U10010 Ultrasonic Echoscope and Accessories

Operating instructions

6/04 ALF

① *Start point for time-dependent amplification*
② *Trigger slope (rise time) for time-dependent amplification*
③ *Width of time-dependent amplification*
④ *Threshold for time-dependent amplification*
⑤ *Transmitter power*
⑥ *Receiver gain*
⑦ *Power supply*
⑧ *Mains switch*
⑨ *Receiver unit*
⑩ *Probe connection for reflection mode or receiver in transmission mode*
⑪ *Reflection/transmission mode changeover switch*
⑫ *Probe connection for transmission mode*
⑬ *Transmitter unit*
⑭ *Clocking unit (time-dependent amplifier)*
⑮ *Connector sockets for oscilloscope*
⑯ *Signal output A scan (LF signal)*
⑰ *Signal output (HF signal)*
⑱ *Signal output for trigger signal*
⑲ *Signal output for time-dependent amplifier ramp*

Safety instructions

For your own safety and that of the equipment, please read the following instructions thoroughly before using this ultrasonic device and its accessories.

The slits in the device are for ventilation and must not be covered to avoid overheating of the equipment. We recommended that the feet on the device be used.

Ensure that the specified operating voltage and safety measures are observed.

Never try to insert objects through the ventilation slits since this could lead to short circuits or electric shocks.

Connect only the ultrasonic transducer supplied by 3B Scientific GmbH to the "PROBE" sockets. Caution: the transmitting transducer may experience voltage pulses as high as 300 V.

Be aware that this is laboratory equipment and not a medical appliance. The ultrasonic sensors are not to be used on people or animals.

Contents

1. Introduction

Ultrasonic echoscopy (also called sonography) has developed into one of the key procedures for medical examination and materials technology. Although there is a confusingly wide range of ultrasonic devices produced for various applications, all of them rely on the same basic principle of emitting a mechanical wave and recording the reflections in an echogram.

2. Components

2.1. Ultrasonic echoscope controls U10010

The U10010 echoscope is an ultrasonic A-image device with an output for pure pulse echo operation and an extra output and converter for operation with two ultrasonic transducers for transmission measurements. The device is equipped with a parallel interface for connection to transfer data to a PC.

To make the principle behind the device clearer, the individual components, receiver, transmitter and time-dependent amplifier can be viewed separately. The gain for the amplification of the received signal can be adjusted in 5-dB steps from 0 to 35 dB. The transmitter power can be adjusted in 10-dB steps from 0 to 30 dB. For time-dependent amplification, the start point, the rise time, the threshold and the width can all be continuously adjusted up to a maximum gain of 35 dB.

Also included is the ASH control software for Microsoft Windows. This allows you to measure amplitude and timing differentials. It also supports the simultaneous display of HF signal and amplitude signal so that, unlike with conventional A-image equipment, the wave nature of ultrasound can be demonstrated. An additional chart simultaneously shows the form of and change in the time-dependent amplification. Other software options include: manually guided B-images; time-motion mode; FFT on a selected signal segment; zoom function; changeover between time and resolution depending on the speed of sound, which can also be adjusted; switching between measuring ranges; data export and print capability; automatic mode display (transmission or refection).

2.2. Ultrasonic transducer

2.2.1. Ultrasonic transducer 1 MHz U10015

For examinations at greater depth or examinations involving high power and low depth resolution, 16-mm piezo-ceramic disc in cast metal housing, preset for water propagated sound, one cable with frequency-coded snap-in plug.

2.2.2. Ultrasonic transducer 4 MHz U10017

For examinations requiring maximum depth resolution at shallow depth, 16-mm piezo-ceramic disc in cast metal housing, preset for water propagated sound, 1-m cable with frequency-coded snap-in plug.

2.3. Accessories

2.3.1. Acrylic block with holes U10027

For determining speed of sound and attenuation of an ultrasonic signal in acrylic (polyacrylate), for pinpointing discontinuities, and investigating imaging errors caused by sound shadows or ground echoes, frequency-dependent resolution capacity and display of a manual B image. To investigate resolution, both the 1-MHz and the 4-MHz transducers are required. Polished polyacrylate block with drilled holes of various diameter for simulating discontinuities at various distances from the surface of the block.

2.3.2. Equipment set for longitudinal and transverse waves U10020

For investigating the propagation of longitudinal and transverse (shear) waves in solid bodies and determining elastic constants (shear modulus, modulus of elasticity and Poisson number) of these bodies. Also for determining ultrasonic attenuation in fluids by means of time-dependent amplitude measurement with moveable reflector.

Ultrasound is first passed vertically through a body under test placed in a trough filled with water. Only longitudinal waves are propagated through the body. The transmission amplitude of these is recorded. In rotating the body to ever greater angles, the amplitude of the longitudinal waves decreases and transverse waves are increasingly propagated through the body. These appear in the amplitude domain as a second peak.

From the angle where total reflection of the longitudinal waves takes place, the speed of the longitudinal waves can be calculated. The speed of transverse waves can be calculated from the angle where the maximum transmission amplitude for transverse waves occurs. If the body is rotated further, total reflection of the transverse component may also occur depending on the magnitude of the speed of sound in proportion to that in the surrounding fluid.

From the two speeds of sound, the elastic constants (shear modulus, modulus of elasticity and Poisson number) for the body under test can be calculated.

Acrylic (included in the scope of delivery), aluminum and polyoxymethylene (POM) plates are available as test bodies. The speed of transverse waves in acrylic (polyacrylate) is almost exactly the same as in water. In aluminum the speed is greater and in POM it is smaller than in water.

Set consists of sounding trough, acrylic test plate in holder with protractor scale and two transducer holders for 1-MHz or 4-MHz ultrasonic transducers that allow for precise positioning of the transducers on the sounding trough.

2.3.3. Aluminum plate with protractor scale U10022

Accessory for longitudinal and transverse waves equipment set for investigating the propagation of transverse waves in metals and for determining the elastic constants such as shear modulus, modulus of elasticity and Poisson number for aluminum; high quality reflector (large reflection coefficient in water) and therefore easy-to-measure signal amplitudes for attenuation measurements in liquids (e.g. water, cooking oil, glycerine).

2.3.4. Polyoxymethylene (POM) plate in test holder with protractor scale U10023

Accessory for longitudinal and transverse waves equipment set for investigating the propagation of transverse waves in plastic and for determining the elastic constants such as shear modulus, modulus of elasticity and Poisson number for POM.

2.3.5. Reflection plate U10025

Polished acrylic plate for investigating multiple echoes and measuring frequency-dependent attenuation. The 4-MHz transducer is particularly suited for measurements of this kind. Initially an echo image with at least three echoes is recorded and the spectrum of the individual echoes analyzed. The result is a shifting of the median frequency to lower frequencies since the higher frequency components are more strongly attenuated.

2.3.6. Set of 3 cylinders U10026

Polished polyacrylate cylinders for determining speed of sound and attenuation of ultrasound in acrylic. Measurements can be made using reflection mode or transmission mode.

2.3.7. Heart valve model U10029

Twin chamber with rubber membrane and pressure regulator for demonstrating the action of heart valves using the time-motion method. During the experiment, the membrane chamber produces an image similar to that produced by a valve of a beating heart in an electrocardiogram as used for medical diagnosis.

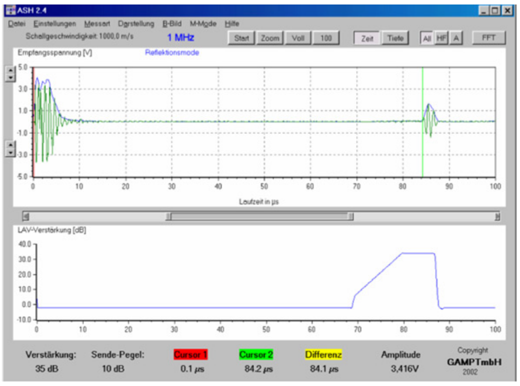
2.3.8. Model of a single breast with benign tumor

Imitation breast made of silicon with a simulated benign tumor for demonstrating B-image mode.

3.Software

3.1. Program operation

As soon as the program is started, the measuring equipment is immediately activated. The user interface is shown in the illustration above. In the top part of the screen, the A-image signal, the current position of the *markers* (vertical red and green lines), the frequency of the receiving transducer that is connected and the current mode (reflection/pulse echo or transmission). The markers can be positioned using the *mouse* (the mouse cursor changes when the markers are to be moved).



Schallgeschwindigkeit: 1000,0 m/s

1 MHz

Reflektionsmode

Verstärkung: 35 dB

Sende-Pegel: 10 dB

Cursor 1 0.1 µs

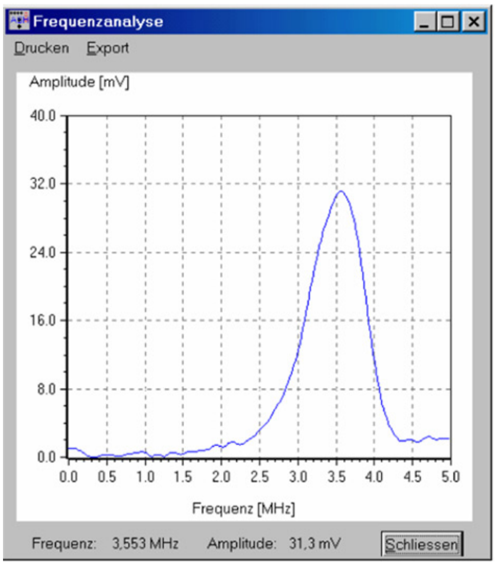
Cursor 2 84.2 µs

Differenz 84.1 µs

Amplitude 3,416V

The scale for the time axis (*time measurement*) can be switched to display distance (*depth measurement*) ["Time"/"Depth" buttons]. An entry for the speed of propagation as required for calculation can be made using the *Settings* option in the menu (default: 1000 m/s). The *UP-DOWN button pairing* at the left-hand edge of the screen is for changing the amplitude resolution (top) and shifting the zero-axis (bottom).

The constant updating of the A image can be suspended (Freeze) by using the "Stop" button and restarted using the "Start button". When the image is frozen, the FFT button becomes active. If this is clicked, the amplitude spectrum of the segment of signal bounded by the markers is displayed in a new window (see illustration below.)



Frequenz: 3,553 MHz Amplitude: 31,3 mV

At the same time, a measurement function using the mouse is activated (crosshair cursor). Frequency and amplitude are displayed at the position where the mouse is situated. The form can be printed (standard printer under Windows), or the spectrum can be saved (as an ASCII table) using the Export function.

The "Zoom" button magnifies the display of a selected depth range. Position and width of the range are set by moving the sliders in the middle of the screen with the mouse. The "Full" button causes the "Zoom" function to be deactivated again.

The button marked "100"/"200" allows the measuring range (maximum time or resolution) to be switched between 100 µs and 200 µs. The "A" [A image], "HF" [High-frequency signal] and "All" [both signals] settings allow you to select the form in which the signal should be displayed.

In the central region of the screen, the characteristics for time-dependent amplification are shown including all parameters (start point, rise time, width, threshold). At the bottom of the window, status information is displayed. Among the items shown here are the time or the depth represented by the current marker positions. The difference between the red and green markers is displayed in yellow. The current transmitted level and primary gain are shown at the bottom left. The bottom right gives the amplitude of the received voltage at the mouse cursor position (the center of the crosshair.)

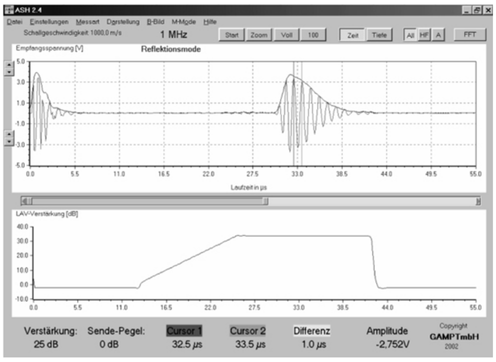
3.2. Menu functions

File	Print Form	Prints the window (form) to the current printer
	Export	Exports the measured values as an ASCII table to a text file (columns: Time, HF data, A image, TGC),
	Exit	Exit the program
Settings	Speed of sound	Entry for the speed of sound to allow correct display of depth (default: 1000 m/s)
	Port	Selection of LPT port for communication with controlling PC
Type of meas.	Duration	Axis = time (default)
	Depth	Axis = depth
Display	A-scan	Displays the A image (A mode)
	HF data	Displays the HF signal (Echo)
	All	Displays both signals (HF echo and A line/ envelope)
B image	Activates the form for displaying a B image (B-mode image)	
M-mode	Activates the form for displaying an M-mode image	

4. Suggested experiments

4.1. Wave nature of ultrasound

With the aid of the software, it is possible to display a signal corresponding to a reflection, e.g. between an acrylic block and air, in HF mode (high frequency oscillation), in A mode (amplitude component = envelope of HF signal) and in both modes at once. This can convey to the student which signal gives rise to a typical A image. Below is a screenshot of the software user interface showing the measured signal at the top and the settings for the amplifier underneath it.



Schallgeschwindigkeit 1000,0 m/s
1 MHz

Verstärkung: 25 dB
Sende-Pegel: 0 dB
Cursor 1 32.5 µs
Cursor 2 33.5 µs
Differenz 1.0 µs
Amplitude -2,752V

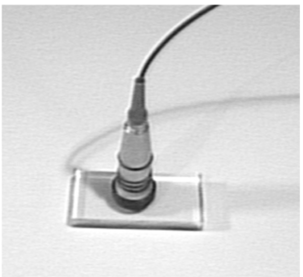
4.2. Determining the frequency of the transducer in use

From the initial echo of the transducer or from a lightly damped reflection, it is possible to determine the distance between two maxima in the high-frequency signal oscillation with the aid of the zoom function. This involves placing the measuring cursors at two adjacent peaks of the high frequency signal as shown in the above screenshot. The time difference can then be read directly from the status bar. With this information, the frequency of the transducer being used may be calculated (in this case 1/1µs = 1 MHz).

4.3. Longitudinal speed of sound in test bodies

An ultrasonic transducer is attached to test bodies made of various materials and the time between the emission of a pulse and the reception of an echo reflected from a boundary layer is measured (see photograph below). Knowing the distance s between the transducer and the edge of the body allows the longitudinal speed of sound c_L to be calculated from the measured time t as follows

$$c_L = \frac{2s}{t} \tag{1}$$



Some results of measurements involving different materials and geometries are shown in the table below.

Material		Time [µs]	Δt [µs]	Distance [mm]	Δs [mm]	Speed of sound longitudinal [m/s]	Δc [m/s]
Acrylic	Rod 1	84.1	0.4	112.9	0.2	2685	18
	Rod 2	112.5	0.6	151.0	0.2	2684	18
	Block Length	111.3	0.4	150.0	0.2	2695	13
	Width	30.3	0.4	40.2	0.2	2653	48
	Height	59.4	0.4	79.8	0.2	2687	25
	Standard value					2610-2750	
PVC	Block Length	84.9	0.4	98.0	0.2	2309	16
	Width	76.8	0.4	87.6	0.2	2281	17
	Height	70.3	0.4	80.7	0.2	2296	19
	Standard value					2220-2380	

4.4. Attenuation of sound in test bodies

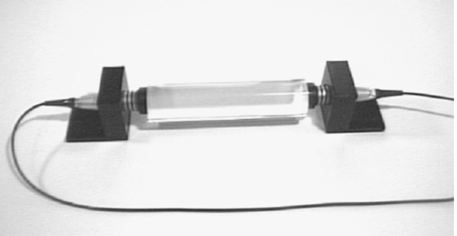
Using the measuring cursor for determining amplitude in the ASH program, the amplitude A of the echo from the rear surface of two bodies of identical but different size can be measured. Applying the law of attenuation to these measurement gives

$$A = A_0 \, e^{-\alpha x} \tag{2}$$

which can be rearranged to give the sound attenuation coefficient α

$$\alpha = \frac{1}{2(x_1 - x_2)} Ln \frac{A_2}{A_1} \tag{3}$$

A_1 is the amplitude for a body of width x_1 and A_2 is that for a body of width x_2. The factor of 1/2 in equation (3) emerges from the fact that sound must traverse the distance twice when the reflection method is used. If a transmitter-receiver arrangement is employed, the factor is omitted.



In all cases care should be taken to ensure that the amplifier settings are kept identical as far as possible in order to achieve reproducible results.

Thus the thicknesses of the objects should not differ greatly. The sound attenuation coefficient in (3) is frequency-dependent so that the frequency used for the measurement should always be quoted along with the result. The theoretical frequency-independent absorption coefficient α_0 is given by (4) (where υ is the frequency of the ultrasonic wave):

$$\alpha = \frac{\alpha}{v^2} \tag{4}$$

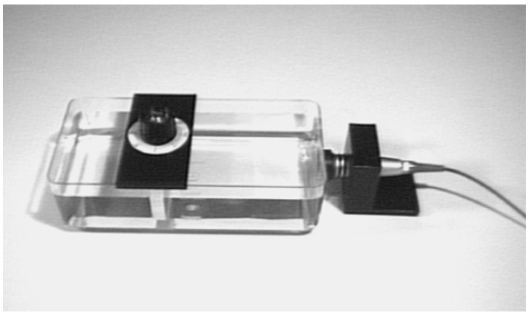
Unfortunately, in most bodies and fluids there is a large scattering component to the attenuation coefficient. Since scattering is dependent on the ratio of the wavelength to the size of the scattering object, this can lead to wide variations in the frequency dependence of the attenuation arising from (4).

When comparing with standard published values, it should be noted that the values are usually given in dB/cm so that the value for α results from (3) thus:

$$\alpha\,[1\,/\,\mathrm{cm}] \text{ or } [\mathrm{neper}\,/\,\mathrm{cm}] = \frac{\alpha[dB/cm]}{20Lg(e)} = \frac{\alpha[dB/cm]}{8.686} \qquad (5)$$

4.5. Attenuation of sound in fluids

By measuring inside a fluid container with a movable reflector it is possible to plot a curve of the reflected amplitude for various values.

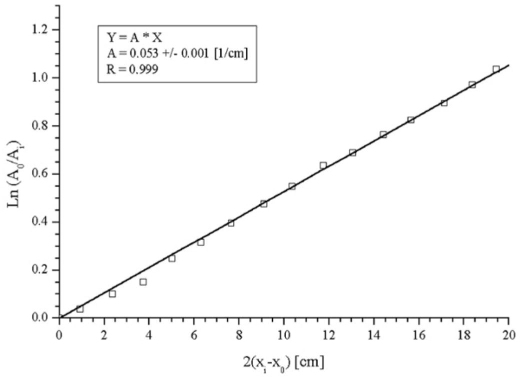


An external program can then derive the attenuation coefficient α by finding a fit for the exponential function in (3) or more simply identifying a linear fit to a line that matches (3) when it is rearranged in the form (6):

$$y = ax$$

$$Ln\,\frac{A_0}{A_i} = \alpha 2(x_i - x_0) \qquad (6)$$

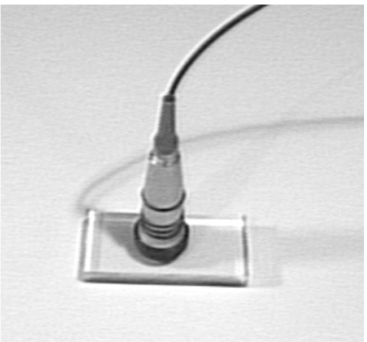
where A_0 is the amplitude of the peak closest to the transducer. All subsequent measurements (i) are related to this value so that the measuring error at greater distances becomes much smaller. If the speed of sound in the fluid has already been determined (e.g. by using the transmission method where measuring both lengthways and across the width eliminates the effect of the container's walls) and entered into the program, the distances of the reflector from the transducer can be read off directly from the software (Depth setting). Attenuation of sound in water is too weak to measure any alteration in amplitude over a distance of around 20 cm. The following diagram shows a graph as measured for sunflower oil.



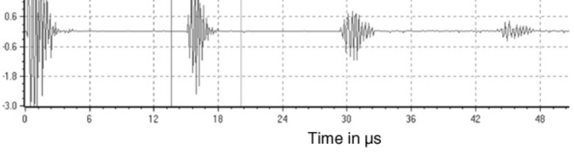
By setting the amplifier appropriately, the entire available path may be used for measurements. Using a frequency of 1 MHz gives a value of about 0.5 dB/cm for the attenuation coefficient, which is close to the published value of 1 dB/cm for frequencies of 1 – 5 MHz.

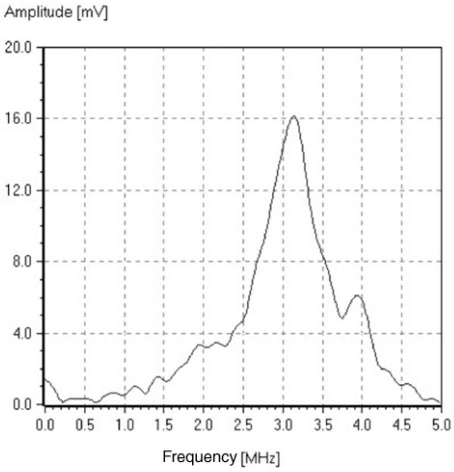
4.6. Frequency-dependent attenuation

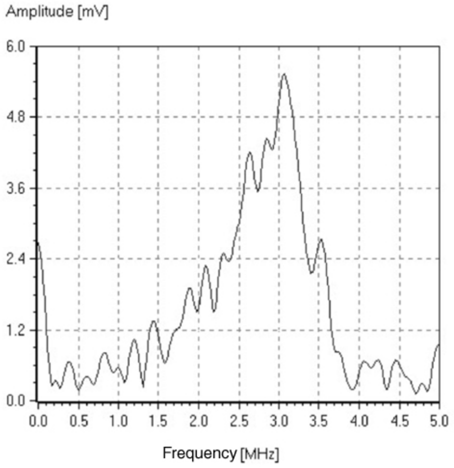
Frequency-dependent attenuation can be studied very well using a thin acrylic plate (thickness 1 – 2 cm approx., see photograph).

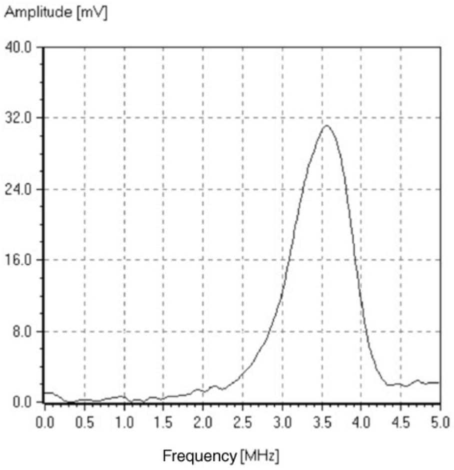


Since parallel surfaces give a series of multiple echoes when the transducer is placed straight against them, the frequency components of individual echo pulses can be investigated using the FFT function built into the program. The following illustration shows the corresponding FFT analyses. It can clearly be seen that higher frequencies are attenuated more acutely as the distance traveled through the plate increases. Thus the median frequency (the frequency component of the highest amplitude) becomes shifted.





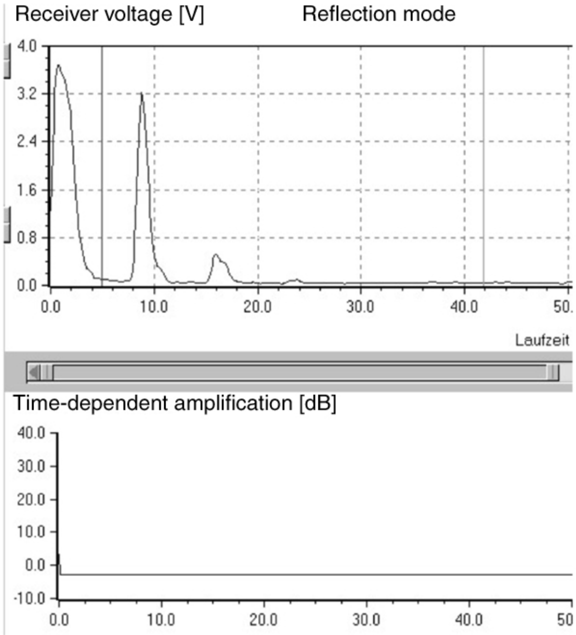




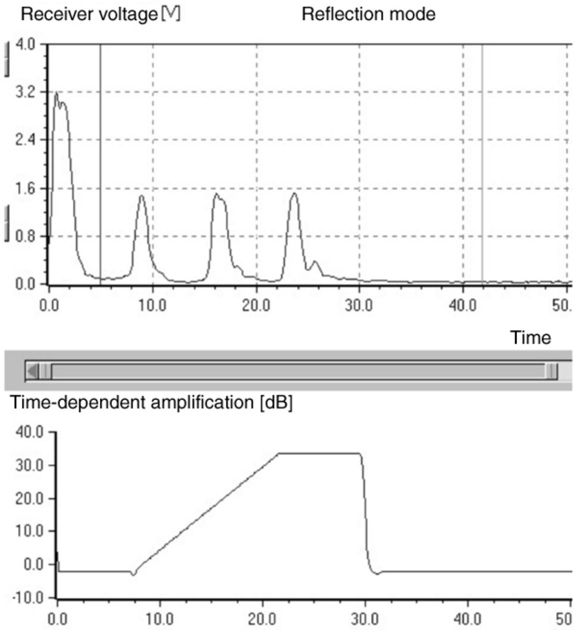
4.7. Time dependent amplification

The plate used in 4.6 can also be used to demonstrate the time-dependent amplification method that is often employed, particularly in medicinal applications.

The rise time, threshold and start point of the amplifier can all be adjusted so that the individual echoes all appear to be of equal magnitude. The time-dependent amplifier thus compensates for the attenuation in the material. Variations in width and point of action can emphasize areas at different depths or even filter certain depths out. An example is shown in the following diagram.



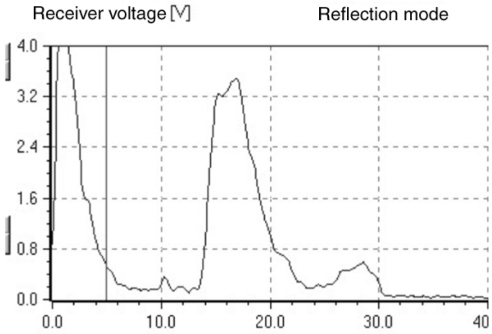
The damping visible in the display above is just about eliminated with the time-dependent amplification settings used in the display below.

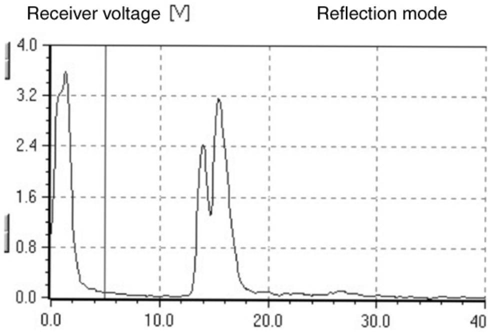


4.8 Frequency dependence of resolution

Two small discontinuities situated close together in a specially manufactured test body (see section 4.9) can be used to demonstrate the frequency dependence of resolution.

The discontinuities are investigated using a 1-MHz and a 4-MHz transducer and the ability to separate the two locations is compared for the two frequencies. The amplitude signals for both frequencies are shown in the following diagrams. The top one is the display for the 1-MHz transducer and the lower is for the 4-MHz transducer.

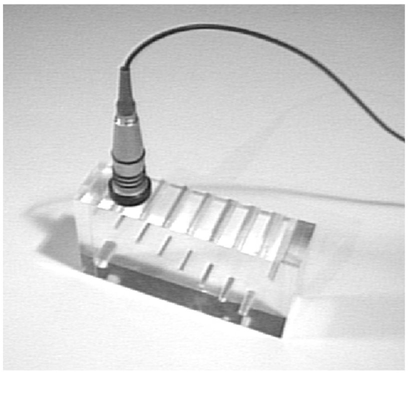




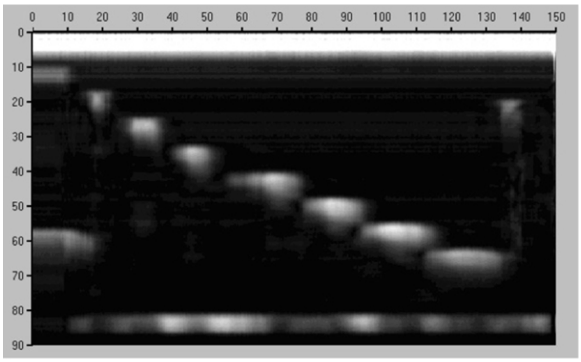
4.9. Manually guided B image

A test body with discontinuities can be used along with the built-in *B-Image* software feature to demonstrate how a B (brightness) image is generated from an amplitude signal.

The 1-MHz transducer (U10015) is slowly and evenly guided over the test body as in the following illustration.



The software converts the amplitude scan into a two-dimensional brightness display.

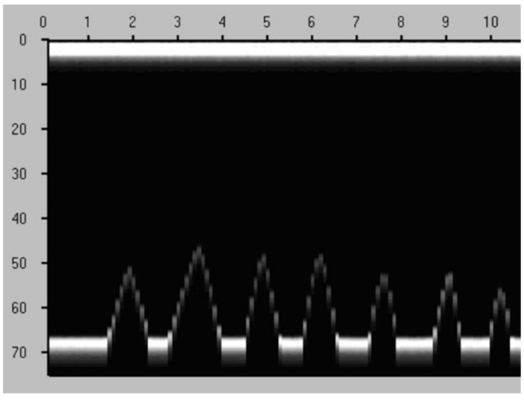


At each of the various discontinuities, the focus of the ultrasonic transducer, the position resolution and image errors (such as sound shadows) can all be displayed.

4.10. Time-motion mode (M-mode)

So-called M-mode allows ultrasonic reflections from moving boundary layers to be displayed. This can be used, e.g. in an echocardiogram, to investigate the valves of the heart. The heart itself can be simulated using the heart valve model (U10029) with a rubber membrane caused to move by a ball-shaped bellows.

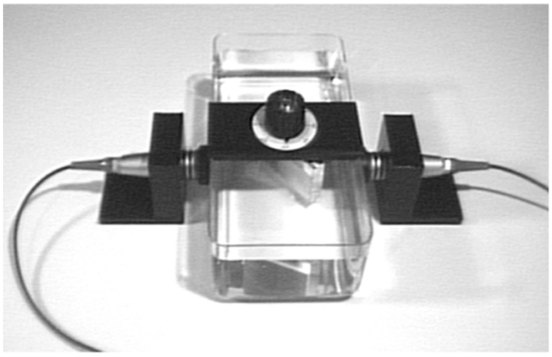
The corresponding software option (M-mode) allows the movements to be shown as a two-dimensional display.



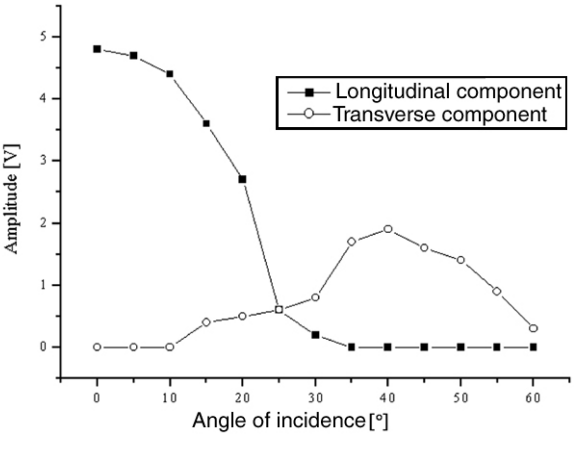
The M-mode image basically corresponds to a displacement-time graph, so that the speed of movement can be determined from the rise time.

4.11. Transmission coefficient and transverse speed of sound

With an experiment set-up like that shown in Figure 2 (transducer in transmission mode attached to a water-filled trough containing a rotatable plate with a specified thickness of 1 cm), by turning the plate it can be demonstrated that when an ultrasonic wave passes from a fluid to a solid body at a non-perpendicular angle, both longitudinal and transverse waves are excited.



Since transverse sound waves are produced by shearing and their speed is lower than that of longitudinal waves, the following regions arise (example with acrylic):
Angle of incidence 0°: only a peak for longitudinal waves possibly with multiple reflections
Small angle of incidence (<=10°): multiple reflections vanish, amplitude decreases
Angle of 10° - 30°: peaks for both longitudinal and transverse waves
Angle >30°: only transverse waves remain with amplitude maxima at an angle of incidence of about 40°. Amplitude becomes smaller at increasing angles
The amplitude in transmission mode or, by measuring the transmission in the absence of the plate, the amplitude transmission coefficient can now be calculated for both longitudinal and transverse waves (see following diagram).



Since the transmission of transverse waves through the plate is greatest at a transmission angle of 45°, the maximum in the transverse amplitude curve may be used to determine the angle of incidence *Φ* and thus the transverse speed of sound by means of the following equation

$$C_T = \frac{\sqrt{\frac{1}{2}}}{sin(\phi)} c_F \tag{7}$$

where c_F is the speed of sound in water (1480 m/s). Fig. 17 shows the measurement results for a test body composed of 1 cm thick acrylic. For an amplitude maximum at 40°, equation (7) gives the speed of transverse waves to be approximately 1600 m/s. The published value is 1450 m/s. Determining the angle more precisely would certainly lead to greater accuracy in this case.
Separation into longitudinal and transverse amplitudes is possible due to the differences in time of travel resulting from the large differences in speed of longitudinally and transversely propagated waves. Even with a plate of only 1 cm thickness, the transverse waves are sufficiently delayed to be measured (see following illustration).
The speed of transverse waves allows the shear modulus (torsion modulus) *G* to be calculated:

$$C_T = \sqrt{\frac{G}{\rho}} \tag{8}$$

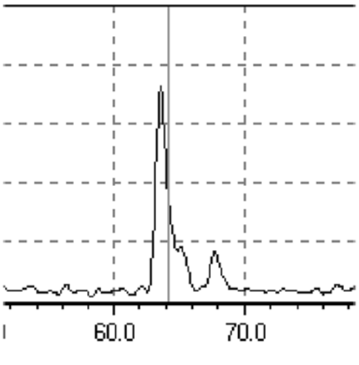
The modulus of elasticity *E* (Young's modulus) for the body can be calculated from the longitudinal speed of sound if the cross-sectional contraction coefficient (υ--Poisson number) is known:

$$C_L = \sqrt{\frac{E}{\rho} \frac{1-\upsilon}{(1+\upsilon)(1-2\upsilon)}} \tag{9}$$

When cross-sectional expansion is negligible (for thin rods):

$$C_L = \sqrt{\frac{E}{\rho}} \tag{10}$$

where ρ is always the density of the body



If c_T and c_L are known, the Poisson number υ can also be calculated by means of equation (11):

$$\frac{c_L}{c_T}=\sqrt{\frac{2(1-\upsilon)}{1-2\upsilon}} \qquad (11)$$

4.12. Combination of B image and A scan for testing materials

To demonstrate the testing of materials, a body with invisible discontinuities is provided. A manually guided B image can be used to gain an initial idea of where the discontinuities lie. The precise coordinates can then be determined and plotted with the help of an A scan.

5. Technical details

5.1 Ultrasonic echoscope U10010

Frequency range:	1 MHz to 5 MHz
Measuring mode:	can be switched between pulse-echo and transmission modes
Transmitted signal:	Dirac pulse (<1µs, 10 V – 300 V)
Transmitter power:	0 30 dB, in 10 dB steps
Gain:	0-35 dB, in 5 dB steps
Time-dependent amplifier:	continuously adjustable threshold, start point, rise time and duration, up to 30 dB gain
Connections:	TGC signal, trigger, NF signal, HF signal all via BNC sockets (Var. Ex)
Computer port:	Sub D-25 socket on LPT via male-male cable
Sampling rate:	10 MHz per channel
Dimensions:	256 x 257 x 156 mm
Mains voltage:	115 V / 230 V switchable
Power consumption:	max. 20 VA

5.2. Ultrasonic transducer 1 MHz U10015

Dimensions:	65 mm x 27 mm ∅

5.3. Ultrasonic transducer 4 MHz U10017

Dimensions:	65 mm x 27 mm ∅

5.4. Acrylic block with holes U10027

Dimensions:	150 x 80 x 40 mm

5.5 Equipment set for longitudinal and transverse ultrasound propagation U10020

Sound trough:	200x100x60 mm
Protractor scale:	360°, with 5° divisions
Acrylic plate:	70 x 45 x 10 mm
Dimensions:	104 x 75 x 50 mm

5.6 Aluminum block with protractor scale U10022

Protractor scale:	360°, with 5° divisions
Aluminum block:	70 x 45 x 50 mm
Dimensions:	104 x 75 x 50 mm

5.7. Polyoxymethylene (POM) plate with protractor scale U10023

Protractor scale:	360°, with 5° divisions
POM plate:	70 x 45 x 10 mm
Dimensions:	104 x 75 x 50 mm

5.8. Reflection plate U10025

Dimensions:	80 x 40 x 10 mm

5.9. Set of 3 cylinders U10026

Dimensions:	40 mm x 40 mm ∅ 80 mm x 40 mm ∅ 120 mm x 40 mm ∅

5.10. Heart valve model U10029

Dimensions:	160 mm x 70 mm

5.11. Model of a single breast with benign tumor L55/1

Model breast made of silicon rubber with simulated benign growth

6. Bibliography

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