Modeling of MEMS resonators: Physics meets application requirements

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Microresonators offer promise to integrate bulky analog and RF components on-chip enabling smaller form and reduced system cost. MEMS resonators have been proposed as one-to-one replacements of macroscopic components such as quartz crystals and SAW filters. Microresonator based oscillators have been demonstrated to meet the stringent phase noise requirements of reference oscillators for wireless communication systems, and resonators have been demonstrated to reach frequencies of over 2 GHz. While small may be desirable, scaling down the resonator also has unavoidable physical limits. The research work of past years allows critical evaluation of these limits and provides tools to analyze feasibility of different microresonator applications.

In this course, we will cover the microresonator basics with the goal of understanding what are the practical applications and limitations of the resonators. We start by modelling of the mechanical resonator with the goal of representing the mechanical resonator as a circuit element (LRC resonator). First, the distributed resonator vibrations are represented with a lumped element. Next, electromechanical coupling mechanisms (capacitive and piezoelectric) are introduced and compared. The theory is expanded to include second order effects such as electrostatic spring softening and nonlinear spring effects. As nonlinear effects effectively set the resonator power handling capacity, the estimation of the nonlinear limit is of fundamental importance for estimating the fundamental limits for miniaturization. Finally, the mechanical resonator and electromechanical transduction models are combined to an electrical equivalent circuit suitable for system design.

In the second part of the tutorial, we compare the model parameters (e.g. motional resistance Rm, electromechanical coupling coefficient kt2) for selected microresonators and commercial devices. These characteristics are compared to application specific criteria.