Frequency Response Limiting Factors for Single Element CMUTs in Non-collapsed Mode

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Microfabrication processes used to implement Capacitive Micromachined Ultrasonic Transducers (CMUTs) provide a large design space for performance optimization. Simple design guidelines become crucial to navigate this large design space for desired frequency response. A set of design guidelines based on single membrane and Bragg resonances was recently proposed for high frequency CMUT imaging arrays [1]. In this work, we experimentally investigate the validity of the proposed guidelines for single element CMUT arrays and further expand them to low frequency devices.

Single element high frequency (30-50MHz) and low frequency (1-5MHz) arrays were fabricated using low temperature Si_3N_4 membrane based process. The high frequency elements were populated with 1.2 µm thick square and circular membranes (15 µm width and diameter) and varying membrane spacing (square membrane d_m=21.4 and 25 µm, circular membrane d_m=17 and 18.8 µm). The low frequency arrays were populated with 1.3 µm thick square membranes of 63 µm, 70 µm and 78 µm width and constant membrane spacing (d_m=5 µm). To clearly differentiate between Bragg and membrane resonance limits and compare with the model, admittance measurements were conducted in a liquid with acoustic impedance similar to water but half the speed of sound (FC-70, c_0=691 m/s, ρ=1940 kg/m^3).

Three limiting factors were found to determine the frequency band of the CMUT array operation. For low frequency arrays fractional bandwidths in excess of 140% were achieved limited by first (low limit) and second (high limit) symmetric membranes resonances of the fluid loaded single membrane even in a slow fluid like FC-70. In contrast, the specific high frequency arrays had high frequency limits determined by the Bragg resonance (c_0/d_m) as confirmed for arrays with the same membrane size but different membrane spacing. The results indicate that these simple design guidelines are applicable across a wide frequency range and different membrane geometries.

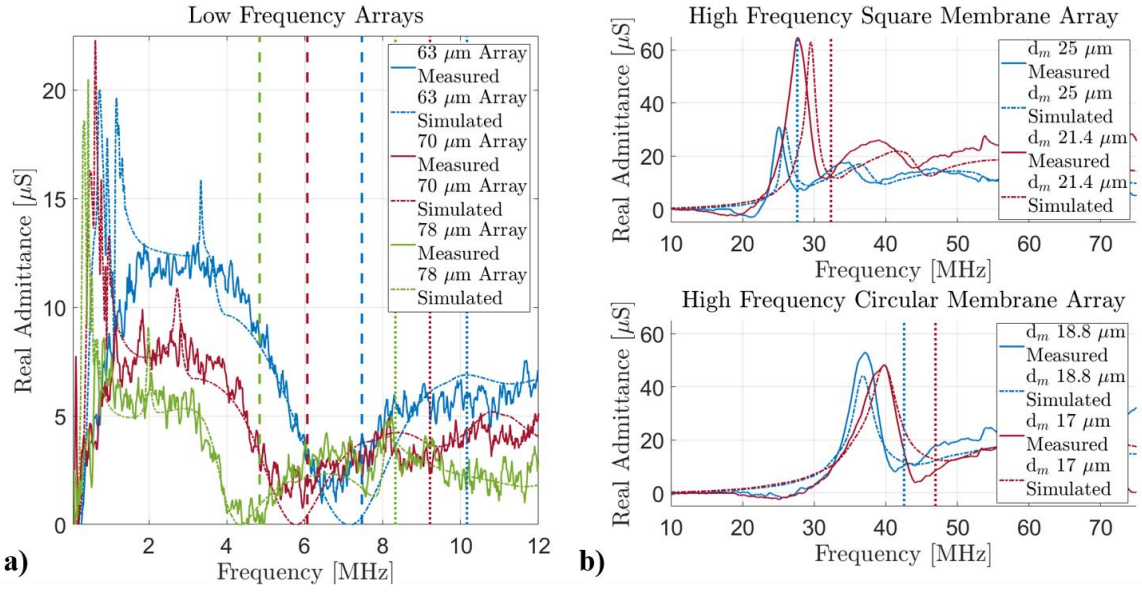

Figure 1: Real admittance of **a)** low frequency and **b)** high frequency CMUT arrays in FC-70. The upper frequency limitation frequencies are denoted as dashed lines for 2nd symmetric membrane mode and dotted lines for Bragg resonance.

[1] E. F. Arkan, and F. L. Degertekin, "Analysis and Design of High-Frequency 1-D CMUT Imaging Arrays in Noncollapsed Mode," *Ieee Transactions on Ultrasonics Ferroelectrics and Frequency Control,* vol. 66, no. 2, pp. 382-393, Feb, 2019.