RF Signal Processing with MEMS Resonators

Abstract:
To advance the concept of radio-on-chip, silicon-based micron-sized devices need to be developed and implemented as frequency-determining elements in communication electronics. We fabricate micromechanical resonators that convert an incoming radio frequency signal into an oscillating temperature field within the structure and then into mechanical motion. We employ both the linear and nonlinear dynamics of the resonator and thermal actuator to implement the functions of standard components found in radio frequency communication receivers.

Summary:
Our research focuses on fabricating and measuring high frequency micro-thermal mechanical resonators for use in RF communications and in scientific studies of materials and non-linear oscillations. The micromechanical resonator used in the study is a thin-film polysilicon membrane, clamped on the periphery and suspended over the substrate in the center. Due to the compressive stress incorporated into the polysilicon, the membrane has a slight degree of curvature [1]. The unique shape allows an easy method for producing detectable displacement in the structure through changing the stress in the membrane. Stress is induced by Joule heat dissipated by a thin film metal resistor defined on the resonator. The extra rigidity provided by the curvature will also increase the natural frequency of the resonator, thus, a relatively large device can be maintained to facilitate motion detection, while sustaining RF frequencies.

High amplitude mechanical vibrations in response to an applied RF excitation are produced at a frequency defined by a resonant mode of the dome membrane analogous to a high quality factor frequency filter. A voltage-controlled oscillator can be implemented by applying positive feedback of the correct phase between the output signal and the driving resistor, producing limit cycle oscillations in the resonator. Additionally, the fact that the range of mechanical motion is proportional to the local temperature increase and hence to the square of the applied RF signal, provides a possibility for a mixer implementation [2]. When two signals are superimposed onto the resistor, the intrinsic nonlinearity of the thermal response will produce sum and difference frequency components. The dome could then respond to the translated components acting as an intermediate frequency filter.

Finally, we use the 3rd order nonlinear behavior of the micromechanical system to demonstrate entrainment of mechanical oscillations to a stable frequency reference. By detuning the natural frequency of the injection locked resonator, we create a RF MEMS oscillator whose output phase and frequency can be continuously controlled [3].

These components would form the basis for a radio frequency communication receiver. Current research is focused on integrating the silicon-based mechanical resonators with standard transistor-based electronics into an integrated circuit fabrication process.

These elements can form the basis of a radio frequency receiver. Current research is focused on implementing micromechanical signal processing along with corresponding solid-state devices into an integrated circuit process.

References:
Figure 1, top right:
A shell-type micromechanical resonator is used as the frequency-determining element for RF signal processing. A 50 Ω gold resistor is used to produce high frequency motion from an applied electrical signal.

Figure 2, below right:
Positive feedback applied to the driving resistor will set the mechanical resonator into limit cycle oscillations where the free running frequency and phase can be controlled by DC voltage.

Figure 3, below left:
A micromechanical mixer. The 50 Ω broadband input impedance allows down conversion from GHz frequencies.