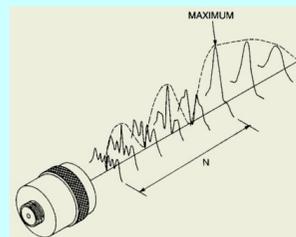
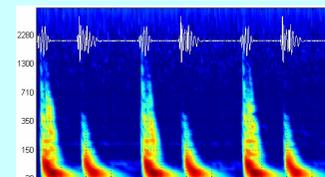


Medical application of US

Therapy – due to absorption of US

Diagnostics – due to reflection of US

Physics of ultrasonography



Reflection of US

material	ρ [kg/m ³]	κ [1/GPa]	c [m/s]	Z [kg/(m ² ·s)]
Air	1,3	7650	331	0,00043·10 ⁶
Lung	400	5,92	650	0,26·10 ⁶
Fat	925	0,51	1470	1,42·10 ⁶
Soft tissue	1060	0,40	1540	1,63·10 ⁶
Eye lens	1140	0,34	1620	1,84·10 ⁶
Done marrow	970	0,36	1700	1,65·10 ⁶
Bones (porous)	1380	0,08	3000	2,2 – 2,9·10 ⁶
Bones (solid)	1700	0,05	3600	6,12·10 ⁶

If $R \approx 1$ \rightarrow Total reflection

interface	R
muscle/blood	0,0009
fat/liver	0,006
fat/muscle	0,01
bone/muscle	0,41
bone/fat	0,48
soft tissue/air	0,99

Reflection of US

material	c (m/s)	ρ (kg/m ³)	Z (kg/m ² ·s)
pulp	1570	1000	1,6 · 10 ⁶
dentin	3800	2000	7,6 · 10 ⁶
enamel	6250	3000	18,8 · 10 ⁶
Al	6300	2700	17 · 10 ⁶
borosilicate	5300	3570	18,9 · 10 ⁶
amalgam	4350	7750	33,7 · 10 ⁶

interface	R
enamel/dentin	0,18
dentin/pulp	0,43
amalgam/dentin	0,40

Reflection of US

Optimal coupling:

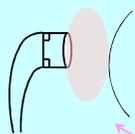
$$Z_{\text{coup}} = \sqrt{Z_1 \cdot Z_2}$$

$$Z_{\text{gele}} \sim 6,5 \cdot 10^6 \text{ kg/(m}^2\text{s)}$$

interface	R
muscle/blood	0,0009
fat/liver	0,006
fat/muscle	0,01
bone/muscle	0,41
bone/fat	0,48
soft tissue/air	0,99



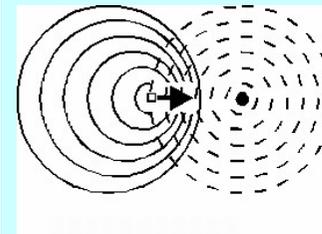
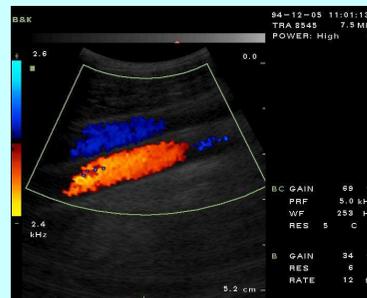
If $R \approx 1$ → Total reflection



Coupling material

5

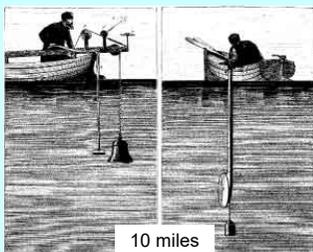
US imaging. Modes of sonography. Doppler-echo.



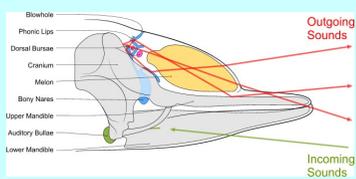
Echo principle

1794 - Spallanzani:
bat's navigation

1822 - Colladen measured
the speed of sound in water



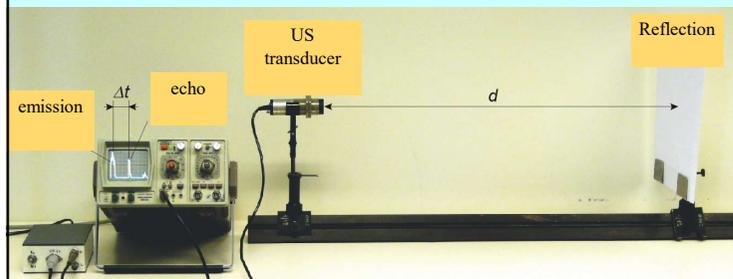
10 miles



bottlenose dolphin

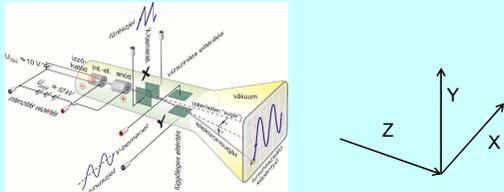
7

Echo principle



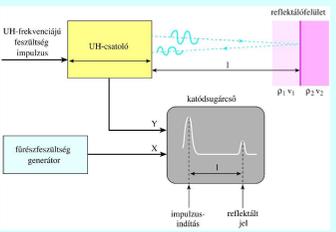
$$c \Delta t = d + d = 2d$$

8



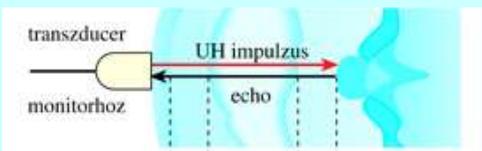
Deflection / controlling

	A-image
X	Time (→ axial distance)
Y	Amplitude (→ I_{refl})
Z	(Brightness)

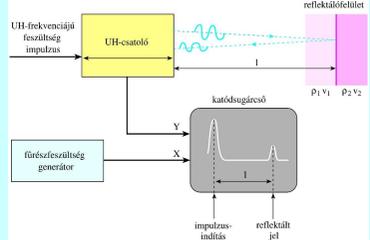


9

A-image - Amplitude



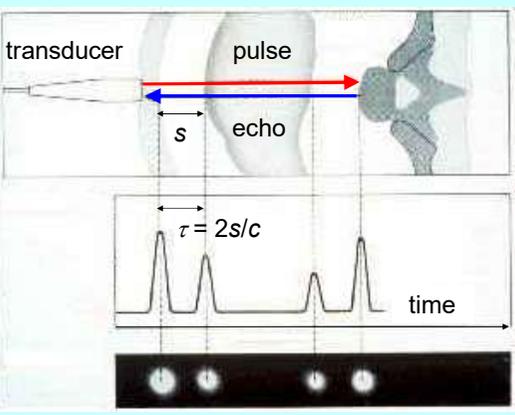
One-dimensional only



$c\Delta t = d+d = 2d$

10

B-image - Brightness



A-mode (Amplitude) only 1-dimensional

B-mode (Brightness) only 1-dimensional

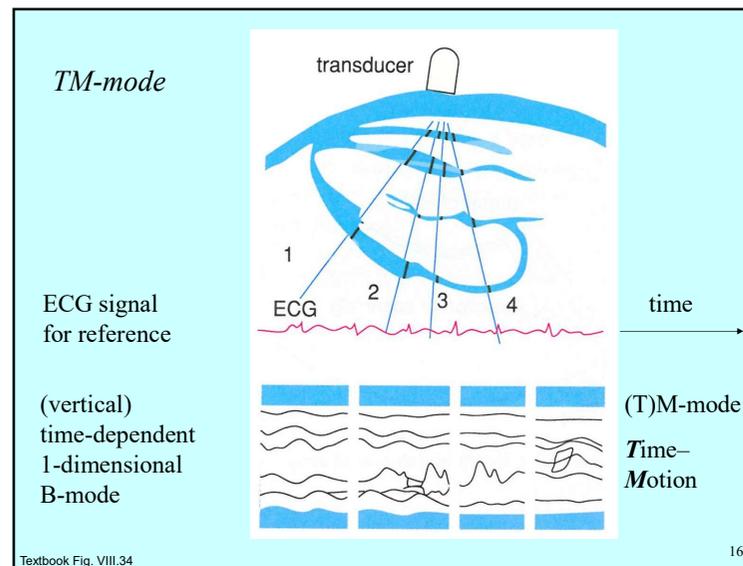
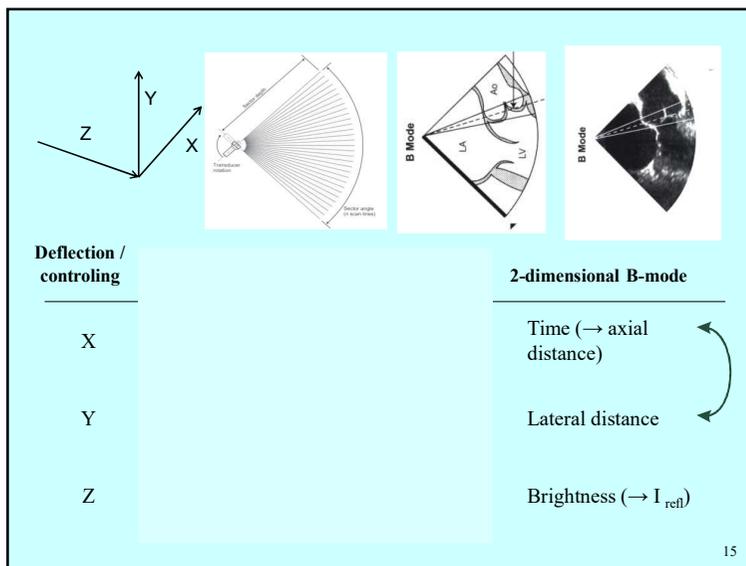
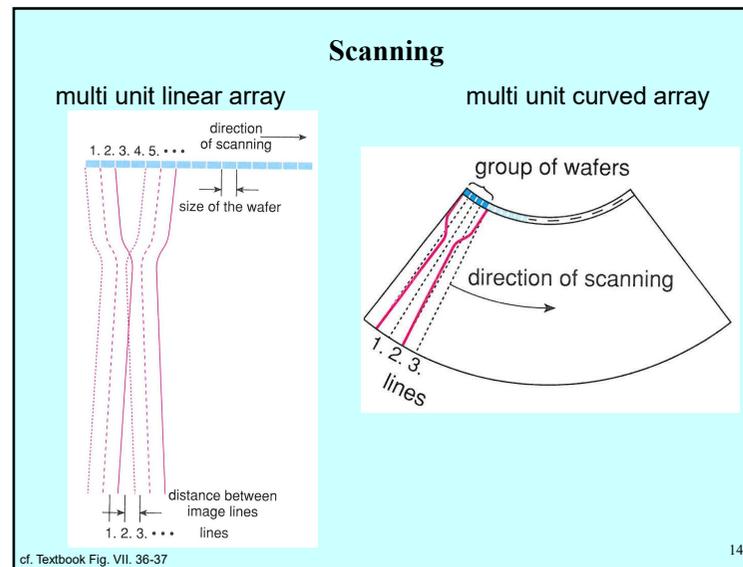
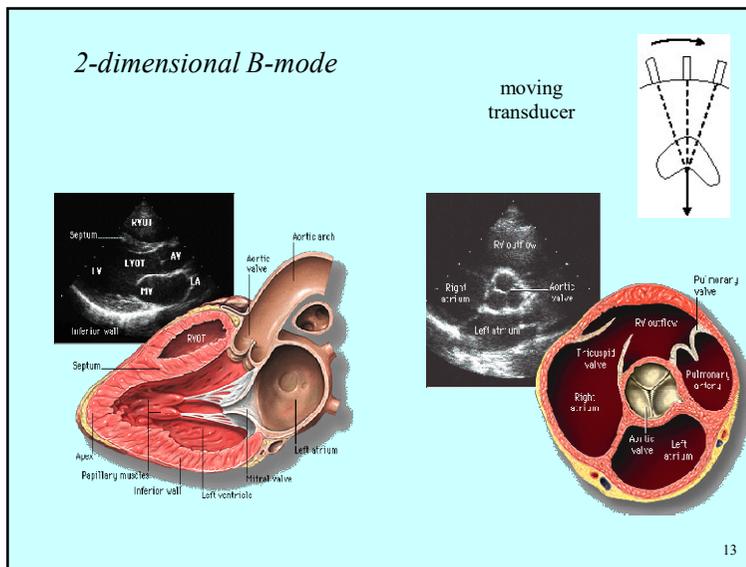
cf. Textbook Fig. VIII.33

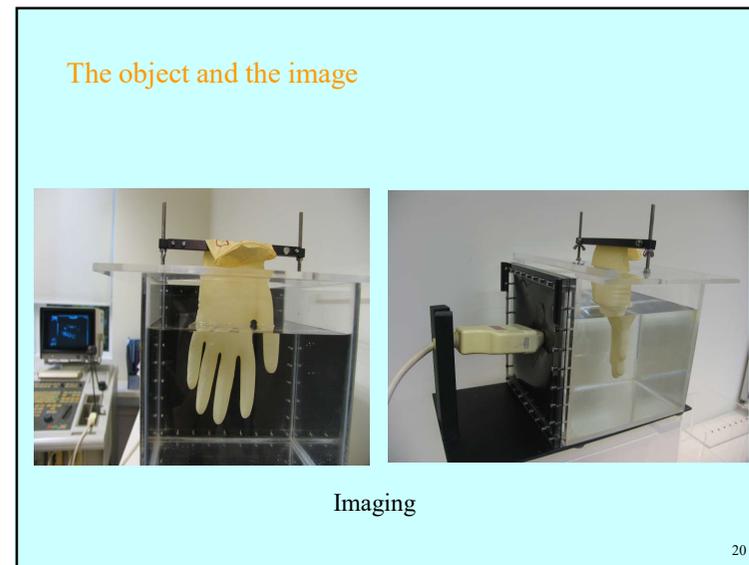
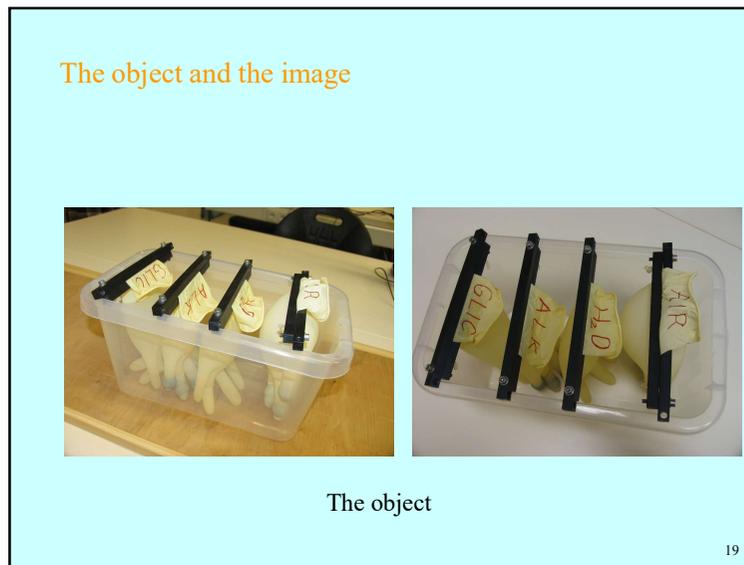
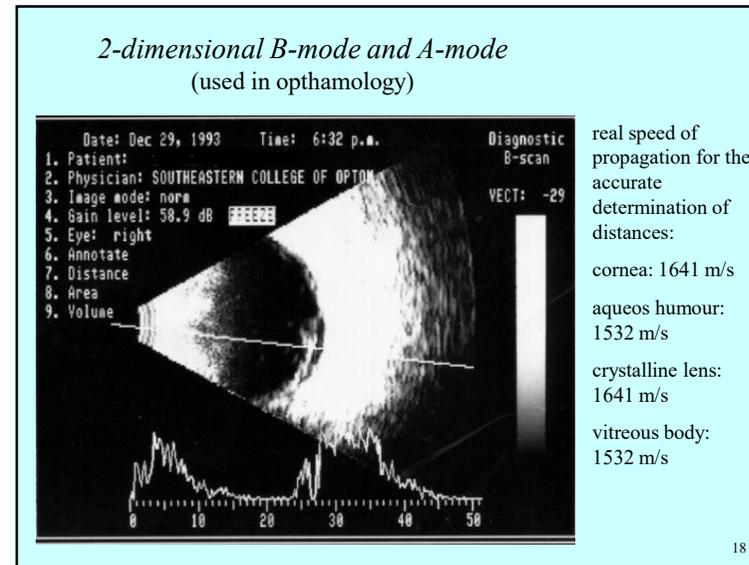
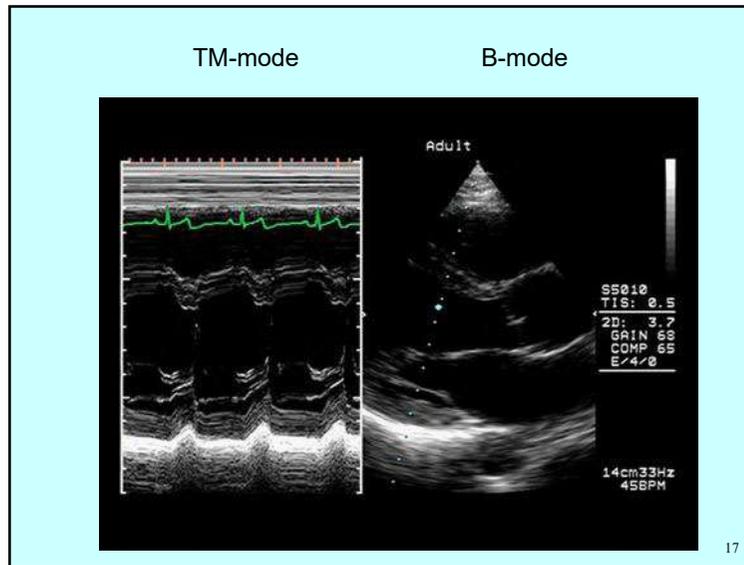
11



Deflection / controlling	A-mode	1-dimensional B-mode
X	Time (→ axial distance)	Time (→ axial distance)
Y	Amplitude (→ I_{refl})	-
Z	(Brightness)	Brightness (→ I_{refl})

12





The object and the image

Water inside and outside

Cross-section

The image

03/12/22
01:01:04
9.5MHz
H F 1
GAIN: 5
X 1.0

21

Detailed description: This slide shows an experimental setup for an ultrasound experiment. On the left, a photograph labeled 'Water inside and outside' shows a yellow container submerged in a larger tank of water. A red circle on the photograph is connected by an arrow to a green circle labeled 'Cross-section'. This green circle is further connected by an arrow to a large ultrasound image labeled 'The image'. The ultrasound image shows several bright, circular structures. A white vertical scale bar is visible on the left side of the ultrasound image. Technical data is displayed in the top left corner of the ultrasound image.

The object and the image

Glycerin inside

Cross-section

The image

03/12/22
01:00:47
9.5MHz
H F 1
GAIN: 12
X 1.0

22

Detailed description: This slide shows an experimental setup for an ultrasound experiment. On the left, a photograph labeled 'Glycerin inside' shows a yellow container submerged in a larger tank of water. A red circle on the photograph is connected by an arrow to a green circle labeled 'Cross-section'. This green circle is further connected by an arrow to a large ultrasound image labeled 'The image'. The ultrasound image shows several bright, circular structures. A white vertical scale bar is visible on the left side of the ultrasound image. Technical data is displayed in the top left corner of the ultrasound image.

The object and the image

Alcohol inside

Cross-section

The image

03/12/22
01:01:57
9.5MHz
H F 1
GAIN: 5
X 1.0

23

Detailed description: This slide shows an experimental setup for an ultrasound experiment. On the left, a photograph labeled 'Alcohol inside' shows a yellow container submerged in a larger tank of water. A red circle on the photograph is connected by an arrow to a green circle labeled 'Cross-section'. This green circle is further connected by an arrow to a large ultrasound image labeled 'The image'. The ultrasound image shows several bright, circular structures. A white vertical scale bar is visible on the left side of the ultrasound image. Technical data is displayed in the top left corner of the ultrasound image.

The object and the image

Air inside

Cross-section

The image

03/12/22
01:00:20
9.5MHz
H F 1
GAIN: 5
X 1.0

24

Detailed description: This slide shows an experimental setup for an ultrasound experiment. On the left, a photograph labeled 'Air inside' shows a yellow container submerged in a larger tank of water. A red circle on the photograph is connected by an arrow to a green circle labeled 'Cross-section'. This green circle is further connected by an arrow to a large ultrasound image labeled 'The image'. The ultrasound image shows several bright, circular structures. A white vertical scale bar is visible on the left side of the ultrasound image. Technical data is displayed in the top left corner of the ultrasound image.

Resolving limit, resolution

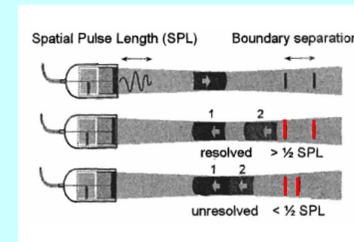
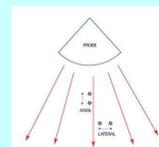
Resolving limit is the distance between two object details which can be just resolved as distinct objects (the smaller the better).

Resolution (resolving power): the reciprocal of the resolving limit (the greater the better)

Lateral resolving limit - is the minimum separation of two interfaces aligned along a direction perpendicular to the ultrasound beam.

Resolving limit, resolution

Axial resolving limit - is the minimum separation of two interfaces aligned along the ultrasound beam. Achieving good axial resolution requires that the returning echoes be distinct without overlap

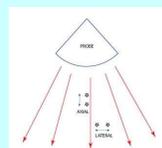


The minimal required separation distance between two boundaries is $\frac{1}{2}$ SPL (about $\frac{1}{2} \lambda$) to avoid overlap of returning echoes

SPL inversely proportional to f

Resolving limit, resolution

Lateral resolving limit - is the minimum separation of two interfaces aligned along a direction perpendicular to the ultrasound beam determined by beam width, beam density and axial position of the object.

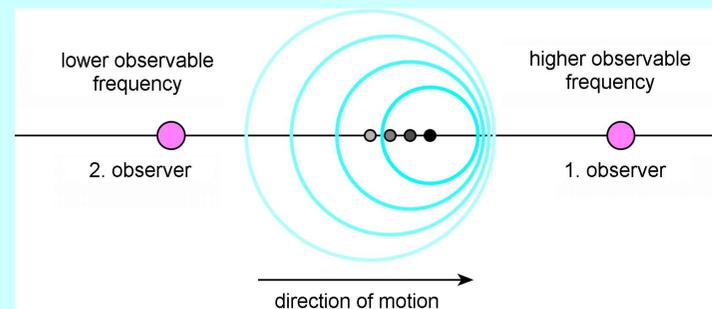


Typical values

frequency (MHz):	2	15
wavelength (mm):	0.78	0.1
penetration (cm):	12	1.6
lateral limit (mm):	3.0	0.4
axial limit (mm):	0.8	0.15

Doppler phenomenon

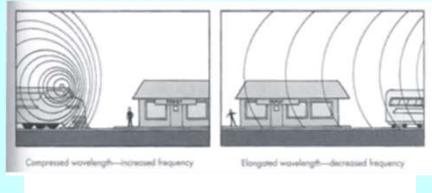
„The pitch of a train whistle seems to get higher as it approaches, then seems to lower as the train whistle moves away.” (C. Doppler, 1842)



Doppler phenomenon

„The pitch of a train whistle seems to get higher as it approaches, then seems to lower as the train whistle moves away.” (C. Doppler, 1842)

Moving source

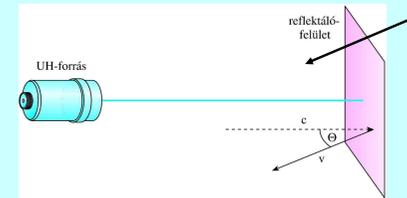


$$f' = f \cdot \left(1 \pm \frac{v}{c}\right)$$

f : initial frequency
f' : altered frequency
v : speed of source
c : speed of US

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Moving reflecting object (surface),



$$f' = f_0 \cdot \left(1 \pm \frac{2v}{c}\right)$$

Doppler-shift

$$f_D = f' - f_0$$

Doppler shift is proportional to the speed of reflecting surface

30

f' : **observed frequency**, f : original frequency

- (a) standing source and moving observer (v_O)
+ : observer approaches the source
- : observer moves away from the source

$$f' = f \left(1 \pm \frac{v_O}{c}\right)$$

- (b) moving source and standing observer
(if $v_S \ll c$, then „same” as (a))

$$f' = \frac{f}{1 \mp \frac{v_S}{c}}$$

- (c) moving source and moving observer

$$f' = f \frac{1 \pm \frac{v_O}{c}}{1 \mp \frac{v_S}{c}}$$

- (d) moving reflecting object (surface),
(if $v_R \ll c$)

$$f' = f \left(1 \pm \frac{2v_R}{c}\right)$$

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Doppler frequency = frequency change = frequency shift

if $v_i, v_R \ll c$ (i= S or O)

rearranging equation (a)
moving source or observer:

$$\Delta f = f_D = \pm \frac{v_i}{c} f$$

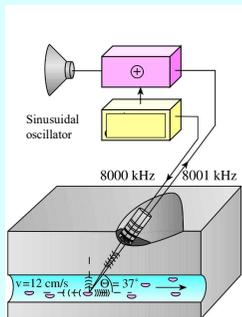
rearranging equation (d)
moving reflecting object or surface:

$$\Delta f = f_D = \pm 2 \frac{v_R}{c} f$$

if v and c are not parallel, then $v \cos \theta$ should be used instead of v (remark: if $\theta = 90^\circ$, $f_D = 0$)

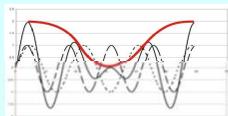
32

1-dimensional Doppler apparatus for measuring average flow velocity.



CW: continuous wave
source and detector are separated

Red blood cells as sound scatterers.



difference signal 1 kHz

Tkv. VIII.41. ábra

33

An artery of 9 mm inner diameter is examined by Doppler ultrasound method. The frequency of the ultrasound is 8 MHz. The average frequency audible for the examiner is 1200 Hz. Calculate the average velocity of blood in the artery. The velocity of the ultrasound in the body is 1500 m/s and we suppose that it propagates parallel to the axis of the blood vessel.

$$f' = f \left(1 \pm \frac{2v_R}{c} \right)$$

$$|f_D| = 2 \frac{v_R \cos \theta}{c} f$$

$$\frac{|f_D| * c}{2f \cos \theta} = v_R$$

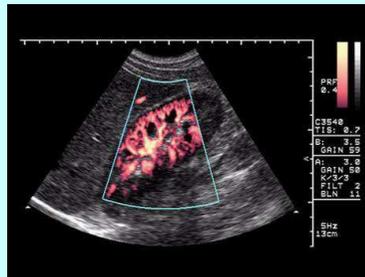
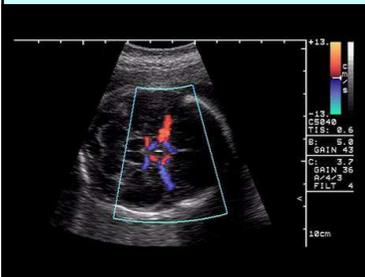
$$\frac{1200 * 1500}{2 * 8 * 10^6} = v$$

$$v = 11,25 \text{ m/s}$$

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Colour coding

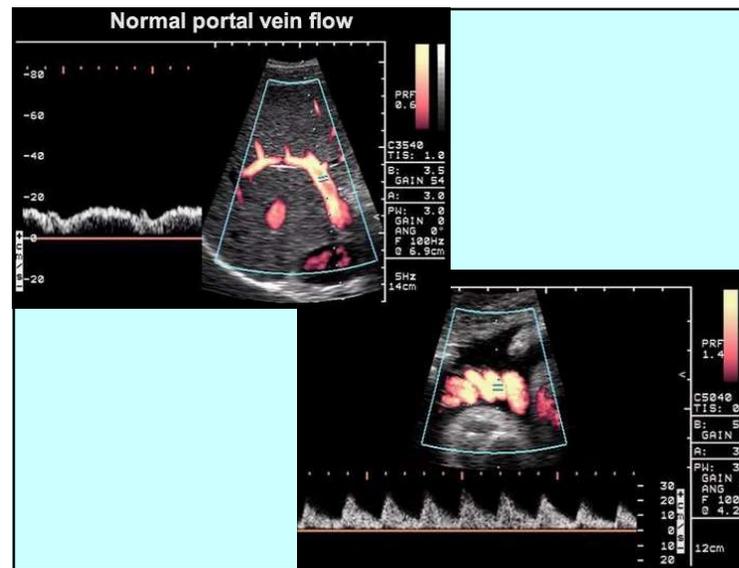
towards the transducer: warm colours
away from the transducer: cold colours



BART: Blue Away Red Towards

power Doppler

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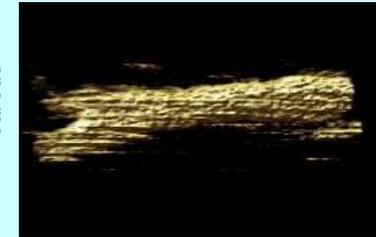
Reconstruction of the face of a fetus



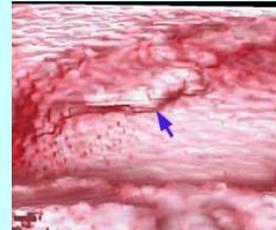
37

3D reconstruction

carotis



bladder

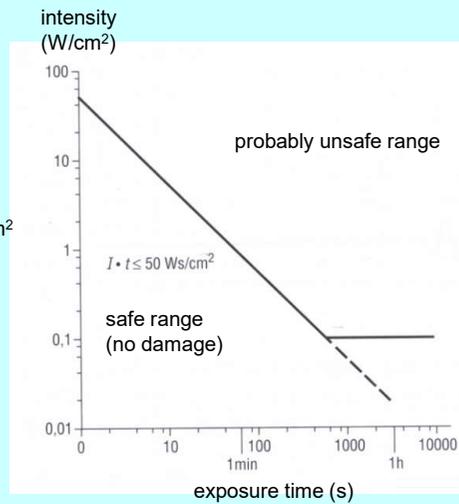


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Safety

in the diagnostics:
 $10 \text{ mW/cm}^2 = 100 \text{ W/m}^2$
 cf. pain threshold: 10 W/m^2

in the therapy: 1 W/cm^2



39

Question of the week

What does Doppler-shift mean?

40

Related chapters

Damjanovich, Fidy, Szöllősi: Orvosi Biofizika

II. 2.4.
VIII. 4.2.