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Design, fabrication, and design verification of 50-kHz CMUTs for high-intensity airborne ultrasound

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ABSTRACT

Capacitive ultrasonic transducers offer good sensitivity and wide bandwidth for airborne ultrasound applications. Capacitive micromachined ultrasonic transducers (CMUTs), which are fabricated using MEMS techniques, offer additional advantages including good control over material properties and feature size, permanently attached plates (membranes), and the option of vacuum-sealed cavities. This work describes the modeling, design, and design verification of CMUTs capable of generating high intensity 50-kHz ultrasound for applications such as generating directional audio using a parametric array. We described the device fabrication at the 2008 IEEE Ultrasonics Symposium. An equivalent spring and mass model describes the dynamic behavior of the CMUT plate. We assume the radiation impedance is the sole source of damping. We choose the plate dimensions for a desired resonance frequency and mechanical Q. Higher Q can give better sensitivity but less bandwidth. The parametric array application requires a center frequency of about 50 kHz and several kilohertz of bandwidth. The most important performance metric is the total source pressure for a given dc bias voltage and ac excitation.

The deflection due to atmospheric pressure is an important design consideration. We show that for Q below ~50 the static deflection causes in-plane stress (tensile forces described by a cubic spring constant) to dominate the deflection. We limit our designs to those that operate in the linear spring constant regime. Even designs with a Q of 100 offer sufficient bandwidth for the parametric array. Increasing Q and decreasing the gap size improves sensitivity but leaves less room for dynamic displacement. A better approach is to size the gap such that for given ac and dc voltages, the dynamic plate displacement equals a large percentage of the gap. Using this approach we show that the maximum pressure increases approximately with the product of the ac and dc voltages raised to the 1/3 power. For a 300-V dc bias and 300-V-peak ac excitation, this analysis estimates a maximum pressure of about 146 dB re 20 uPa at 50-kHz. We fabricated devices optimized for a 300-V ac and 300-V dc bias voltage. From impedance measurements and laser-interferometer velocity measurements, we extract the electromechanical model parameters that best fit the fabricated devices. We compare these model parameters with those in the design. This comparison shows good agreement for capacitance, equivalent spring-constant and mass but larger-than-expected damping. The increased damping is likely due to losses in addition to radiation impedance.