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Time-dependent study of pressure waves generated by square array MEMS ultrasound transducers

Matthijs Suijlen, Reinout Woltjer
Novioscan, Nijmegen, The Netherlands
matthijs.suijlen@gmail.com

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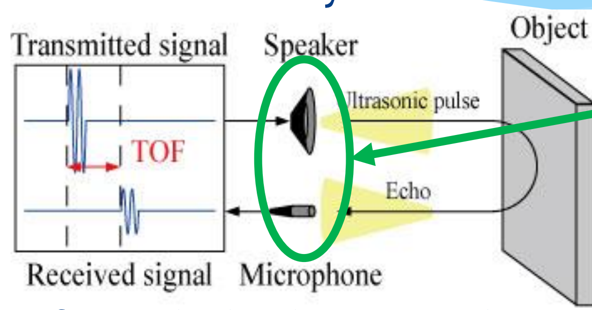
wearable ultrasound

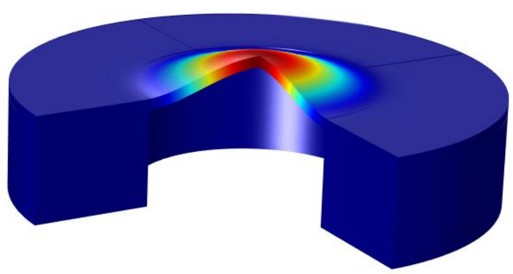
Development of piezo-electric MEMS ultrasound transducers (PMUT)

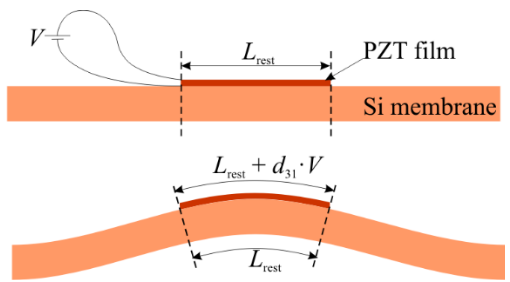
- Echo sounding application in human body



Functions combined in ultrasound transducer

- PMUT with large number of circularly clamped silicon membranes





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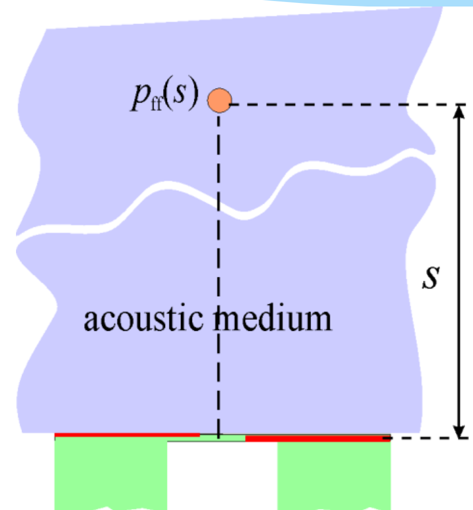
Radiation pressure amplitude in far-field p_{ff}

Cylindrical piston approximation:

$$p_{ff}(s) = \rho_{aco}\, c_{aco} \frac{A_{piston}}{\lambda_{aco}\, s} u_{avg}$$

given $\frac{A_{piston}}{\lambda_{aco}\, s} \ll 1$



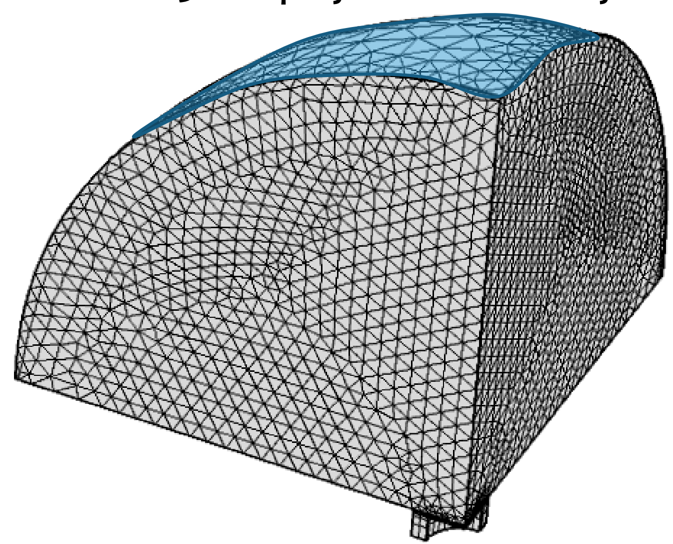
How to find u_{avg}?

Build a COMSOL simulation model!

COMSOL 5.2 simulation model

- 3D model set up from the pre-defined **Acoustic-Piezoelectric Interaction, Transient** interface
- Hemispherical water domain to simulate human tissue volume
- Free tetrahedral mesh to ensure isotropic solution conditions for radiated pressure waves
- Spherical wave radiation condition on shell surface

~160k quadratic elements,
~6.5 GB physical memory



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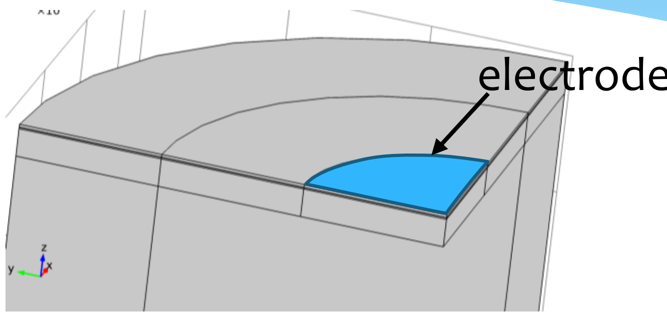
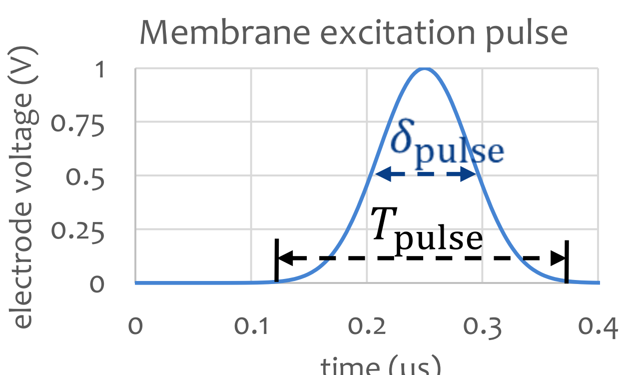
Pulse excitation on membrane electrode



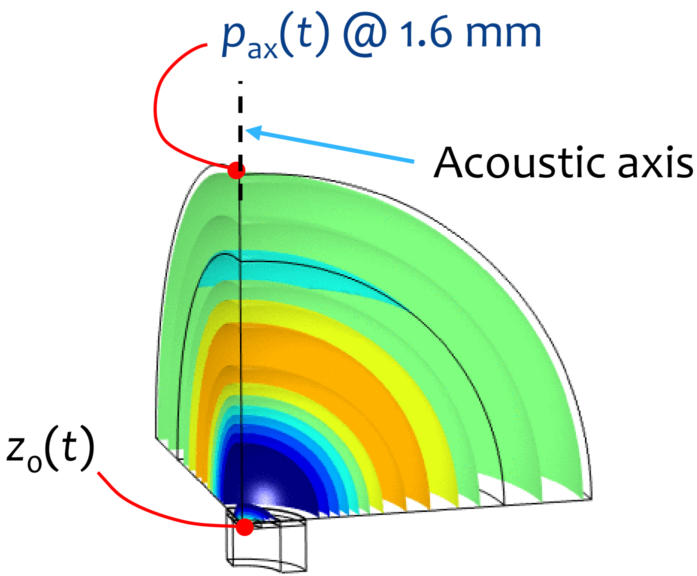


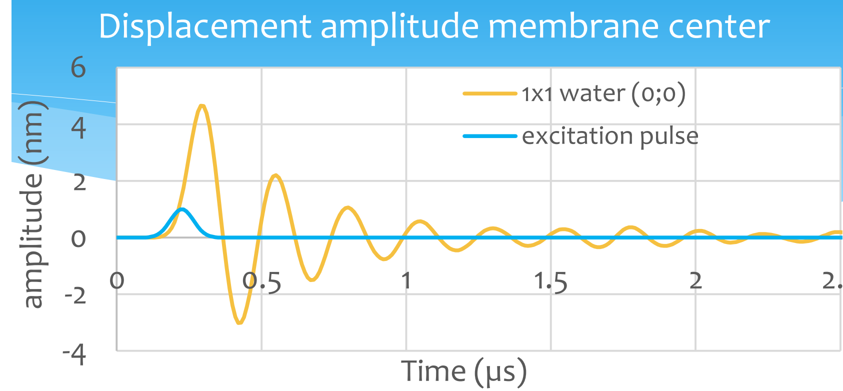
Gaussian pulse shape used

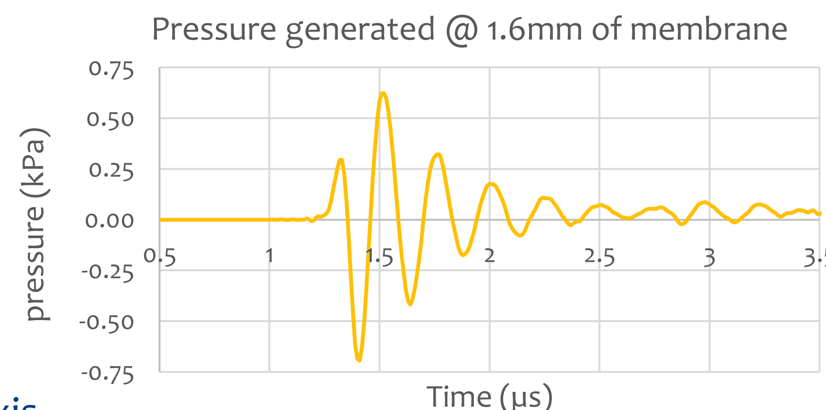
$$V(t) = V_0 \cdot e^{-2\pi^2 (f_{\text{pulse}} t - 1)^2}$$

- $V_0 = 1.0 \text{ V}$
- $f_{\text{pulse}} = 4.0 \text{ MHz}$
- $\delta_{\text{pulse}} = \frac{1}{\pi \cdot f_{\text{pulse}}} = 0.080 \text{ μs}$
- $T_{\text{pulse}} = \frac{1}{f_{\text{pulse}}} = 0.25 \text{ μs}$

Simulation output for 1.0 V excitation pulse







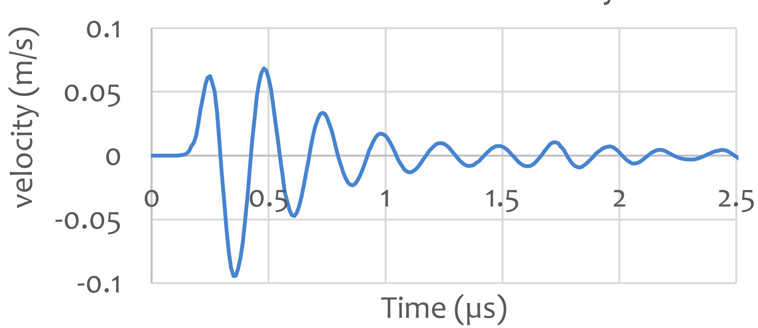
Study in time of:

- Membrane center displacement $z_0(t)$
- Acoustic pressure amplitude $p_{ax}(t)$ on intersection of shell surface with acoustic axis

Single membrane peak far-field pressure @ 0.10 m

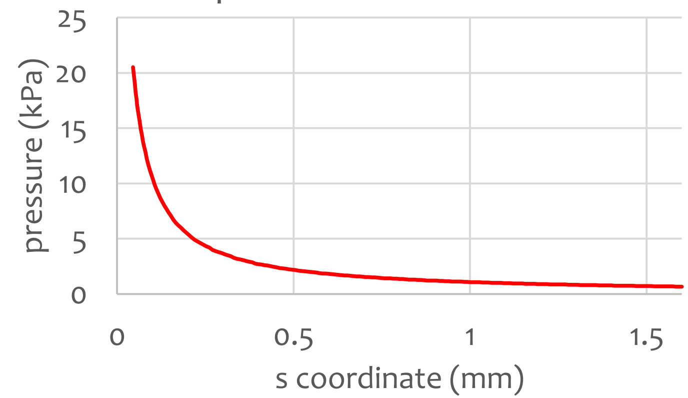
Calculation from membrane center peak velocity $u_{\text{peak,cent}}$ using:

- $p_{\text{peak,ff}}(s) = \rho_{\text{water}}\, f_{\text{wave}} \frac{A_{\text{piston}}}{3\,s}\, u_{\text{peak,cent}}$ for s = 0.10 m
- $|u_{\text{peak,cent}}| = 0.09\,\frac{\text{m}}{\text{s}}$ and $f_{\text{wave}} = 4.0\ \text{MHz}$ in simulated result



- $p_{\text{peak,ff}}(0.10\ \text{m}) = 11.4\ \text{Pa}$

$\frac{1}{s}$-extrapolation of simulated peak pressure values along central (acoustic) axis edge:

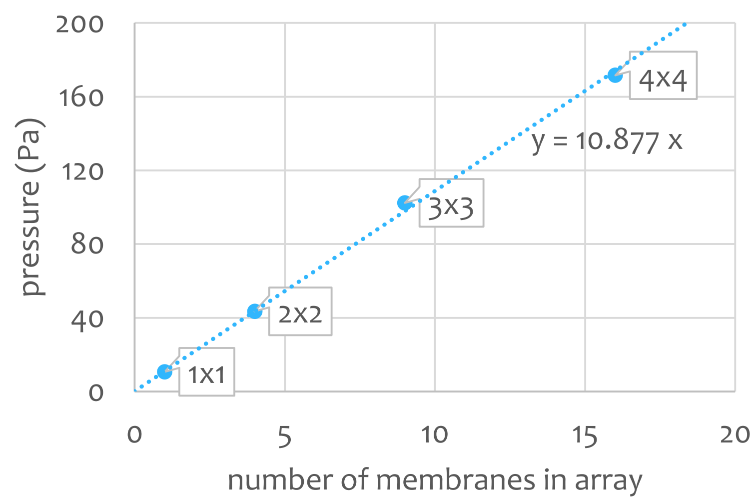


- $p_{\text{peak,ff}}(0.10\ \text{m}) = 10.9\ \text{Pa}$

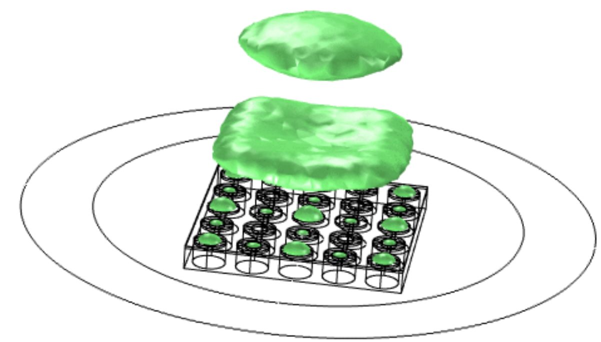
Results for square lattice *n×n* membrane array

Peak far-field pressure @ 0.10 m for:

1. 2×2, 3×3 and 4×4 simultaneous excited membranes



Acoustic pressure isosurface radiated from 5×5 simultaneous excited membranes

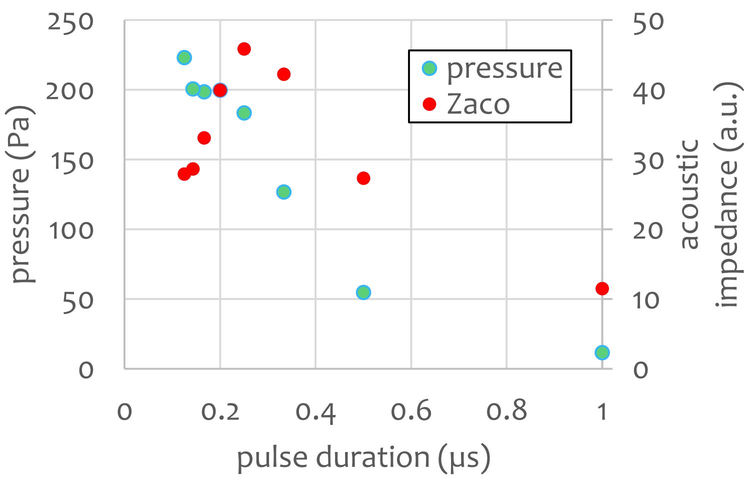


Peak far-field pressure linearly proportional to number of membranes!

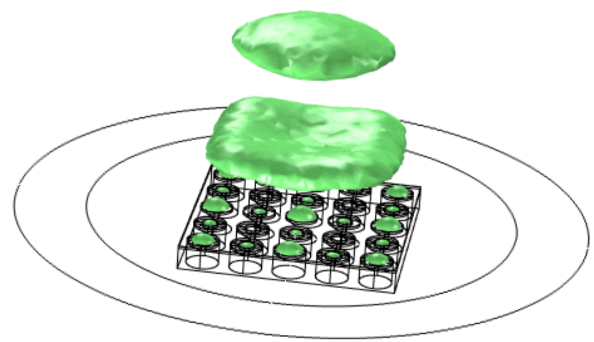
Results for square lattice *n×n* membrane array

Peak far-field pressure @ 0.10 m for:

2. Variable T_{pulse} on 4×4 simultaneous excited membranes



Acoustic pressure isosurface radiated from 5×5 simultaneous excited membranes

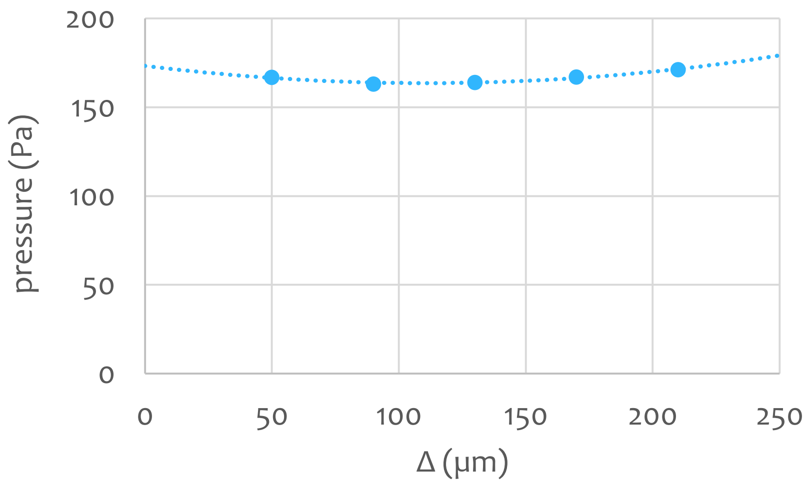


For pulse duration close to the membrane's natural vibration period, transfer of movement to pressure is strongest!

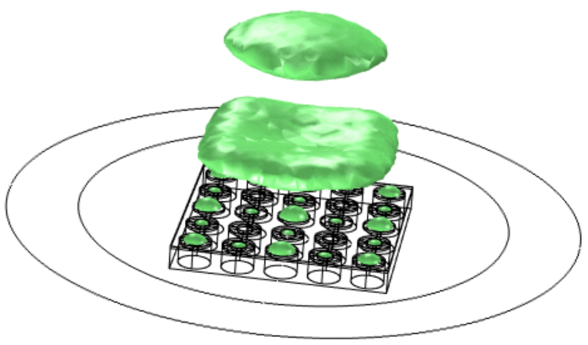
Results for square lattice $n \times n$ membrane array

Peak far-field pressure @ 0.10 m for:

3. Variable membrane spacing distance Δ on 4×4 simultaneous excited membranes



Acoustic pressure isosurface radiated from 5×5 simultaneous excited membranes



Peak far-field pressure appears to be minimum for Δ = 100 µm = D_{memb}!

Conclusion

Presented simulation model brings:

- An accurate and flexible tool to calculate the far-field acoustic peak pressure for PMUTs
- A rich collection of data on membrane displacement and pressure variations in the acoustic (water) domain to study during experimental measurements on the prototype PMUTs

Thanks for your attention

Questions…