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Updated results on finite element modelling of a transmit-receive ultrasound measurement system. Comparison with experiments in air.

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The present paper represents an update from [1], based on the work in [2]. The background and motivation for this work are given in [2], and also in [1]. The system model theory, simulation setup and experimental setup are presented in [1, 2]. This summary presents results from [2] not shown in [1]. Comparison of simulation and measurement results for the voltage to voltage transfer function[1] has previously been presented in [2] and in part in [1]. This paper includes time-domain results, the results of an improved post-processing method for extracting the peak-to-peak voltage from the measured signals, and includes electrical components in the system model.

In Fig. 1, two measurements with different generator excitation voltage (V_{pp}) are compared to the simulated voltage to voltage transfer function calculated using the finite element based system model. The transfer function is defined as

$$H^{VV}_{0m6,\alpha} = \frac{V_{6,\alpha}}{V_{0m}}, \tag{1}$$

where V_{0m} is the input voltage to the transmitting transducer and $V_{6,\alpha}$ is the output voltage from the receiving transducer. The two excitation voltages are 2 and 20 V peak-to-peak. These voltages are chosen in order to reduce the non-linear effects ($V_{pp} = 2$ V), and to increase the signal-to-noise ratio over the frequency range ($V_{pp} = 20$ V). The two measurements are combined in order to benefit from the use of both excitation voltages. $V_{pp} = 2$ V is used from 90 to 119 kHz, and from 230 to 258 kHz, and $V_{pp} = 20$ V is used from 50 to 90 kHz, from 119 to 230 kHz and from 258 to 300 kHz.

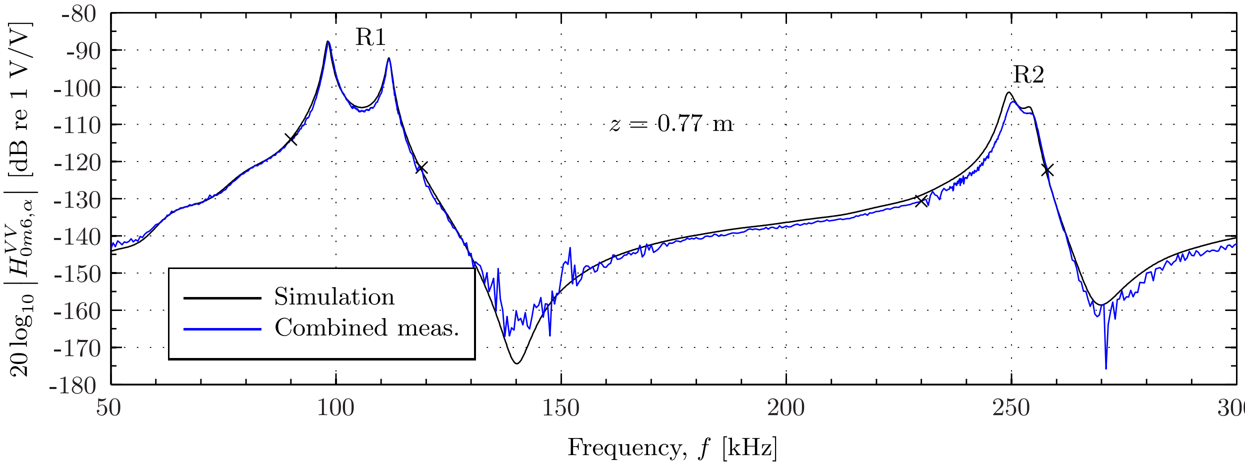

Figure 1: Comparison of measured and simulated $\left|H^{VV}_{0m6,\alpha}\right|$, plotted against frequency. The measurement is combined from two measurements with $V_{pp} = 2$ V and $V_{pp} = 20$ V. The points where the voltages are changed are marked with "×".

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[1] Refer to [2] for definitions of variables and overview of the notation used.

In Fig. 1 an overall fair agreement is seen between the simulation and combined measurements. The effect of measurement noise is still visible in the dips following the radial modes. The difference between the simulation and measurements is seen to increase slightly with higher frequencies. This is probably caused by some misalignment of the transmitter and receiver, visible at the higher frequencies as the beamwidth decreases. In Fig. 2 the recorded waveforms of V_{0m} and $V_{6,\alpha}$ are compared to time response simulations using finite element modelling combined with Fourier synthesis. Comparisons are done for frequencies 98.2 kHz (a - d), 112 kHz (e - h) and 116 kHz (i - l). These frequencies correspond to the first peak (98.2 kHz), the second peak (112 kHz), and a frequency just above the second peak (116 kHz) in Fig. 1. For the piezoelectric ceramic disks used here the first peak in Fig. 1 is associated with transmission and the second peak with reception. The time traces are measured/simulated using $V_{pp} = 20$ V in order to illustrate the presumably non-linear effects in the transducers.

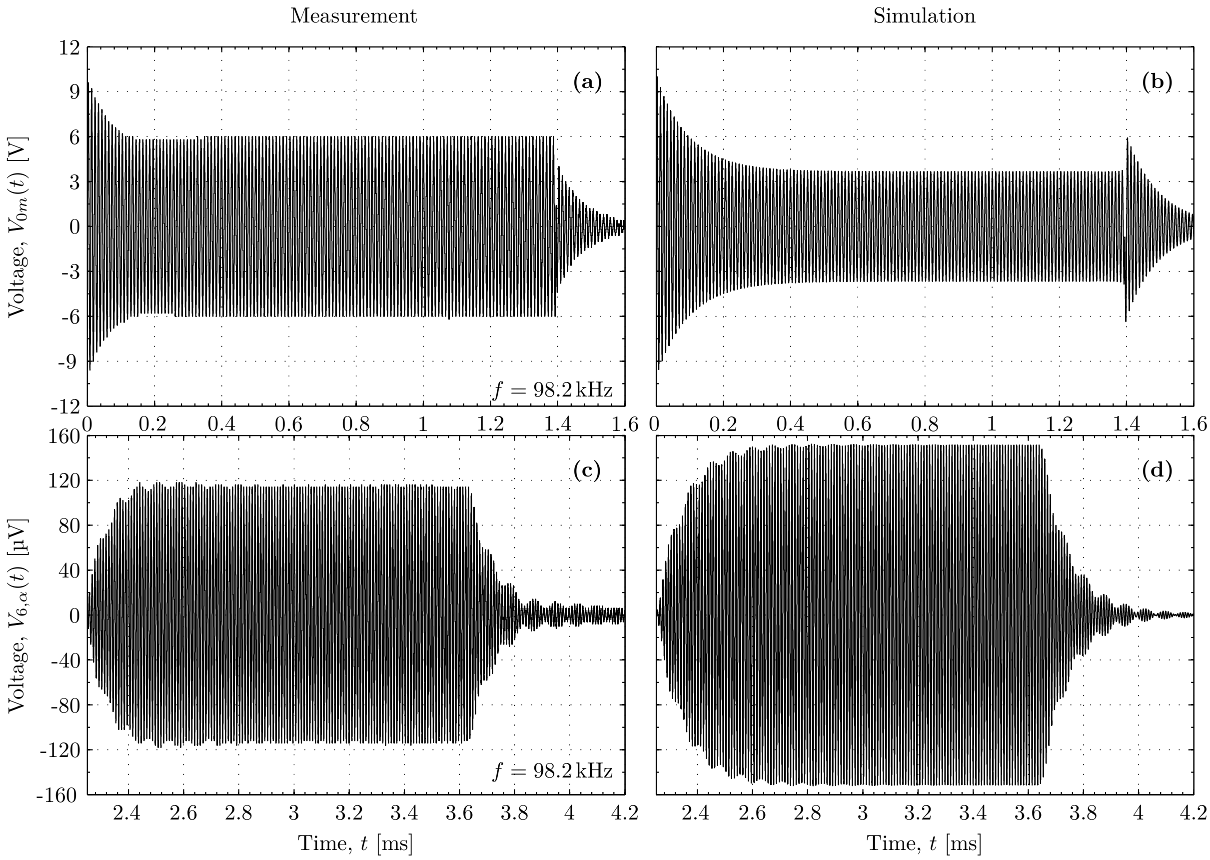

Figure 2: Comparison between time domain measurements (left column) and simulations (right column). Both V_{0m} and $V_{6,\alpha}$ are shown for three frequencies; 98.2 kHz (a - d), on the next page; 112 kHz (e - h) and 116 kHz (i - l).

From Fig. 2 (a-d) it can be seen that both V_{0m} and $V_{6,\alpha}$ show different amplitudes when comparing simulations and measurements. The simulated V_{0m} is lower than the measurements while the simulated $V_{6,\alpha}$ is higher. Since the electrical impedance measurement of the transducer is done at relatively low voltage (0.3 V_{rms}), and these disagreements in amplitude at $f = 98.2$ kHz are not seen for $V_{pp} = 2$ V, this effect is believed to originate from non-linear effects in the transmitting transducer. In Fig. 2 (e - l) it can be seen that there is a qualitative and fair quantitative agreement between the shape and magnitude of the simulations and measurements.

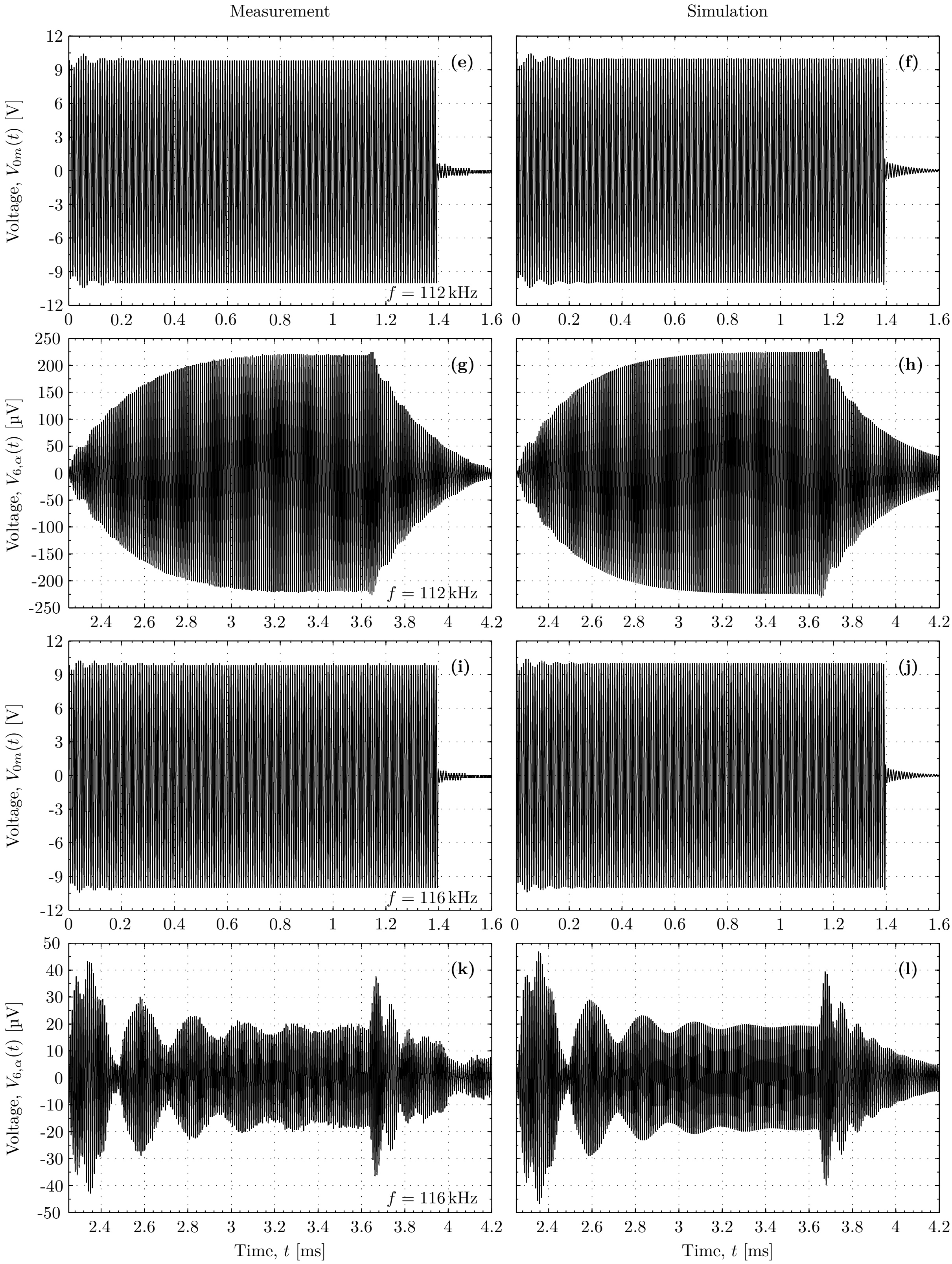

Figure 2: The continued plot from the previous page.

To summarize, a finite-element based linear axisymmetric system model is developed for an ultrasound transmit-receive measurement system. Reasonable agreement is seen between simulations and measurements in air at 1 atm., for both time and frequency domain results. The FEM-based simulation model accounts for magnitude and phase responses of the voltage-voltage transmit-receive transfer function shown in Fig. 1. However, as phase measurements have not been addressed here, comparison of measurement and simulation results is made for the magnitude of the transfer function only. An objective for future work is to further develop the measurement setup to enable precise phase measurements.

References

[1] R. Hauge, E. Mosland, E. Storheim, P. Lunde, M. Vestrheim, and J. Kocbach, "Finite element modeling of ultrasound measurement systems for gas. Comparison with experiments in air.", in *Proceedings of the 36th Scandinavian Symposium on Physical Acoustics - Geilo 3rd February - 6th February* (2013).

[2] R. Hauge, "Finite element modeling of ultrasound measurement systems for gas. Comparison with experiments in air.", Master thesis, University of Bergen, Bergen, Norway (2013).