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Fabrication and Characterization of a Prototype Forward-Looking Single-Cable 64-Element Intra-Vascular Ultrasound Probe

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***Abstract*—This paper presents the integration steps towards a prototype forward-looking intra-vascular ultrasound probe. An ASIC (Application Specific Integrated Circuit) is laser cut to create a 1.6 mm circular shaped die that can be integrated at the tip of a small catheter. The ASIC is designed such that it can be used to transmit and receive on 64 piezo-electric transducers while using a single cable for the supply, communication, transmit signals and amplified receive signals. Piezo elements are directly integrated on top of the ASIC to create a miniature probe. Electrical tests show that the circuitry still operates correctly after laser cutting. The functionality of a prototype has been successfully demonstrated in a 3D imaging experiment.**

***Index Terms*—Laser cutting, intra-vascular ultrasound, front-end ASIC, cable count reduction, single cable, integration**

I. Introduction

Ultrasound imaging is crucial for minimally-invasive interventions: it is safe, cheap, and can provide real-time imaging at the tip of a catheter. One of the main challenges in realizing 3D catheter-based ultrasound probes is to interface the transducer elements to an imaging system using a small number of cables, in order to facilitate a flexible probe shaft and to leave room for other required pieces (guidewire, optical fiber, etc.). Moreover, integrating the transducers and ASIC in the limited space available in the lumen of a catheter poses challenges on the probe fabrication.

Prior work has shown integration of transducers in a circular shape by dicing them on a flat surface and then bending them around the circular lumen of a catheter [1]. An alternative approach is presented in [2] where etching is used to cut the ASIC into a circular shape. To address this integration challenge, we have developed an application-specific integrated circuit (ASIC) of 1.5 mm diameter that interfaces 64 transducer elements using only a single coaxial cable. The elements are mounted directly on top of the ASIC to realize a forward-looking device. By using a single cable the integration is greatly simplified as it only requires two connections to be made with the coaxial cable. In previous work [3], we have demonstrated results obtained with a square diced ASIC mounted and wire-bonded on a printed-circuit board. In this work, we present results of a prototype in a form to be used in catheters for (pre-)clinical applications.

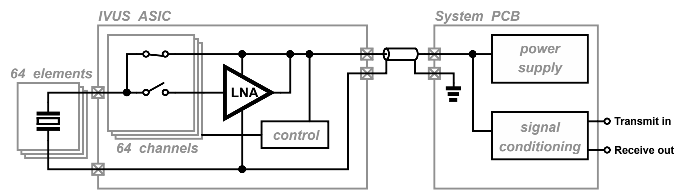


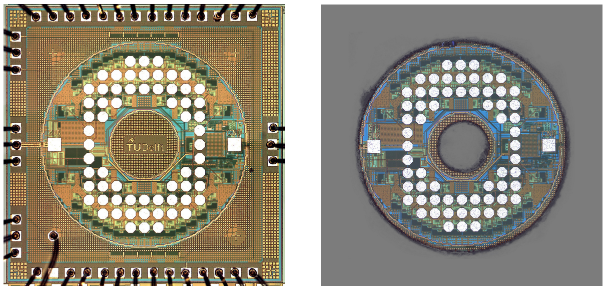
Fig. 1: Block diagram of the single cable ASIC.

II. ASIC implementation

An ASIC has been developed that is able to perform imaging experiments using 64 piezo elements while operating using a single coaxial cable. Fig. 1 shows a block diagram of the circuit. To transmit an acoustic pulse, one or multiple of the 64 transducers elements can be connected to the cable with a transmit switch, to pass a unipolar transmit signal of up to 30 V. In receive a transducer element can be switched to a low noise amplifier (LNA) that amplifies and buffers the signal in order to prevent the cable from loading the transducer and degrading the echo signal received by the transducers. A control circuit sets the transmit and receive switches on the ASIC according to the chosen imaging scheme. The switches can be programmed by super-imposing pulse-width modulated data onto the power supply of the ASIC.

III. Fabrication

The ASIC has been fabricated in TSMC 180nm BCD technology using a multi-project wafer service, and arrives from the foundry diced into a square shape of 2×2 mm. To allow the ASIC to be mounted on a catheter, it is laser cut into a circular shape with a hole in the middle for a guidewire (outer diameter: 1.6 mm, hole diameter: 0.4 mm).



(a) (b)

Fig. 2: Die micrograph of (a) uncut ASIC and (b) laser cut ASIC.

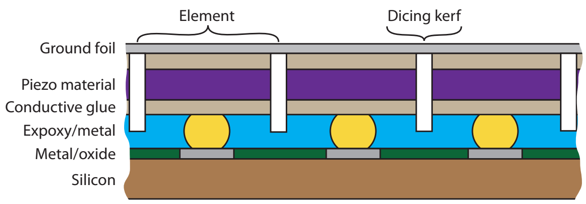


Fig. 3: Cross-sectional drawing of piezo-on-ASIC integration.

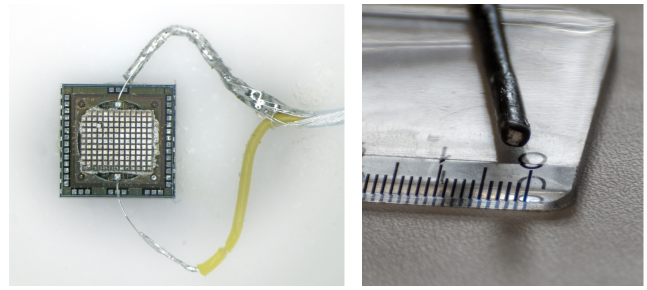
A Talon UV laser (355 nm) was used to cut the silicon die. Several small cutting passes are performed to prevent overheating and damaging the ASIC, resulting in a total cutting time per ASIC of about 80 s. Fig. 2 shows a die micropgraph of the ASIC before and after laser cutting. The circular sealring in the ASIC layout prevents the circuit from deteriorating over time. The two square bondpads inside the circular sealring are the connections to the cable, the octagonal bondpads are used for the piezo transducers. The bondpads on the edge that were removed by cutting the ASIC, are intended for test purposes only.

A piezo stack was mounted on top of the ASIC and diced into a matrix of elements with a pitch of 100 µm. Each element is directly connected to circuitry on the ASIC by a wire-bonded gold-ball, as shown in Fig. 3 and discussed more elaborately in [4]. A single micro-coaxial cable was connected to the ASIC (Fig. 4a) and used for powering and controlling the device, as well as transmitting and receiving the ultrasound pulses as discussed in section II. The device was mounted at the tip of a small cylindrical holder to mimic the tip of a catheter (Fig. 4b). The end of the tube was coated in black silicone rubber to make the prototype water tight.

IV. Electrical Characterization

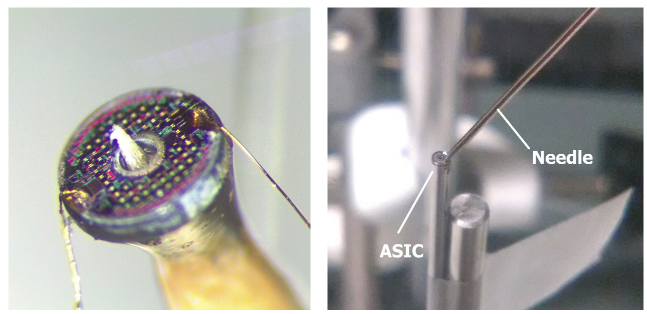
The laser-cut ASIC was first tested electrically by mounting it on a cylinder, without the piezo transducers, and then probing the transducer bondpads with a needle as shown in Fig. 5. The signal on the bondpads was measured with the transmit-switch turned on and off. Fig 6 shows the 3-cycle transmit signal on the same bondpad with the transmit switch in on and off state.

The electrical tests show that the performance of the ASIC does not degrade by the laser cutting process.



(a) (b)

Fig. 4: (a) Intermediate fabrication step and (b) ASIC integrated on a steel tube (on metric ruler).



(a) (b)

Fig. 5: (a) Lasercut ASIC being mounted to the coaxial cable and (b) electrical testing using a needle to probe.

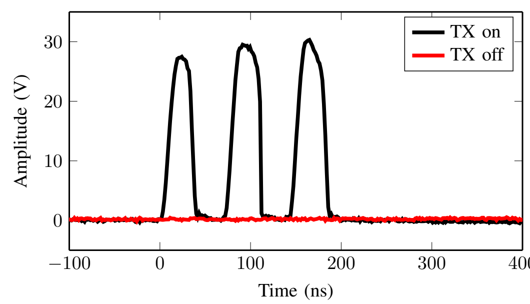


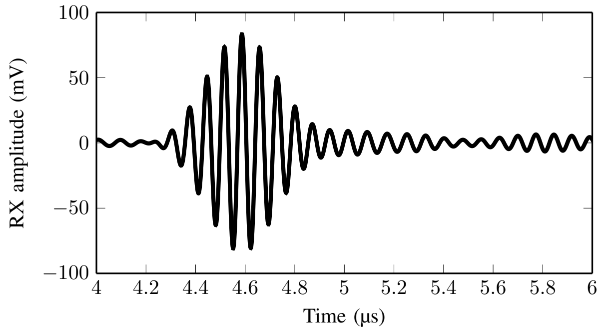
Fig. 6: Electrical measurement of a 3 cycle transmit pulse with the transmit switch on and off.

V. Experimental Results

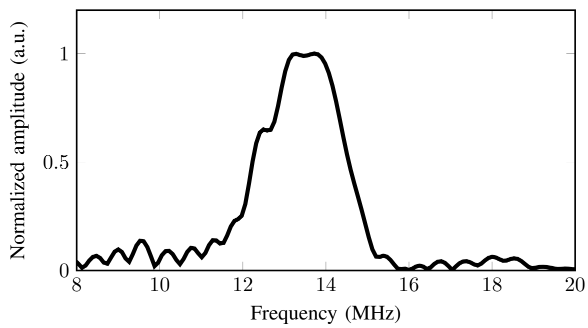
To measure the performance of the ASIC in its intended application, the ASIC was connected to the system side circuit using a single 1.5 m long AWG-42 coaxial cable.

For acoustic characterization, the prototype probe was put with its tip in a water tank in which a hydrophone was placed. The hydrophone measurements show that the transducer center frequency is about 14 MHz and the -6 dB bandwidth is 45%. The hydrophone measurements also show that almost all elements were working, with a transmit sensitivity up to 0.70 kPa/V at 5 mm distance.

Fig. 7 shows the received signal of a pulse-echo measurement with a plate reflector in time and frequency domain, for



(a)



(b)

Fig. 7: RX waveform from pulse-echo measurement in (a) time and (b) frequency domain.

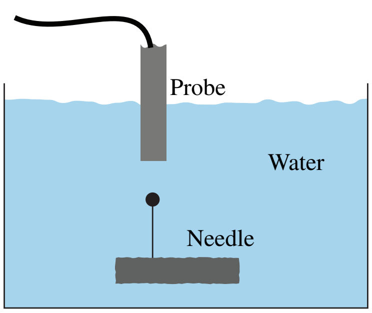


Fig. 8: Watertank with needle phantom in front of the probe.

a 3-cycle transmit pulse, which is commonly used in imaging.

A needle phantom was then placed, as shown in Fig. 8, located at a depth of 9 mm from the transducer array. An imaging experiment was performed by successively pulsing the 64 elements and successively capturing the echoes received by all 64 elements. A projection of the volumetric image was obtained with a full synthetic aperture acquisition scheme. The image, shown in Fig. 9, clearly shows the needle placed in front of the array. The artefacts visible in the image are to be expected for the regular array topology and smaller aperture in one direction, with the chosen imaging algorithm.

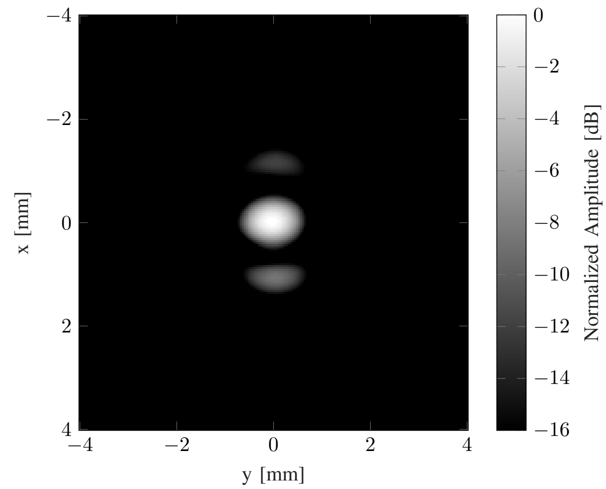


Fig. 9: Maximum projection of a 3D image of a single needle, reconstructed using synthetic aperture beamforming.

VI. Conclusion

This work shows that a miniature single cable probe can be fabricated by laser cutting the silicon die. Measurements have shown that the ASIC remains fully functional after laser cutting.

With a prototype probe we were able to successfully image spheres using synthetic aperture beamforming. These initial imaging results demonstrate the feasibility of 3D forward looking ultrasound imaging through only a single cable addressing a total of 64 elements via the laser-cut ASIC.

Acknowledgment

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