
Supervisor: Daniel Kiefer (daniel.kiefer@fau.de)
Deadline 1 (present first results): July 27th, 2020
Deadline 2 (submission): August 4th, 2020
Presentation: August 5th, 2020 during exercise class.

Project 1: Ultrasonic Phased Array Transducer

A typical ultrasonic probe for medical imaging is shown in Figure 1. It is a transducer array consisting of N piezoelectric elements made of PZT-5H that can be excited individually with a voltage between their top and bottom electrodes. By setting appropriate phase delays between the elements, both steering and focusing of the emitted or received beam can be achieved. The active elements are embedded in a highly attenuating silicone backing (not silicon!). The specimen that is to be insonified is represented by the semi-infinite water domain on top of the ultrasonic transducer. Note that water exhibits very similar properties to common biological tissue. The distance between two adjacent elements is $w_{\text{pitch}} = 0.305$ mm. The width of the elements is $w_{\text{elem}} = 0.27$ mm, while their thickness h_{elem} needs to be chosen according to the specification below.

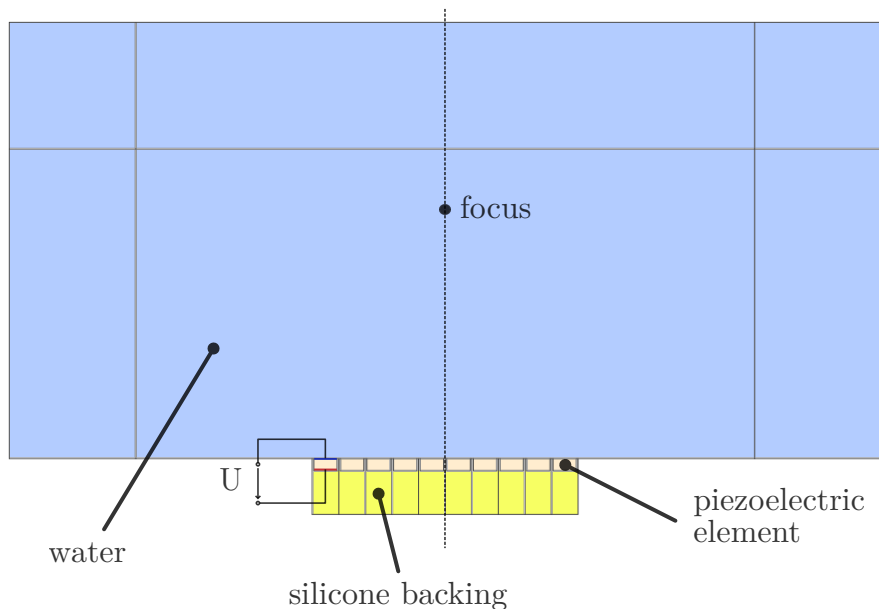


Figure 1: Setup of the piezoelectric phased array transducer

The main objectives of this project are:

- Learn the working principle of ultrasonic transducers
- Investigate on common beam-forming mechanisms
- Design the transducer with Finite Element techniques

1 Preparation and modeling hints

- 1.1. Assume there is one ray propagating from the center of each of the elements. Answer the following questions:
 - 1.1.1. You want to focus ultrasound on the point on the center line with distance F to the transducer. What should the delay Δt with respect to the center element be, so that all rays meet at the same time in the focal point?
 - 1.1.2. You want to steer the beam by an angle α out of the transducers normal. What should the delay Δt with respect to the center element be in order to achieve this?
Tip: The wave front of the beam is orthogonal to the propagation direction. The rays should hit the wave front simultaneously.
- 1.2. Model the geometry as depicted in Fig. 1. Thereby, keep all parameters variable. Use the *Transformations*→*Array* feature of Comsol to also keep the number N of piezoelectric elements variable. When specifying the excitation later on, it might be easier to use an odd number of elements N . For the project you can restrict to odd N (in contrast to Fig. 1, which uses an even value N).
- 1.3. The transducer can be regarded as mechanically fixed at its bottom boundary.
- 1.4. Use a perfectly matched layer (PML) to model the open water domain.
- 1.5. You can perform [harmonic simulations](#) for all of the tasks.

2 Analysis and design tasks

As a first step, model only one piezoelectric element and its surrounding backing:

- 2.1. Choose the thickness h_{elem} of the piezoelectric element such that the thickness resonance is approximately at $f_c = 5.1$ MHz. You can plot, for instance, the electrical impedance for this task.
- 2.2. Make sure to account for the mechanical damping in silicone by adding a Rayleigh damping model. Choose the damping ratio ξ to be 0.2 at 1 MHz below and above f_c . How does the electrical impedance change if you change the damping ratio ξ ? In case your resonance moved, make sure that f_c is again approximately at 5.1 MHz.

Now add the other elements and the specimen to your simulation. You can start with a value of $N = 9$. For the following tasks, it is sufficient to operate the transducer at its center frequency f_c .

- 2.3. Set individual phases for the electrical excitation of the elements in order to focus the beam onto the focal point at a distance $F = 5$ mm.
Tips: Define F as a global parameter. Implement the function derived in task 1.1.1. as an analytical function in Comsol depending on F and the element index. Evaluate the function by manually passing the element index when specifying the voltage of the electrodes. The functions in Comsol must be real valued, but you can specify complex valued voltages in the boundary condition nodes using the complex exponential notation, e.g., `exp(1i*an1(3))`.
- 2.4. Investigate the effect of N on the focal point, e.g., its -6 dB-size and/or the maximum acoustic amplitude. Start with $N = 1$.
- 2.5. Investigate how well sound can be focused onto different focal points F .
- 2.6. Set an electrical excitation in order to steer the beam by an angle of $\alpha = 10^\circ$.
- 2.7. Steer and focus at the same time.
- 2.8. How can the above techniques be useful for ultrasonic imaging?

3 Presentation

Prepare for a **ten minutes** presentation followed by a **five minutes** discussion. Your presentation should consist of the following blocks:

- 3.1. Introduce yourselves (names, fields of studies).
- 3.2. Motivate and introduce the topic, i.e., what is this project about, how does the shown sensor/actor/assembly work in practice, what is it used for, what are the main objectives.
- 3.3. Present the major aspects of your modeling and analysis, i.e., what quantities were analyzed, are there any analytic estimates, what major difficulties had to be solved, how did you overcome these difficulties, etc.
- 3.4. Show and discuss your results in a descriptive way using graphs, screenshots, videos, etc.
- 3.5. Give a short conclusion.

Some remarks

- **Brainstorm a concept** on how to proceed and think about the desired goals and how you can achieve them. Focus on the relevant aspects of the project.
- **Start early** with your project and meet regularly to work together and/or exchange ideas. You might be able to distribute some tasks inside your group.
- The task description is rather **vague on purpose** and has room for your own interpretations. If you face uncertainties, e.g., regarding the choice of some parameter, discuss in the group first and think about reasonable choices. Only if this does not help, contact your supervisor.
- Present your project milestones to your supervisor **once or twice** during the course of the project. Discuss your “almost” final slides with your supervisor **before the first** deadline. Keep in mind, that you might need to make substantial changes and/or more simulations after this discussion.
- You can/should use Matlab where you deem it useful.
- When making animations, make sure to fix the color range of surface plots.

Submitting your project

One member of the group must hand in the

- Comsol .mph file and
- the slides for the presentation, either as a PowerPoint or PDF document.

Upload the above files **before the second deadline** to the project section on StudOn:
<https://www.studon.fau.de/exc3189285.html>.

Important: Make sure to delete all results and meshes from the Comsol file before handing in. This reduces the file size. Refer to the Comsol Tutorial on how to do this.