Frequency-tunability of a collapse-mode CMUT: from modelling to pre-clinical imaging

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Martin Pekař[1,2], Nenad Mihajlović[1], Alexander F. Kolen[1], Harm Belt[1], Jeannet van Rens[1], Frank Budzelaar[1], Bas Jacobs[1], Frank van Heesch[1], Wendy U. Dittmer[1], Debbie Rem-Bronneberg[1], Stephan H. M. van Nispen[3], Rob H. B. Fey[3], Sergei Shulepov[1], Henk Nijmeijer[3], Imo E. Hoefer[4], Tamas Szili-Török[2], Hendrik J. Vos[2,5], Johan G. Bosch[2], Gijs van Soest[2], Nico de Jong[2,5], Antonius F. W. van der Steen[2,5]

[1]Philips Research, Eindhoven, the Netherlands

[2]Erasmus MC, Rotterdam, the Netherlands

[3]Department of Mechanical Engineering, Eindhoven University of Technology, the Netherlands

[4]Faculty of Veterinary Medicine, Utrecht University, the Netherlands

[5]Dept. of Imaging Physics, Delft University of Technology, Delft, the Netherlands

E-mail: martin.pekar@philips.com

In intracardiac echocardiography (ICE) it might be beneficial to provide ultrasound images acquired at multiple frequencies to provide high resolution and high penetration combined in a single ICE catheter. The objective of the presented work is to investigate the feasibility of a frequency-tunable imaging with a capacitive micromachined ultrasonic transducer (CMUT) operated in a collapse mode.

We have developed a semi-analytic model of collapse-mode CMUT [1]. The modelled collapse-voltage is 59 V. Simulated impulse response predicts center frequency of 12.9 MHz and 16.6 MHz at a bias voltage of 100 V and 160 V, respectively. Experimental validation with a manufactured CMUT prototype [2] shows that the dynamic response and frequency-tunability are modelled with a satisfactory accuracy as shown in Fig. 1.

Further experimental studies show that the center frequency of a collapse-mode CMUT can be controlled between 8 MHz and 15 MHz, if the lower bias voltage range is extended and the driving pulse is optimized. Mechanically-scanned B-mode imaging is performed on a phantom at 8 MHz, 11 MHz, and 15 MHz as a first proof of principle of a frequency-tunable imaging with a collapse-mode CMUT [4].

A 2x2 mm^2 32-element phased-array CMUT is integrated with front-end electronics in a rigid probe prototype and connected to Verasonics system (Kirkland, WA, USA) for 2-D real-time imaging and data acquisition [4]. CMUT imaging performance is quantified in terms of resolution and penetration depth at a range of bias voltages, driving pulse frequencies, and number of pulse cycles. Based on this characterization settings for high-penetration, generic, and high-resolution imaging modes are identified. The first 2-D imaging results are shown.

The developed probe prototype is tested *ex vivo* in a passive heart platform [5]. Images of an aortic valve acquired in high penetration (6 MHz), generic (12 MHz), and high-resolution (18 MHz) mode combine satisfying image quality and penetration depth between 2.5 cm and 10 cm as shown in Fig. 2.

Next, the CMUT probe prototype is further miniaturized into a 12-Fr steerable, forward-looking ICE catheter. The ICE catheter prototype is tested *in vivo* using a porcine animal model [5]. Images of an aortic valve are acquired in the three imaging modes with the ICE catheter placed in an ascending aorta at multiple depths. It was found that the combination of the forward-looking design and frequency tuning capability allows visualizing intracardiac structures of various sizes at different distances relative to the catheter tip, providing both wide overviews and detailed close-ups.

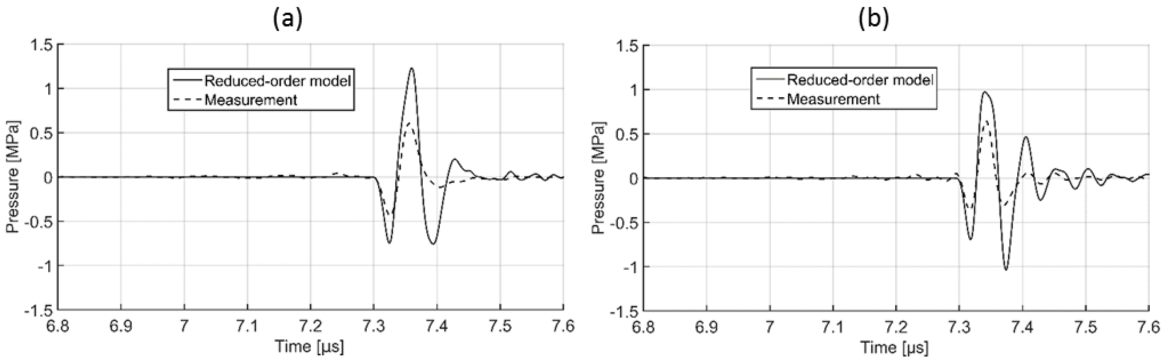

Fig. 1. Modelled and measured impulse response of a fluid-loaded CMUT array at a bias voltage of (a) 100 V and (b) 160 V.

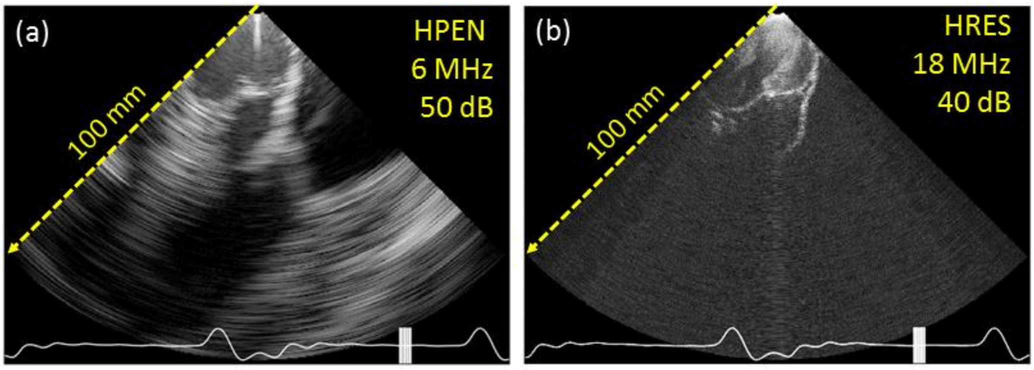

Fig. 2. Long-axis view of aortic valve obtained with the developed frequency-tunable, forward-looking, steerable CMUT catheter prototype *ex vivo*.

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