

## **ULTRASOUND ECHO SOUNDER**

Ultrasonography (USG) is currently one of the most important diagnostic techniques applied in medicine. It is used both for imaging of internal organs in a patient body (A and B presentation modes, the latter applied also in a 3-dimensional version), and for measurements of blood circulation rate in vessels (Doppler methods). Information about the state of patient's internal organs and blood circulation can be recorded and presented simultaneously („colour Doppler image”).

Imaging of patient's internal organs is based on the method of impulse echolocation. The ultrasound probe generates a very short ultrasound impulse that penetrates tissues and undergoes reflections from interfaces. These reflections generate echoes. The echoes come back and are recorded by the probe. This is possible because an ultrasound probe can work both as a generator of impulses and as a detector of echoes. In fact, in an ultrasound probe, short periods of ultrasound impulse generation are followed by much longer periods of detection of echoes. If an echo was recorded at time  $t$  after the generation of the impulse, one can calculate the distance between the probe and the interface producing the echo,  $S$ , applying a simple equation:

$$S = \frac{vt}{2} \quad (1)$$

where  $v$  is an average speed of the ultrasound in tissues. The time  $t$  is equal to the time of impulse propagation from the probe to the echo-producing interface plus the time of echo propagation from the interface to the probe. The time of impulse propagation is equal to the time of echo propagation, therefore the actual time of echo propagation is equal to a half of the  $t$ . Another important feature of an echo, besides the time of propagation, is its intensity in relation to the intensity of the generated impulse. This provides a piece of useful information about a difference of acoustic resistance between the tissues forming the echo-generating interface.

In this practical we apply an ultrasound probe to visualize an unknown (not seen by students) structure, that symbolizes an organ in a patient's body. This structure is formed by three cubes (cuboids) stacked one above another. During visualization the impulse echolocation is applied to find out the spatial location and size of the cubes. In contrast to a real USG imaging, which usually contains many echoes, only one echo, at the interface between air and the top wall of a cube, is generated during this scanning. This is because the difference in acoustic resistance between air and cube material is very high, so the ultrasound beam is totally reflected from the interface between air and the top wall of the cube. Because of this total reflection, the beam can not penetrate the internal part of the cube and it can not produce other echoes.

In this practical we assume, such as it occurs in case of a real USG imaging, that the reflection of the ultrasound beam takes place in the axis of the beam.

In case of all methods applying ultrasound for a spatial location of objects, also during medical USG examination, we have to deal with artifacts in the recorded image. Such artifacts are also recorded during this practical. In Figure 1 we can see an ultrasound image of the top

wall of a cube placed in the recording system box, recorded applying the impulse echolocation method.

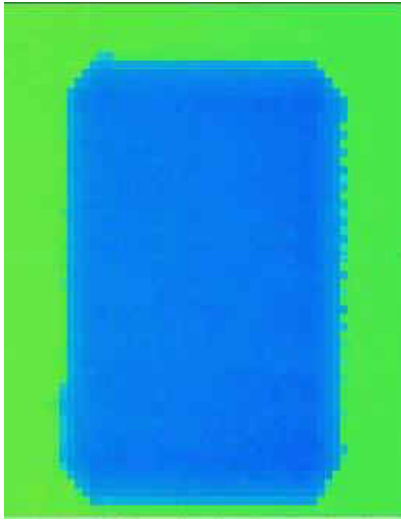


Figure 1

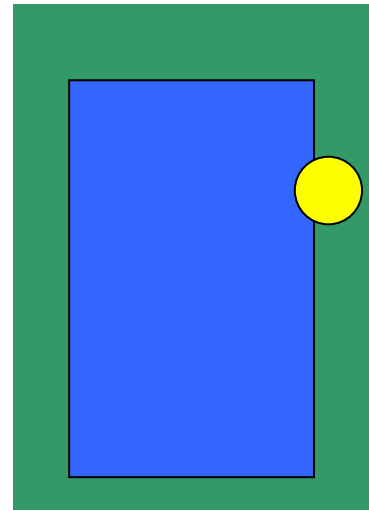


Figure 2

Ultrasound beams applied for scanning were perpendicular to the bottom of the box. The value of time of echo recording  $t$  is displayed on the figure for each position of the probe as a colour pixel. The longer  $t$ , displayed as green pixels, correspond to echoes generated on the bottom of the box, whereas the shorter  $t$ , displayed as blue pixels, correspond to the upper wall of the cube. It is easily remarkable that the apexes of the cube are „truncated”. This is a consequence of the so-called „beam width artifact”, related to the size of the beam, which is significantly higher than zero. The ultrasound beam, shown as a yellow circle, in relation to the real size and location of the top wall of the examined cube is depicted in Figure 2. If only a small part of the ultrasound beam is reflected from the top wall of the cube, the echo is generated. The rest of the beam will be reflected from the bottom of the box and will produce another echo. However, the ultrasound probe records only one echo at one position. This is the echo that comes as the first one to the probe. In this case this is the echo generated at the interface between air and the top wall of the cube. Only this echo will be displayed on the monitor. Therefore, the whole area scanned by the beam presented as a yellow circle in Figure 2 will be shown as a part of the top wall of the examined cube. This is not true, according to the real size and location of the top wall of the cube shown in Figure 2, and leads to an artificial „enlargement” of the examined object.

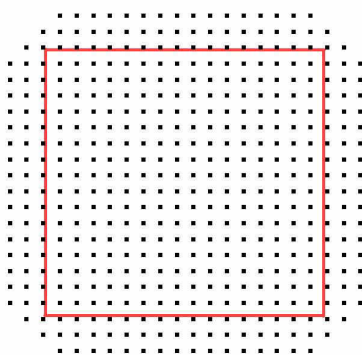


Figure 3 depicts a computer-made simulation of this artifact assuming that the beam width is significantly higher than the distance between two neighbouring recording positions of the probe (in this practical this is really the case). Small black squares cover the area that is shown in the image as the top wall of the examined cube, whereas the red line shows the real size and location of the object. As it can be seen, this artifact produces both an artificial „enlargement” of the size of the wall and an artificial „truncation” of its apexes.

Such an artifact will **surely** be recorded during the practical, therefore we need to know its nature to increase accuracy of imaging of the cubes scanned.

### Equipment

- *Scanning system with an ultrasound probe to generate and record echoes and a power supply.* The probe generates an ultrasound impulse with the frequency of 380 kHz and records, in the recording mode, one echo. The electrical signal generated upon recording of the echo, gives information about the time of echo recording  $t$ . Movement of the probe that enables ultrasound scanning of the whole examined area (recording system box below) is provided by computer-driven electric motors.
- *Data recording system* (NI USB 6008) – records time  $t$  in a form of an analog voltage signal and converts it to a digital signal. The digital signal is then sent to the computer.
- *Computer with a software* – drives the scanning process and displays the obtained results.

### Course of measurements:

#### **I. Time course of measurements:**

1. Turn on the computer.
2. Using the left mouse button click twice the shortcut „sonda” („probe”) on the computer screen; this will open the software.
3. Turn on the power supply (switch is located on the back side of the power supply box). Then, two diodes will shine: the red one on the power supply box and the green one: „Głowica” („Probe”) on the scanning system box. The ultrasound probe is now ready to work.
4. Turn on the scanning system – the red diode „Skaner” will shine on the scanning system box.
5. Run the program „sonda” by clicking the white arrow located near the upper left corner of the screen. Choose the option „Skan demonstracyjny” („*Demonstration scan*”). During such a demonstration only one cube will be scanned. The values of time of echo recording  $t$  will be displayed on the screen as colour pixels (range of the values of  $t$  corresponding to each colour will be displayed on the right side of the screen). The co-ordinates  $x$  and  $y$  (in whole numbers) display the position of the probe on the scanning plane, the  $x$ -axis is parallel to the longer side of the scanning system box. The end of a scan is announced by a proper comment on the computer screen. The ultrasound image of the whole scanned area will be displayed on the screen (note the appearance of the „beam width artifact” described above!). After the end of scanning the option „Wykres 3D” („*3-Dimensional image*”) is active. By clicking the left mouse button you can activate this option that enables seeing the scanned object images from different directions of observation.
6. After having seen the demonstration scan (both in a two- and three-dimensional image) click the button „Zakończ demonstrację” („*End of demonstration*”).
7. Now, the teacher will put 3 cubes into the scanning system and will close the box. After that, students should start scanning by pressing the button „Skan pełny” („*Full*”).

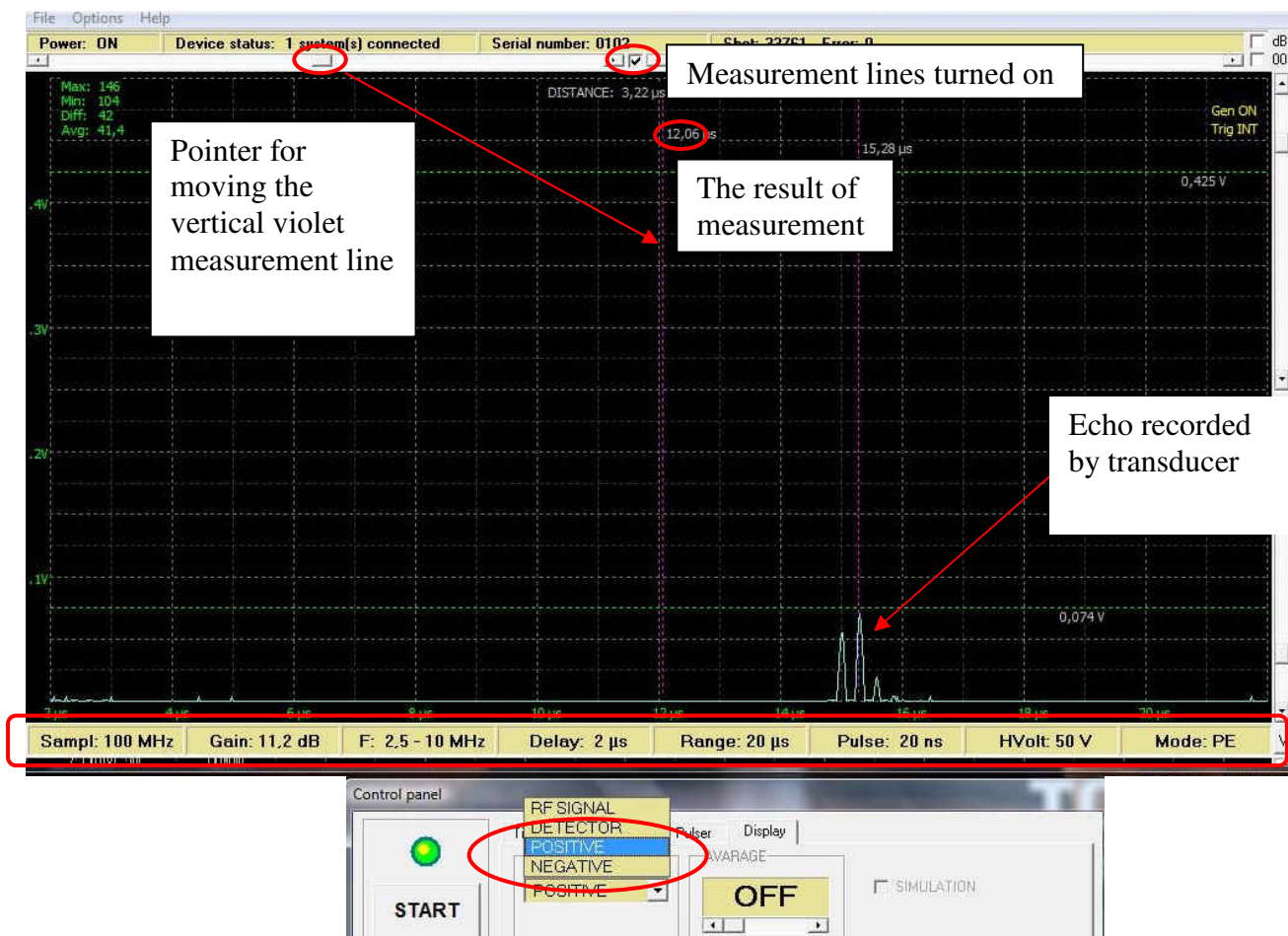
scan"). The scanning will be performed similarly to the demonstration scan described in the point 5. However, in contrast to the demonstration scan, the time of echo recording  $t$  will not be displayed as a colour pixel. The scanned area will be marked in a blue colour and the area not yet scanned in a black colour. The end of the scan will be announced by a proper comment.

Recorded data containing information about the positions of the probe (co-ordinates  $x$  and  $y$ ) and the corresponding time of echo recording  $t$  (in microseconds) will be stored as a list on the computer hard disk. Any data from this list ( $x, y, t$ ), can be displayed on the right side of the screen in the windows: „Polożenie  $x$ ” ( $x$ -axis position), „Polożenie  $y$ ”, ( $y$ -axis position) and „Czas powrotu” („time of echo recording”), respectively. In order to display the time of echo recording  $t$  for a given position of the probe on the  $x$  and  $y$  axes, one should move the red cursor to the proper place on the screen. The cursor can be moved using the keys ( $\leftarrow$ ), ( $\uparrow$ ), ( $\rightarrow$ ) and ( $\downarrow$ ) on the keyboard.

### Part B

The main purpose of this experiment is to measure the return time of the ultrasonic impulse. This time will be used to calculate the speed of the ultrasound in different materials and to determine the location of the holes in the phantom.

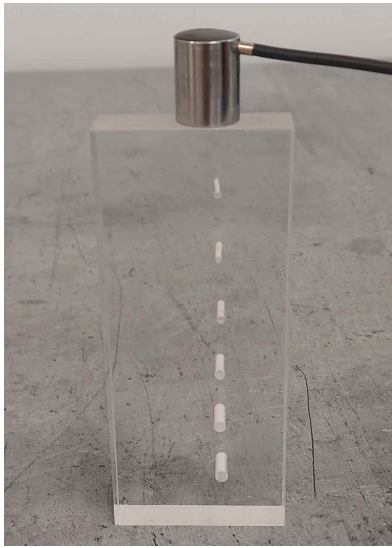
1. Start VSystem program, and then begin recording by pressing the "start" button.
2. Check whether the appropriate parameters are set, such as those indicated in the photo below in the red horizontal frame.



3. Using a caliper, measure the heights of the solids received from the tutor:
  - THE OBJECT MARKED WITH NUMBER 1 is made of organic glass (plexiglass),
  - THE OBJECT MARKED WITH NUMBER 2 is made of flint-type lead glass,
  - THE OBJECT MARKED WITH NUMBER 3 is made of crown-type potassium glass.

The measurement results should be entered in the appropriate place on the test form.

4. Apply the gel to one surface of the analyzed object. Then put the ultrasonic transducer on the object and read the echo return time at its maximum (the return time is the time, in which the sound wave moved through the solid twice).
5. Repeat the procedure for all three objects.
6. Calculate the velocity of sound waves in the analyzed objects. In which material it is the fastest and in which it is the slowest?



7. Using the same ultrasound probe, measure the distances between the individual holes and the surface of the phantom (see photo on the right). Set Delay to 7  $\mu\text{s}$ , Gain to 40 dB and Range to 40-80  $\mu\text{s}$ . In the calculations, take into account the velocity of sound in the plexiglass obtained in the previous measurement. If no echo return from a given hole is recorded, enter a dash in the appropriate place in the table.

8. Determine how many distances from the surface of the phantom to the holes can be measured using the 2MHz probe? Explain why the echo amplitude decreases with the increasing depth of the hole's placement and why we cannot record echoes from further holes?

## II. Presentation and control of the results:

1. Changing the co-ordinates  $x$  and  $y$  and observing the displayed time of echo recording  $t$  find out the maximal value of  $t$ . This value corresponds, obviously, to the situation, when the ultrasound beam is reflected from the bottom of the scanning box system. Write down the maximal value of the  $t$  to the Table. I. Calculate the distance between the probe and the bottom of the scanning box system applying the Equation no (1). Assume that the speed of ultrasound in the air is equal to 330 m/s.

2. In order to find out the location and size of the three cubes in the recording system box, change the co-ordinates  $x$  and  $y$  of the probe carefully observing the value of time of echo recording  $t$ . If this time changes **significantly** (it means by tens of microseconds), it means that the beam has crossed the borderline between the box bottom and a cube, or a borderline between two cubes (cubes may lie one on another!). If the time  $t$  does not vary significantly it means that the beam is being reflected from the bottom of the scanning box system (if the  $t$  value is maximal) or it is being reflected from the top wall of a cube (if the  $t$  value is less than maximal, but does not vary significantly). Difference in the co-ordinates  $x$  and  $y$  for points having not significantly different values of the time  $t$  is proportional to the size of the top wall of a cube, whereas the value of time  $t$  for these points enables estimation of the distance between the probe and the wall.

**Mark the points having similar values of the  $t$  on the computer screen using the „Enter” key until the image of the whole top wall of each cuboid is obtained.**

Deletion of all these points can be done using the key „Escape”. For each cube, write down following parameters to the Table II:

- time of echo recording  $t$  (with an accuracy of 1 microsecond)
- distance between the probe and the top wall of the cube calculated applying the equation (1)
- the real length ( $\Delta X_{\text{real}}$ ) and the real width ( $\Delta Y_{\text{real}}$ ) of the cube. Calculate these parameters applying the equations:  $\Delta X_{\text{real}} = \Delta X \cdot d$  oraz  $\Delta Y_{\text{real}} = \Delta Y \cdot d$ , where  $\Delta X$  and  $\Delta Y$  are differences in the co-ordinates measured in the axes X and Y of the ultrasound image, whereas  $d$  is the distance between two neighbouring values of the co-ordinates equal to 2 mm. Remember that the axis X corresponds to the longer wall of the recording system box.  
*Attention:* To increase the accuracy of estimations of the values  $\Delta X_{\text{real}}$  and  $\Delta Y_{\text{real}}$  take into account the influence of the *beam width artifact* on these values. For this purpose, compare the Figure 1 to the Figure 3.
- the real position of the apex of the cube closest to the point with co-ordinates equal to  $X = 1$ ,  $Y = 1$ . Calculate this position applying the same equation as in the point (iii):  $X_{\text{apex,real}} = X_{\text{apex}} \cdot d$  and  $Y_{\text{apex,real}} = Y_{\text{apex}} \cdot d$ , where the point  $(X_{\text{apex}}, Y_{\text{apex}})$  defines the co-ordinates of the apex in the ultrasound image.

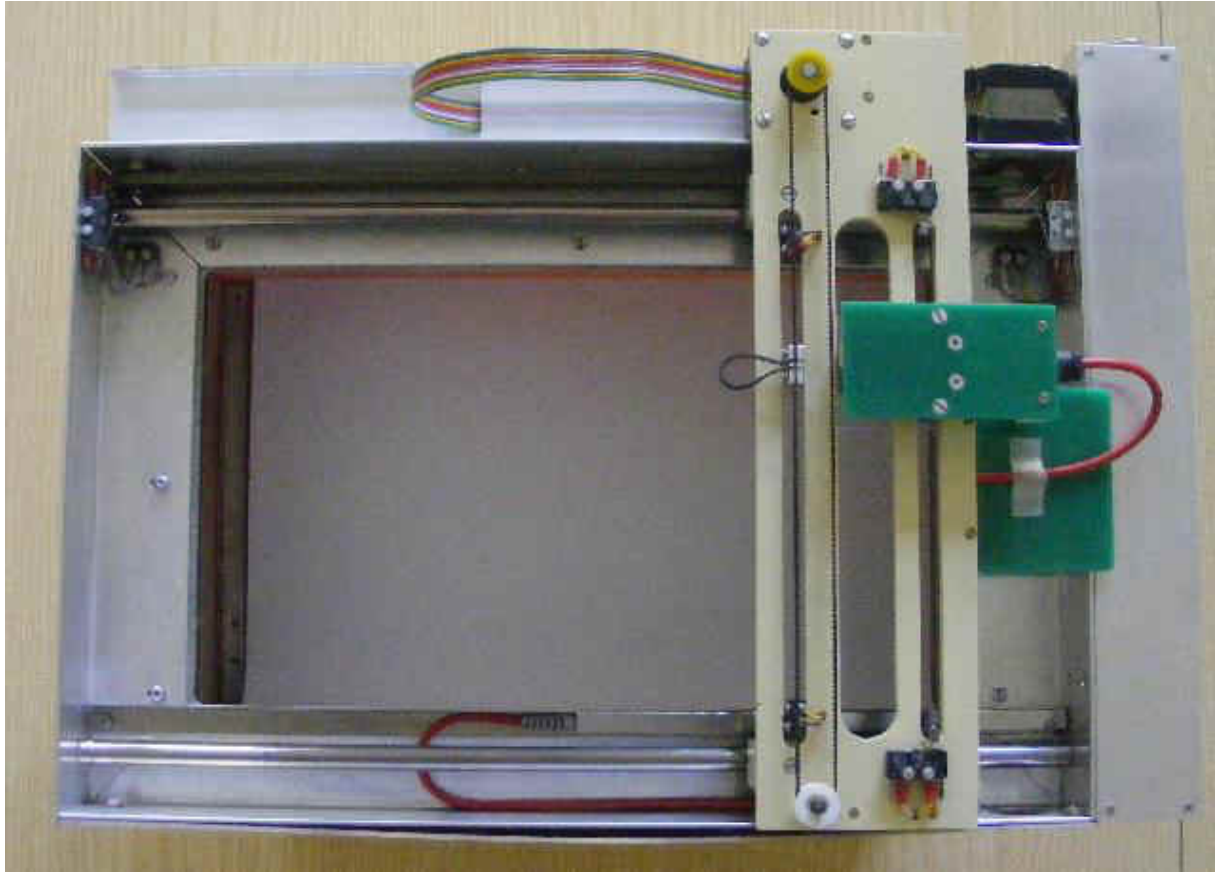
Having calculated the distance between the probe and the top wall of each cube, calculate the height of each cube (defined as the difference between the distance probe-bottom of the scanning system box and the distance probe- upper wall of the cube) and write the calculated values down to the Table II.

3. On the basis of obtained data draw the views of the scanned cubes in a natural size (1:1 scale) on a sheet of a plotting paper in: xy plane (scanning plane), xz plane (front plane of the scanning system box) and yz plane (side plane of the scanning system box).
4. Press the button „zobacz” („look”). A new window with the comment: „type the password” will appear on the screen. The teacher will type and confirm the password. Then, the view of the scanned cubes in the xy plane will appear on the screen. Compare this view with the view drawn on the plotting paper. Then, look on the three-dimensional image, by using the option „Wykres 3D” (3D-image). Push the button „zakończ program” („end of program”) and confirm this decision in the dialogue window.
5. Ask the teacher to uncover of the scanned area. Compare the scanning image with the real view.
6. Turn off the scanning system and the power supply. Close the computer program and turn off the computer.

### **Required theoretical knowledge:**

1. Ultrasound as a mechanic wave. Wavelength, frequency and propagation rate of ultrasound.
2. Impulse echolocation as a method of a spatial localization of organs inside a body in an ultrasound image. The axial resolution of an ultrasound beam and its dependence on the frequency of ultrasound.
3. Ultrasound echo presentation modes A and B.
4. Artifacts in an ultrasound image.





Scanning system box – view from the top.



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|-------------------------------------------------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------|
| <b>Wroclaw Medical University</b><br><b>Department of</b><br><b>Biophysics and Neuroscience</b> | <b>Practical No 25</b><br><b>Ultrasound echo sounder</b> |                                                  |
| .....<br>.....<br>.....<br>Names of students                                                    |                                                          | Faculty: .....<br>Group No: .....<br>Date: ..... |
| Grade:                                                                                          | Tutorial signature                                       |                                                  |

**Table I. Determination of the distance between the probe and the bottom of the scanning system box**

| Maximal time of echo recording [ $\mu\text{s}$ ] | Distance between the probe and the bottom of the scanning system box [ $\text{cm}$ ] |
|--------------------------------------------------|--------------------------------------------------------------------------------------|
|                                                  |                                                                                      |

**Table II. Determination of the geometry of the system**

|                                                                              | Cube I                                               | Cube II                                              | Cube III                                             |
|------------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|
| Time of echo recording [ $\mu\text{s}$ ]                                     |                                                      |                                                      |                                                      |
| Distance between the probe and the top wall [ $\text{cm}$ ]                  |                                                      |                                                      |                                                      |
| Real length $\Delta X_{\text{real}}$ [ $\text{cm}$ ]                         |                                                      |                                                      |                                                      |
| Real width $\Delta Y_{\text{real}}$ [ $\text{cm}$ ]                          |                                                      |                                                      |                                                      |
| Real position of the apex closest to the point $X=1$ , $Y=1$ [ $\text{cm}$ ] | $X_{\text{apex,real}} =$<br>$Y_{\text{apex,real}} =$ | $X_{\text{apex,real}} =$<br>$Y_{\text{apex,real}} =$ | $X_{\text{apex,real}} =$<br>$Y_{\text{apex,real}} =$ |
| Height [ $\text{cm}$ ]                                                       |                                                      |                                                      |                                                      |



**Part B.**

| Object                         | Height [mm] | Echo return time [ $\mu\text{s}$ ] | Velocity [m/s] |
|--------------------------------|-------------|------------------------------------|----------------|
| (1) Organic glass (plexiglass) |             |                                    |                |
| (2) flint-type lead glass      |             |                                    |                |
| (3) crown-type potassium glass |             |                                    |                |

|                                                                       | Hole I | Hole II | Hole III | Hole IV | Hole V |
|-----------------------------------------------------------------------|--------|---------|----------|---------|--------|
| Echo return time [ $\mu\text{s}$ ]                                    |        |         |          |         |        |
| Distance between individual holes and the surface of the phantom [mm] |        |         |          |         |        |

Why does the echo amplitude decrease with increasing hole location depth, and why do we not see echoes from further holes?

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