load the resonator Q, reducing it.

The approach used in this work is different: the DC voltage would be applied directly to the resonant structure and the filter shape would be obtained by combining two near resonance modes frequency responses, in particular the balanced (out-of-phase) and unbalanced (in-phase) lateral resonance modes of a single MEMS resonator. For this purpose, a double-ended tuning fork (DETF) resonator topology, shown in Fig.1(a), was chosen. Relevant

---

* Corresponding author. Tel.:+34-93-581-1361; fax: +34-93-581-2600.
E-mail address: nuria.barniol@uab.cat.

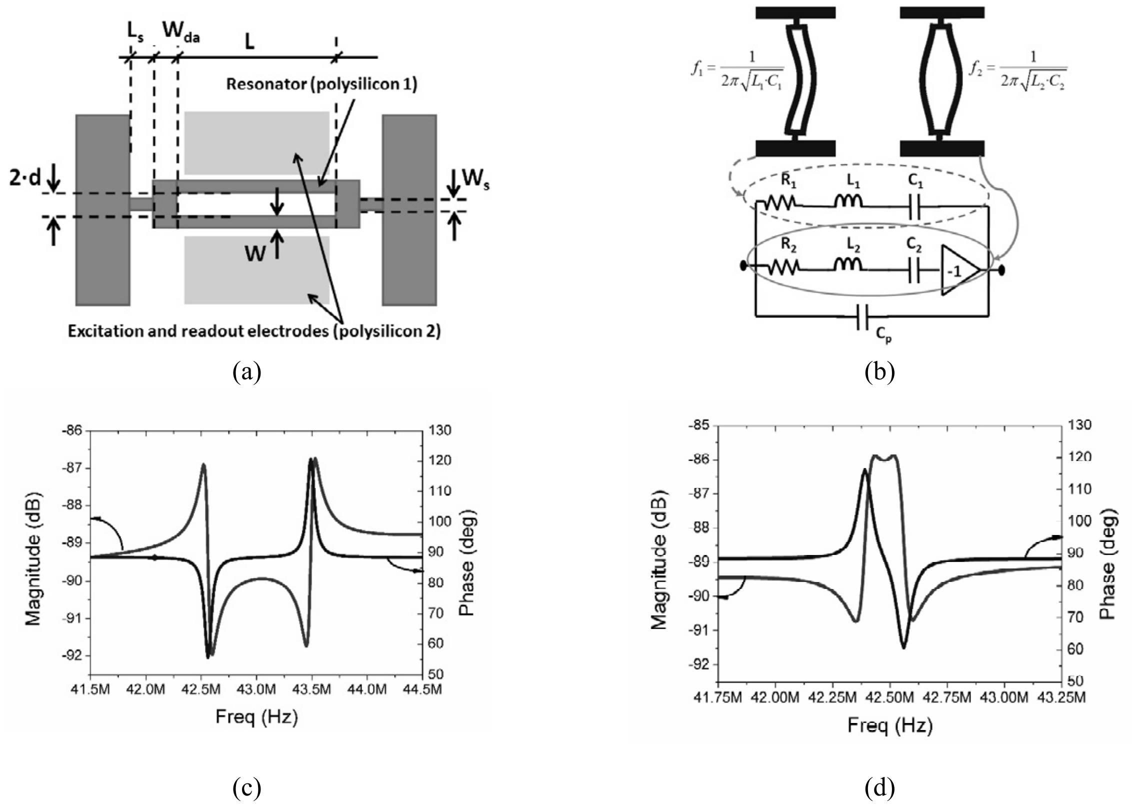
doi:10.1016/j.proche.2009.07.282

dimensions are: beam or tine length (*L*), Support length (L_s), decoupling area width (W_{da}), resonator width (*W*), support width (*k*) and distance between tines ($2\cdot d$).

Fig1(b) shows the electric equivalent circuit of the resonator in which each RLC branch models each resonance vibration mode. The inverter in one of the branches models the different sign phase shift between the resonance modes that was observed in experiments [6, 3]. Fig.1(c and d) show electrical simulations for two scenarios: a) The balanced or out-of-phase mode frequency (f_2) is higher than the one of the unbalanced or in-phase (f_1) and b) the opposite situation. It can be observed the shape of a bandpass filter on the second scenario ($f_2 < f_1$).

2. Resonator fabrication and description

The used resonator is completely fabricated on a CMOS commercial technology, AMS 0.35μm CMOS technology, using the capacitor module composed by two polysilicon layers, and is released using a one-step maskless etching, according to the technique used in [7, 8]. Resonator dimensions are: L=8.7 m, W=470 nm, W_{da}=400 nm, L_s=400 nm and W_s=700 nm whereas the gap distance is set to 100nm. Fig.2 shows the SEM image of the released resonator and Fig.3 shows the FEM simulations of the structure that demonstrates that for the given resonator dimensions balanced resonance frequency is lower than the one of the unbalanced mode, and consequently the measured magnitude response shape is expected to be like Fig.1(d). The frequency difference between modes (in-phase and out-of-phase) and their order can be modulated as a function of the double-ended tuning fork tines separation (*2d*) [5]



(a) (b)

(c) (d)

Fig.1 (a) DETF resonator topology, relevant dimensions are shown. (b) Electrical equivalent model of the DETF resonator considering balanced (out-of-phase) (f_2) and unbalanced (in-phase) (f_1) lateral resonance modes. (c) Electrical model simulation with $f_1 < f_2$. (d) Electrical model simulation with $f_2 < f_1$

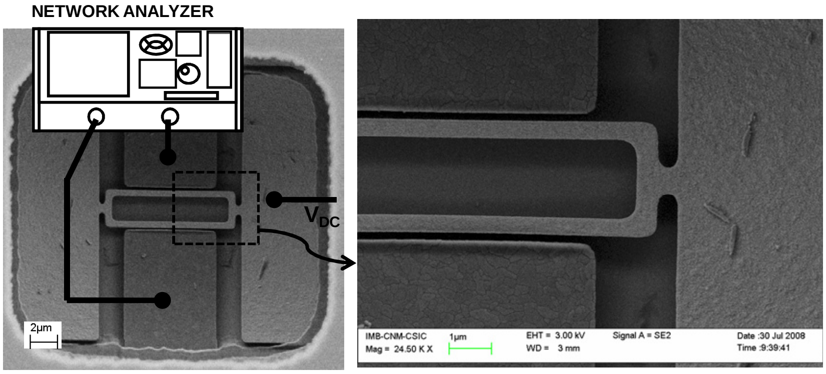


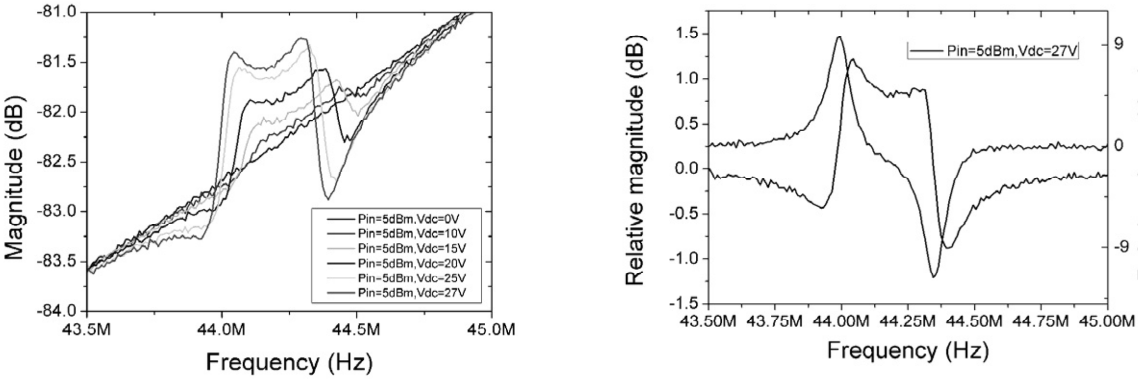
Fig.2 SEM images of the released DETF resonator.

Fig. 3: FEM mechanical simulations (using Coventor) of the two first lateral modes. (a) in phase and (b) out of phase

3. Experimental results and discussion

This MEMS filter is measured using a manual probe table for direct on-chip measurement and a network analyzer (Agilent E5100A), using the test setup depicted also in Fig.2.. Fig.4(a) shows the S21 frequency response of the DETF filter for different DC biasing voltages. Fig.4(b) shows the relative frequency response (subtracting the feedthough signal) to easily appreciate the band-pass filter shape. These measurements show (as predicted) a band-pass like frequency response, similar to the electrical simulations. Although the stop-band attenuation is below 3dB, and therefore no bandpass can be defined, the present resonator demonstrates the feasibility of obtaining a band-pass filter using a single resonator and a single DC supply. In particular a band pass filter with central frequency of 44MHz, 0.6% bandpass and 0.5dB ripple is demonstrated.

Compared to other reported works [4, 5, 3], the presented CMOS-MEMS resonator gives similar performance but provides the benefit of monolithical integration with CMOS, enhancing the possibilities for RF-MEMS in filtering applications. We expect that using CMOS circuitry to prevent Q loading [9] and reducing the transducing gap up to 40 nm [8] will enhance the stop band attenuation providing a better filter performance than the state-of-the-art using mechanical coupling [3].



(a) (b)

Fig. 3: (a) Magnitude frequency response measurement of the DETF resonator with different applied DC voltage values. (b) Relative magnitude and phase variations for V_{DC}=27V.

4. Conclusions

In this paper a double-ended-tuning-fork electrostatically excited and monolithically integrated in a standard CMOS technology is presented. The convenient election of resonance frequencies for the in-phase (larger frequency) and out-of-phase (smaller frequency) lateral resonant modes and the possibility to use two-port readout, provides a direct band-pass filter response. Even though the measured performance of the shown resonator is not as good as desired for a standard band-pass filter, it opens new perspectives to obtain filters using smaller devices. Additionally, we expect to increase its performance using the benefits of the CMOS technology used: implementing on-chip amplification circuitry and reducing the gap from 100nm to 40nm.

Acknowledgements

This work was funded by project TEC2006-03698/MIC.

References

1, Lin L, Nguyen C T C, Howe R T and Pisano A P *Microelectromechanical filters for signal processing.* In MEMS '92 pp 226-31
2. Bannon F D, Clark J R and Nguyen C T C *High-Q HF microelectromechanical filters* J. Solid-State Circuits, 35 (4) 512-26
3. Yan J, Seshia A A, Phan K L and van Beek J T M *Mechanical phase inversion for coupled Lamé mode resonator array filter.* In: MEMS'2008,
4. Yan J, Seshia A A, Phan K L, Steeneken P G and van Beek J T M *Narrow Bandwidth Single-Resonator MEMS Tuning Fork Filter.* In: Frequency Control Symposium, 2007, pp 1366-9
5. Yan J, Seshia A A, Phan K L and van Beek J T M *Internal electrical phase inversion for FF-beam resonator arrays and tuning fork filters.* In: MEMS 2008. pp 1028-31
6. Lopez J L, Torres F, Murillo G, Giner J, Teva J, Verd J, Uranga A, Abadal G and Barniol N *Double-ended tuning fork resonator in 0.35um CMOS technology for RF applications*. In: PRIME 2008, pp 89-92
7. Lopez J L, Verd J, Uranga A, Giner J, Murillo G, Torres F, Abadal G and Barniol N *A CMOS–MEMS RF-Tunable Bandpass Filter Based on Two High-Q 22-MHz Polysilicon Clamped-Clamped Beam Resonators* Electron Device Letters 30 (7) 718-20
8. Teva J, Abadal G, Uranga A, Verd J, Torres F, Lopez J L, Esteve J, Perez-Murano F and Barniol N *VHF CMOS-MEMS resonator monolithically integrated in a standard 0.35um CMOS technology*. In: MEMS'07, pp 779-82
9. Verd J, Uranga A, Abadal G, Teva J L, Torres F, Lopez J L, Perez-Murano E, Esteve J and Barniol N *Monolithic CMOS MEMS Oscillator Circuit for Sensing in the Attogram Range* Electron Device Letters (2) 146-8