Ultrasonic

Question 1 **(9 points)**

General questions about ultrasound and wave propagation.

(a) Give the formal definition of the reflection coefficient R and the transmission coefficient T with perpendicular incidence of the sound waves. How do these depend on the acoustic impedance Z? **(2 points)**

(b) Ultrasonic waves in muscle tissue with a density $\rho_{0,1} = 1.04\mathrm{g} \cdot \mathrm{cm}^{-3}$ and a bulk modulus of $\mathrm{K}_1 = 2.555 \times 10^9 \mathrm{kg} \cdot \mathrm{m}^{-1} \cdot \mathrm{s}^{-2}$ fall perpendicularly onto a smooth planar boundary layer of adipose tissue with a density of $\rho_{0,2} = 0.97\mathrm{g} \cdot \mathrm{cm}^{-3}$ and a bulk modulus of $\mathrm{K}_2 = 2.078 \times 10^9 \mathrm{kg} \cdot \mathrm{m}^{-1} \cdot \mathrm{s}^{-2}$. What percentage of the sound intensity is transmitted.
Notice: $Z = \sqrt{\mathrm{K} \cdot \rho_0}$ **(2 points)**

(c) Now be the angle of incidence $a_1 = 10°$. At what angle propagates the transmitted wave further?
Notice: speed of sound: $c = \sqrt{\frac{\mathrm{K}}{\rho_0}}$. Use the information from task part (b). **(3 points)**

(d) What is the name of the principle that makes it possible to clearly demonstrate the propagation of complex wave fronts? Explain it. **(2 points)**

Solution:

a)

$$R = \frac{J_r}{J_0} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

$$T = \frac{J_t}{J_0} = \frac{4 \cdot Z_1 \cdot Z_2}{(Z_1 + Z_2)^2}$$

b)

$$Z = \sqrt{K \cdot \rho_0}$$

Adjust units of K to units of ρ.

$$\frac{kg}{m \cdot s^2} = \frac{10g}{cm \cdot s^2}$$

This allows the sound impedances to be determined:

$$Z_1 = 1.63 \times 10^5 \frac{g}{cm^2 \cdot s} \quad \text{and} \quad Z_2 = 1.42 \times 10^5 \frac{g}{cm^2 \cdot s}.$$

or

$$Z_1 = 1.63 \times 10^6 \frac{kg}{m^2 \cdot s} \quad \text{and} \quad Z_2 = 1.42 \times 10^6 \frac{kg}{m^2 \cdot s}.$$

With the transmission coefficient from a) you get exactly the requested information: T≈99.5%

c) The speeds of sound are $c_1 = 1567 \frac{m}{s}$ and $c_2 = 1464 \frac{m}{s}$

And for the refraction angles: $$\frac{\sin\alpha_1}{\sin\alpha_2} = \frac{c_1}{c_2}.$$

It follows: $$\alpha_2 = \arcsin\left(\frac{c_2 \cdot \sin\alpha_1}{c_1}\right) = 9.34°$$

d) Huygens principle: A spherical wave propagates from every point on a wavefront. The superposition of these elementary wave fronts results in the actual complex wave front.

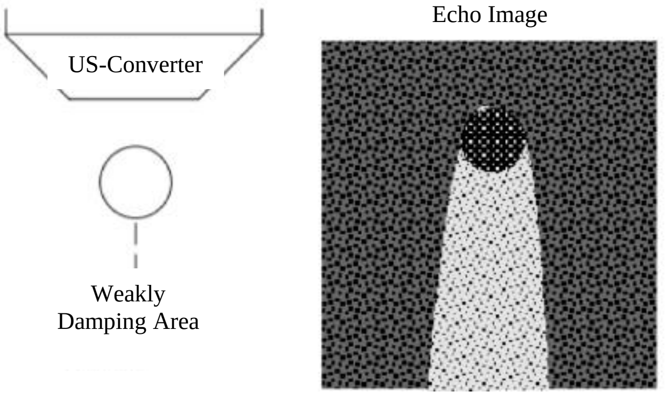
Ultrasonic

Question 1 **(8 points)**

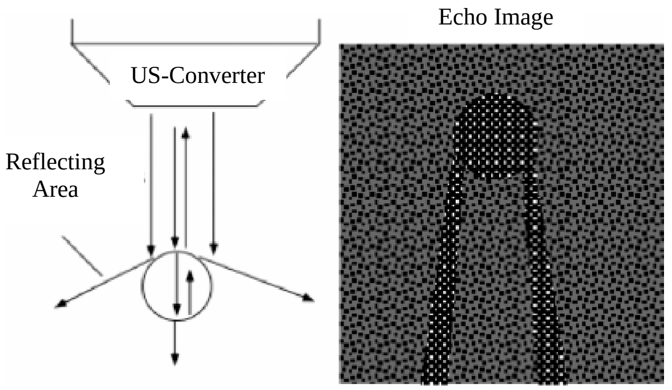
What artifacts are known for US imaging? (At least 4 types, each with a sketch and a short description)

Solution:

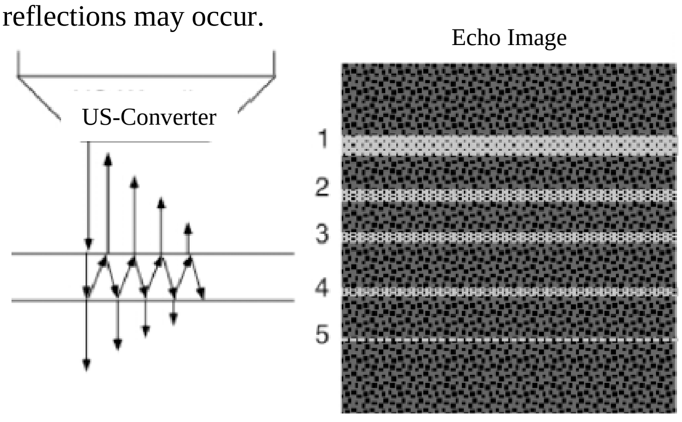
1. There is an apparent signal increase behind weakly damping areas due to the time gain compensation.



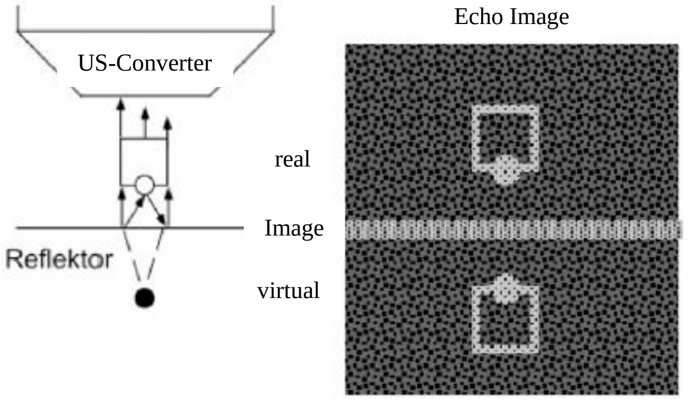
2. Shadowing occurs behind slanted edges that reflect relatively strongly.



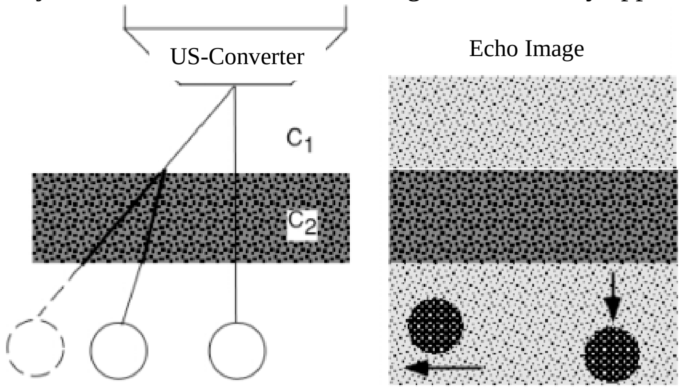
3. In case of two strongly reflecting, approximately parallel boundary surfaces, multiple reflections may occur.



4. Objects in front of highly reflective surfaces mav appear twice as a virtual image.



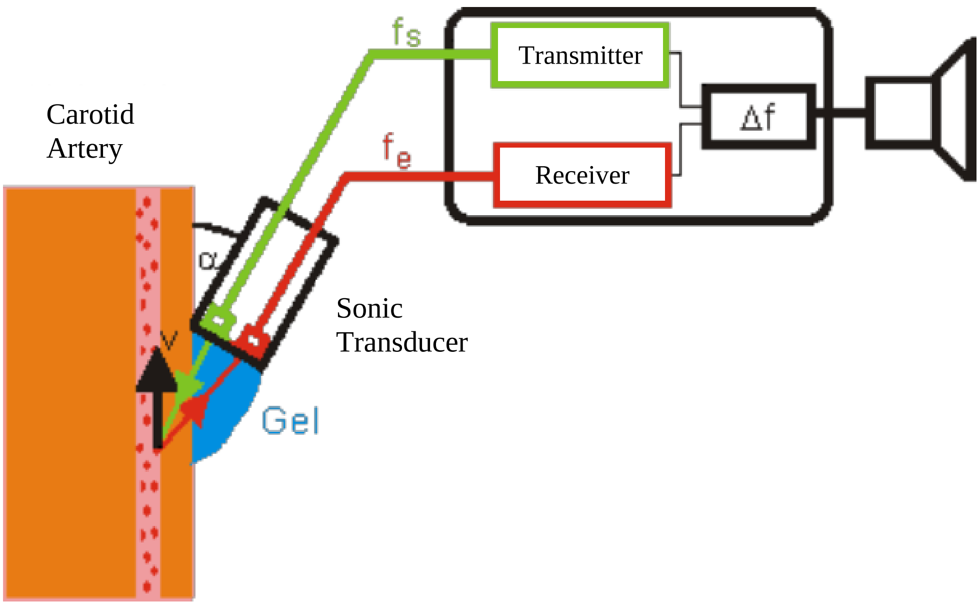
5. Objects behind areas with deviating sound velocity appear shifted.



Ultrasonic

Question 2 **(9 points)**

Doppler sonography
In Doppler sonography to determine the flow rate of the blood, ultrasound of the frequency f_S is sent on the moving blood cells. The sound scattered by the blood cells has the frequency f_E. The beat frequency $\Delta f = f_E - f_S$ can be made audible through a loudspeaker.



(a) Why must a gel be used for the examination? **(1 points)**

(b) Blood cells move with speed v in the carotid artery up. The transducer is placed on the neck at an angle α (see sketch). What proportion of v is to consider for calculation of frequency shift Δf? **(1 points)**

(c) How does the frequency shift Δf depend on the speed of sound c, the angle α, the speed v of the blood cells and the transmission frequency f_S? (Equation) **(1 points)**

(d) What is the blood flow rate when at the transmit frequency $f_S = 15\ MHz$ under the angle α =30° a frequency shift of $\Delta f = 1.99\ kHz$ is measured?
(Notice: speed of sound in blood: 1570 m/s) **(2 points)**

(e) Sketch and describe a CW Doppler US system. **(4 points)**

Solution:

a) The gel has the same refractive index for the sound waves as the tissue. In this way, sound reflections on the skin are avoided (adaptation of the sound impedance). In addition, the gel effectively prevents air between the transducer and the body.

b) The velocity component normal (perpendicular) to the transducer is critical:

$$v_N = v \cdot \cos(\alpha)$$

(c)

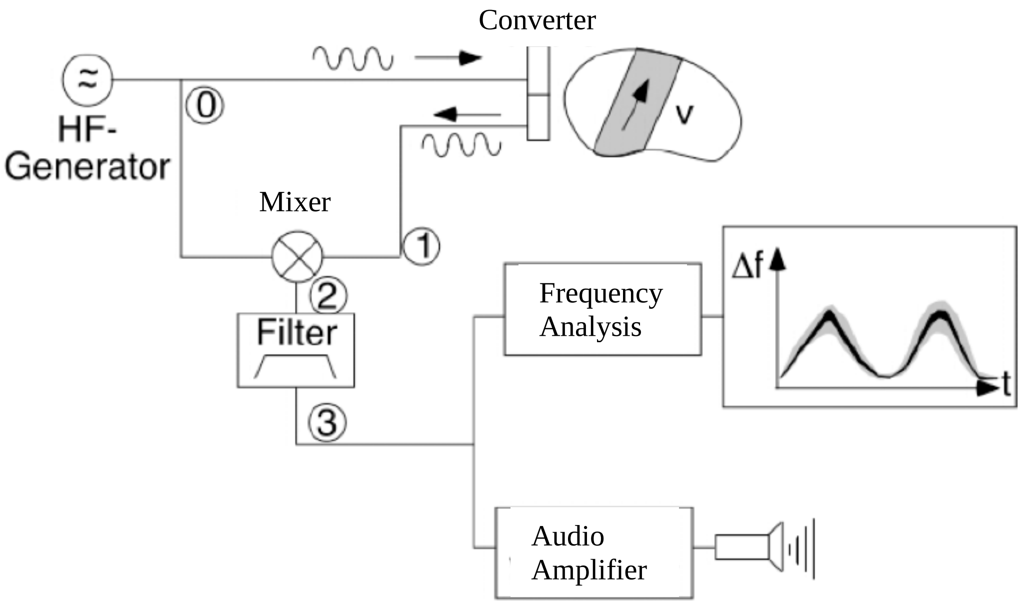
$$\Delta f = \frac{2f_S}{c} \cdot v \cdot cos(\alpha)$$

(d)

$$v = \frac{\Delta f \cdot c}{f_S \cdot 2 \cdot cos(\alpha)}$$

$$v = \frac{1,99 \cdot 10^3\, Hz \cdot 1,57 \cdot 10^3\, m/s}{15 \cdot 10^6\, Hz \cdot 2 \cdot \cos(30°)} \approx 0,12\, m/s$$

(e) Continuous Wave Doppler System: US transmitters and receivers operate continuously. In order to determine the Doppler shift, the received signal is mixed with the transmitted signal, i.e. multiplied. The output signal contains a DC component, the Doppler frequency and a signal with twice the input frequency. After bandpass filtering, the resulting signal can be subjected to frequency analysis or output directly to a loudspeaker.



Ultrasonic

Question 1 **(9 points)**

(a) What is meant by:
- A mode
- B mode
- M mode

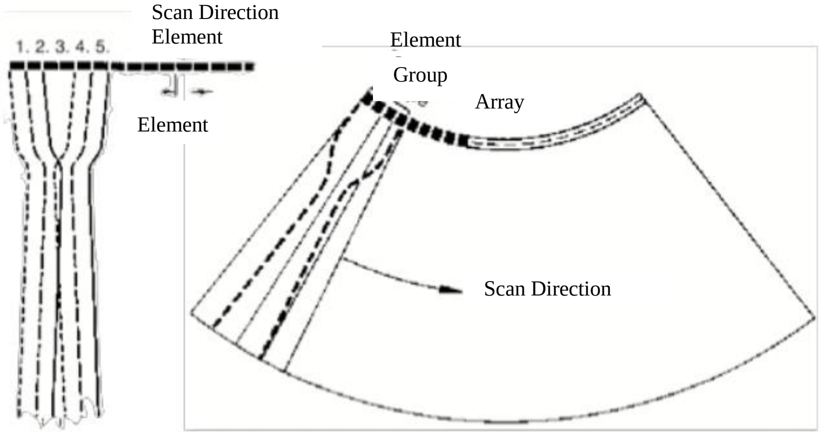
Go into the dimensionality of the figure in keywords and give a brief explanation. **(3 points)**

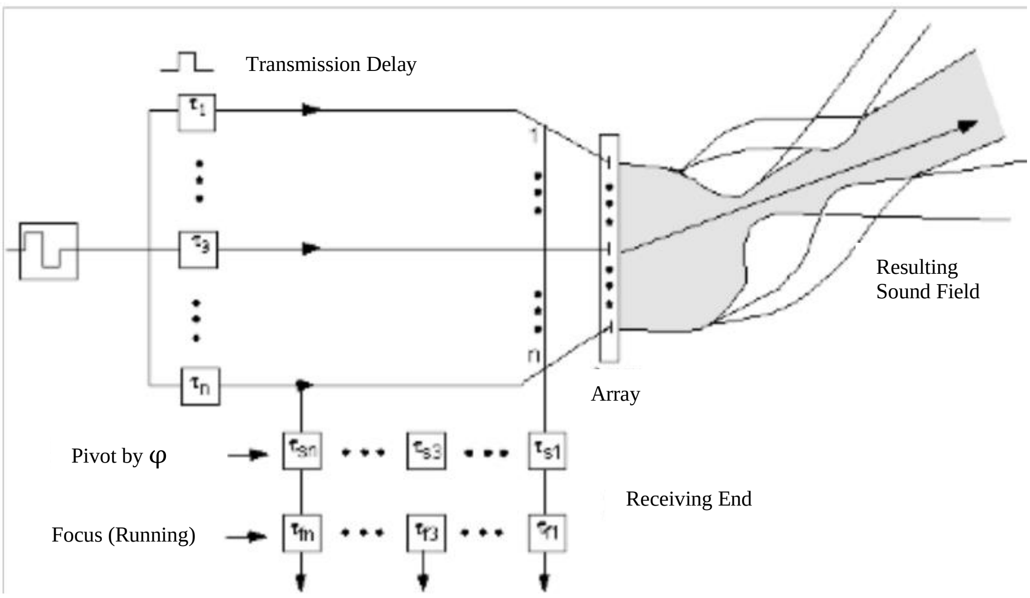
(b) What transmission and reception systems are there for B-mode? Present 3 variants, each with a sketch and a short explanation. **(6 points)**

Solution:

a)
- A mode (**A**mplitude modulation) denotes 1D ultrasound measurements; Map of reflected US intensity along a single ray into the body.
- B mode (Brightness modulation) refers to 2D ultrasound measurements; Signal intensities are converted into grey values.
- M mode (Motion modulation) denotes time-dependent 1D ultrasound measurements; Representation of moving organs by plotting the signals over time.

b)
- Linear array
- Curved array
- Phased array





With the linear and curved arrays, many small US transducers are arranged in an array. Converters are activated in groups. The whole group is then pushed on element by element for scanning. With a curved arrangement of US transducers (curved arrays), an image section can be displayed in the form of a segment of a circle.
With the phased array, each transducer element of an array can be controlled with an individual delay both when transmitting and when receiving.

Ultrasonic

Question 2 **(8 points)**

(a) What does the theoretical limit of the axial resolution in ultrasound diagnostics depend on (reason)? **(2 points)**

(b) What axial resolution in muscle tissue can theoretically be achieved with a US frequency of 2 MHz? (Speed of sound in muscle $1586\frac{m}{s}$) **(1 points)**

(d) In which area is the lateral resolution greatest? **(2 points)**

(e) What is the range of the greatest lateral resolution for the case from b) if the diameter of the US transducer amounts to 5 mm?
Notice: $N = \frac{D^2}{4\lambda}$ **(1 points)**

Solution:

a) The axial resolution is proportional to the US wavelength to a first approximation. Echoes from two interfaces can be distinguished if their distance is greater than half the wavelength. Added to this is the bandwidth of the sending and receiving system (see part c)).

b) With

$$\lambda = \frac{c_{muscle}}{f}$$

And

$$d = \frac{\lambda}{2}$$

results a theoretical limit of

$$d = \frac{c_{muscle}}{2 \cdot f} = \frac{D^2 \cdot f}{4 \cdot c_{muscle}} = \frac{(5\ mm)^2 \cdot 2 \cdot 10^6\ Hz}{4 \cdot 1586\ \frac{m}{s}} \approx 0.39\ mm$$

(d) The lateral resolution is greatest in the focal area and decreases in the near and far range. The focus range is between $\frac{x}{N} = 1$ and $\frac{x}{N} = 2$ with $N = \frac{D^2}{4\lambda}$.

(e) For the given values, the resulting focus range is

$$x_{min} = \frac{D^2 \cdot f}{4 \cdot c_{muscle}} = \frac{(5\ mm)^2 \cdot 2 \cdot 10^6 Hz}{4 \cdot 1586 \frac{m}{s}} \approx 8\ mm$$

$$x_{max} = 2 \cdot x_{min} \approx 16\ mm$$

Ultrasonic

Question 1 **(9 points)**

(a) Give the formula for sound intensity as a function of penetration depth for homogeneous tissue. Using a sketch, explain the relationship between the sound frequency and the attenuation coefficient. Which components does the attenuation coefficient consist of? **(3 points)**

(b) Sketch the components of a US system for A-mode. Explain Time Gain Compensation. **(5 points)**

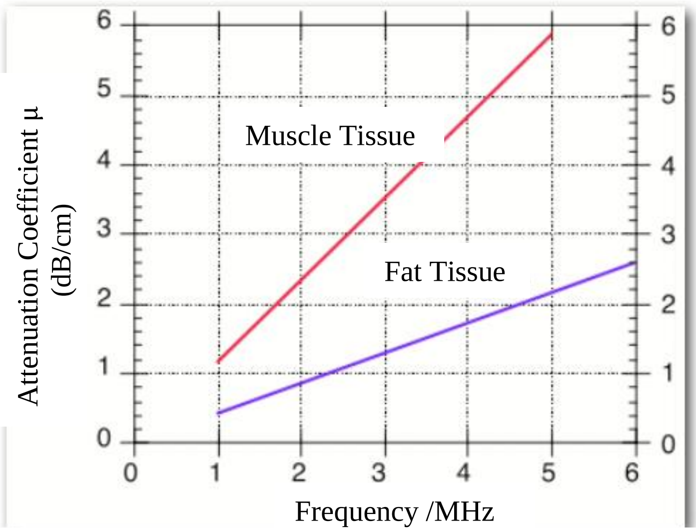
(c) On which parameters does the lateral resolution in ultrasound diagnostics depend? Also describe the dependency of the lateral resolution on the distance to the transmitter. **(2 points)**

(d) The average speed of sound in tissue is about 1540 m/s. Calculate the theoretically achievable axial resolution at a sound frequency of 2 MHz **(3 points)**

Solution:

a)

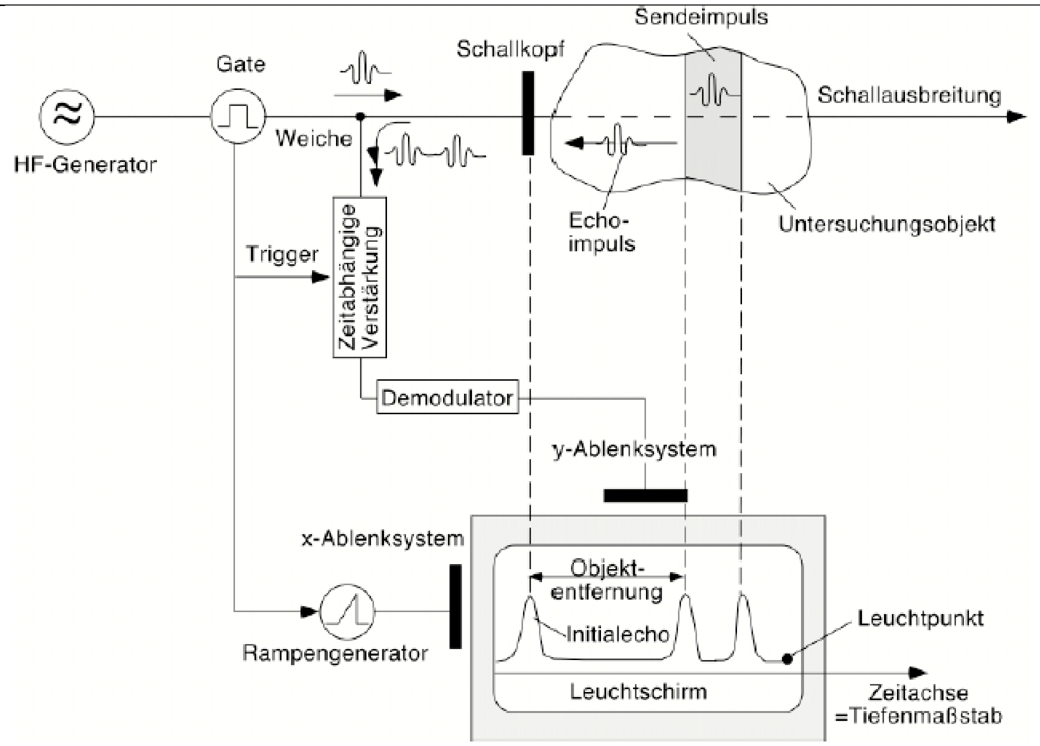
$$J(x) = J_0 \cdot \exp(-\mu \cdot x) \qquad \mu = \mu_a + \mu_s$$



With

- J = sound intensity
- μ_s = stray fraction
- μ_a = absorption fraction

b) Time Gain Compensation: time dependent amplifier. Echoes arriving later, which become weaker and weaker due to absorption, are thus amplified more than signals from the surface.



c) Lateral resolution is proportional to US wavelength and inversely proportional to US transducer diameter. This applies in the so-called focus area. At greater distances, resolution decreases linearly with distance.

d) The theoretical limit is at $d = \frac{\lambda}{2}$

$$d = \frac{c}{2 \cdot f}$$

$$d = \frac{D^2 \cdot f}{4 \cdot c_{muscle}} = \frac{1540\ \frac{m}{s}}{2 \cdot 2 \cdot 10^6\ Hz} \approx 0.38\ mm$$

With

- c = mean speed of sound
- f = frequency of the sound wave
- d = frequency of the sound wave

Ultrasonic

Question 2 **(10 points)**

(a) Artifacts often occur in PW Doppler US when the actual blood velocity exceeds the theoretically determinable blood velocity v_{max}. How does this artifact come about? Derive the relation between the maximum detectable speed v_{max} and the repetition rate $T_{0,max}$.
Notice: Frequency shift $\Delta f = \frac{2 \cdot f0}{c} \cdot v_{max} \cdot \cos\theta$. **(2 points)**

(b) Sketch the quadrature detector. Describe the basic mode of operation of the quadrature detector and what can be determined with this method? **(8 points)**

Solution:

a) The artifacts arise when the sampling theorem is violated (aliasing artifact).

sampling theorem: $\Delta f_{max} = \frac{1}{2 \cdot T_{0max}}$

with: • $T_{0,max}$: longest possible repetition distance
• Δf_{max}: max. frequency shift

Maximum flow velocity according to the Doppler equation:

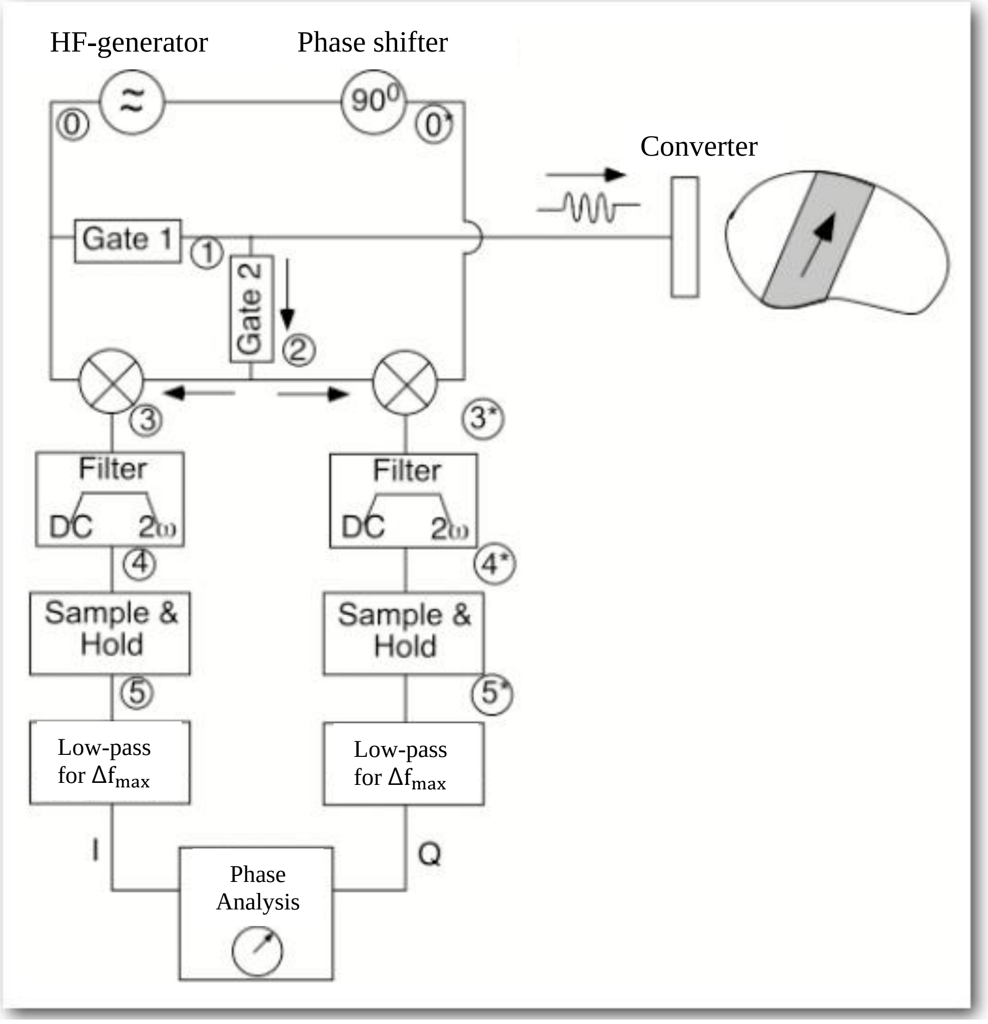
$$\Delta f_{max} = \frac{2 \cdot f_0}{c} \cdot v_{max} \cdot \cos\theta$$

with: • v_{max}: Max Blood Velocity
• Θ: angle of incidence
• f_0:Frequency of the irradiated US wave
• c:Velocity of the US wave in the medium

The relationship between the maximum detectable speed and the repetition rate is therefore:

$$v_{max} \cdot \cos\theta = \frac{c}{4 \cdot f_0 \cdot T_{o,max}}$$

b) Sketch:



Description:

(0) continuously radiating HF generator, in a second channel the echo is generated with a 90° phase-shifted RF generator mixed
(1) Gate 1: leaves short wave packets in the distance T through
(2) Gate 2: a short section is let through from the incoming echo
Delay between both gates determines depth from which the signal comes
(3) Signals are mixed (result: signal with $\Delta\omega+2\omega$ and $\Delta\omega$)
(4) 2ω-Filter; $\Delta\omega$ is left
(5) Sample & Hold and Low Pass

Advantage: Determining the direction of blood flow since the sin-term is not symmetric to zero (when $\Delta\omega$ is negative, then the blood flows away from the US converter)

Ultrasonic

Question 1 **(9 points)**

General questions about ultrasound and wave propagation.

(a) Give the formal definition of the reflection coefficient R and the transmission coefficient T with perpendicular incidence of the sound waves. How do these depend on the acoustic impedance Z? **(2 points)**

(b) Ultrasonic waves in muscle tissue with a density $\rho_{0,1} = 1.02 \text{ g} \cdot \text{cm}^{-3}$ and a bulk modulus of $K_1 = 2.434 \times 10^9 \text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-2}$ fall perpendicularly onto a smooth planar boundary layer of adipose tissue with a density of $\rho_{0,2} = 1.7 \text{ g} \cdot \text{cm}^{-3}$ and a bulk modulus of $K_2 = 2.203 \times 10^9 \text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-2}$. What percentage of the sound intensity is transmitted.
Notice: $Z = \sqrt{K \cdot \rho_0}$ **(2 points)**

(c) Now be the angle of incidence $\alpha_1 = 7°$. At what angle propagates the transmitted wave further?
Notice: speed of sound: $c = \sqrt{\frac{K}{\rho_0}}$. Use the information from task part (b). **(3 points)**

(d) What is the name of the principle that makes it possible to clearly demonstrate the propagation of complex wave fronts? Explain it. **(2 points)**

Solution:

a)

$$R = \frac{J_r}{J_0} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

$$T = \frac{J_t}{J_0} = \frac{4 \cdot Z_1 \cdot Z_2}{(Z_1 + Z_2)^2}$$

b)

$$Z = \sqrt{K \cdot \rho_0}$$

Adjust units of K to units of ρ.

$$\frac{kg}{m \cdot s^2} = \frac{10g}{cm \cdot s^2}$$

This allows the sound impedances to be determined:

$$Z_1 \approx 1.576 \times 10^5 \frac{g}{cm^2 \cdot s} \quad \text{und} \quad Z_2 \approx 6.120 \times 10^5 \frac{g}{cm^2 \cdot s}$$

With the transmission coefficient you get exactly the requested information:
T≈65.138%

c)

The speed of sound is obtained with: $c = \sqrt{\frac{K}{\rho_0}}$

And for the refraction angles: $\frac{\sin \alpha_1}{\sin \alpha_2} = \frac{c_1}{c_2}$.

The speeds of sound are $c_1 = 1544.757 \frac{m}{s}$ and $c_2 = 3599.937 \frac{m}{s}$

It follows: $\alpha_2 = \arcsin\left(\frac{c_2 \cdot \sin \alpha_1}{c_1}\right) = 16.499°$

d)

Huygens principle: A spherical wave propagates from every point on a wavefront. The superposition of these elementary wave fronts results in the actual complex wave front.

Ultrasonic

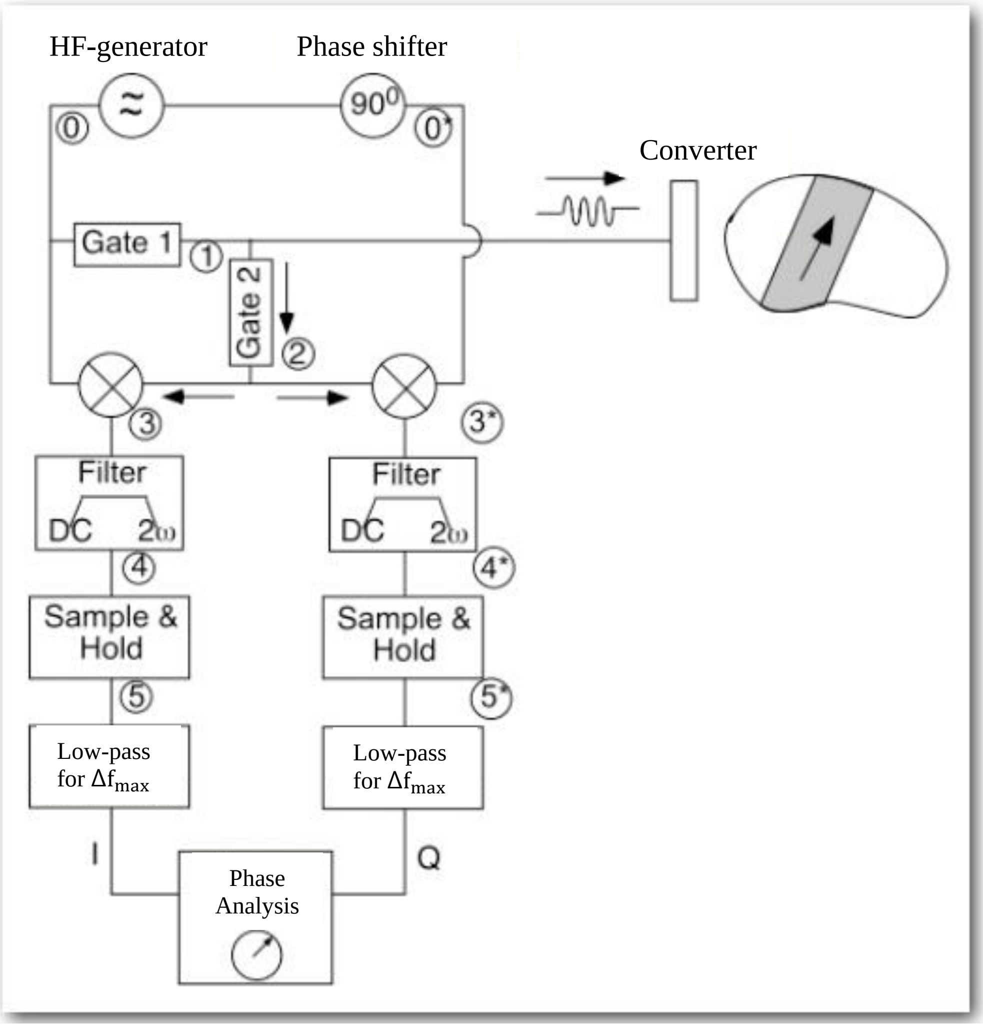
Question 2 **(10 points)**

(a) Sketch a pulse wave Doppler ultrasound system with a quadrature detector. Label the components and explain the signal paths and signal analysis. **(8 points)**

(b) What additional information does the quadrature detector provide? How is this information determined? **(2 points)**

Solution:

a) Gate 1 is used to deliver a short US pulse into the body, Gate 2 cuts out the echo from an area (eg a vein). Mixing creates the sum- and difference- frequencies between the transmitted and received signals. The sum frequency is eliminated with the low-pass filter. The difference frequency contains the Doppler frequency, but because of Gate 2 only piecemeal. The complete Doppler frequency is reconstructed with the sample & hold element and the low-pass filter (signal I).



b) The direction of blood flow velocity. through the 90° phase shift in the second evaluation channel, a so-called quadrature signal (imaginary part) is obtained. If this runs ahead of the in-phase signal (real part), then $\Delta\omega$ is negative, otherwise positive.

Ultrasonic

Question 3 **(12 (15) points)**

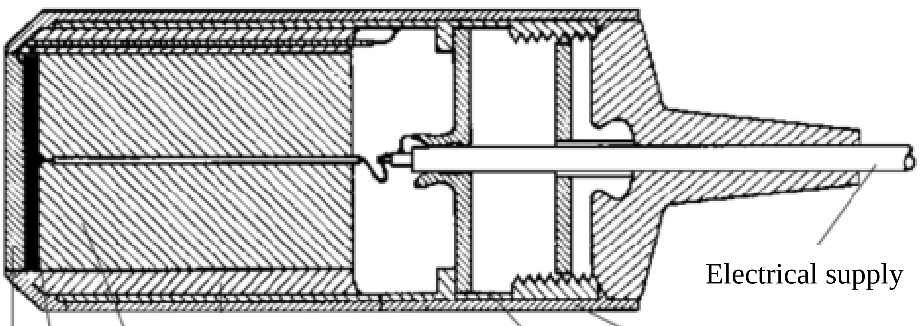
Ultrasonic measuring heads

(a) Sketch and label a single typical electrical ultrasonic transducer. **(3 points)**

(b) Name three different ultrasonic measuring heads for 2D US systems and briefly describe their functional principle. **(9 points)**

Solution:

a)



b)

- Mechanical scanner: Mechanical panning of the US transducer.
- Linear Arrays and Curved Arrays: Transducer group arranged as a linear array. It sends a subgroup of the converters at a time. The sending group is switched to the pan.
- Phased Array: All converters transmit simultaneously, but with an individual time offset. This means that the sound cone can be panned completely electronically by suitably selecting the time delays. It is also possible to focus the sound cone.

Ultrasonic

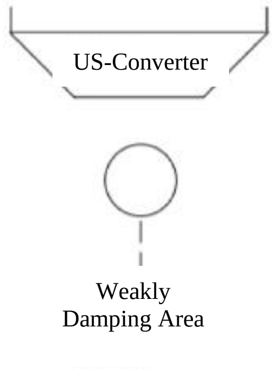
Question 1 **(8 points)**

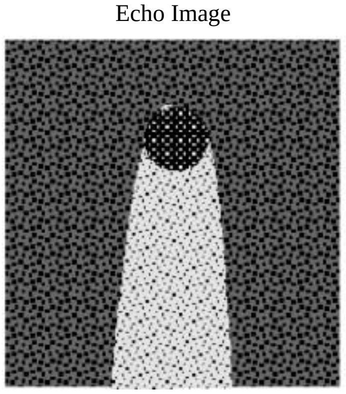
Artifacts in US imaging

What artifacts are known for US imaging? (At least 4 types, each with a sketch and a short description)

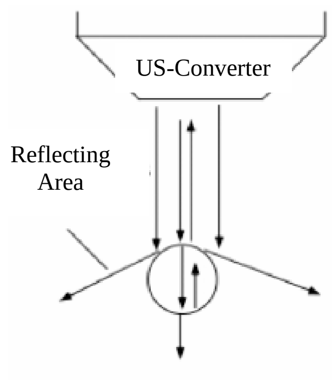
Solution:

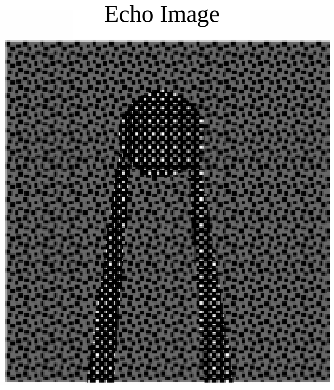
6. There is an apparent signal increase behind weakly damping areas due to the time gain compensation.



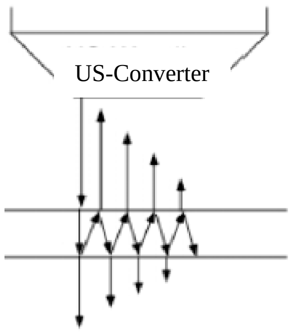


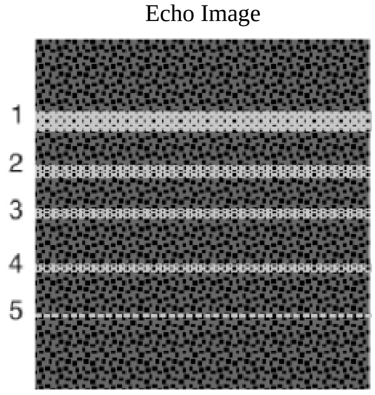
7. Shadowing occurs behind slanted edges that reflect relatively strongly.



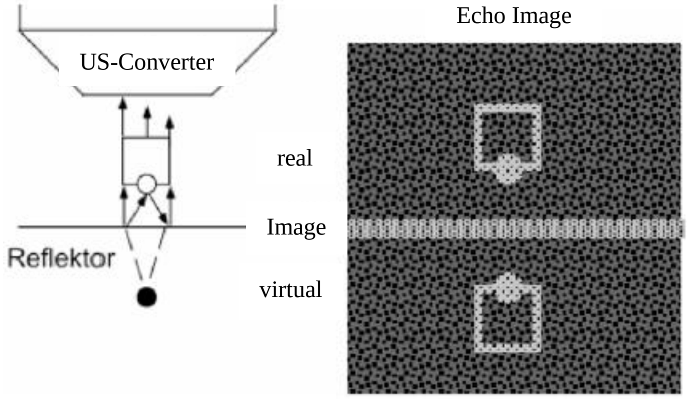


8. In case of two strongly reflecting, approximately parallel boundary surfaces, multiple reflections may occur.

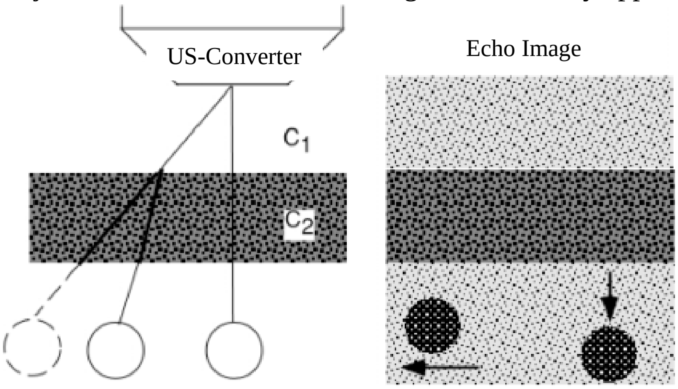




9. Objects in front of highly reflective surfaces mav appear twice as a virtual image.



10. Objects behind areas with deviating sound velocity appear shifted.



Ultrasonic

Question 2 **(10 (14) points)**

(a) How and for what purpose is the Doppler effect used in US imaging? How to calculate the Doppler frequency? **(4 points)**

(c) What difficulties arise? Name 3 problems and how to fix them. **(6 points)**

Solution:

a) The Doppler effect occurs when a sender and/or receiver of a wave move relative to each other. The frequency shift that occurs is proportional to the relative speed. In Doppler ultrasound diagnostics, the speed of the blood flowing in the blood vessels or in the heart is most often examined. The blood cells scatter the US wave and thus become a moving transmitter themselves. The total frequency shift detected at the US receiver is:

$$\Delta f = \frac{2 \cdot f}{c} \cdot v \cdot \cos\theta$$

with the Doppler frequency Δf, the ultrasonic frequency f, the speed of sound c, speed of the scattering particle v and θ the angle between vessel and US probe.

c) Difficulties encountered and how to resolve them:
• Errors in estimating the angle between the blood vessel and the US probe falsify the flow velocity result. Stereo measuring heads allow the flow velocity to be recorded without knowing the angle.
• The disadvantage of the continuous wave US measurement system is that the depth from which the signal with the shifted frequency comes cannot be determined. The Pulsed Wave US system with two built-in gates can help. The delay between Gate 1 and Gate 2 determines the depth from which the signal comes from which the Doppler shift is to be determined.
• The systems described do not give any information about the direction of the flow velocity. In order to also determine the flow direction, the echo is evaluated in a second evaluation channel with a 90◦ phase-shifted RF signal mixed. (“quadrature detector”)

Ultrasonic

Question 3 **(11 points)**

(a) For an ultrasonic measurement in near-surface layers, two transducers with different frequencies are available.
• Converter 1: $f_1 = 20\ MHz$
• Converter 2: $f_2 = 3.5\ MHz$
Which converter is to be preferred for the measurement? (short mount of choice) **(2 points)**

(b) Calculate the optimal thickness of the transducer plate for the selected transducer from part (a) (Notice: speed of sound in piezoceramics: $c = 4350\frac{m}{s}$. **(2 points)**

(c) Why would a measurement in the close range of an ultrasonic transducer lead to bad results? **(1 points)**

(d) Which distance is suitable for the measurement, and at what distance is this for the selected frequency from part (a), with a transducer diameter $D = 1\ mm$? (If you could not solve part (a), calculate with a frequency of $f_3 = 11.5\ MHz$
(Notice: It applies $N = \frac{D^2}{4\lambda}, c_{Water} = 1480\frac{m}{s}$) **(3 points)**

(e) What lateral resolution can be expected for this converter (6 dB width)? **(1 points)**

(f) Explain how the axial resolution results theoretically and calculate the theoretical resolution for the present case. **(2 points)**

Solution:

a) Transducer 1 is preferable for US measurements in near-surface layers. Higher frequencies lead to a lower penetration depth and higher resolution. Since the penetration depth plays a subordinate role on the surface, you can benefit from the higher resolution.

b) The thickness of the piezoelectric transducer plate is chosen to just fit a standing wave of the desired ultrasonic frequency. From this follows an optimal thickness of λ/2.
• Converter 1: 109 µm
• Converter 2: 620 µm

c) In the close range, there are strong interference phenomena and thus a very inhomogeneous intensity distribution.

d) The focus range is in the distance range between $x = N$ and $x = 2N$.
For the different frequencies follows with

$$\lambda = \frac{c}{f}$$

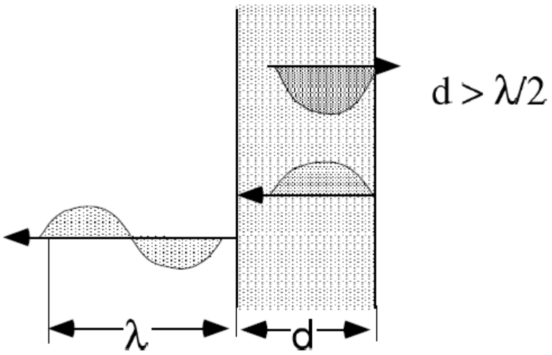
• λ1=0,074 mm
• λ2=0,423 mm
• λ3=0,129 mm
It comes with

$$N = \frac{D^2}{4\lambda}$$

• N1=3,4 mm
• N2=0,59 mm
• N3=1,9 mm
The focus areas are as follows:
• focus1=3,4 mm− 6,8 mm
• focus2=0,59 mm− 1,08 mm
• focus3=1,9 mm− 3,8 mm

e) The lateral resolution is approximately: $d = \frac{1}{3D} = \frac{1}{3}mm$

f) The theoretical limit of the axial resolution is half the US wavelength, since in this case the reflection of a wave train (/wave group) can be resolved at two layers.



The following resolutions result for the given wavelengths:

- $\lambda 1/2$ = 0,037 mm
- $\lambda 2/2$ = 0,211 mm
- $\lambda 3/2$ = 0,064 mm

Ultrasonic

Question 1 **(4 points)**

(a) Give the relationship between the sound intensity and the penetration depth in homogeneous tissue. **(1 points)**

(b) What are the components of the attenuation coefficient μ? **(1 points)**

(c) In which frequency range are the US signals in imaging? **(1 points)**

(d) How depends μ on the ultrasonic frequency? **(1 points)**

Solution:

a)

$$I(x) = I_0 \cdot \exp(-\mu x)$$

b)

$$\mu = \mu_a + \mu_b$$

with:
μ: attenuation coefficient
μ_a: absorption coefficient
μ_b: scattering coefficient

c) $1 - 50$ MHz

d) The attenuation coefficient increases with increasing ultrasonic frequency.
(For muscle tissue applies:
at 1 MHz the attenuation is 1 dB/cm
at 2 MHz the attenuation is 2 dB/cm)

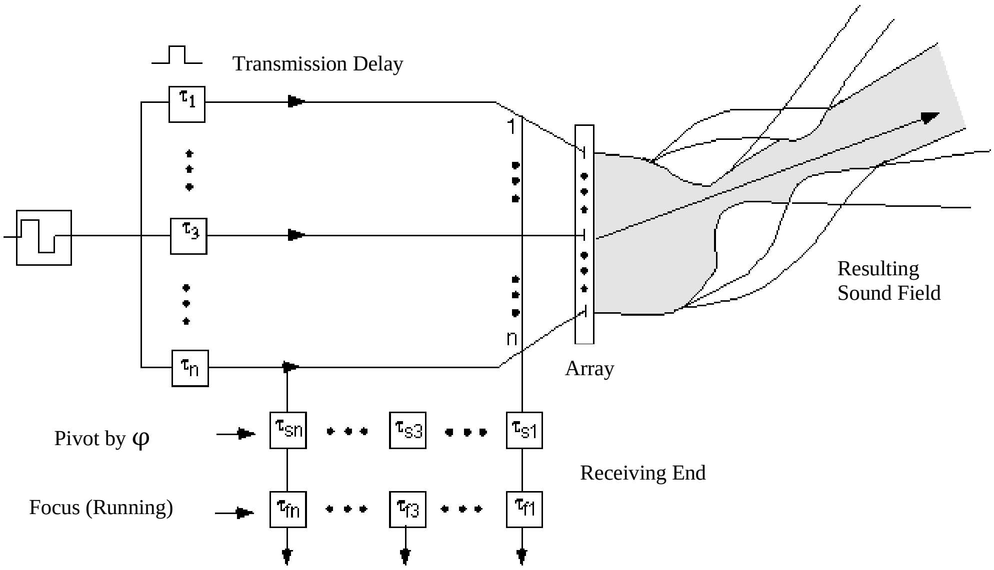
Ultrasonic

Question 2 **(11 points)**

(a) Explain how a phased array measuring head works and draw the associated block diagram. **(6 points)**
(b) Name other types of ultrasonic transducers for 2D US systems? **(2 points)**
(c) What advantages does the phased array have over the other methods? **(3 points)**

Solution:

a) With the phased array, each transducer element in a row can be controlled with an individually adjustable delay both when transmitting and when receiving. (1 point)
The spherical waves emitted by each transducer element have a precisely defined phase shift (1 point).



(4 points for the blcok diagram)

b) Mechanical transducers, linear array, curved array (2 points)

c) The advantages of the phased array are as follows:
Since all transducers radiate simultaneously, a high power can be radiated and still a high spatial resolution can be achieved (1 point).
Due to the phase shift, additional focusing is possible and thus a higher resolution (1 point).
Dynamic Focusing: Reception can be dynamically focused based on the depth the echoes are coming. (1 point)

Ultrasonic

Question 1 **(9 points)**

Ultrasonic systems
What is meant by (explain each in keywords)

(a) A mode **(1 points)**

(b) B mode **(1 points)**

(c) M mode **(1 points)**

(d) Which electronic systems for the B-mode are there (3 variants)? Solutions each with a sketch and a short explanation. **(6 points)**

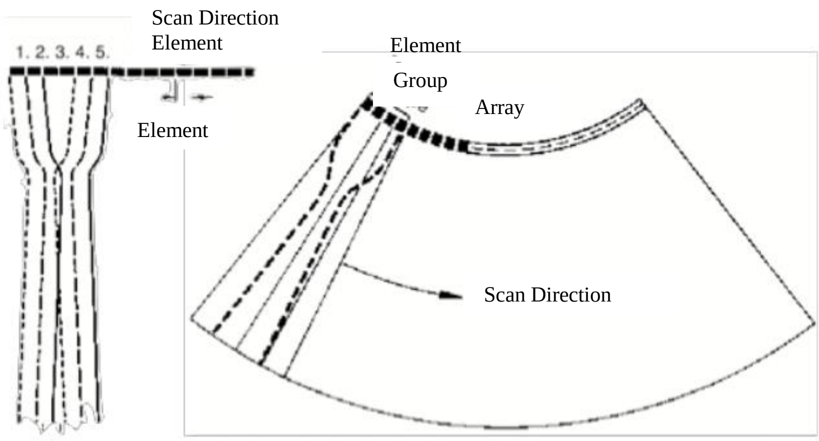
Solution:

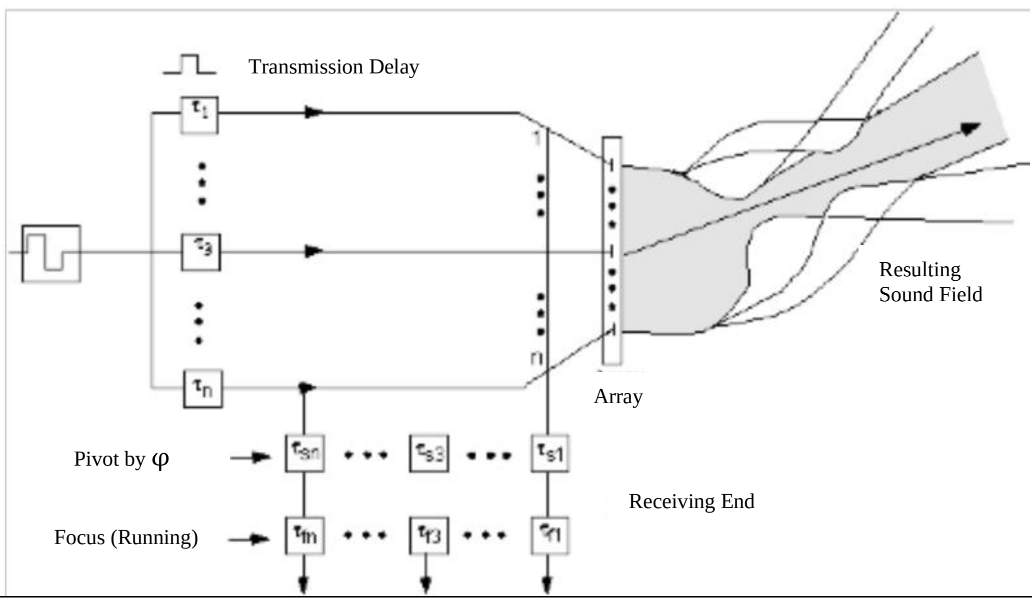
a) A mode (**A**mplitude modulation) denotes 1D ultrasound measurements;
Map of reflected US intensity along a single ray into the body.

b) B mode (Brightness modulation) refers to 2D ultrasound measurements;
Signal intensities are converted into grey values.

c) M mode (Motion modulation) denotes time-dependent 1D ultrasound measurements;
Representation of moving organs by plotting the signals over time.

d) Linear array, curved array and phased array US-measuring heads





With the linear and curved arrays, many small US transducers are arranged in an array. Converters (/Transducers) are activated in groups. The whole group is then pushed on element by element for “scanning”. With a curved arrangement of US transducers (curved arrays), an image section can be displayed in the form of a segment of a circle.

With the phased array, each transducer element of an array can be controlled with an individual delay both when transmitting and when receiving. As a result, the spherical waves emitted by each transducer have a precisely defined phase shift (electronic pivoting of the sound lobe).

Ultrasonic

Question 2 **(7 points)**

Resolution in ultrasound imaging

(a) What does the axial resolution in ultrasound diagnostics depend on (reason)? What axial resolution in muscle tissue can theoretically be achieved with an US frequency of 2 MHz (sound velocity in muscle $1586\,\frac{m}{s}$)? (Explanation)? Why is this not achieved and where is the resolution typically achieved?

(4 points)

(b) In which area is the lateral resolution greatest? What is this range for the case in (a) when the diameter of the US transducer is 5 mm? **(3 points)**

Solution:

a) The axial resolution is proportional to the US wavelength to a first approximation. (1 point) Two different echoes appear when they have been reflected at two interfaces that are more than half the wavelength apart (1 point).

With $\lambda = \frac{c_{\mathrm{muscle}}}{f}$

And

$$d = \frac{\lambda}{2}$$

results a theoretical limit of

$d = \frac{c_{\mathrm{muscle}}}{2 \cdot f} = \frac{D^2 \cdot f}{4 \cdot c_{\mathrm{muscle}}} = \frac{(5\ \mathrm{mm})^2 \cdot 2 \cdot 10^6\ \mathrm{Hz}}{4 \cdot 1586\,\frac{\mathrm{m}}{\mathrm{s}}} \approx 0.39\ mm$ (1 point).

However, the wave packets are smeared by the finite bandwidth of the transmitter and dispersion. Typical achievable resolutions in muscle tissue are about 0.8 mm axial (1 point).

b) The lateral resolution is greatest in the focal area and decreases in the near and far range (1 point). The focus range is between $\frac{x}{N} = 1$ and $\frac{x}{N} = 2$ with $N = \frac{D^2}{4\lambda}$ (1 point).
For the given values, the resulting focus range is 8 mm to 16 mm (1 point).

$$x_{\mathrm{min}} = \frac{D^2 \cdot f}{4 \cdot c_{\mathrm{muscle}}} = \frac{(5\ \mathrm{mm})^2 \cdot 2 \cdot 10^6\mathrm{Hz}}{4 \cdot 1586\,\frac{\mathrm{m}}{\mathrm{s}}} \approx 8\ mm$$

$$x_{\mathrm{max}} = 2 \cdot x_{\mathrm{min}} \approx 16\ mm$$