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ACOUSTIC CHARACTERISATION OF A 32×32 ELEMENT PZT-ON-ASIC MATRIX TRANSDUCER FOR 3D TRANSESOPHAGEAL ECHOCARDIOGRAPHY

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ABSTRACT

Echocardiography is a portable, safe, and low-cost imaging technique for accurate assessment of the heart. In transesophageal echocardiography (TEE) the esophagus is utilized as the imaging window to examine the cardiac anatomy and function. In conventional TEE probes, a one-dimensional (1D) ultrasound array is employed to obtain two-dimensional (2D) cross-sectional images of the heart. Since cardiac morphology, leakage of valves and function of the outflow tracts are all three-dimensional (3D) phenomena, it is beneficial to interpret them from 3D images. Therefore, there is high clinical demand for matrix TEE probes that are capable of providing real-time volumetric images [1]. Several matrix arrays (Philips X7-2t, Siemens V5M TEE, General Electric 6VTD) have been developed for this purpose, however all of them are large in size (~10 cm³) and uncomfortable to use on non-anesthetized patients [2]. We aim to develop a matrix TEE probe with a small head volume (<1 cm³), which is suitable for long term monitoring of cardiac system on adults and in babies.

We have developed a prototype of a small matrix TEE probe, which consists of a piezoelectric matrix transducer directly mounted on an Application Specific Integrated Circuit (ASIC) [3]. The ASIC performs the task of micro-beamforming, signal amplification and efficient data reduction. The piezoelectric matrix array consist of a 32×32 PZT elements with a pitch of 150 μm × 150 μm. The transmit aperture consists of 8×8 elements at the centre of the array, which are directly wired out to the ultrasound system. The remaining 864 elements are used in receive and are organized in 96 sub-arrays of 3×3 elements to reduce the cable count with a factor of 9. The signals from the individual elements in a sub-array are combined to a single output signal using a micro-beamformer on the ASIC. The micro-beamformer allows pre-steering of 0°, ±17°, and ±37° angles in both lateral and elevation directions. By recording datasets for different pre-steering angles, and by processing and combining them, a large volume image can be constructed.

Acoustic performance of the prototype is evaluated in a water tank. The transmit transfer function of a single element is measured by applying a 20 cycle sinusoidal voltage, sweeping from 3 to 8 MHz with steps of 50 kHz. The output pressure is recorded by a calibrated hydrophone. It is found that the transducer has a central frequency of 5 MHz, a bandwidth of 40% and a transmit efficiency of 6.4 kPa/V (at 51 mm). To characterize the micro-beamforming function, three delay angles of 0°, 17° and 37° were programmed. While transmitting with a well-defined external source, the output voltage from a sub-group was recorded from -50° to +50° degrees. We observe that the theoretical values of the beam profile agree well with the measurement results, especially with regard to the position of the grating lobes and side lobes.

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- [1] S. Salgo, "Three-dimensional echocardiographic technology," *Cardiol. Clin.*, vol. 25, pp. 231–239, May 2007.
- [2] W. G. Daniel et al., "Safety of transesophageal echocardiography. A multicenter survey of 10,419 examinations," *Circulation*, vol. 83, pp. 817–821, 1991.
- [3] C. Chen, S.B. Raghunathan, Z. Yu, M. Shabanimotlagh, Z. Chen, Z.Y. Chang, S. Blaak, C. Prins, J. Ponte, E. Noothout, H.J. Vos, J.G. Bosch, M.D. Verweij, N. De Jong, M.A. Pertijs, "A prototype PZT matrix transducer with low-power integrated receive ASIC for 3-D transesophageal echocardiography" *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 63 (1) pp. 47-59, 2016.

Acoustic Characterization of a 32x32 element Matrix Transducer for 3D TEE

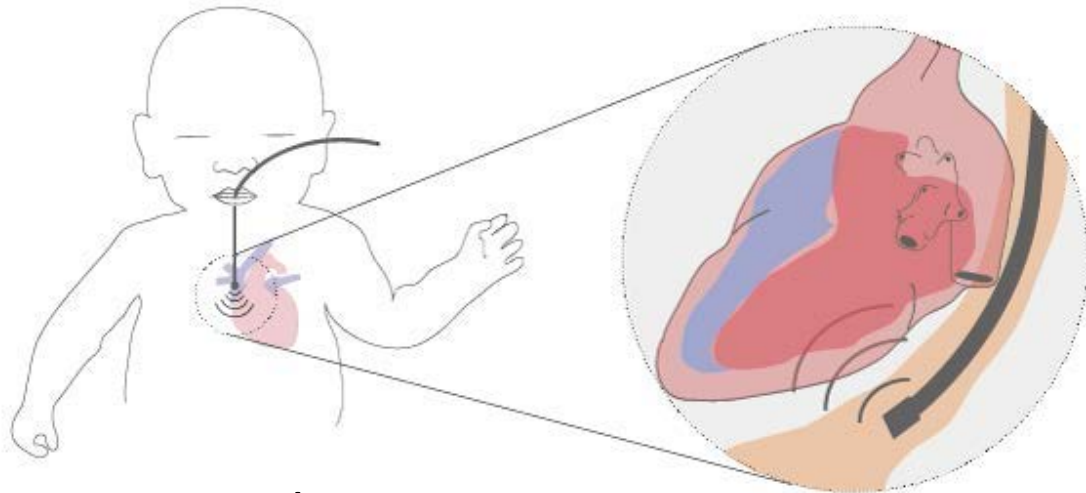
Maysam Shabanimotlagh, Shreyas Raghunathan, Deep Bera, Chao Chen, Zhao Chen, Varya Daeichin, Emile Noothout, Zu-yao Chang, Henrik Vos, Christian Prins, Jacco Ponte, Johan Bosch, Michiel Pertijs, Nico de Jong, Martin Verweij

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Jan 2017

Introduction – TEE Probes

- Uses the esophagus as the imaging window
- Adult probe: For 3D real time imaging
 - Relative large size of probes
 - Used exclusively in adults
 - Short duration: to limit patient discomfort
- Baby probe: capable of making 2D images

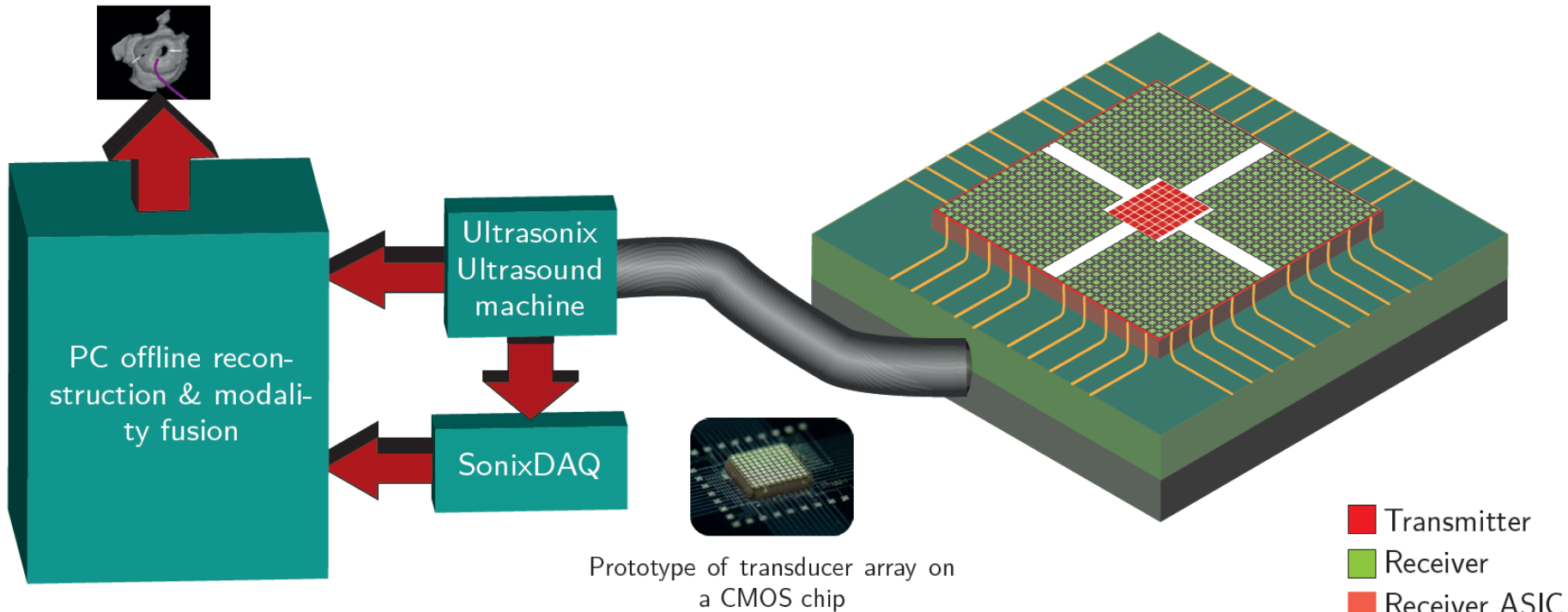


Research motivation:

A miniature ultrasound for real-time 3D cardiac imaging in adults, neonates, children

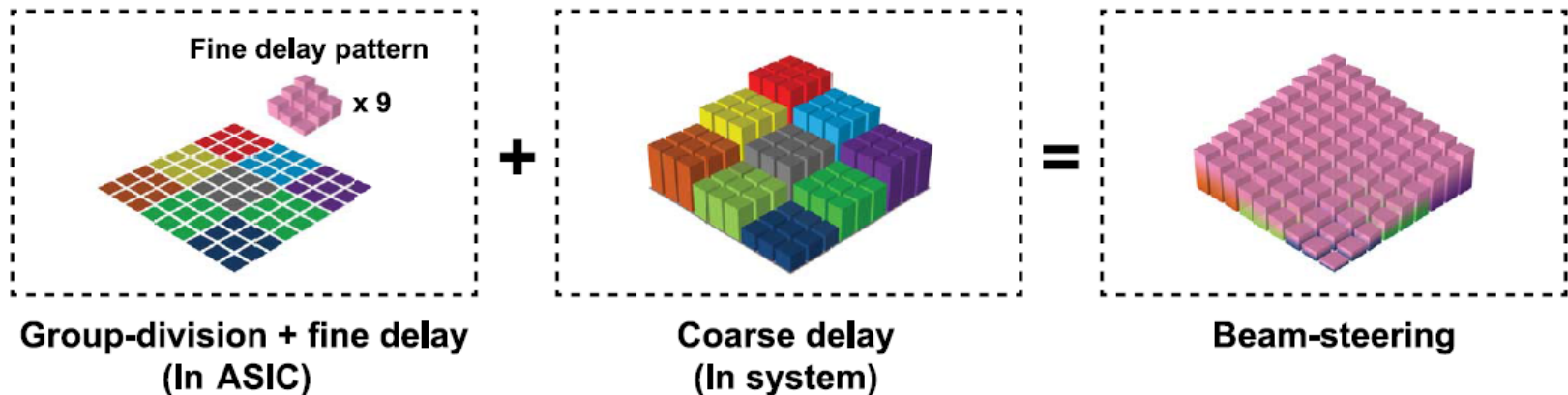
Design requirements

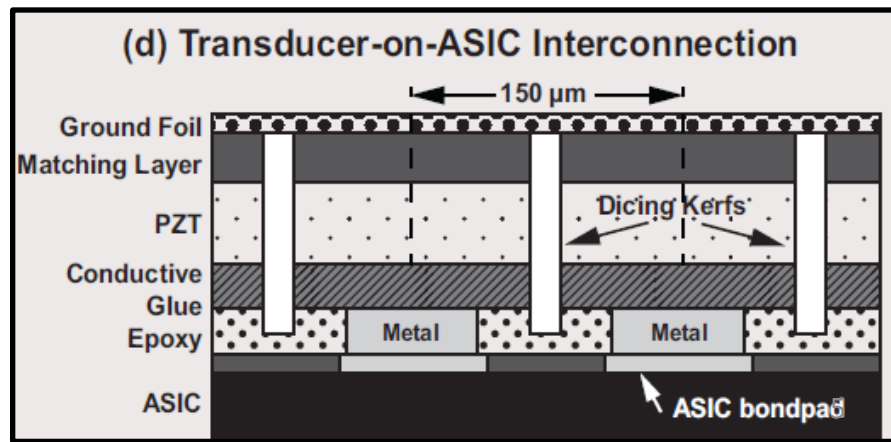
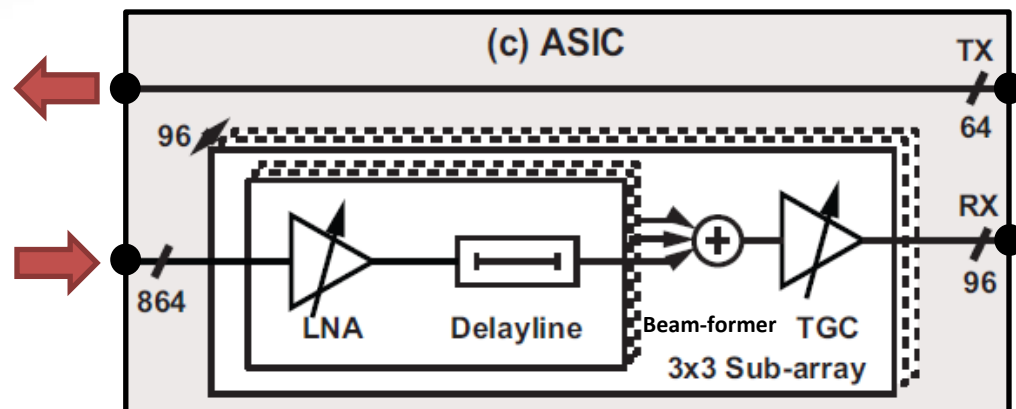
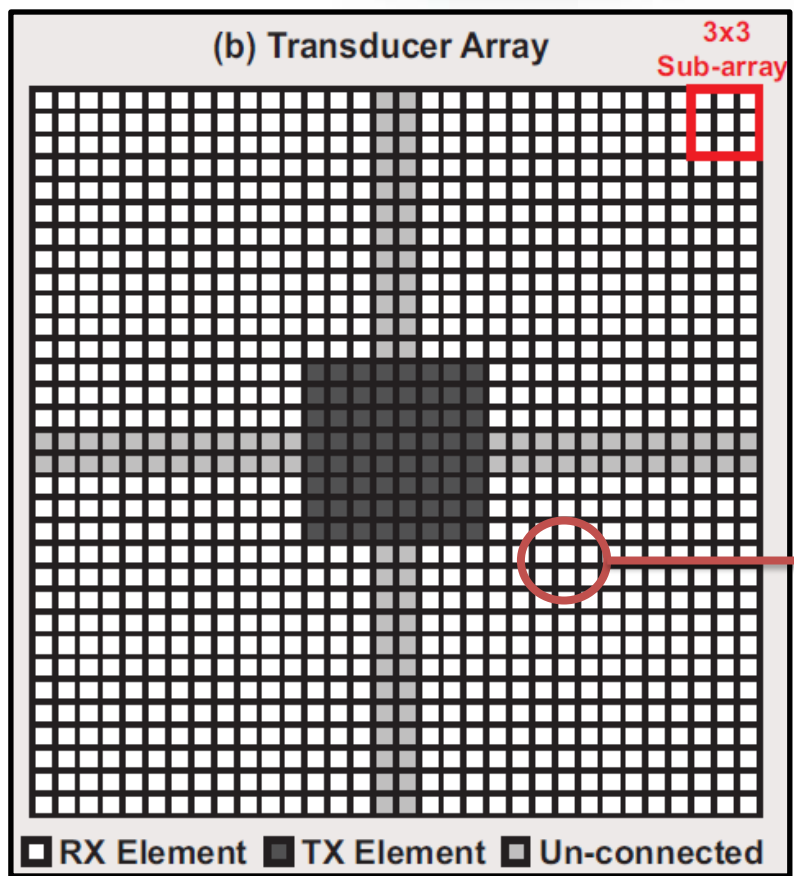
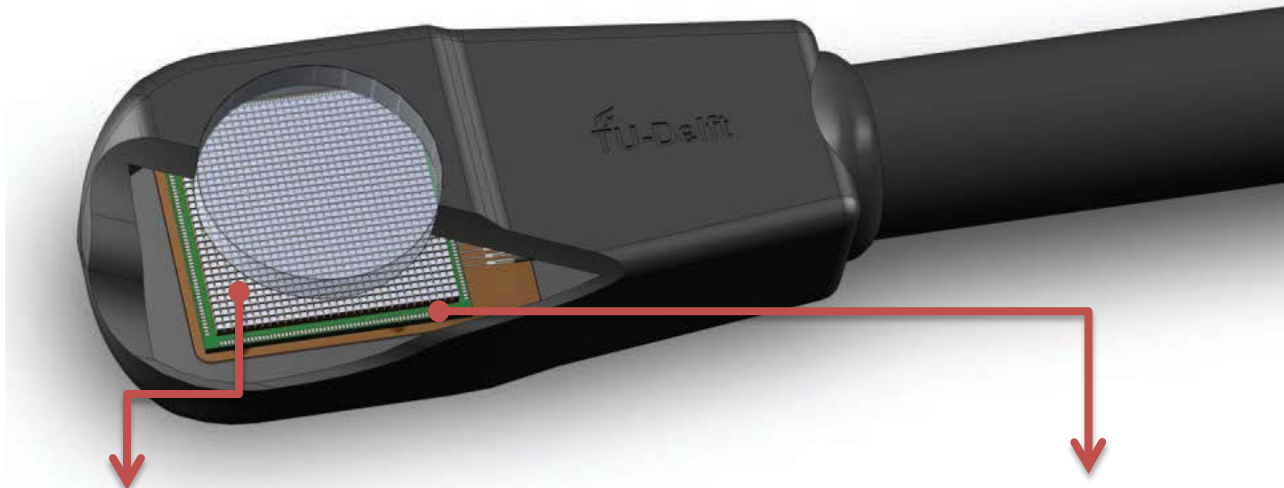
- Head Volume: less than 1 cm³
- Less than 200 individual cables in the shaft
- Surface Area of the matrix: 5 × 5 mm²
- Intended penetration depth for cardiac imaging: 3–12 cm.
- Allowable Surface Temperature < 41 °C



Design Choices

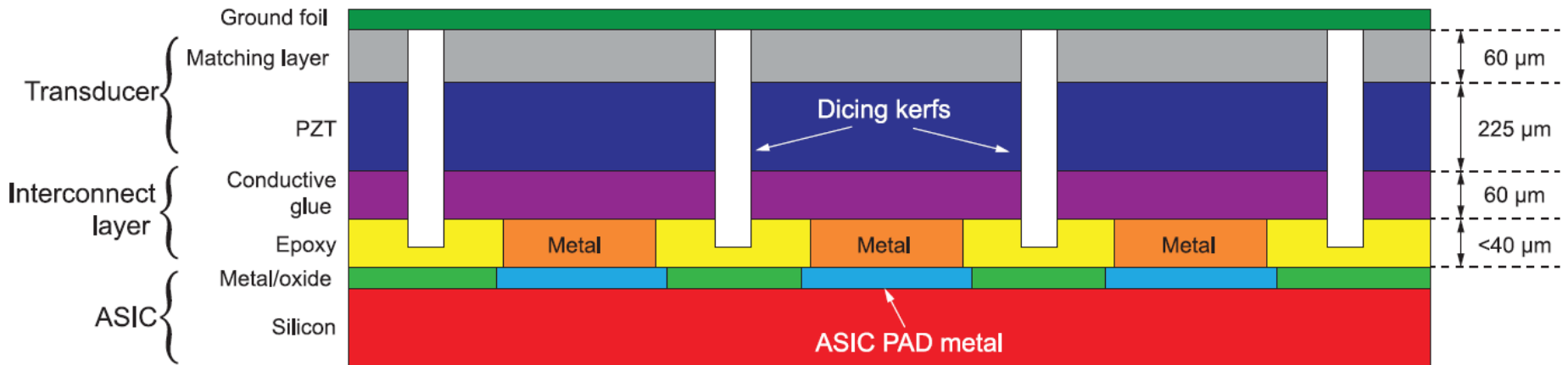
- 32×32 PZT array.
 - Transducer pitch: $150\ \mu\text{m} \times 150\ \mu\text{m}$.
 - Centre Frequency of 5MHz.
 - Bandwidth $\approx 50\%$.
 - Steering angles: $0, \pm 17^\circ, \pm 37^\circ$ in both x, y directions.
- Application Specific Integrated Circuit (ASIC): Reduce the cable count and local signal processing.
- Partitioned design: Separate transmitter and receiver.
- Group 3x3 element for 2 stage beamforming:





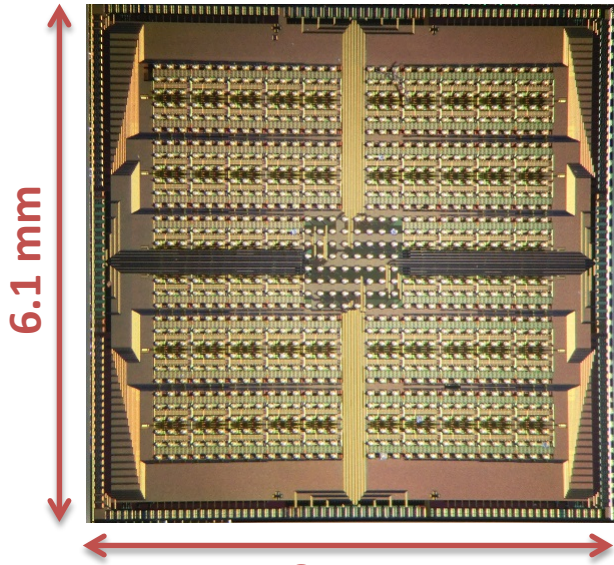
Acoustical Design of Transducer

PZFlex simulation model for optimization the acoustic stack:

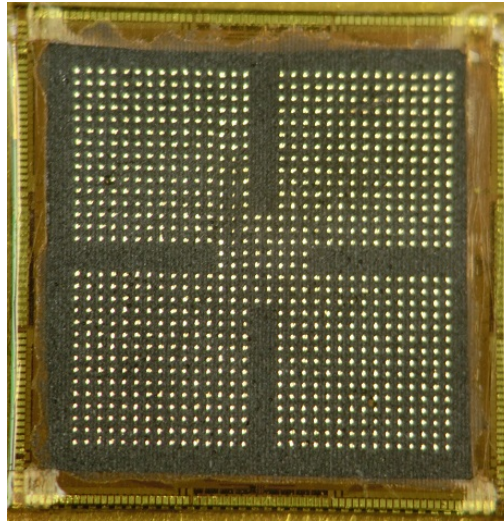


Manufacturing steps

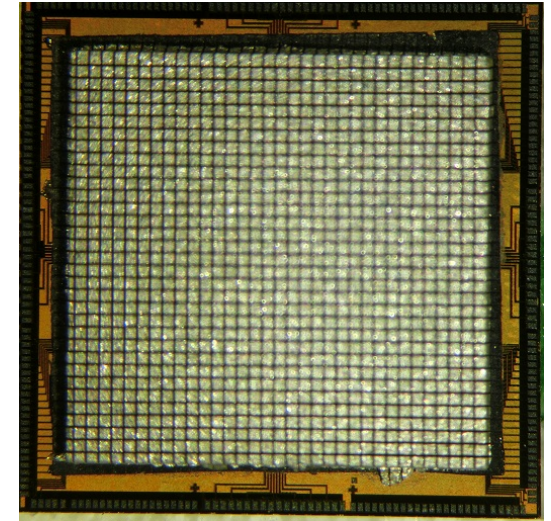
Die



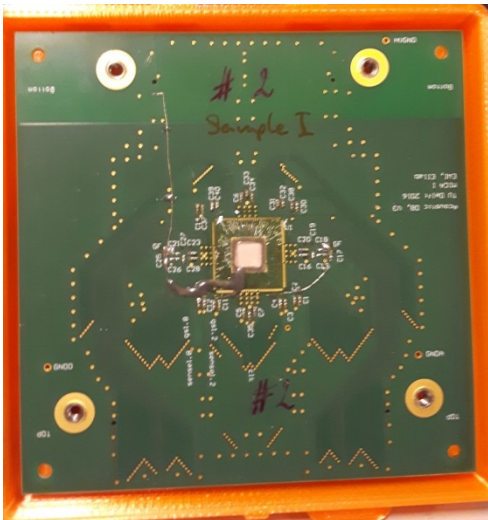
Electrical Connections



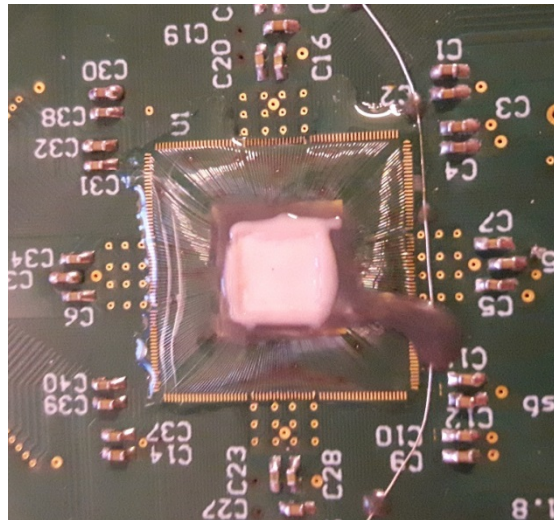
Transducer Elements



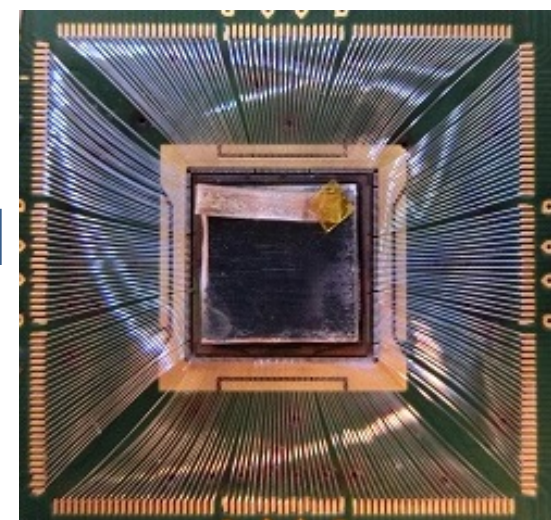
Ready for Measurement



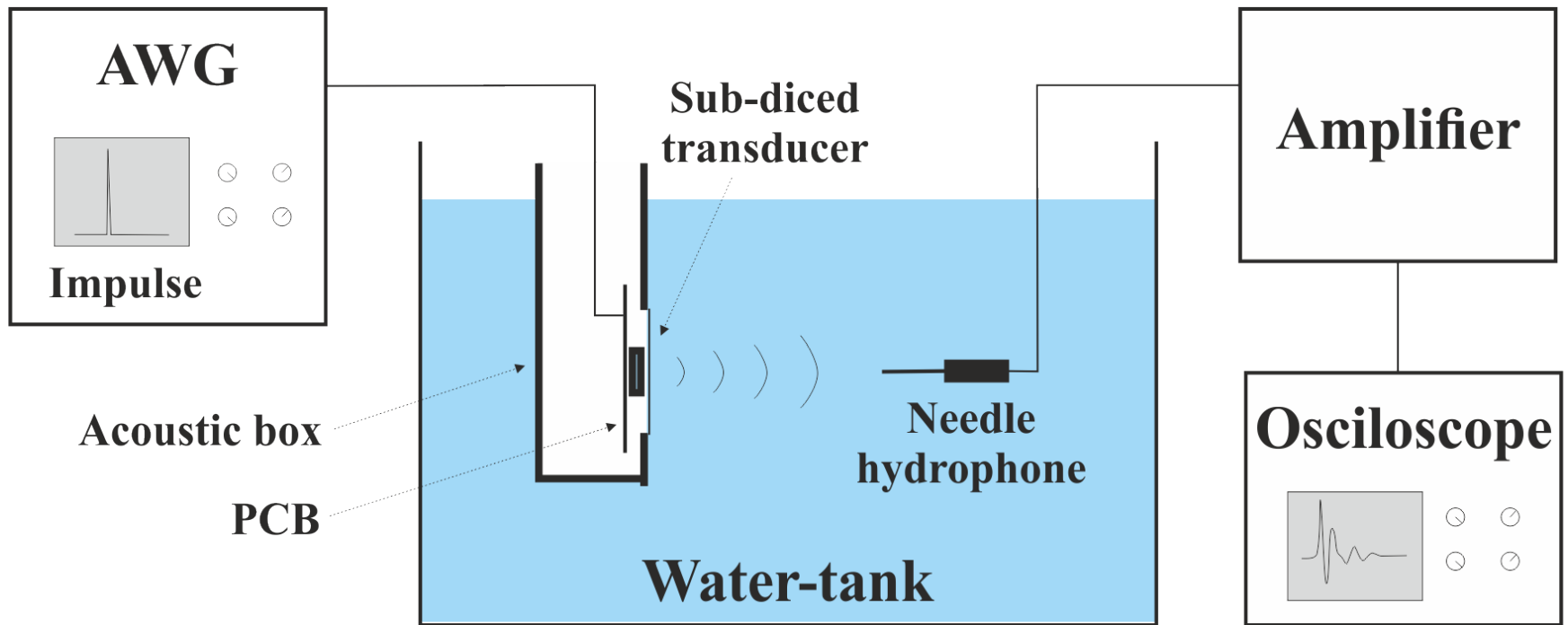
Apply Epoxy



Wire Bonding

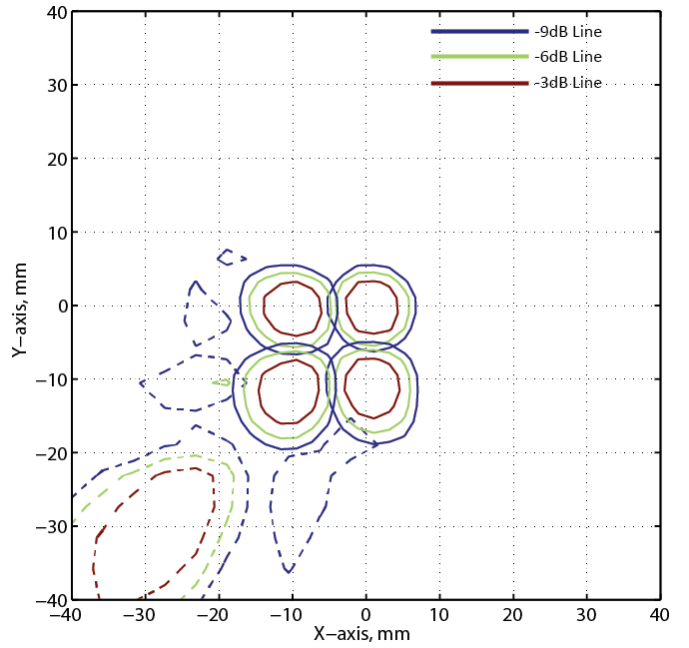


Measurement setup

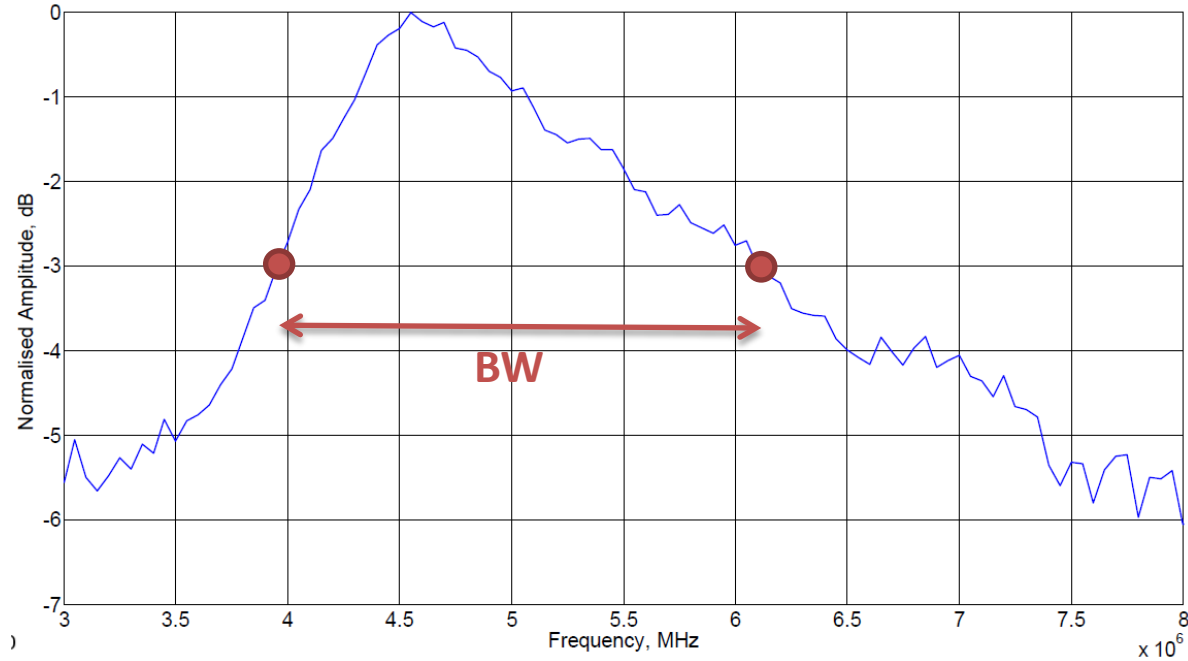


Results - Transmitter

Steering capabilities of the transmitter



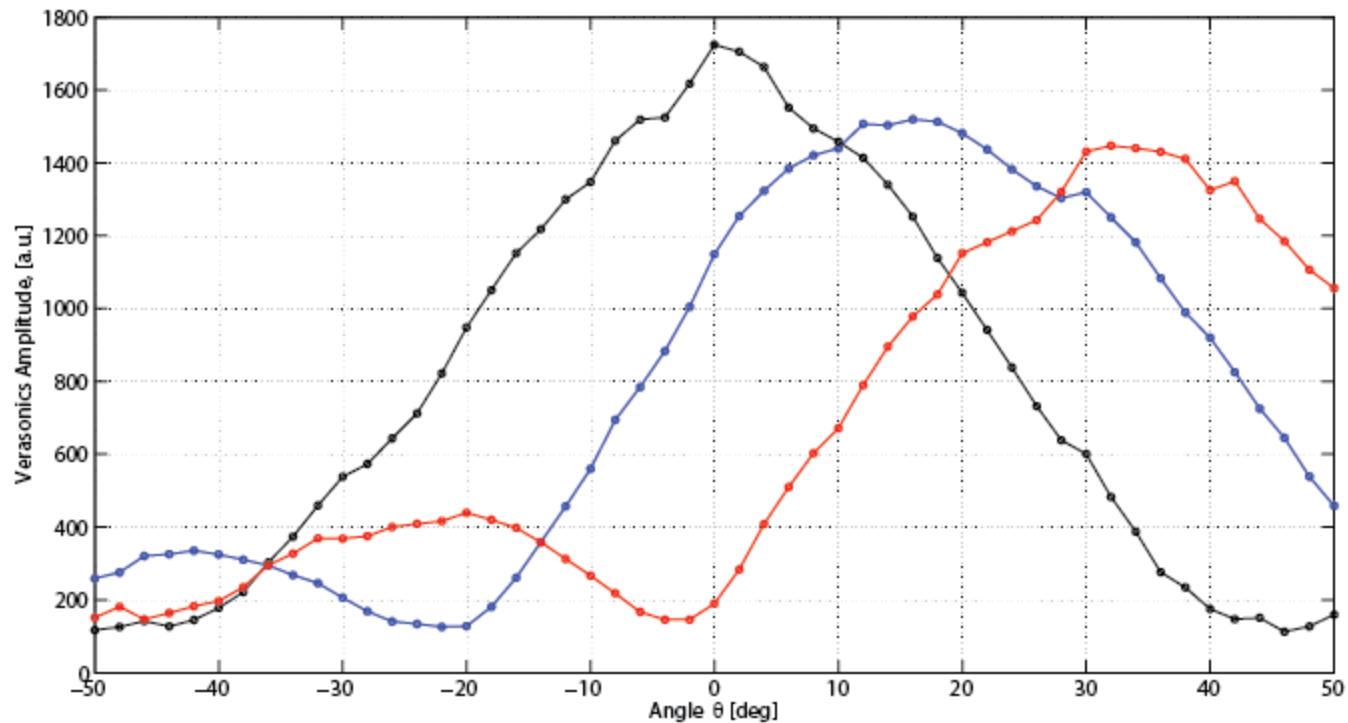
Frequency response of the acoustic stack



Centre Frequency: 5 MHz
Transmit Efficiency: 6.4 kPa/V at 51mm.
Bandwidth: $\approx 40\%$.

Results – Receiver

Beam profile of a sub-group: Steered to 0°, 17° and 37°



Receive Sensitivity: 5 $\mu\text{V}/\text{Pa}$.

Preliminary Results – Phantom image



Phantom configuration:

- 7 point scatterers (steel balls) at 34 mm
- 169 tx-rx events

Reconstruction:

- DAS on micro-beamformed datasets
- Reconstruction angle = $\pm 45^\circ$
- 65x65 image lines

Conclusions

- Designed and manufactured a 32×32 PZT-on-CMOS matrix transducer for 3D TEE.
- ASIC reduces the channel count by a factor of 9.
- Illustrated the imaging capabilities of this 3D TEE prototype.

Thanks!

