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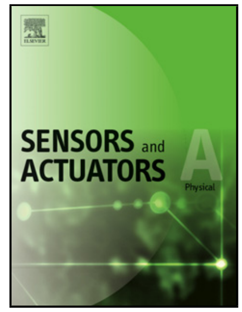

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Probe development of CMUT and PZT Row–Column-Addressed 2-D Arrays

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Abstract

This paper presents the characterization of two prototyped fully integrated 62+62 row–column-addressed (RCA) 2-D transducer array probes which are based on capacitive micromachined ultrasonic transducer (CMUT) and on piezoelectric transducer (PZT) technology, respectively. Both transducers have integrated apodization to reduce ghost echoes and were designed with similar acoustical features i.e. 3 MHz center frequency, $\lambda/2$-pitch and $24.8 \times 24.8\,\text{mm}^2$ active footprint. The transducer arrays were assembled in a 3-D printed probe handle with electromagnetic shield and integrated electronics for driving the 128-channel coaxial cable to the scanner. The electronics were designed to allow all elements, both rows and columns, to be used interchangeably as either transmitters or receivers. The transducer characterization i.e. bandwidth, phase delay, surface pressure, sensitivity, insertion loss, and acoustical crosstalk, were based on several single element measurements, including pressure and pulse-echo, and were evaluated quantitatively and comparatively. The weighted center frequency was 3.0 MHz for both probes and the measured $-6\,\text{dB}$ fractional bandwidth was $109 \pm 4\%$ and $80 \pm 3\%$ for the CMUT and the PZT probe, respectively. The surface pressures of the CMUT and PZT were $0.55 \pm 0.06\,\text{MPa}$ and $1.68 \pm 0.09\,\text{MPa}$, respectively, and the receive sensitivities of the rows (receiving elements) were $12.9 \pm 0.7\,\mu\text{V/Pa}$ and $13.7 \pm 2.1\,\mu\text{V/Pa}$.

Keywords: CMUT, PZT, Row–column-addressing, Ultrasound, Volumetric Imaging

1. Introduction

For the last 30 years, time resolved 3-D (4-D) imaging has received considerable interest, since it offers several advantages over conventional 2-D imaging. Images acquired using a traditional 2-D probe are dependent on position and scan angle. This makes some imaging planes inaccessible due to the anatomy of the human body. Volumetric imaging does not have the same drawback, since any view angle is possible from the volume data. It also offers more accurate estimation of the size of organs, cysts, and tumors without relying on the assumptions and the operator skills needed when using 2-D imaging estimations.

To obtain real time-resolved volumetric imaging with frame rates higher than 20 Hz, 2-D transducer arrays are necessary [1, 2]. Such transducers were first seen in the early 1990s [3]. By placing the elements in a rectangular grid, the beam can be steered electronically in two perpendicular directions (azimuth and elevation) and hereby acquire data from a volume. To obtain an image quality similar to that of a 1-D transducer, the same number of elements in both lateral dimensions is needed. A 1-D array of 128 elements would translate into $128 \times 128 = 16,384$ elements in a 2-D matrix array. From a transducer fabrication perspective, this poses a great challenge for providing electrical connections to all the elements while maintaining a high element yield. The interconnecting wires between the 16,384 elements and the ultrasonic system result in a large, heavy cable, which excludes it from any practical use.

The issue of reducing channel counts, whilst maintaining the size of the array aperture, was addressed in the earlier versions of 2-D matrix arrays by introducing sparse arrays. Here only a subset of elements is active at the same time. Amongst these are Mills cross arrays, random arrays, and Vernier arrays, each presenting their benefits and drawbacks [4–8]. However, all of them suffer from reduced signal-to-noise ratio (SNR), due to the reduced active area, and they introduce higher sidelobes and/or grating lobes. Recently, fully populated arrays with reduced channel count have become available by integrating electronic pre-beamformers inside the transducer probe [9–11]. Approaches to include the integrated circuit (IC) directly on a capacitive micromachined ultrasonic transducer (CMUT) has also been investigated, both by flip-chip bonding the CMUT to the IC [12–14] and by monolithically integrating the CMUT on the CMOS [15, 16]. Integrating the electronics in the handle can result in much fewer signals to be funneled out to the ultrasound scanner. An example of such a state-of-the-art fully populated matrix transducer, is the X6-1 PureWave xMATRIX Array from Phillips (Eindhoven, Netherlands), with 9,212 elements. Despite the recent advances in real-time 3-D ultrasound imaging, the ultrasound systems supporting such imaging modalities are highly advanced and rely on cutting edge software, hardware, and manufacturing technology. This results in expensive equipment that impairs the low-cost advantage of ultrasound, and