

## 4. Ultrasound Sonography

### 4.1 Medical reference and aim of the experiment

Ultrasound is used mainly in the medical diagnostics in different image producing methods and in blood flow measurement by means of Doppler sonography. Ultrasound diagnostics are preferred over the x-ray diagnostic, because it produces as a rule fewer damage. Ultrasound is not basically without damage owing to heat production and mechanical deformation of the body tissue. These in diagnostics unwanted effects are used in therapeutic applications (for example diathermy and smashing of kidney- and gallstones).

The image producing methods produce multidimensional pictures of structures of the inner of the body (Fig. 4.1.1). For their interpretation knowledge of basic working principles is required. The measurement is based as a rule on the measurement of **travel times** of short ultrasound pulse which are reflected at **boundaries of tissue**: A ultrasound transmitter emits a short ultrasound pulse and the receiver detects the reflected pulse and the time passed between emission and reception of the pulse. You will investigate in this experiment how spatial information of tissue structures can be reconstructed from measured travel times. The most ultrasound devices are using ultrasound transducers<sup>17</sup>, which work alternating as transmitter and receiver, because generation and registration of ultrasound is based on the same physical principle. Thus only the reflected parts can be recorded. This experiment uses equipment with separated transmitter and receiver and test bodies which are placed different locations. You examine first the propagation of ultrasound pulses in water, which is very similar to that in body liquids and soft tissue. An important aspect for the generation of the image is the relation between the time delay measured and the distance covered by the ultrasound pulse, like shown in the picture.

In the next part, test bodies of different materials are placed in the water, partially reflecting the ultrasound pulse. The measurements shall demonstrate how one- or two dimensional ultrasound pictures are produced from the reflections recorded, and what actually is shown in such pictures.

---

<sup>17</sup>They are called “transducer” because they transform (as transmitter) electrical signals in sound signals or (as receiver) sound signals in electrical signals.



Figure 4.1.1: *Example of an ultrasound picture: fetus, 30 weeks old.*

Effects as multiple reflections or (partial) shadows can produce artefacts here, as in medical ultrasound recordings, and must be taken into consideration for the interpretation of the measured signals.

For the measurement and time resolved representation an oscilloscope is required because the signal consists of fast transients (typical run times lay in the range of micro- to milliseconds). A computer equipped with a fast voltage sampling replaces the oscilloscope in this experiment. You become acquainted with its operations in the first part of the experiment.

**Note:** Read the chapter *operating the computer*, S. 3, before the afternoon of experimentation!

## 4.2 Experiment

### 4.2.1 Warning!

The experiments take place in a big water basin (c. 15 l), in the direct proximity of electronic devices and of the computer! **Splash water can destroy the devices.** Work calm and careful and report any leaks of the water filled basin immediately!

### 4.2.2 Operation of the devices

An essential cornerstone of image formation in sonography is the propagation of ultrasound in human tissue. This is very similar to that in water; therefore, in the following a tank filled with water is used. The following equipment is at disposal (c.f. Fig. 4.2.2):

- A water basin with two guiding rails.
- An ultrasound generator with connected transceiver.
- A receiver with amplifier and power supply.
- A small box with connections for the voltage measurement by the computer.

- A computer.

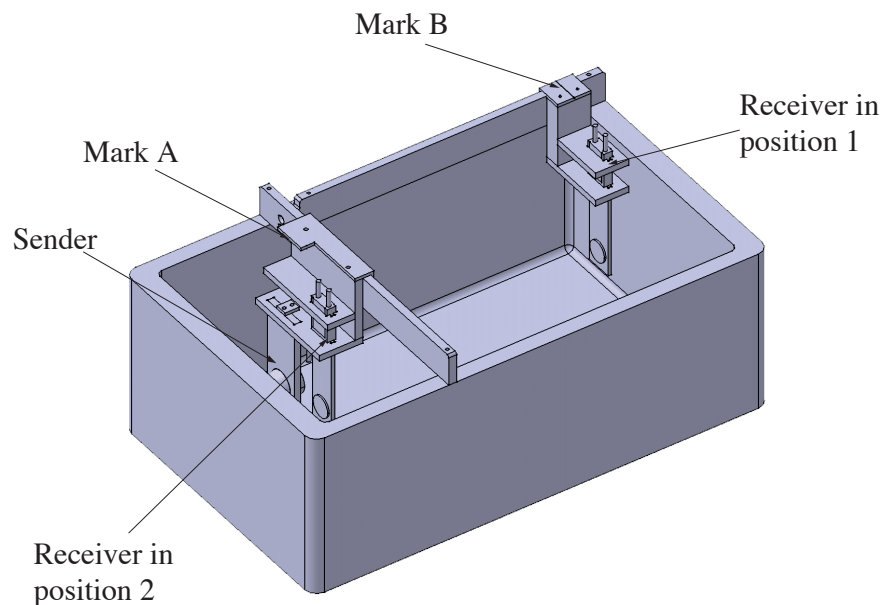


Figure 4.2.1: *Structure of the basin with leading rails: The position of the transmitter and both possible positions of the receiver are given. Note the position of the marks for the distance measurement. An absorber is installed behind the transmitter to minimise disturbing reflections at the back side of the basin.*

The device used here has separate transmitter and receiver. The ultrasound transmitter stays fixed in the holder on the shorter rail (cf. Fig. 4.2.1). The receiver has two places, one opposite to the transmitter on the longer rail (position 1), the other beside the receiver (position 2). Take care during handling the receiver! Do not touch the front side of transmitter and receiver with the fingers or other objects!<sup>18</sup>

The setup of the experiment is shown in Fig. 4.2.2:

- Place the receiver opposite to the transmitter in the holder on the long leading rail (position 1). Take care that the quartz looks in direction of the transmitter. Move the transmitter sideways until both are facing each other.

<sup>18</sup>Both transducers are quartz plates with very thin metal films as electrodes. These are damaged and loose their efficiency by contact and scratches.

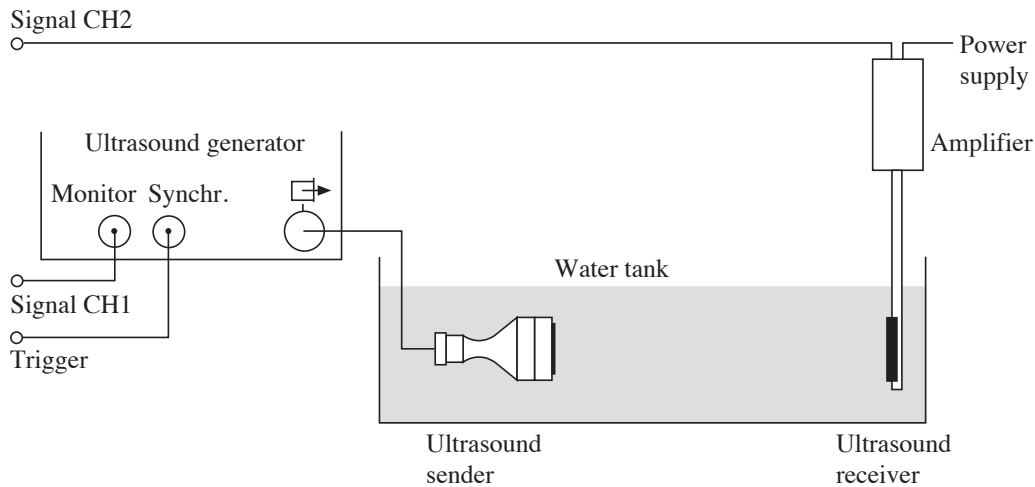


Figure 4.2.2: Setup of the first experiment – run time measurement: the receiver is placed opposite to the transmitter.

- The plastic housing directly connected to the receiver contains the amplifier. It has two connectors on its top side: one is connected to the power supply plugged into an outlet. The other should be connected by a coaxial BNC-cable to CH2 of the measurement input box which is connected to the computer.
- The output “Monitor” of the generator (Fig. 4.2.2) should be connected by a BNC-cable to CH1 and the output “Synchr” to “Ext. trigger” of the measurement box (cf. Fig. 4.2.2).
- Start the computer and, if it is not already displayed, select the user „Physics Practical Course X“ to log in (*operating the computer*, S. 3).
- Start the programme *Ultrasound* on the user interface by double-clicking on the icon.
- To start the programme, you must specify where the receiver is located, select "Position 1". This will then be selected in the programme at the top left under the option **time view** and can be adjusted subsequently.

The computer is now ready for a measurement. The next step is the generation of ultrasound pulses. The ultrasound generator and the controls are displayed in Fig. 4.2.3. It generates a high frequency electric signal (800 kHz), which is sent to the transmitter. The latter is a quartz plate with electrodes, that transforms the electric signal in a mechanical oscillation.

The recording of pictures in the ultrasound diagnostics is based on the measurement of travel times of very short ultrasound pulses (Principle of echo sounding and of the SONAR).

- Make sure, that the button “Pulsed Mode” of the generator is activated (Fig. 4.2.3).
- The transmitter must at all times be completely immersed in water (otherwise there is danger of overheating!). If this is not the case although the transmitter is correctly mounted please

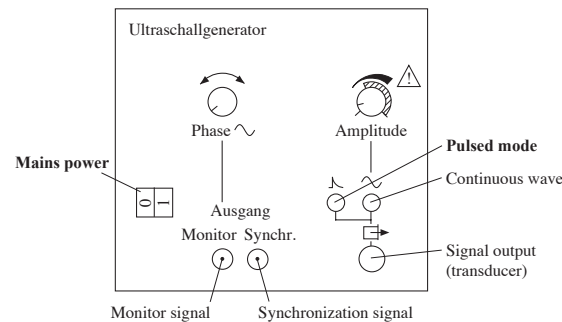


Figure 4.2.3: Control elements of the ultrasound generator; only the buttons “Pulsed Mode” (“Impulsbetrieb”), the power switch and the three outputs are relevant for this experiment.

add deionized water with the help of an assistant. The water level should be about 1 cm above the transmitter. (a too high water level leads to more signal interference).

- Only the transmitter and the receiver should be in the basin for now. Take out all other objects.
- Turn on the generator using the power switch (Fig. 4.2.3). The light buzz you hear, does not stem from ultrasound, the ultrasound-frequency is above the audible range, it is the repetition rate of the pulses (about 500 per second).
- After starting, the programme is in **time view** mode. In this mode you can choose whether the transmitter or the receiver signal is to be measured, therefore the start buttons are labelled accordingly.
- Click on the **Sender** button in the programme. You can see from the green light on the button that the measurement is running, the button is now labelled **Stop**. The transmitter signal is displayed on the left side in the graph. The amplitude should be between 0.8 and 1.1, click at least once on the button **Auto-scale** so that the scaling factor is recalculated and displayed in the legend below the graph. Use the arrow buttons to manually adjust the scaling in small steps. Click on **Stop** to stop the measurement.
- To measure the receiver signal, click on the **Receiver** button. This signal is displayed on the right side of the graph. Use the button **Auto-scale** and the arrows again to set an amplitude between 0.8 and 1.1. As long as the option **Remove sender noise** is activated, signals up to approx. 7 cm (position 1) or 15 cm (position 2) in front of the receiver are filtered out, as the transmitter often causes strong interference signals in this range.
- When the receiver is switched on or moved, it usually takes 1-2 seconds for the signal to stabilise. Once the signal is stable, the measurement can be stopped by clicking the button again, which is now labelled **Stop**, so that the signal can be analysed.

The following happens between start and stop of a single measurement: the generator produces a short electrical pulse and the transmitter transforms it into an ultrasound pulse. Almost simultaneously, it also sends an electronic signal to the computer (the so-called synchronisation signal or „trigger“), whereupon the computer records 1000 data points within 1 ms.

The computer measures the voltages applied to channel 1 (CH1 on the measuring box) or channel 2 (CH2 on the measuring box) for 1 ms at intervals of  $1 \mu\text{s}$ <sup>19</sup>. The voltage values are displayed on the screen as a function of time. The measurement is repeated several times a second so that you can directly observe changes in the setup.

- Via **CH1** the voltage applied to the sender is measured – the pulse in the signal shows the time at which the transmitter emits an ultrasonic pulse. There is a time delay between the trigger signal mentioned above and the transmitter signal; to determine this, the transmitter signal must be measured at least once at the start of the practical. The time delay remains constant for each unit. Therefore, it is sufficient if the transmitter signal is recorded once, it is then inserted at the corresponding position during the time measurements of the receiver signal.
- The voltage registered at the receiver is measured via **CH2**. This functions similarly to a microphone and converts incoming ultrasound signals into electrical signals.

The **amplitudes** of the voltage signals are **proportional** to those of the ultrasound signals (this is valid for sender and receiver). After both a sender and a receiver measurement have been carried out, a signal curve with at least two deflections (pulses) should be visible on the screen. The first (at the left edge of the screen in green colour) comes from the sender (monitor signal). The red signal curve on the screen represents the time course of the ultrasound signal registered by the receiver.

*Important:* The amplitudes of the transmitter and receiver are normalised, the actual scaling factors by which they must be multiplied to determine the actual value are given in the legend of the graph.

◇ Which physical quantities correspond to the abscissa ( $x$ -axis) and ordinate ( $y$ -axis)?

◇ Print the first test measurement and stick it in here. Instructions for printing can be found in the chapter *Bedienung des Computers*, S. 3.

---

<sup>19</sup>In order to be able to use the full temporal resolution for receivers, only one of the two channels is read out by the computer at a time

*Signal recorded with receiver in position 1:*

- ◇ Determine from the graph the amplitude  $A$  of the strongest deflection registered by the receiver, which means the maximum voltage reached in it, be aware of the scaling factor. Give this amplitude in the unit volt (V).

$$A =$$

- ◇ Determine on the screen the time delay  $\Delta t_0$  to the first (transmitted) pulse and the Pulse interval  $\Delta t$  between the first and second (received) pulse, i.e. the time that lies between the maxima of the two pulses. To do this, move the two lines in the graph to the corresponding positions with the mouse. The values are shown in the display below the graph in the unit microseconds. Note  $\Delta t_0$  and calculate the pulse interval.

$$\Delta t_0 =$$

$$\Delta t =$$

In the following, you will carry out several measurements of amplitudes and pulse intervals.

### 4.2.3 Propagation of ultrasound pulses (in water)

- ◇ Start a measurement by a mouse click on the button **Start**. Move the transmitter sideways back and forth and observe the position at which the strongest signal is detected by the receiver. What do you conclude from this observation for the propagation of the ultrasound pulse in the water?
  
- ◇ Now place the transmitter again directly opposite the receiver in the guide rail and slowly move the receiver back and forth in the longitudinal direction. What do you observe on the screen? Can you relate this observation to the propagation of the ultrasound pulses in the water and the movement of the receiver?
  
- ◇ In order to measure the speed of sound in water you must know the distance and the travel time of the pulse propagation between transmitter and receiver in the water. Where can you read the distance between transmitter and receiver (have a careful look to the arrangement of the experiment and Fig. 4.2.1), and where can you read the travel time?

distance:

travel time:

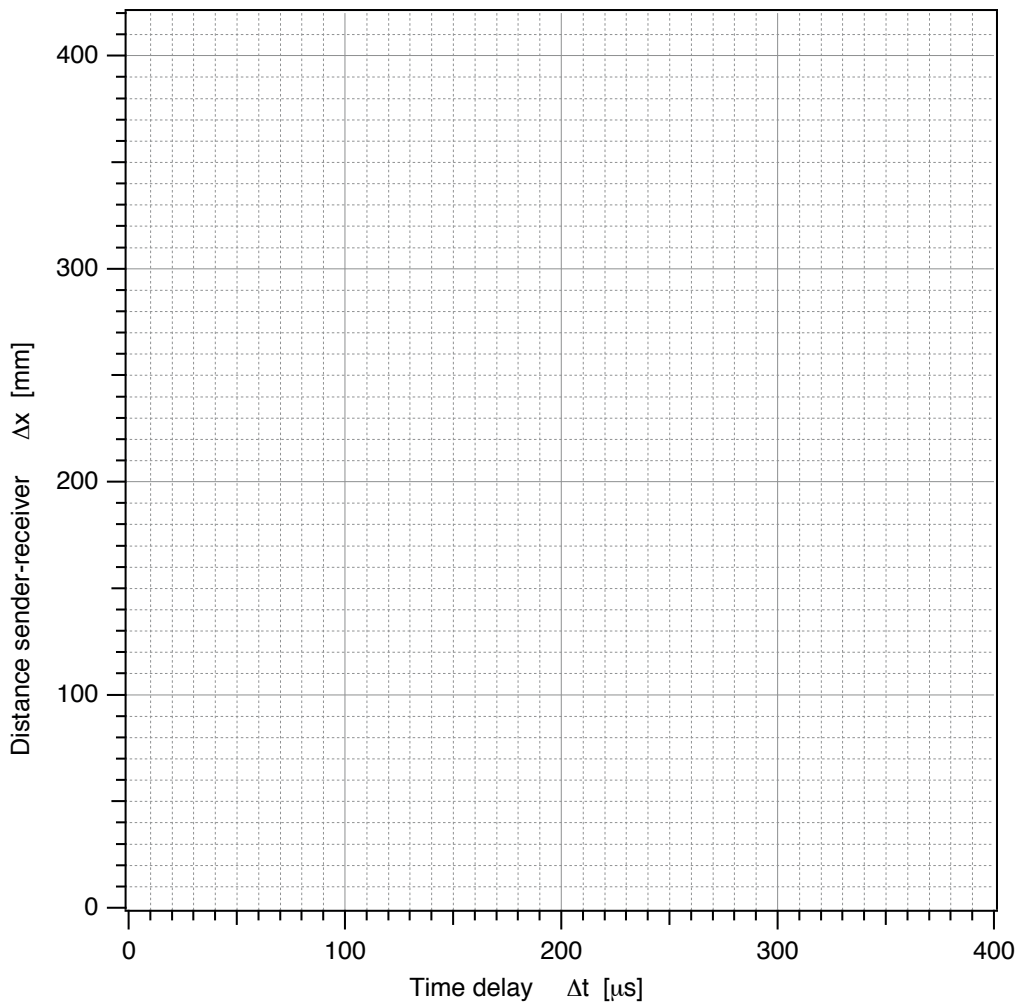
- ◇ To determine the correlation between running distance and –time, measure 6 different running distances  $\Delta x$  (distributed over a range as wide as possible) and calculate the associated running time  $\Delta t$ . Add the correct units in the table!

To suppress the whistling sound between the individual test parts, you can switch the generator to continuous operation (fig. 4.2.3).



Determination of the speed of sound in water						
$\Delta x$ [    ]						
$\Delta t$ [    ]						

- ◇ Enter the measured values in the following diagram ( $\Delta t$  versus  $\Delta x$ )



- ◇ Determine the speed  $c$  by calculating the slope of the best fitting line in the diagram (use the unit m/s). Is the velocity for this measurement constant?

$c =$

This velocity is called **speed of sound**. The basic idea of ultrasonic imaging methods is to conclude from the travel time using the known (average) speed of sound on the corresponding distance in the tissue, which is not accessible for direct measurement. We will do such imaging later on (c.f. 79).

**Important!** For correct location scaling, you must now enter the value  $c$ . Since the computer starts timing when it receives the trigger signal, you must also enter the time delay for the transmitter signal.  $t = 0$  s is then set at the maximum value of the transmitter:

- Click with the mouse on the button **Speed of Sound**.
  - Enter the measured value for  $c$  in the upper field in the unit m/s.
  - In the lower field, enter the time delay  $\Delta t_0$  between the trigger signal and the transmitter signal in  $\mu\text{s}$ .
  - Confirm the entries by clicking **OK**.
  - The values can be changed subsequently in the two fields that are now displayed.
- ◇ To check your result: Using the speed of sound and the first value of the running time from the table, calculate the distance at which you hooked the transmitter and receiver into the guide rail at the beginning of the first part of the experiment:

The calculated distance should not differ by more than 2-3% from the measured distance

#### 4.2.4 Image formation by reflection of ultrasound pulses

Up to now transmitter and receiver were kept separate and opposite. For imaging, both have to be oriented in the same direction like in SONAR or sound logging devices. In real medical devices, one transducer is used for both, emission and reception of the signals. Such a transducer with integrated transmitter and receiver will be simulated:

- Put the receiver beside the transmitter at position 2. The receiver quartz must be orientated in the same direction as the transmitter. Now change to "Position 2" at the top left under the option **Time view - A-mode scan**.
  - The signal amplitude is still displayed against time. The time scale is now adjusted so that the zero corresponds to the emission of the transmission pulse. You can therefore read the running times directly from the abscissa.
  - Start a measurement (Generator switched on?).
- ◇ If the signal amplitude is very high or low, click on **autoscale**. Stop the measurement and determine the running time of this pulse using the cursor (running time = cursor position at the maximum) and calculate the corresponding distance from this (using the speed of sound).

$$\Delta t =$$

$$\Delta x =$$

- ◇ What is the relationship (formula) between the distance  $\Delta x$  of the pulse measured in this way and the distance  $d$  of the reflecting surface from the transducer?
  
- ◇ Which surface reflected the signal?
  
- Now place the **empty plastic bottle** in the middle of the tub so that the ultrasound signal passes through and the wide side of the bottle is perpendicular to the direction of propagation.
- ◇ What changes (additional or disappearing pulses) can be observed in the registered ultrasound signal? To which face can you assign the now registered pulses? (To simplify the assignment, you can move the bottle back and forth a little).
  
- ◇ To check whether your assignment is correct, first determine the position for all faces from the time measurement and then directly with the scale on the tub. Sketch the structure and note down all possible positions in the following table (the number of lines is not important!). Compare the results.

<b>Empty plastic bottle</b>			
Surface	Travel time	Distance from pulse travel time	Distance according to ruler

- ◇ Look at the peak, that is caused by reflection at the edge of the basin. You can locate it by lifting the bottle out of the water. What happens when you put back the empty bottle?
  
- ◇ You could test your assumption by (carefully) holding the receiver *behind* the empty bottle into the ultrasound beam. Do you see a signal?

- ◇ What can be concluded for the imaging of surfaces located behind a gas bubble or volume (lungs, gut)? For now, we only consider the one dimensional A-Scan, which we are currently dealing with. The conclusions are, however, directly applicable to the B-Scan and the two dimensional representation, which will be discussed later.

Note: Signals like multiple reflections, which can be observed here frequently, are disturbing medical ultrasound signals. They mimic additional, non-existing surfaces in the body, if they are not identified as artifacts.

- Replace the empty bottle with the **plastic bottle filled with water** and repeat the experiments and measurements.
- ◇ Which differences do you observe now with respect to imaging of an empty or the signals without bottle? Which surfaces are matching the signal peaks recorded now?
- ◇ Write down again the travel times, the corresponding positions and the values measured with the ruler in the following table.

<b>Plastic bottle filled with water</b>			
Surface	Travel time	Distance from pulse travel time	Distance according to ruler

- ◇ Why can you recognize **several** surfaces lying in a row here, in contrast to the case of the empty bottle ?

- Replace the filled plastic bottle with the one **filled by water and small glass beads** and repeat the experiments and measurements again.
  - Important:** When measuring with this bottle, autoscaling should not be used!
- ◇ Describe the observed signal, in particular in comparison to the case of the empty bottle:
  
- ◇ Based on your previous experiments, how can you explain the new signal by reflection of ultrasound pulses at the surfaces of the glass beads?

The bottle with water and glass beads represents an inhomogeneous (porous) solid body and is therefore structurally comparable with human bones. Signals reflected from bones imbedded in tissue are similar to the signals you observe from many small glass beads.

- ◇ What kind of image do you expect therefore for bones and structures behind bones in the ultrasound images? How can we distinguish an surface “tissue/bone” from an surface “tissue/gas”?

- Stop any running measurements.

## 4.2.5 Generation of two-dimensional ultrasound images

### 4.2.5.1 Brightness representation of a signal

The method used before is called **A-Mode-Scan** or **A-Scan** in medical diagnostics. It produces a curve representing the signal amplitude (hence A scan) is shown on the ordinate. The distance plotted on the abscissa was calculated using the signal propagation time and the constant propagation speed, it is proportional to the distance of the reflecting interface, the abscissa can therefore be understood as **spatial coordinate**.

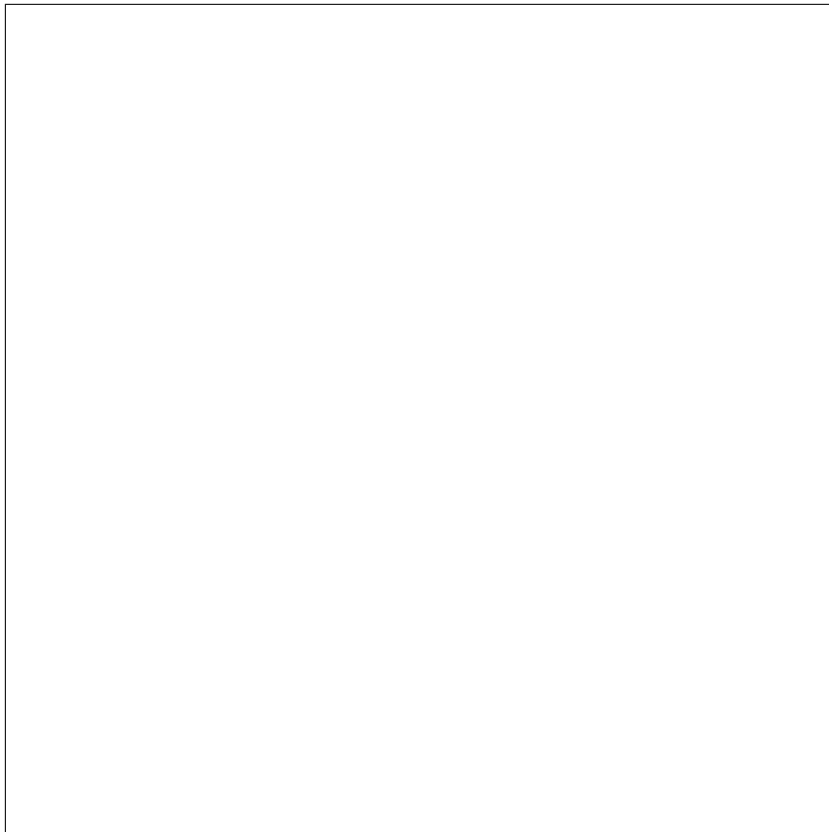
In the one-dimensional **B-scan**, the same information is represented pictorially and only the intensity is coded differently. The distance is also plotted on the abscissa and represents the location coordinate in the direction of propagation. The signal amplitude is not represented by a curve (as in the A-scan), but by its brightness: large amplitude corresponds to large brightness and vice versa. An ordinate is not needed for this representation. Instead of pure grey tones, colors are used in the following, so that more details can be perceived.

With the A-scan as well as with the one-dimensional B-scan, only a one-dimensional section through the object along the direction of propagation of the ultrasound pulse is recorded.

- Select **1D A and B Mode Scan** on the left under **Distance View**.

Two graphs are now displayed on the right. In the upper graph, the amplitude of the registered signal is plotted as before, this time against spatial coordinates, which are calculated with the help of the run time and the entered sound speed. Below, the exact same signal is shown in the brightness display. The individual measuring points at the top correspond to segments at the bottom, whose brightness depends on the measured signal amplitude.

- ◇ Place the plastic bottle filled with water in the water again. Sketch the arrangement in the basin from top view (true to scale) in the area below. Measure the distances and write them down in the sketch.



- Start a measurement by clicking on **Start**. The computer builds an average over several measurements and stops automatically (duration about 1-2 s).
- Play with the contrast by moving the slider below the graph, until you can well recognize the signals of the bottle.
- Print the picture and paste it here.

### One-dimensional B-scan

#### 4.2.5.2 Formation of a two-dimensional image from single line scans

The one dimensional B-Scan-representation of the reflected ultrasound signals can be understood as **one line** of a two-dimensional ultrasound image. A two-dimensional image is generated by assembly using many such lines; it shows a two-dimensional cut through the examined object (two-dimensional B-Scan).<sup>20</sup>

---

<sup>20</sup>This is not possible in the A-Scan-representation, because the second dimension is needed there as axis for the intensity.

If many transducers are arranged in parallel and measuring simultaneously, it is called a scanner. Such devices are routinely used in ultrasound diagnostics. The single line measurements of the single transducers are then treated numerically and arranged such that a two-dimensional image can be obtained. Another possibility to obtain images with only one transducer is the following: The transducer <sup>21</sup> will be moved along the object during a continual recording. The computer assembles all these one-dimensional records to a two dimensional image.

A pulse needs about  $600 \mu\text{s}$  in the water to the opposite border of the basin and back. The computer then needs several milliseconds for data processing. Furthermore, the data are averaged over several cycles in order to improve the image quality. This all leads to rather slow measurements. Thus, in order to avoid image distortions, the transducer should be moved slowly and with constant speed.

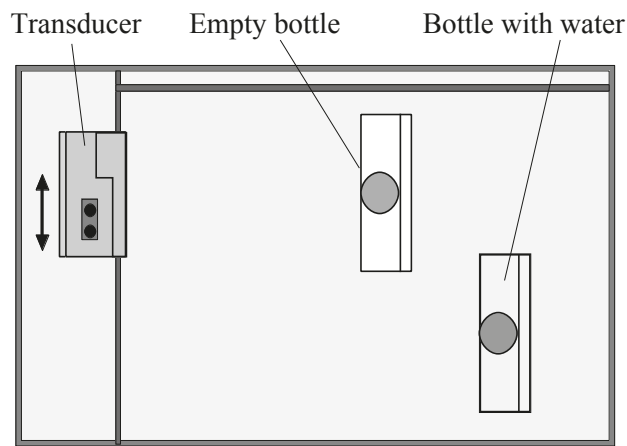


Figure 4.2.4: *Example for an arrangement of the objects for the two dimensional B-Scan.*

For recording a two-dimensional image, proceed in following way:

- Arrange two bottles in the basin such that they overlap partially – one possible arrangement is depicted in Fig. 4.2.4. Take into account that the receiver will always have at least 10 cm distance to the upper edge. Use the bottle filled with water, you may choose how to arrange them.
  - In order for the display on the screen to match the situation in the basin, you must push the transducer all the way to the bottom (closer to you) edge of the tub.
  - In the computer program, change to the two dimensional mode with a mouse click on **2D B-Scan**. A new window with a big (and initially black) area appears. The scale in the direction of sound is presented as spatial coordinate, the second axis is yet unscaled.
- ◇ Guess how the final ultrasound image should look like, given your arrangement.

<sup>21</sup>Frequently only one transducer is used in diagnostics as transmitter and receiver.



- ◇ *Please read the complete task before the measurement!*  
In the field **maximum steps**, enter how many individual measurements are to be recorded, this information is required for the live display. You can stop the measurement manually if you reach the edge of the basin beforehand.
- ◇ Click on the **Start** button below the graphic to start recording the two-dimensional image. After a short countdown, start moving the transducer (transmitter and receiver) slowly and *evenly* to the top of the basin (If you have problems with moving evenly, check that the affected areas are dry). Once there, click **stop** (should your measurement reach the maximum number of strits specified, it will automatically stop). When the measurement is finished, the computer will rescale the second direction using the maximum travel distance of the receiver (20 cm) - but this scale will only be an approximation. Optimise the contrast of the obtained image similar to the one-dimensional scan and print it out – if no reasonable image results despite the contrast optimisation, check the scaling of the amplitude in A-scan mode (it should not go above 1.1 or be too low) and repeat the measurement.
- ◇ Print the picture and insert it here.

#### Two dimensional recording (B-Scan)

- ◇ Measure the visible dimensions of the bottle filled with water using the rulers of the two axes. Compare the measured sizes with the dimensions of the bottle - how is the agreement?

“true” thickness/width of the bottle:

Values measured with the ultrasound setup:

If you wish and have time

- ◇ you could try to image your fingers. Take all objects out of the basin, hold your hand in the basin such that the fingers are at the same height as the transducer and repeat the two dimensional recording - Do you recognize your fingers?
  - ◇ Analogous to the 2D B-mode scan, you can also try the 3D A-mode scan. Think about what you see exactly and how the image should or should not be interpreted.
- 
- After the end of the experiment, please switch off the generator.
  - Close the programme.
  - Turn off the computer.