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Parametrically Excited MEMS Oscillators with Filtering Applications

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Microelectromechanical systems (MEMS) offer minimal packaging constraints, low power consumption, low damping, ease of parameter tuning, and relatively simple integration with electronics. These benefits are desirable in a wide array of applications, including the filters used in wireless communication devices, such as cellular phones and tactical radios. In fact, MEMS-based filters have the potential to offer performance that is significantly superior to traditional electronic or mechanical filters [1]. To date, bandpass filter designs, including MEMS versions, make use of the usual primary resonance in order to attenuate signals that are outside of a given frequency band. In the present work we describe the novel use of parametric resonance in MEMS oscillators for filtering.

Figure 1 shows a previously studied MEMS oscillator that exhibits parametric resonance [2]. Here the input voltage provides a fluctuating electrostatic stiffness component through the non-interdigitated comb drives, labeled “N” in the figure. The mass is dominated by the backbone “B”, which is connected to ground via beam springs “S”. The interdigitated combs “C” on either end are used for direct drive (not employed here) and sensing. The key benefit of using the parametric resonance of such a device for filtering is that it features nearly ideal stopband rejection, that is, the response is essentially zero (at the noise floor) outside of the instability zone, which is taken here to be the filter passband, thereby offering an extremely sharp response roll-off in the frequency domain [3]. However, the introduction of parametric resonance and the associated instability into the system is not without difficulties, since this phenomenon results in a response bandwidth that is dependent on the amplitude of the excitation signal, as well as a nonlinear input/output relationship. In addition, it introduces the possibility of higher order resonances, and the possible existence of non-trivial responses outside of the passband. Fortunately, most of these deficiencies can be overcome, or at least partially negated, through systematic design and tuning, features that are particularly suited to MEMS implementations.

Of particular concern in this filtering approach is the amplitude dependent nature of the oscillator’s instability zone and, accordingly, its bandwidth. However, this dependency can be overcome through a special linear tuning that shifts the oscillator’s natural frequency as a particular function of the excitation amplitude [3]. Similarly, the existence of non-trivial responses outside of the oscillator’s passband can be overcome through design of the device’s effective nonlinearity, which arises from both mechanical and electrostatic effects. This nonlinearity can be tuned such that the system exhibits hardening or softening characteristics, as desired [2]. In this manner, the oscillator can be made to function as an ideal high-pass or low-pass frequency switch. Using a simple logic implementation, two such switches, one high-pass

with hardening nonlinearity and the other low-pass with softening nonlinearity, can be combined to create a bandpass filter with nearly ideal response characteristics. The output characteristics of the proposed device, based on simulations, are shown in Figure 2, which shows the frequency response in a dimensionless version of the input voltage vs. input frequency parameter space. The insets show sample responses of the overall system, demonstrating the key feature of ideal stopband rejection. The presentation will focus on the issues outlined above and provide simulation and experimental results from a filter device.

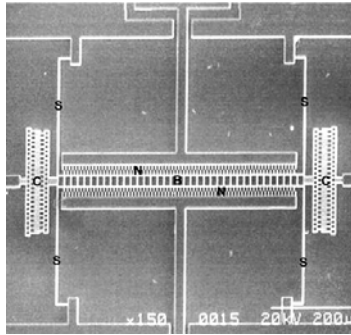


Figure 1. A parametrically excited MEMS oscillator; from [2].

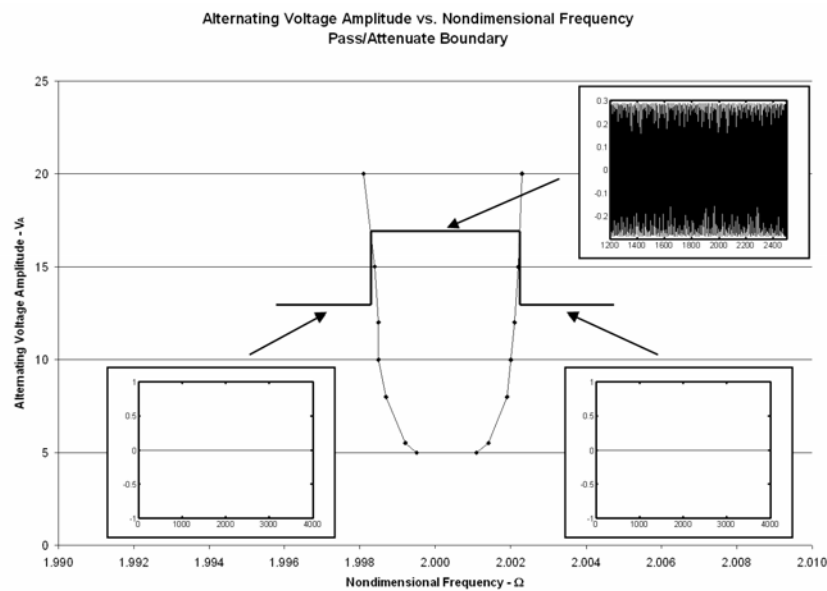


Figure 2. Simulation of the MEMS bandpass filter.

Selected References

1. Nguyen, C.T.-C. *Micromechanical Circuits for Wireless Communications*. 2000 *European Solid-State Device Research Conference*. 2000. Cork, Ireland.
2. Zhang, W., R. Baskaran, and K.L. Turner. *Tuning the Dynamic Behavior of Parametric Resonance in a Micromechanical Oscillator*. *Applied Physics Letters*. 2003. **82**(1): p. 130-132.
3. Shaw, S., K. Turner, J. Rhoads, and R. Baskaran. *Parametrically Excited MEMS-Based Filters*. *IUTAM Symposium on Chaotic Dynamics and Control of Systems and Processes*. 2003: (to appear).