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Characterization of MEMS resonators via feedthrough de-embedding of pulsed-mode response

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Summary

In this paper, we analyze and give experimental evidence of the efficiency of pulsed-mode actuation for the characterization of capacitive MEMS resonators. In particular, we show how to process the output signal in pulsed mode to eliminate feedthrough parasitic effects and characterize the resonator. We test our approach on a pressure sensor, developed by Thales Avionics, used for avionics applications. Contrary to the existing state-of-the-art techniques, the method described in this paper can be used to characterize an electrostatic MEMS without a spectrum analyzer or high-performance ADC.

Motivation and results

Feedthrough is a major obstacle to the characterization of capacitive MEMS resonators via electrical measurements [1-4]. Feedthrough effects distort the open-loop frequency response, resulting in poor estimations of the natural frequency and Q-factor of the resonator. Previous work has addressed direct parameter extraction from feedthrough-embedded frequency response via considerations on the Nyquist plot [1] but they require precise measurements of both phase and amplitude. Another alternative consists in de-embedding parasitic feedthrough by using subharmonic actuation [2][3]. This method is proven but requires a spectrum analyzer or a high-resolution ADC to extract the low amplitude motional signal from the large subharmonic feedthrough signal. To illustrate this issue, Fig. 2 shows a typical shape of the signal obtained with subharmonic excitation. These obstacles gave impulse to our search for alternatives.

The resonant MEMS pressure sensor studied in this paper has been developed by THALES [5] and is industrially assembled by the fusion-bonding of three etched silicon wafers (Fig. 1). It consists of a silicon beam resting on a rectangular diaphragm. The beam is encapsulated in vacuum in order to achieve a high mechanical Q-factor (≈ 20000). The resonance frequency f_0 of the device is around 65 kHz.

In our set-up (Fig. 2), a 10V-bias voltage is applied to the resonator which is directly actuated in open-loop by a waveform generator delivering 150ns-wide and 2V-amplitude pulses. The period between pulses is swept around $T_0 = 1/f_0$. The motion of the resonator gives rise to a current which is integrated in a charge amplifier (Fig. 3). The output of the charge amplifier is recorded for every pulse frequency. Consequently to our capacitive actuation and detection scheme, the output signal exhibits voltage pulses, superposed on the motional signal (Fig. 4). As highlighted in Fig. 4, feedthrough effects are localized within the pulses. We remove the pulses from the recorded waveforms with MATLAB. Fig. 5 shows a typical result of this process. Finally, a sine-wave curve fitting on each one of the resulting waveforms yields the frequency response of the resonator. Fig. 6 shows a comparison of characterization results with sine-wave and pulsed-mode actuation. Contrary to [4], our localized signal processing of pulsed-mode responses suppresses nearly all the parasitic feedthrough effects and permits a better characterization of the resonator. Hence, our work highlights the pertinence of pulsed-mode actuation for the characterization of MEMS resonators. Further work will aim towards a wholly automated resonator characterization procedure.

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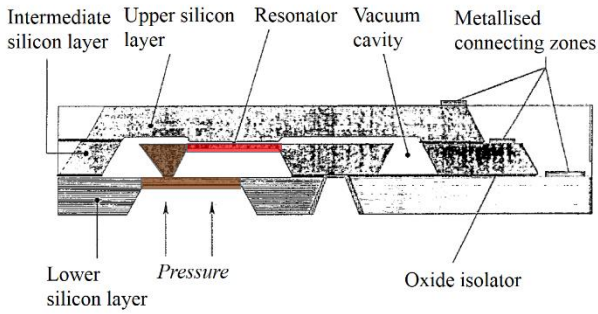


Fig. 1: Sensor structure (from [5]). The sensing element consists in a resonant silicon beam encapsulated in vacuum, with a massive stud bonded to a silicon diaphragm. The beam is capacitively actuated and sensed with the facing electrode.

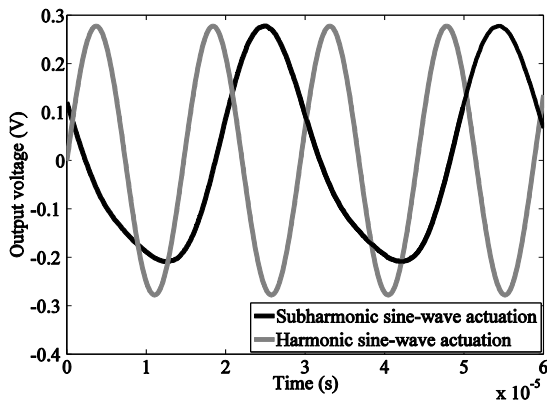


Fig. 2: Experimental shape of the output close to resonance with subharmonic actuation (dark line) and harmonic actuation (grey line). On the dark line, the large feedthrough signal (frequency $f_0/2$) overshadows the small amplitude motional signal (frequency f_0). A spectrum analyzer or a large-resolution ADC would be needed to extract the motional signal.

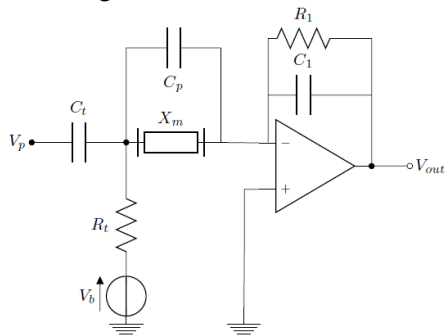


Fig. 3: Test circuit. The X_m -element is the resonator. $V_b = 10V$ is the bias voltage and V_p the 2V-amplitude and 150ns-width pulses. $C_t = 1\mu F$, $R_t = 1k\Omega$, $C_1 = 10pF$ and $R_1 = 1.0M\Omega$. C_p is the unknown parasitic capacitance.

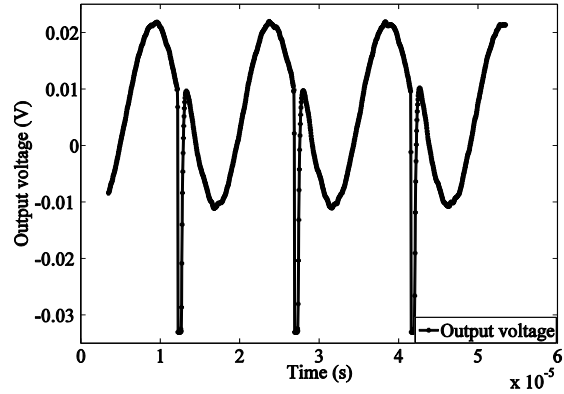


Fig. 4: Typical shape of the output voltage close to resonance with pulsed-mode actuation. Feedthrough is localized in the pulses and in their close neighbourhood, due to the finite bandwidth of the feedthrough path.

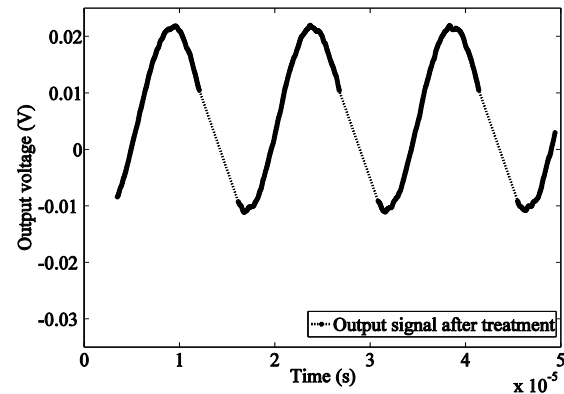


Fig. 5: Output voltage after “cleaning out” the pulses. This localized signal processing leaves the remaining signal completely free of feedthrough. Knowing the excitation frequency, it is simple to fit a sine wave to the remaining signal and extract its amplitude.

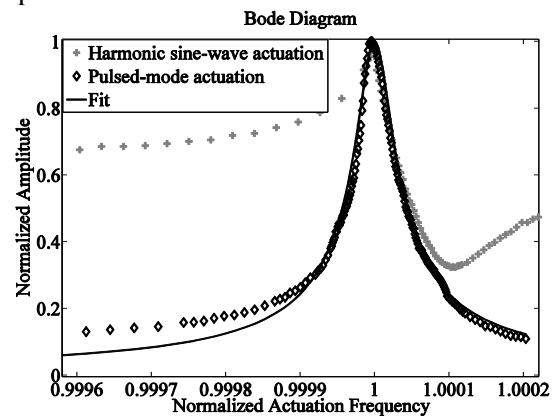


Fig. 6: Bode diagram obtained with harmonic sine-wave actuation (grey crosses) and pulsed-mode actuation after de-embedding (diamonds). The continuous dark line shows the curve fitted to the pulsed-mode response.